Net-Zero Logistics: The Contribution of Rail Transport

Europe's Rail Joint Undertaking

Final Report

June 2025

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Europe's Rail

EY Parthenon

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List of Abbreviations

B/C ratio	Benefit-Cost Ratio
BEV	Battery Electric Vehicle
bn	Billion
CB	Costs and benefits
CBA	Cost-Benefit analysis
DAC	Digital Automatic Coupling
EC	European Commission
EGD	European Green Deal
ERTMS	European Rail Traffic Management System
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
HDV	Heavy Duty Vehicle
HGV	Heavy Good Vehicle
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engine
IWW	Inland Waterways
km	Kilometre
M	Million
MS	Member States
NPV	Net Present Value
tkm	Tonne-kilometre

1. Introduction

The European Union (EU) has historically been at the forefront of global efforts to reduce greenhouse gas (GHG) emissions and address climate change. Notably, the European Green Deal (EGD) paves the way for making the EU climate-neutral by 2050, including a vast range of policies to promote renewable energy, enhance energy efficiency, and foster sustainable development.

Building on this framework, among the seven priorities for the 2024-2029 mandate of the European Commission defined by its President, Ursula von der Leyen, is the introduction of a Clean Industrial Deal to enshrine the 2040 EU climate target as well as to support EU's competitiveness, create quality jobs, and introduce an industrial decarbonisation accelerator act to aid companies in the transition.

Despite these ambitious plans, the EU's progress in decarbonising its economic system varies across sectors. While the power sector has seen significant advancements thanks to the increased adoption of renewable energy sources, the transport sector has lagged behind in its decarbonisation efforts.

This discrepancy was also recently highlighted in the Draghi Report (2024)[1]: "*transport can play a critical role in the decarbonisation of the EU economy, but whether it proves to be an opportunity for Europe depends on planning. Transport accounts for one-quarter of all greenhouse gas emissions and unlike other sectors, CO_2 emissions from transport are still higher than in 1990. However, lack of EU-level planning for transport competitiveness is hindering the ability of Europe to capitalise on the possibilities of multimodal transport to lower carbon emissions*". By addressing these challenges and ensuring comprehensive planning and investment, the EU can further accelerate its progress towards a climate-neutral future.

The decarbonisation of logistics[2] represents one of the most pressing challenges in this context. Logistics activities currently account for 10–11% of global CO_2 emissions, with freight transport contributing the vast majority[3]. This sector, heavily reliant on fossil fuels, faces the dual challenge of meeting steeply rising demand while achieving significant reductions in carbon intensity. Rail freight transport, as a critical component of logistics chains, must undergo profound transformations to fulfil this objective. While rail and inland waterway transport are inherently more carbon-efficient than road freight nowadays, the long-term modal share of rail freight has been eroded due to factors such as accessibility, flexibility and transit times. As highlighted by McKinnon (2018)[3], reversing this trend requires not only technological innovations but also a fundamental shift in how modes of transport are integrated and optimised across logistic chains.

This question lies at the heart of this study, which aims, through the analysis of the key dynamics between different modes of freight transport – rail, road, and inland waterways – to identify strategies to achieve substantial carbon reductions while ensuring economic efficiency, resilience, and ensuring that the sector fully contributes to enhancing the competitiveness of the European economy.

[1] *Draghi M. (2024), The future of European competitiveness. Retrieved from: [EU competitiveness: Looking ahead - European Commission](#).*

[2] *Logistics, as defined by McKinnon (2018), involves a "complex mix of freight transport, storage, handling, inventory management and all the IT required to co-ordinate these activities". Retrieved from: https://www.alanmckinnon.co.uk/.*

[3] *McKinnon A.C. (2018), Decarbonising Logistics: Distributing Goods in a Low Carbon World. Retrieved from: https://books.google.be/books/about/Decarbonizing_Logistics.html?id=USxdDwAAQBAJ&redir_esc=y.*

With the dual objective of ensuring the independence of the study and grounding it in the latest developments in academic literature, a group of scholars has been formed to frame the development of the methodology[4]. Furthermore, to ensure that the study reflects a wide range of perspectives, a Steering Committee[5] has been established, representing various key organisations and associations.

The approach adopted involves defining three scenarios that vary in their level of ambition and focusing the analysis on five key corridors. Each project scenario encompasses a set of measures, and the modelling exercise evaluates their effects on CO_2 emissions, other external impacts as well as cost savings, in comparison to a reference scenario, which embeds the most ambitious assumptions for the decarbonisation of road transport. A simplified cost-benefit analysis (CBA) is then performed to assess the socio-economic benefits associated with each scenario.

Several important results emerge from this analysis:

- First, all measures considered for the development of rail freight have a significant impact on the CO_2 emissions trajectory, even in a context where other transport modes, particularly road transport, undergo substantial decarbonisation during the period under review.
- Second, beyond the impact on CO_2 emissions, the modelling results reveal highly significant benefits in reducing other externalities, foremost among which are road traffic accidents and congestion. Despite the substantial investments required to implement some of the measures analysed, the magnitude of the socioeconomic benefits ensures that the CBA yields a positive outcome, providing a compelling rationale for such investments. These results are particularly robust given that, by design, the cost-benefit analysis does not account for the costs of decarbonising road transport[6], which amount to € 211 billion on the five corridors according to the estimations developed for this study[7]. This amount is more than four times higher than the investments considered in the high ambition scenario for the CBA (€ 50 billion – not discounted)[8]. Additionally, driven by improvements in energy efficiency combined with the higher energy efficiency of rail transport compared to road transport, the modal shift generated by the high ambition scenario results in a marked reduction in energy consumption, amounting to savings of €146 billion (not discounted) over the period considered. The savings represent significant resources that could be reinvested, notably to contribute to bolster the EU's competitiveness agenda.
- Third, it should be highlighted that, due to the fact that the outcomes should be interpreted in relation to a baseline scenario incorporating high ambitions for the decarbonisation of road transport, it ensures that the impact of the measures considered in the project scenarios are not overestimated. Furthermore, the results of the sensitivity analysis conducted indicate that, under a more realistic baseline for road transport, the effect of the proposed measures is significantly

[4] *The panel included the following academic experts:*
- *Juan Montero (European University Institute).*
- *Oliviero Baccelli (Bocconi University – GREEN).*
- *Florent Laroche (Laboratoire Aménagement Economie Transports).*
- *Anna Dolinayová (University of Zilina – Department of Railway Transport).*

[5] *The Steering Committee was composed of the following organisations: EU-Rail JU, CER, UNIFE, ETP-Alice, UIRR, CLECAT, EIM, UIP, ERFA and the European Commission DG MOVE.*

[6] *This stems to the fact that decarbonisation assumptions for road transport are embedded in the baseline scenario. See the methodological section (section 2) for more details on this point.*

[7] *As specified in section 2.3.4, the period considered for calculating these costs spans from 2025 to 2040, by which time 90% of road transport is expected to be zero-emissions according to the objectives defined by the EU.*

[8] *As indicated in section 2.3.6, the CBA only considers capital expenditures associated with the implementation of the measures and the costs of rail rolling stock electrification are not taken into account. However, the difference is such that, even when accounting for these costs as well as operational costs associated with the different measures, it is reasonable to believe that the total investment required for the high ambition scenario would still be lower than the cost of decarbonising road transport until 2040.*

stronger than in the main model. This results further highlights the strong potential contribution of the measures included in the high ambition scenario to the overall decarbonisation and efficiency of logistic chains in Europe.

The outcomes of the study clearly reveal the critical socio-economic benefits of developing rail freight as part of net-zero logistics chains. Moreover, the development of rail freight not only supports decarbonisation but also enhances the overall efficiency of the transport system, which will benefit to other transport modes, particularly road. By improving the performance of logistic chains, it will indeed help optimise freight flows, reducing inefficiencies resulting from empty truck runs or road congestion for example. It can therefore play a crucial role in strengthening the industrial competitiveness of Europe by reducing logistical costs and ensuring more sustainable and resilient supply chains. It is also worth noting that the rail manufacturing industry continues to thrive in Europe. Consequently, an increase in rail freight will not only bolster the domestic supply market but also enhance global competitiveness by creating a larger critical mass within the domestic market. For these reasons, these outcomes further underscore the great potential of rail freight in contributing to the ambitions of the EU's Clean Industrial Deal, the European Industrial Deal call by the Antwerp Declaration of February 2024[9] as well as the Sustainable and Smart Mobility Strategy[10].

It is worth underlining that these findings are grounded in an unprecedented effort, to EY-Parthenon's knowledge, to gather robust rail traffic data specifically for a study of this nature. The accuracy of the traffic estimates is crucial to the reliability of the impact assessments and, for that reason in particular, the project will likely bring significant added value to the understanding of the decisive advantages of rail transport and the actions required to unlock its full potential.

The structure of the report is as follows: Section 2 details the methodological approach, Section 3 presents the results of the modelling exercise. Section 4 provides concluding remarks and recommendations. The annex (Section 5) includes, notably, the description of the list of measures together with the values of the parameters chosen for the analysis, the presentation of the outcome of the sensitivity analysis conducted as well as a more detailed overview of some of the results of the modelling exercise.

[9] *More information can be found here: https://antwerp-declaration.eu/.*

[10] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789*

2. Methodological approach

2.1 The methodology at a glance

In a nutshell, the study consists in the assessment of the economic and environmental impacts of a range of investments and policy initiatives (referred to as measures hereafter) aiming to harness the development of net-zero logistics chains through, in particular, a better integration of rail transport.

The measurement of decarbonisation presents several key challenges and necessitates the use of carefully selected metrics. At its core, the decarbonisation trajectory is shaped by several interrelated factors that require precise calibration. These include the demand for freight transport, the evolution of CO_2 intensity, changes in energy intensity, and shifts in the modal mix. The interplay of these components is critical to understanding their collective impact. By analysing them, it becomes possible to shape mode-specific trajectories for CO_2 emissions resulting from the implementation of the measures under consideration.

In addition to establishing the metrics, a significant effort was dedicated to collecting and consolidating data. This foundational step was essential to calibrate the model accurately and enable it to generate robust and actionable insights.

As further detailed below, the analysis was structured using scenario-building for five key corridors, providing a detailed and robust framework to assess the effects of the series of measures considered. The exchanges with the academic experts and the Steering Committee concluded indeed that creating scenarios allows for a more precise comparison of the potential impacts of different policy approaches, ensuring a structured and comprehensive assessment. Such approach can therefore directly support decision-makers in identifying the most effective and feasible pathways to unlock the potential of rail freight transport for the development of net-zero logistic systems.

These scenarios focus on the primary transport modes – rail, road, and inland waterways – and encompass both the main transport lines and logistics hubs critical to each corridor. The results derived from these scenarios serve as the foundation for extrapolating outcomes at the regional catchment area of the corridors.

The analysis is structured around four main components:

- A freight traffic study to collect detailed and granular data on the chosen corridors.
- The development of the scenarios, bringing together a different set of measures.
- A CBA analysis per scenario, notably accounting for a range of sustainability dimensions (such as CO_2 emissions), to estimate the socio-economic benefits of the different measures and scenarios.
- An estimation of the wider economic impacts at EU level.

To structure the scenario analysis, the selected measures are categorised into three groups, each defining a distinct level of ambition: *low*, *moderate* and *high*. In addition to the three scenarios, a baseline scenario has been established to serve as a reference point, enabling comparative analysis across the different scenarios.

It is expected that each scenario will result in a different trajectory in terms of CO_2 emissions reduction in particular and, more generally, on external costs. The *low ambition* scenario reflects modest efforts, the *moderate ambition* scenario represents a balanced approach, and the *high ambition* scenario aims to achieve the maximum potential for reducing CO_2 emissions and other external costs through more comprehensive measures.

To assess the effects of the different measures across scenarios, a comprehensive model has been developed. Harnessing all the relevant data sources that EY-Parthenon was able to identify, the model allows for an estimation of the effects of the various measures on the demand for each mode of transport and, in turn, the associated effect on CO_2 emissions and broader external costs. To contribute to a structured and objective assessment of the economic, social and environmental benefits of the set of measures included in the study, the model has been designed to allow for the development of a CBA per scenario.

As a corollary, it also enables the estimation of the effects in terms of energy usage. These are important complements as savings in this respect can free up financial resources, enabling reinvestment in other critical areas such as infrastructure improvements or operational upgrades. This capability underscores the model's potential not only for environmental impact analysis but also for supporting broader economic efficiency within the transport and logistics sectors.

2.2 Delineating the scope

2.2.1 Geographical scope

While the study aims to cover the entire European territory, the modelling exercise has been restricted to five key corridors:

- North-Sea-Rhine Mediterranean.
- Scandinavian-Mediterranean.
- Baltic-Adriatic.
- Mediterranean.
- Western Balkans – Eastern Mediterranean.

The coverage of the different corridors is illustrated in Figure 1 below (details on the different corridors are provided in the annex).

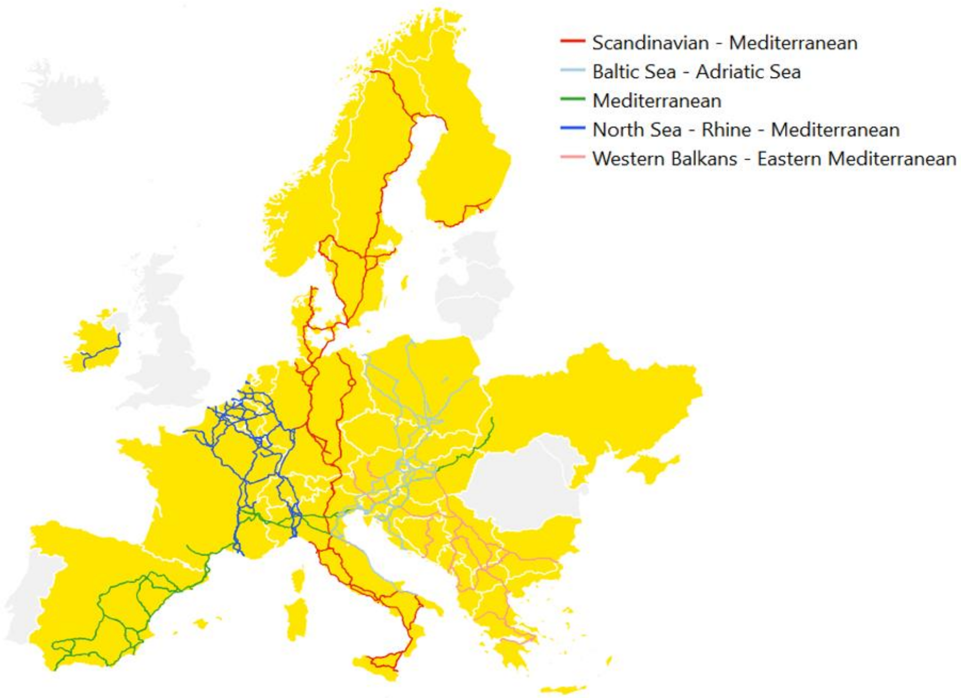

Figure 1: Corridors covered in the study

As mentioned above, drawing from discussions with the academic experts and the Steering Committee, it was agreed that a corridor analysis, while de facto limited in scope, can actually serve as a solid basis to extrapolate the results at macro level for different reasons.

First, it provides for a structured and very granular approach to assess the impact of a range of measures on the freight transport market, including those concerning hubs. Such analysis would hardly be feasible with a more holistic approach.

Second, focusing on these corridors also allows to build on the body of studies that have been dedicated to them. It is worth noting, however, that this project differs significantly since it focuses specifically on developing more efficient logistic chains combinations to reach the decarbonisation and competitiveness of freight in Europe.

Third, these corridors have been selected to ensure a high degree of representativeness of the European rail system (both in terms of volume, structure of the logistic chains and geographical coverage). These corridors account for a very large part of the overall rail freight demand in tonne-kilometre (tkm) for 2024, demonstrating their critical role in logistic activities across the EU. The significance of these corridors is further highlighted by their extensive geographical coverage, reaching 80% of EU countries equipped with a rail system. Moreover, the corridors traverse countries that account for 95% of the total EU GDP and 95% of the total EU population[11]. Not only this underscores the economic importance of the connected regions, but it also allows for a robust assessment of the effects of the measures under consideration on the development of net-zero logistic chains. Besides, in addition to connecting major seaports such as Hamburg, Antwerp, Rotterdam, Trieste, Genova, Gioia Tauro, Le Havre, and Gdansk, the set of corridors includes both the East-West and North-South axes as well as a connection to Ukraine. These characteristics further cements their status as key logistics axis across the EU.

The strategic importance of these corridors is further underscored by their status as the segments of the network facing the greatest challenges in accommodating the anticipated increase in cross-border freight traffic. They generate major investment challenges, as enhancing the capacity and efficiency of these corridors will be paramount in meeting the growing needs to develop efficient and net-zero logistic chains. By focusing the analysis on these corridors, the project allows to identify key areas where targeted measures can yield significant improvements in logistic chains, thereby supporting the EU's broader goals of economic sustainability, competitiveness and growth.

Building on the detailed assessment conducted for the five corridors, an assessment of the wider economic impacts is then realised.

2.2.2 Components of the logistics chains and transport modes

The study includes the entire inland logistics chain in the assessments: rail, road and inland waterways (IWW) freight transport. Logistics hubs are included through a dedicated measure aiming at increasing their capacity to accommodate future demand increase[12].

Deep-sea shipping is not considered since measures to achieve Net-Zero in this area partially fall outside the scope of the EU's responsibility.

Intra-EU freight transport by air has also been excluded due to its limited share of EU freight transport performance (based on tkm performed). In 2022, air transport accounted for only 0,2% of freight

[11] *Source: Eurostat.*

[12] *It should be noted that, due to the lack of detailed and robust data, the CO_2 emissions of logistics hubs have not been included in the study.*

transport volumes in the EU, with its market share remaining quite stable in all EU countries since 2012[13]. Intra-EU freight transport by air is also responsible for a relatively small share of GHG emissions compared to other transport modes. According to the Annual European Union greenhouse gas inventory 1990 – 2022 and inventory document 2024, domestic aviation including passenger and freight transport was responsible for only 0,3% of EU GHG emissions in 2022[14].

2.2.3 Time horizon

To align with the EU's climate policy cycles, the model enables an assessment of the impact of various measures over the entire period from 2025 to 2050. This approach offers a comprehensive perspective for the entire timeframe, while also providing insight at key EU milestones in 2030, 2040, and 2050.

Yet, to fully account for the long-term effects of the investments considered in the series of measures selected, the time horizon has been extended to 2060 for the cost-benefit analysis.

2.3 Modelling the impact of the selected measures and the scenarios

As mentioned above, an extended economic model has been developed to analyse rail transport's contribution to achieving net-zero logistics. The model consists of two main parts:

- A demand assessment tool to develop freight transport demand forecasts per corridor.
- A CBA building on the outputs of the demand assessment to estimate economic and environmental effects of the range of selected measures.

The figure below (Figure 2) illustrates the structure of the model.

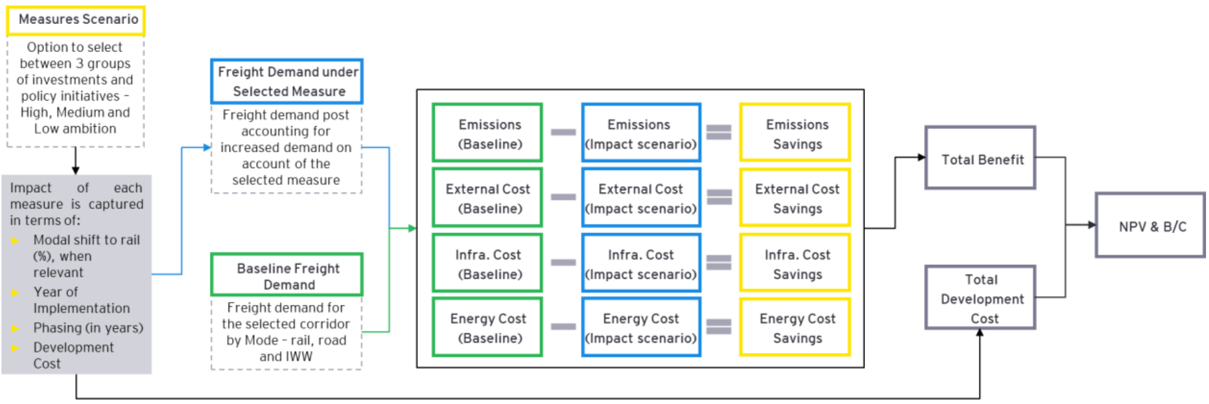

Figure 2 : Overview of the model

[13] EC (2024). Freight transport statistics - modal split. Retrieved from: Freight transport statistics - modal split - Statistics Explained.

[14] EEA (2024). Annual European Union greenhouse gas inventory 1990 – 2022 and inventory document 2024. Retrieved from: Annual European Union greenhouse gas inventory 1990-2022 and inventory document 2024 | European Environment Agency's home page.

2.3.1 Key metrics

Estimating the impact of various measures on the trajectory of CO_2 emission reduction involves a comprehensive analysis of several key and interrelated levers:

- The evolution of demand for transport, which directly influences the volume of CO_2 emissions associated with the transport modes across the logistic chains.
- The shift in modal share towards transportation modes that generate less CO_2, such as rail or IWW.
- The changes in CO_2 intensity. This component examines how the carbon emissions per unit of freight transported are expected to change over time. It takes into account advancements in energy efficiency as well as the adoption of cleaner energy sources.
- The evolution of energy intensity related to freight transportation. This involves assessing how the energy consumption per unit of freight transported is expected to evolve, notably due to changes in the modal shift towards transportation modes that are less energy-intensive, or the use of more efficient transportation equipment can further enhance this energy efficiency.

2.3.2 Evolution of the baseline demand for transport

Due to a lack of recent usable data, significant work was undertaken to collect and process data to establish demand by corridor at the beginning of the period for each mode. Very detailed data for rail transport at corridor level was provided by RailNetEurope (RNE) for the years 2023 and 2024. Given the large volume of data and the complexity of the processing required, a Python model was developed to process this data and extract a demand value by corridor in tkm. It is important to underline that this represents a significant contribution of the study. Despite the extensive research conducted by EY-Parthenon, no precise and recent data could be identified in terms of tkm per corridor. In this regard, this study has established a solid foundation of traffic volumes by corridor, upon which further studies will be able to build.

To establish traffic projections for rail transport per corridor, an econometric model was developed to estimate the relationship between past traffic in tkm and key variables such as GDP per capita and oil prices. Due to the lack of corridor-specific data, the modelling utilised traffic data in tkm by country provided by Eurostat for the period 2004-2022. Various grouping of these economic variables was done based on the country coverage of each of the corridors. Once the coefficients were estimated, they were applied to projections of the explanatory variables to establish traffic projections for the period 2025-2050, based on initial traffic values determined from the data provided by RNE for 2023 and 2024.

Given the absence of recent data available, the initial demand levels for road and IWW transport were determined by using the overall market share of each of the three transport modes in Europe (as provided by Eurostat for the year 2023). The respective volume of each mode has been determined by using the value for rail transport provided by the RNE data for that same year. It is important to note that for IWW, this only concerns the corridors where there is actually such transport mode, namely the North-Sea-Rhine Mediterranean and Baltic-Adriatic corridors.

The projection method used for road transport is the same as for rail transport. As for IWW transport, the econometric models did not result in usable outcomes. It was therefore decided to adopt an annual growth rate of 1% starting from 2024.

The figure below (Figure 3) illustrates the baseline demand projections for the three transport modes over the period. It shows that the overall demand increases from 1437 bn tkm in 2025 to 1989 bn tkm in 2050.

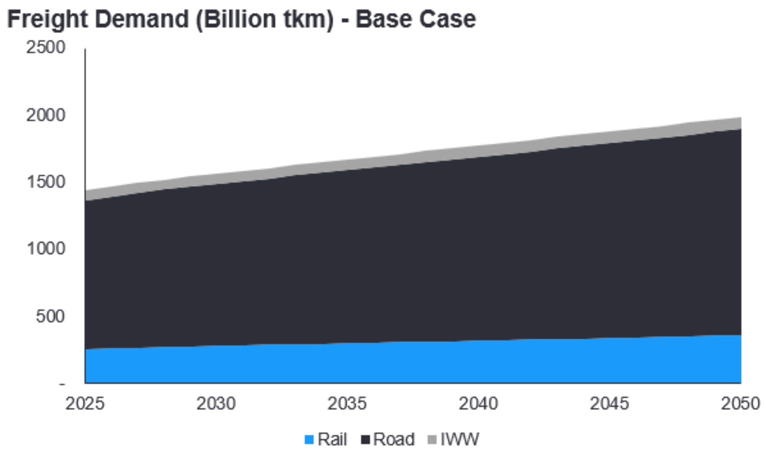

Figure 3: Evolution of demand for freight transport in the baseline scenario

2.3.3 Evolution of the demand for rail transport in the project scenarios

The evolution of demand for rail transport in the project scenarios results from the modal shift generated by the measures[15]. For simplicity, it is assumed that an increase in rail transport demand (in tkm) due to a change in the modal shift would correspond to an equivalent reduction in road transport demand, with the demand for IWW transport remaining unchanged. While this is a simplifying assumption, it appears reasonable, especially since IWW transport represents a relatively small share of the overall traffic volumes and only concerns two corridors out of the five considered (North-Sea-Rhine Mediterranean and Baltic-Adriatic corridors).

It should be noted here that the percentage change in demand in the context of a modal shift can be applied either to rail demand only or to the whole demand (i.e., including road and IWW transport). By default, this percentage has been applied to the total demand, except for three specific measures, for which it currently seems more accurate to apply it only to rail demand: the deployment of DAC, ERTMS, and the roll- out of Europe's Rail technical outputs.

It is also to be underlined that the modal shifts estimated does not apply to road traffic under 300 km, as shorter distances typically favor road transport due to lower operational costs and faster delivery times. Therefore, for traffic under 300 km, the shift to rail is less likely to occur in practice. The model accounts for this by excluding such traffic, focusing on the distances where rail transport can be a viable alternative to road haulage. It does so by applying the modal shifts to 70% of the road demand, which corresponds to the share of road traffic in tkm above 300 km in Europe[16,17].

Similarly, the model accounts for the capacity constraints related to the large-scale rail infrastructure modernisation projects that will happen in some countries crossed by the corridors (e.g. Germany and Italy). For that purpose, the potential modal shift per scenario has been capped at 10% until 2040 for the all the corridors.

[15] *It should be underlined that not all measures generate modal shift (e.g., the development of alternative fuels or the investment in multimodal terminals – see annex for more details on this point).*

[16] *Source: Eurostat (2024). Road freight transport statistics. Retrieved from: Road freight transport statistics - Statistics Explained.*

[17] *This threshold distance is likely to evolve due to the implementation of various measures considered in the study, as they may help making rail transport more competitive over short distances. For the sake of simplicity, this potential evolution is not taken into account in the study, but it would certainly be relevant to assess its effects in the context of further work.*

2.3.4 Changes in energy intensity, including for the baseline scenario

The model takes into account the expected evolution of energy intensity across modes[18]. The energy intensity determines the amount of energy required by unit of transport, making it a key factor in operating costs and CO_2 emissions.

The values used in the model for rail energy intensity for diesel and electric traction are presented in Table 1. The chosen values are derived from the analysis developed by EU-Rail (2024)[19] on energy savings in rail. The report provides an average energy intensity of 0,22 MJ/tkm for rail freight transport. To disaggregate the average energy intensity value into separate values for diesel and electric trains, it is necessary to first specify the efficiency values for each type of traction. According to EU-Rail (2024, p. 27), diesel trains operate at approximately 40% efficiency, while electric trains achieve an efficiency of 87,3%. Under the assumption that traction energy accounts for 80% of the total system's energy intensity (EU-Rail, 2024, p. 26) and non-traction energy intensity identical for both, the diesel-to-electric energy intensity ratio is therefore 2,18 (yielding values of 0,30 MJ/tkm for diesel traction and 0,14 MJ/tkm for electric propulsion).

A reduction in energy intensity for rail transport towards 2050 is applied in the moderate and high ambition scenarios as their corresponding measures are expected to drive an increase of energy efficiency[20]. For the baseline scenario and the low ambition scenario, the value is kept unchanged at its current level indicated in Table 1. The decreasing trend is directly taken from the EU-Rail report (2024) and applies to diesel and electric traction.

Traction type	Current	2030 (for moderate and high ambition scenario only)	2040 (for moderate and high ambition scenario only	2050 (for moderate and high ambition scenario only)
Diesel	0,30	0,29	0,24	0,20
Electric	0,14	0,13	0,11	0,09

Table 1: Rail transport energy intensity for diesel and electric traction [MJ/tkm]

For alternative fuel traction, a slightly different approach has been adopted to model the reduction of energy intensity, taking into account the progressive deployment of alternative fuels across the three project scenarios. An initial energy intensity value of 0,30 MJ/tkm has been selected for the year 2025, based on the exclusive use of biodiesel in the alternative fuel mix, which exhibits similar energy intensity to diesel traction.

The reduction in energy intensity has been differentiated across scenarios as follows:

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[18] *For simplicity, the evolution of the energy intensity of inland waterways (IWW) are not accounted for in this analysis. It appears to be a reasonable simplification, given that inland waterway transport (IWW) has a low modal share and is not significantly affected by the measures analysed. Furthermore, due to the assumptions made regarding the evolution of transport demand over time, its modal share is decreasing in the baseline scenario, which further justifies its exclusion.*

[19] *Europe's Rail (2024). Energy saving in Rail: Consumption assessment, efficiency improvement and saving strategies, overview report. Retrieved from: ERSIPB-EDSIPB-B-S2R-219-01_-_20240314_Energy_saving_measures_in_rail_report_changes__2_.pdf.*

[20] *The increase in train length (as part of the high ambition scenario) is, for example, expected to lead to significant energy efficiency increases.*

- Low Ambition Scenario: Energy intensity decreases from 0,30 MJ/tkm in 2025 to 0,20 MJ/tkm by 2050.
- Moderate Ambition Scenario: Energy intensity reduces from 0,30 MJ/tkm in 2025 to 0,15 MJ/tkm by 2050.
- High Ambition Scenario: Energy intensity falls from 0,30 MJ/tkm in 2025 to 0,11 MJ/tkm by 2050.

These variations are driven by differing assumptions regarding the inclusion of hydrogen and battery-operated traction within the scenarios:

- Low Ambition Scenario: Biodiesel remains the sole component of the alternative fuel mix.
- Moderate Ambition Scenario: Hydrogen and battery-operated traction account for 20% each of alternative fuels traction, the rest being biodiesel.
- High Ambition Scenario: Hydrogen and battery-operated traction constitute 40% each of alternative fuels traction, the rest being biodiesel.

Regarding the energy efficiency of road transport, the model uses the conservative assumption that rail transport is 3,5 times more energy efficient than road transport. For diesel and electric traction, the energy efficiency values are obtained by multiplying the values for rail energy efficiency presented in presented in Table 1 by this factor[21]. The values used in the model for diesel and electric traction are therefore obtained by multiplying the values for rail energy efficiency presented in Table 1 by this factor. For the sake of clarity, the full set of values used for alternative fuels is not presented here. They have however been determined using the same approach, by multiplying rail energy intensity values per 3,5.

It is worth noting that that they are consistent with the estimates provided by the Smart Freight Centre (2024)[22] for diesel-powered trucks. It should be noted that, as for rail transport in the moderate and high ambition scenario, these values reflect an improvement in energy efficiency over the period. By construction, this evolution is akin to that of rail transport.

Traction type	Current	2030	2040	2050
Diesel	1,06	1,00	0,85	0,69
Electric	0,48	0,46	0,39	0,31

Table 2: Road transport energy intensity for diesel and electric traction [MJ/tkm]

These values reflect the fact that rail transport is more energy-efficient than road transport. This can be attributed to several factors, including better aerodynamics, lower resistance forces and a more linear rail infrastructure.

It should also be underlined that changes in energy efficiency figures directly impact well-to-tank and tank-to-wheel CO_2 emissions and thus external costs. The model account for this effect in the estimations of CO_2 emissions and external costs in the different project scenarios.

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[21] *These values follow the same trend as that of rail energy intensity values in the moderate and high ambition scenarios.*

[22] *Smart Freight Centre (2024). Global Logistics Emissions Council Framework. Retrieved from: GLEC_FRAMEWORK_v3_UPDATED_02_04_24.pdf.*

2.3.5 Changes in CO_2 emissions, including for the baseline scenario[23]

The measurement of CO_2 emissions is considering both well-to-tank and tank-to-wheel components. Well-to-tank emissions reflect the carbon intensity of energy production and supply, capturing the emissions generated from energy production, transportation, and distribution. Tank-to-wheel emissions, on the other hand, focus on the emissions produced by vehicles during operation, depending on the type of fuel used and the efficiency of the vehicle technology.

The initial values to calculate emissions per mode in g of CO_2 per tkm are derived from the Fraunhofer et al. study (2020) on a "Methodology for GHG efficiency of transport modes", updated according to the analysis developed by the European Environment Agency in 2023[24,25,26,27].

The baseline scenario adopts the most ambitious decarbonisation assumptions for road and IWW transport. This choice, resulting from guidance received from the academic experts and the Steering Committee, serves a dual purpose.

First, by establishing an ambitious baseline for the other transport modes, the model can more accurately isolate and assess the unique contribution of rail freight development to CO_2 emissions reductions. This approach ensures that the impact of rail freight measures is not overestimated by assuming a less progressive baseline for other modes, thereby providing a more robust and transparent analysis of their effectiveness.

Second, this methodology allows the study to account for the broader economic environment in which transport systems operate, highlighting the critical role of intermodal coordination and complementarity in achieving decarbonisation targets. It underscores the importance of evaluating rail freight development within a context where all modes are expected to contribute to emissions reductions through ambitious measures.

Consequently, the road transport component of the baseline scenario incorporates the EU's ambitious targets for heavy goods vehicles (HGVs). The EC regulation on CO_2 emission standards for heavy-duty vehicles set clear milestones for tank-to-wheel CO_2 emissions reductions[28]: 45% by 2030, 65% by 2035, and 90% by 2040, compared to 2019 levels. As these targets pertain to new vehicles entering in circulation, which will be done progressively, the model builds on the assumption that there will be a 90% reduction (compared to 2019 levels) in the total emission levels of HDVs by 2050. Modelling this reduction involves two key factors: the evolution of the composition of road traffic and the changes in tank-to-wheel emissions for each mode over the period. The initial value for tank- to-wheel diesel HGVs emissions is taken from the Fraunhofer et al. study on a "Methodology for GHG efficiency of transport modes" (2020). The initial value for alternative fuel traction (3,64 gC02/tkm) is obtained by assuming that the emissions represent 3,4% of diesel emissions, based on the unit values for

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[23] *Here and throughout, all CO_2 emission values are given in CO_2 equivalent.*

[24] *Fraunhofer, CE Delft and Ramboll (2020), Methodology for GHG Efficiency of Transport Modes. Retrieved from:* https://cedelft.eu/wp-content/uploads/sites/2/2021/05/CE_Delft_200258_Methodology_GHG_Efficiency_Transport_Modes.pdf.

[25] *EEA (2024), Greenhouse gas emission intensity of electricity generation in Europe. Retrieved from:* https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-mission-intensity-of-1.

[26] *The analysis developed by the European Environment Agency in 2023 leads to a significant reduction (37%) of the WtT value given by Fraunhofer (2020) for rail transport. This decrease reflects the EU's ongoing efforts to transition to renewable energy sources and improve energy efficiency transmission and improve the sustainability of electric trains compared to diesel.*

[27] *It is worth noting that, due to the lack of more detailed data, average values across the EU have been used, which conceals significant cross-country disparities. The relatively higher well-to-tank emissions for electric rail freight are mainly due to the fact that electricity generation in some Member States remains carbon-intensive. However, the relative values ratio between electric and diesel emissions shifts rapidly in the project scenarios, as a result of the assumptions made for the decarbonisation of well-to-tank emissions (see Table 1) associated with diesel traction.*

[28] *Regulation (EU) 2024/1610 of the European Parliament and of the Council of 14 May 2024 amending Regulation (EU) 2019/1242 as regards strengthening the CO_2 emission performance standards for new heavy-duty vehicles and integrating reporting obligations, amending Regulation (EU) 2018/858 and repealing Regulation (EU) 2018/956.*

emissions of each of the modes presented in section 5.1.2.3 dedicated to the alternative fuels measure[29]. Both emissions follow a decreasing trajectory, similar to that of energy intensity (see section 2.3.4). It should be noted that tank-to-wheel emissions are set to zero for the electric traction mode. By combining these trajectories with a projected evolution of road traffic distribution over the period (see Table 3), this results in an overall reduction of tank-to-wheel emissions by more than 90% over the period. Table 4 presents the details of the values used in the model[30].

Traction type	Current	2030	2040	2050
Diesel	100%	85%	40%	0%
Electric	0%	5%	30%	50%
Alternative Fuels	0%	10%	30%	50%

Table 3: Evolution of the composition of road transport in the baseline scenario.

Traction type	Current	2030	2040	2050
Diesel	108,00	102,60	82,08	53,35
Electric	-	-	-	-

Table 4: Average tank-to-wheel emission factors for road transport [gCO_2/tkm].

Additionally, well-to-tank emissions for road transport reflect the fact that, according to IEA's projections, 90% of electricity generation will come from clean energy sources by 2050 under the Net-Zero scenario[31]. As for tank-to-wheel emissions, the initial value for well-to-tank diesel HGVs emissions (0,98 gC02/tkm) is taken from the Fraunhofer et al. study (2020) on a "Methodology for GHG efficiency of transport modes". The chosen value for electric vehicles was obtained by applying a ratio representing the difference in energy intensity between rail and road transport. The determination of the value for alternative fuel traction follows the same methodology used for tank-to-wheel emissions. Similar to what has been done for tank-to-wheel emissions, both emissions (for diesel and alternative fuels traction) follow a decreasing trajectory, identical to that of energy intensity (see section 2.3.4). Table 5 presents the details of the values used in the model for this parameter[32].

[29] *This ratio has been calculated using an equal split between bio-diesel, hydrogen and battery.*
[30] *As for the evolution of energy intensity, the detailed values for alternative fuels are not presented here.*
[31] *International Energy Agency (2024). Net Zero by 2050. A Roadmap for the Global Energy Sector. Retrieved from https://www.iea.org/reports/net-zero-by-2050.*
[32] *As for the evolution of energy intensity, the detailed values for alternative fuels are not presented here.*

Traction type	Current	2030	2040	2050
Diesel	29,00	27,55	22,04	14,33
Electric	33,60	23,52	13,44	3,36

Table 5: Average well-to-tank emission factors for road transport [gCO_2/tkm].

The baseline scenario also includes the pathway to zero emissions for IWW transport, as defined by the NAIADES III strategy and targets from the Central Commission for the Navigation on the Rhine (CCNR). Accordingly, IWW vessels are expected to become zero-emission by 2050 for the tank-to-wheel component, driven by the adoption of clean energy technologies[33,34]. The assumptions as regard well-to-tank emissions are the same as for road transport.

For rail transport, the baseline scenario includes the assumption that rail transport through electric trains will achieve net-zero well-to-tank emissions by 2040 through the implementation of Green Power Purchase Agreements (PPAs) for example, enabling the rail sector to source electricity exclusively from clean energy (see Box 1). The base values, which remains constant in the baseline scenario, are sourced from the Fraunhofer et al. study (2020) on a "Methodology for GHG efficiency of transport modes". The estimation of the value used for the alternative fuel traction has been made using a reference ratio of 9,4%[35] between diesel and the alternative emissions. It should be noted that the values for diesel and alternative fuels traction for rail transport remain constant in the baseline scenario as it is assumed that the improvement of energy efficiency will occur only in the moderate and high ambition scenario, under the influence of the measures they embed.

The resulting values for the rail baseline scenario are given in Table 6:

Traction type	Current	2030	2040	2050
Diesel	1,64	1,64	1,64	1,64
Electric	9,60	6,72	-	-
Alternative Fuels	0,15	0,15	0,15	0,15

Table 6: Average well-to-tank emission factors for rail transport in the baseline scenario [gCO_2/tkm]

[33] *European Commission (2021) NAIADES III Boosting future-proof European inland waterway transport. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0324&from=EN.*

[34] *CCNR (2021), Study on financing the energy transition towards a zero-emission European IWT sector. Retrieved from: Final_overall_study_report.pdf.*

[35] *This ratio has been derived from the unit values for emissions of each of the modes presented in section 5.1.2.3 dedicated to the alternative fuels measure. It differs from the value used for road transport as a different distribution between bio-diesel, hydrogen and battery is assumed. Due to the assumption on the evolution of the composition of the alternative fuels category across scenario, this ratio of 9,4% is constant for baseline and low ambition scenario but for the other scenarios (moderate and high ambition) it evolves to 5,8% and 2,2% respectively by 2050.*

As for tank-to-wheel emissions for rail transport, no decarbonisation measures are accounted for in the baseline, maintaining the current emissions trajectory estimated by the CE Delft study for the European Commission on the external costs of transport as a reference point. The value for alternative fuel traction was determined similarly to wheel-to-take emissions, by using the ratio of 9,4% between diesel and the alternative fuels emissions. The average tank-to-wheel emission factors for rail transport in the baseline scenario are presented in Table 7.

Traction type	Current	2030	2040	2050
Diesel	7,06	7,06	7,06	7,06
Electric	-	-	-	-
Alternative Fuels	0,67	0,67	0,67	0,67

Table 7: Average tank-to-wheel emission factors for rail transport in the baseline scenario [gCO_2/tkm]

The baseline scenario also includes a progressive electrification of rail rolling stock[36]. The values used as regard the evolution of the traffic mix are presented in the table below (Table 8):

Traction type	Current	2030	2040	2050
Diesel	18,4%	15,0%	10,0%	10,0%
Electric	81,6%	85,0%	90,0%	90,0%
Alternative Fuels	0,0%	0,0%	0,0%	0,0%

Table 8: Evolution of the composition of rail transport in the baseline scenario

[36] *The assumption as regard vehicle electrification are as follows: the share of freight demand using electric traction increases from 81.6% currently and to 90% by 2040. The actual share of freight traffic using electric traction is taken from data provided by UNIFE, retrieved from: https://www.unife.org/activities/environment-and-sustainability/diesel-traction/.*

In the three project scenarios (low, moderate and high ambition), the trajectories of rail CO_2 emissions incorporate differentiated hypotheses due to the corollary effects of their corresponding measures on energy efficiency. It should be noted that these reduction trajectories of energy intensity and their effects on CO_2 evolutions in the project scenarios only concern diesel and alternative fuels traction modes. Indeed, regarding electric traction, the simulated evolution of well-to-tank CO_2 emissions for rail transport follows a different logic that does not involve changes in energy intensity. As for the baseline scenario, they are gradually reduced to 0 by 2040 to reflect that, as mentioned above, it is assumed that the rail sector should be able to source electricity exclusively from renewable energy by 2040. Regarding tank-to-wheel emissions from electric traction modes, they are assumed to be null as for the baseline.

For the low ambition scenario, the levels of well-to-tank and tank-to-wheel emissions for diesel traction remain unchanged compared to the baseline scenario because it is assumed that the two measures characterising it will not have any particular impact on energy intensity for this traction mode. As for well-to-tank and tank-to-wheel emissions associated alternative with fuels traction, they follow a decreasing trend following the evolution of energy intensity in the low ambition scenario (see section 2.3.4).

For the high ambition scenario, it is assumed that the measures will lead to a significant reduction in energy efficiency for diesel traction and consequently, a reduction of the same proportion in well-to-tank and tank-to-wheel CO_2 emissions. This reference evolution is presented in Table 1. The evolution of emissions from alternative fuels reflects the reduction trajectory of energy efficiency presented in section 2.3.4.

For the moderate ambition scenario, it is assumed that the more modest nature of the considered measures will lead to a less pronounced reduction in energy intensity and, consequently, in CO_2 emissions over the period. For simplicity, we assume an energy intensity decrease to half of the full trajectory used within the high ambition scenario, both for diesel and alternative fuels traction.

The tables below (Table 9, Table 10, Table 11, Table 12, Table 13, and Table 14) present the values of well-to-tank and tank-to-wheel emissions used in the different project scenario. The emissions values for the low ambition scenario as the same as for the baseline scenario (see Table 6 and Table 7).

Traction type	Current	2030	2040	2050
Diesel	1,64	1,64	1,64	1,64
Electric	9,60	6,72	-	-
Alternative Fuels	0,15	0,15	0,12	0,08

Table 9: Average well-to-tank emission factors for rail transport in the low ambition scenario [gCO_2/tkm]

Traction type	Current	2030	2040	2050
Diesel	1,64	1,60	1,44	1,23
Electric	9,60	6,72	-	-
Alternative Fuels	0,15	0,15	0,10	0,05

Table 10: Average well-to-tank emission factors for rail transport in the moderate ambition scenario [gCO_2/tkm]

Traction type	Current	2030	2040	2050
Diesel	1,64	1,56	1,25	0,81
Electric	9,60	6,72	-	-
Alternative Fuels	0,15	0,15	0,07	0,02

Table 11: Average well-to-tank emission factors for rail transport in the high ambition scenario [gCO_2/tkm]

Traction type	Current	2030	2040	2050
Diesel	7,06	7,06	7,06	7,06
Electric	-	-	-	-
Alternative Fuels	0,67	0,63	0,51	0,33

Table 12: Average tank-to-wheel emission factors for rail transport in the low ambition scenario [gCO_2/tkm]

Traction type	Current	2030	2040	2050
Diesel	7,06	6,88	6,21	5,27
Electric	-	-	-	-
Alternative Fuels	0,67	0,63	0,41	0,20

Table 13: Average tank-to-wheel emission factors for rail transport in the moderate ambition scenario [gCO_2/tkm]

Traction type	Current	2030	2040	2050
Diesel	7,06	6,71	5,37	3,49
Electric	-	-	-	-
Alternative Fuels	0,67	0,63	0,31	0,08

Table 14: Average tank-to-wheel emission factors for rail transport in the high ambition scenario [gCO_2/tkm]

The project scenarios are also including a measure dedicated to the development of alternative fuels. In that perspective, a hypothesis has been made for the development of alternative fuel traction across the scenarios. The share of alternative fuels gradually increases to 2% in 2050 in the low ambition scenario, 5% in the moderate ambition scenario and 10% in the high ambition scenario. This evolution occurs at the detriment of the share of diesel traction, the share of electric traction over the period remaining unchanged compared to the baseline scenario.

Box 1

Power Purchase Agreements (PPAs) are contracts that facilitate the purchase of renewable energy, helping companies transition to green electricity. Although a PPA can technically pertain to contracts for any type of energy, it typically refers to those involving the purchase of renewable energy in recent years. Many companies rely on PPAs to source green electricity, reducing the uncertainty primarily associated with electricity price fluctuations.

Large companies purchasing substantial amounts of power from electricity suppliers face risks of cost instability and unpredictability. PPAs are primarily driven by the need to hedge against energy price volatility, leading many corporations to sign agreements at prices above market value for long-term price stability. Corporate PPAs bring significant benefits to both producers and companies. For renewable energy developers, long-term PPAs, typically exceeding ten years at fixed prices, enhance the ability Being major consumers of electricity, railway operators are increasingly relying on PPAs to source renewable electricity for train traction, for passenger as well as for rail freight transport activities. Many railway companies in Europe are setting targets to progressively become climate neutral, implying a progressive reduction in their transport-related GHG emissions using more and more renewable power. For example, in the case of Deutsche Bahn (DB), a major target is to rely on 80% green traction power by 2030 and 100% green by 2038.

Complementary to PPAs, railway companies do sometimes rely on the purchase of guarantees of origin, which certify the renewable origin of the purchased electricity, as well as on electricity produced from on-site renewable installed capacity (e.g. solar PV, wind turbines).

2.3.6 Cost-benefit analysis

2.3.6.1 Methodology

Building on the demand forecast, the CBA estimates the net benefits associated with the introduction of the series of measures selected. It does so by comparing the benefits associated with the implementation of the measures with their respective costs, all expressed in real Euro. The socio-economic impacts of the measures have been assessed in accordance with the European Commission's guidelines for CBAs on transport infrastructure[37].

The method used here for the CBA is the differential approach. It consists in preparing the projections and calculations for the base and project scenarios separately. The difference between the results of project scenario and the base scenario describes the impact of the scenario and its added value.

Results are measured through a Net-Present Value (NPV) and Benefit- Cost ratio:

- The NPV is the difference between discounted total social benefit and social cost, valued at shadow prices, and expressed in monetary values.
- The B/C ratio is the ratio between discounted economic social benefits and social costs.

For an economically viable project, the NPV must be positive, while the B/C ratio must be greater than 1.

The study undertakes a simplified CBA as it only considers the costs and benefits which were available for all measures and could be re-used for the macro-level CBA. No default assessment has been carried out to fill the gaps.

2.3.6.2 CBA timeline and social discount rate

The CBA is built on a 33-year timeline, which is a little longer than the standard recommendation for rail projects[38] assessments. Yet, the scenarios include a bundle of measures which are deployed progressively, and some of the measures are expected to last more than 30 years after deployment (e.g. ERTMS, DAC).

The first year of the calculation is the first year of investment (2028), meaning that costs and benefits will be considered for the period 2028-2060.

The CBA is done in nominal terms, meaning inflation is not taken into account.

The social discount rate used for this analysis is set at 3%, as recommended by the EU Better Regulation Toolbox 2021[39] and Economic Appraisal Vademecum 2021-2027[40]. It means that future costs C_n and benefits B_n from year n are discounted by the following formula:

$$NPV(B_n \text{ or } C_n) = (B_n \text{ or } C_n) \times \frac{1}{(1+3\%)^{(n-2028)}}$$

[37] *European Commission (2021). Economic Appraisal Vademecum 2021-2027. Retrieved from: Economic appraisal vademecum 2021-2027 - Publications Office of the EU.*

[38] *European Commission (2022) "Guide to the cost-benefit analysis for investment projects". Retrieved from: https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf.*

[39] *European Commission (2021). Better regulation toolbox. Retrieved from: https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en.*

[40] *European Commission (2021). Economic Appraisal Vademecum 2021-2027 - General Principles and Sector Applications. Retrieved from: https://ec.europa.eu/regional_policy/en/information/publications/guides/2021/economic-appraisal-vademecum-2021-2027-general-principles-and-sector-applications.*

2.3.6.3 Geographical scope

The geographical scope considered in the CBA is focusing on the to five key corridors described in section 2.2.1:

- North-Sea-Rhine Mediterranean.
- Scandinavian-Mediterranean.
- Baltic-Adriatic.
- Mediterranean.
- Western Balkans – Eastern Mediterranean.

2.3.6.4 Benefits

The benefits from the measures identified are mainly driven by the modal shift from road to rail. This modal shift is usually translated in two main indicators:

- The economic surplus, which represents the benefits for the final customer (the shipper) to transfer its goods from road or inland waterway to rail thanks to the improved performance of rail. The relative performance of each mode of transport is usually represented by several factors such as the price of each mode, the travel time, or the reliability of the service, which are translated into a generalised cost. The increase in rail performance leads to a reduction of the generalised cost of rail (GC in Figure 4 below), which, in turn, triggers an increase in rail traffic (T in Figure 4 below). This can be represented in the figure below (Figure 4):

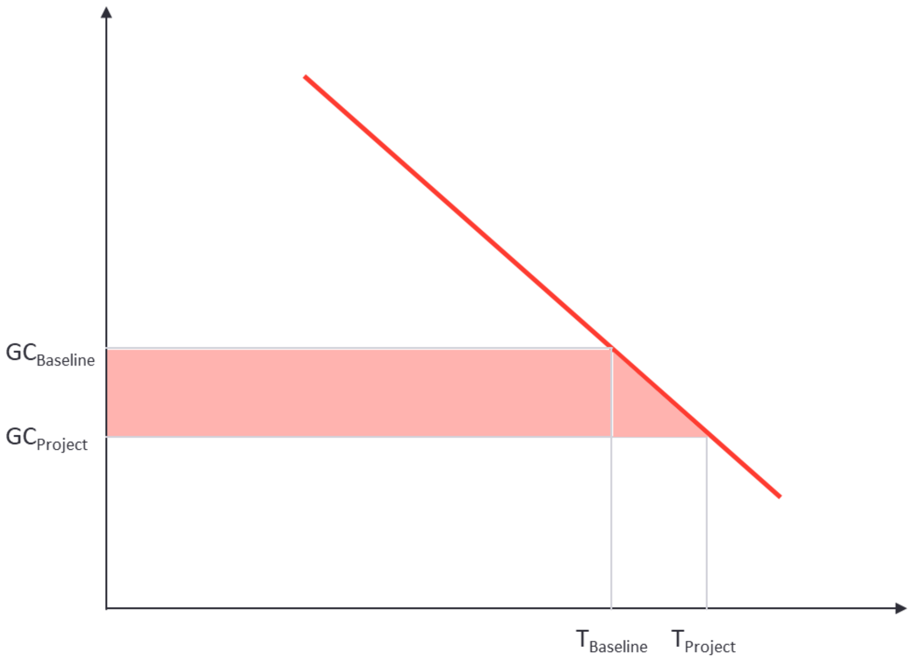

Figure 4: Economic surplus

- Savings in infrastructure costs, as the savings on road maintenance costs are higher than the extra cost of rail maintenance costs (see Table 16).
- Savings on external costs, as rail is generating less pollution, accidents and congestion than road transport.

The economic surplus is traditionally derived from two key components:

- Benefits to existing rail traffic, which experiences enhanced performance.
- The surplus created by the modal shift itself (represented by the triangle in the figure above).

These energy savings are calculated using the energy intensity factors described in section 2.3.4 above, combined with energy prices presented in Table 15[41]:

Energy Price (€ / MJ)	Current	2030	2040	2050
Diesel	0,04	0,04	0,04	0,05
Electric	0,11	0,11	0,12	0,13
Alternative Fuels	0,06	0,03	0,01	0,03

Table 15: Energy price per type of energy [€ / MJ]

The differences in infrastructure costs between the transport modes have also been considered in the analysis, using the marginal costs presented in Table 16[42]:

Mode	Marginal infrastructure cost (c€ / tkm)
Rail	0,55
Road	0,72
Inland waterway	0,13

Table 16: Marginal infrastructure costs [c€ / tkm]

Finally, savings on external costs have also been considered in the calculation. External costs are referred to as "*the effect of production or consumption of goods and services imposing costs or benefits on third-parties which are not reflected in the prices charged for the goods and services being provided*"[43]. As for transport, seven types of externalities are typically considered and thus included in the model[44]:

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41 *Various sources have been used to determine the values presented in this table, including the World Energy Outlook of the International Energy Agency.*

42 *Source: CE Delft (2019). Overview of transport infrastructure expenditures and costs. Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/7ab899d1-a45e-11e9-9d01-01aa75ed71a1.*

43 *OECD (2021). Glossary Of Industrial Organisation Economics and Competition Law. Retrieved from https://www.oecd.org/regreform/sectors/2376087.pdf.*

44 *The description of the externalities is taken from European Commission (2019). EU Handbook on the external costs of transport (Version 1.1). Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu).*

- **Climate Impact**. Transport results in emissions of CO_2, N_2O and CH_4 (methane), all of which are greenhouse gases contributing to climate change.
- **Air Pollution.** The emission of air pollutants can lead to different types of damages. Most relevant and probably best analysed are the health effects due to air pollutants. However, other damages such as building and material damages, crop losses and biodiversity losses are also relevant.
  - **Health effects**. The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$) and nitrogen oxides (NO_x) leads to a higher risk of respiratory and cardiovascular diseases. These negative health effects lead to medical treatment costs, production loss at work (due to illness) and, in some cases, even to death.
  - **Crop losses**. Ozone as a secondary air pollutant (mainly caused by the emission of NO_x and VOC) and other acidic air pollutants (e.g. SO_2, NO_x) can damage agricultural crops. As a result, an increased concentration of ozone and other substances can lead to lower crop yields (e.g. for wheat).
  - **Material and building damage**. Air pollutants can mainly lead to two types of damage to buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (e.g. nitrogen oxides NO_x or sulphur oxide SO_2).
  - **Biodiversity loss**. Air pollutants can lead to damage to ecosystems. The most important damages are the acidification of soil, precipitation and water (e.g. by NO_x, SO_2) and the eutrophication of ecosystems (e.g. by NO_x, NH_3). Damages to ecosystems can lead to a decrease in biodiversity (flora & fauna).
- **Noise Pollution**. Traffic noise is generally experienced as a disutility and is accompanied by significant costs. Noise emissions from traffic pose a growing environmental problem due to the combination of a trend towards greater urbanisation and an increase in traffic volumes. Whilst the increase in traffic volume results in higher noise levels, the increase in urbanisation results in a higher number of people experiencing disutility due to noise. As a result, the costs of traffic noise are expected to grow in the future despite potential noise-reducing improvements in vehicles, tyres and roads.
- **Accidents**. Accidents occur in all forms of traffic and result in substantial costs, consisting of two types of components: material costs (e.g. damages to vehicles, administrative costs and medical costs) and immaterial costs (e.g. shorter lifetimes, suffering, pain and sorrow). The EU Handbook on External Costs of Transport has laid out monetary value of each life, light injury and serious injury alike that occurs and modelled this as € per tkm for each transport mode. This is thus taken as the most adequate source.
- **Congestion**. Congestion is a condition where vehicles are delayed when travelling. In particular, a congestion cost arises when an additional vehicle reduces the speed of the other vehicles of the flow and hence increases travel time. Road congestion cost can be defined on the basis of a speed-flow relationship in a given context, for example at an urban or inter-urban level[45].
- **Well-to-tank**. Emissions produced during the production and distribution of energy for transportation generate costs related to their environmental and health impacts. These costs account for the negative effects of these emissions on air quality and public health. These external costs are assumed to decrease with electrification and a move to net-zero propulsion types and the decarbonisation of the energy mix.

[45] *Externality descriptions taken from European Commission (2019). EU Handbook on the external costs of transport. Version 1.1. Retrieved from [Handbook on the external costs of transport - Publications Office of the EU (europa.eu)](#).*

- **Habitat damage.** Transport infrastructure and operations can cause significant ecological damage, leading to costs for habitat restoration and biodiversity protection. These costs include efforts to repair damaged ecosystems and preserve natural habitats. As explained in the EU Handbook on External costs of transport, the different negative effects of transport on nature and landscape can be described as the following:
  - Habitat loss, as transport infrastructure requires land and/or natural surfaces;
  - Habitat fragmentation, as transport infrastructure can also have additional fragmentation and separation effects for animal populations
  - Habitat degradation due to emission (this dimension is already covered in air pollution).

The table below (Table 17) presents the values (in 2024 €-cent/tkm) of the external costs used in the model, as specified by the EU Handbook on External costs of transport[46].

Cost category	Road	Rail		IWW
	HGV - total	Electric freight	Diesel freight	Inland Vessel
Accidents	1,40	0,07	0,07	0,07
Air Pollution	0,85	0,00	0,76	1,44
Climate	0,59	-	0,28	0,30
Noise	0,55	0,72	0,50	-
Congestion	0,89	-	-	-
Well-to-Tank	0,23	0,17	0,15	0,15
Habitat damage	0,22	0,27	0,27	0,22
Total	4,2	1,1	1,8	1,9

Table 17: Average external costs for freight transport [2024 €-cent/tkm]

It should be underlined that the values for air pollution, climate change and well-to-tank change over time to take into consideration the evolution in energy intensity and emission factors as described in sections 2.3.4 and 2.3.5 above. The total external costs also depend on the evolution of the traffic mix per mode over the period considered.

2.3.6.5 Costs

The study only considers capital expenditures (CAPEX) associated with the implementation of the measures. Although it is clear that certain measures have an impact of operational costs, very limited data availability prevent their inclusion in the analysis. Furthermore, these costs should be accounted for in the economic surplus but, for the reasons detailed above (see section 2.3.6.4), such analysis cannot be conducted due to the specificities of the rail transport market in Europe.

[46] *European Commission (2019). EU Handbook on the external costs of transport. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)/.*

All values are derived from reliable sources, often using the same references for both costs and effects. When specific costs per corridor are not available but are provided at the EU level, the cost per corridor is estimated using the corridor's share of the overall traffic demand at the EU level.

The cost of decarbonising road transport is determined by using the marginal cost of removing one kilogram of CO_2, based on the IRU Green Compact Research Study[47]. Using a conservative value of € 1,28[48] per kg CO_2 reduced, the total decarbonisation cost would amount to € 211 bn (not discounted) between 2025 and 2040 in the baseline. It is worth underlining that this cost is not included in the scope of the CBA as it pertains to the baseline scenario. In the high ambition scenario, the different measures will reduce the cost of decarbonising road transport by €44 (not discounted) bn to € 167 bn (not discounted).

2.4 Defining the different scenarios

2.4.1 Baseline scenario

The baseline scenario builds on analysis of the existing situation and delineates the associated impacts in terms of CO_2 emissions with no action taken to foster rail development. As mentioned above (see sections 2.3.4 and 2.3.5), it takes into account the most ambitious projections for other modes of transport (i.e. road and IWW) in terms of energy intensity and CO_2 emissions' reduction[49].

2.4.2 Project scenarios

The following table presents the list of measures selected per scenario. The model assesses the individual impact of each of the different measures either on the modal shift (e.g. ERTMS) or on CO_2 emissions (e.g. development alternative fuels traction). This analysis then allows to estimate the effect of each measure on external costs, including CO_2 emissions.

It worth underlining that, in certain cases, synergies may exist between measures, where their combined effects exceed the sum of their individual impacts. In other words, measures that complement or reinforce each other can amplify overall outcomes, creating a multiplier effect that enhances the effectiveness of the proposed initiatives. An example of this is the complementarity between the adoption of more flexible capacity management and the introduction of IT solutions to manage multimodal transport. One can assume that with the combination of both measures, shippers will be able to book capacity close to on-demand. Yet, due to a lack of data and dedicated studies allowing to quantify these synergies, they are not accounted for in the current model. It would certainly be worthwhile to analyse the effects of these synergies in the context of future work on the subject.

Additionally, some measures may exhibit a high degree of dependency on one another, meaning that their successful implementation relies on the concurrent or prior deployment of other measures. A clear example of this is the relationship between DAC and ERTMS where the full benefits of one cannot

[47] *IRU (2023), IRU Green Compact Research Study: Europe Executive Summary. Retrieved from: IRU Green Compact - Research Study: Europe - General information | IRU | World Road Transport Organisation.*

[48] *This unit cost per includes investments in new vehicles, charging and refuelling infrastructure and investments in electricity grid capacity.*

[49] *As indicated in section 2.3.5 the baseline scenario also includes the assumption that rail transport through electric trains will achieve net-zero well-to-tank emissions by 2040, notably through the implementation of Green Power Purchase Agreements (PPAs), enabling the rail sector to source electricity exclusively from clean energy.*

be realised without the other[50]. Understanding and accounting for these interdependencies is critical to ensuring that the analysis provides a comprehensive and realistic perspective on the potential impacts and feasibility of the measures under consideration.

It is worth underlining as well that the scenarios are cumulative in nature: the 'Moderate' scenario incorporates the measures outlined in the 'Low' 'scenario, and the 'High' scenario adds on both the 'Low' and 'Moderate' scenarios. A description of the different measures, including the chosen value for their different parameters, is provided in the annex.

Scenario	List of measures	Description
Low	Moderate improvement of operational rules.	Moderate harmonisation of EU railway operational rules to reduce cross-border dwelling times, improving efficiency and interoperability.
	Alternative fuels.	Low transition to diesel locomotives to biofuels, hydrogen, and battery-electric solutions to cut CO_2 emissions.
Moderate	DAC deployment.	Implementation of DAC to automate coupling, enhance rail freight efficiency, and improve worker safety.
	Capacity management at EU-level.	Harmonising capacity allocation across EU rail networks to optimise infrastructure use and improve cross-border freight transport.
	Alternative fuels.	Partial transition to diesel locomotives to biofuels, hydrogen, and battery-electric solutions to cut CO_2 emissions.
	Moderate deployment of ERTMS.	Deployment of ERTMS on the Core Network to standardise signalling, enhance safety, and improve interoperability.
	Moderate investments in multimodal terminals to foster intermodality.	Building and upgrading 50% of the intermodal terminals considered in the FERRMED report (2023)[51].
High	Increasing train length to 740m.	Infrastructure upgrades to enable 740-meter freight trains, including extending sidings, track adaptations, and station upgrades.
	Full deployment of ERTMS.	Expanding ERTMS to the Comprehensive TEN-T Network and national networks per Member States' plans.

[50] *The interaction between DAC and ERTMS deployment is already accounted for in this report. Indeed, by design, the two measures are combined in both the moderate and high ambition scenario.*

[51] *FERRMED (2023), Study of Traffic and Modal Shift Optimisation in the EU. FERRMED A.S.B.L. Retrieved from: https://ferrmed.com/wp-content/uploads/2023/11/FERRMED_study_291123.pdf.*

Scenario	List of measures	Description
	Full harmonisation of operational rules.	Full harmonisation of EU railway operational rules to reduce cross-border dwelling times, improving efficiency and interoperability. It also considers the harmonisation of DAC operations.
	Full deployment of EU-Rail JU technical outputs.	Implementing EU Rail innovations at a high ambition level. The technologies included within this measure are expected to further boost some of the other measures such as ERTMS deployment. The game changers can for example fully unlock the capacity-enhancing potential of ERTMS.
	Major investments in multimodal terminals to foster intermodality.	Full-scale investment (100%) in new intermodal terminals considered in the FERRMED report (2023)[51].
	Alternative fuels.	Strong transition to diesel locomotives to biofuels, hydrogen, and battery-electric solutions to cut CO_2 emissions

Table 18: List of measures per scenario

2.5 Accounting for capacity constraints

Most of the measures included in the analysis are expected to drive an increase in demand for rail (including through a modal shift from road transport), leading to a significant increase in rail freight traffic. However, this projected evolution raises a critical question: to what extent will capacity constraints on rail lines and at key hubs allow this modal shift to materialise? These constraints could potentially limit the ability of the logistic infrastructure to absorb the additional demand, which is essential for achieving the intended outcomes of the proposed measures.

Capacity constraints on the rail transport network can have various origins. Key limitations may stem for example from the rail infrastructure itself, including insufficient track availability and the aging state of some lines which may significantly reduce operational speed. Technical limitations, such as the tortuosity and gradients of certain lines, further restrict network capacity. Additionally, the interaction with passenger traffic, which is often prioritised on shared networks, presents a significant capacity challenge for rail freight transport. Lastly, inefficiencies in capacity management by infrastructure managers, including inadequate coordination of infrastructure maintenance and works, exacerbate these constraints, limiting the full realisation of potential capacity gains.

To account for these structural capacity constraints, which are not fully addressed within the model, a cap has been applied to the modal shift estimates in the low and moderate ambition scenario. This adjustment reflects the realistic limitations of the rail network's ability to accommodate increased freight volumes despite the implementation of the series of measures. In this analysis, the modal shift potential calculated in the scenarios is capped at 80%, representing the impact of capacity constraints issues on the scalability of rail freight. This cap has been applied throughout the entire timeframe of the study[52].

In the context of the high ambition scenario, it is assumed that the group of measures that compose it could allow for overcoming the vast majority of capacity constraints that affect the deployment of modal shift under the low and moderate ambition scenario. The pooling of these measures indeed allows for a significant increase in capacity for rail freight. The combination of ERTMS and DAC, for example, enables better integration of freight movements with passenger movements on shared networks. The development of EU-Rail JU technical outputs as well as the increase of train length also helps alleviate capacity constraints.

As mentioned in section 2.3.3, the model also accounts for the capacity constraints related to the large-scale rail infrastructure modernisation projects that will happen in some countries crossed by the corridors (e.g. Germany and Italy). For that purpose, the potential modal shift per scenario has been capped at 10% until 2040 for all the corridors. For the sake of simplicity, the 80% cap applied in the low and moderate ambition scenario has been removed in the high ambition scenario.

[52] *This value is somewhat arbitrary as it is not based on a comprehensive study, which would have gone beyond the scope of this report. Section 0focusing on the sensitivity analysis present the results of relaxing this assumption.*

3. Key findings

This section presents the outcomes of the different scenarios. Their respective impacts are measured and presented through the evolution of the demand for freight transport, CO_2 emissions reduction, savings in energy costs, external costs reduction and net present value. It is crucial to point out that all results must be interpreted in comparison to a baseline scenario which includes the most ambitious assumptions for the decarbonisation of road transport and inland waterway (IWW) transport. A sensitivity analysis on key parameters of the model has also been carried out. The corresponding outcomes can be found in the annex.

3.1 Freight transport market forecast

The series of charts presented in the below illustrates the evolution of transport demand (rail, road and IWW) across the corridors over the study period, as derived from the modelling exercise. Due to the methodology employed, the progression of traffic is linear and follows a steady increase throughout the period.

Figure 5 presents the evolution of the demand in the baseline scenario: over the period considered (2025-2050) rail demand grows from 255 bn tkm to 360 bn tkm in the baseline scenario, road demand from 1111 bn tkm to 1538 bn tkm, and IWW demand from 71 bn tkm to 92 bn tkm over the period considered.

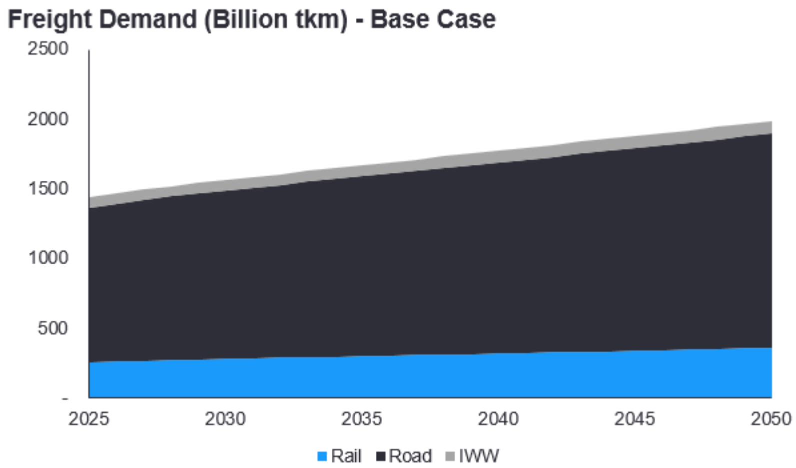

Figure 5: Freight demand for all modes in the baseline scenario

Figure 6 depicts the evolution of transport demand across all modes and for each project scenario (i.e. low, moderate and high ambition scenarios). It highlights a significant increase in the rail modal share within the context of overall growth in traffic across all three modes[53]. This results from the modal shift generated by the range of measures considered. As expected, the magnitude of the modal shift depends on the ambition of the scenario.

Low ambition scenario | Moderate ambition scenario | High ambition scenario

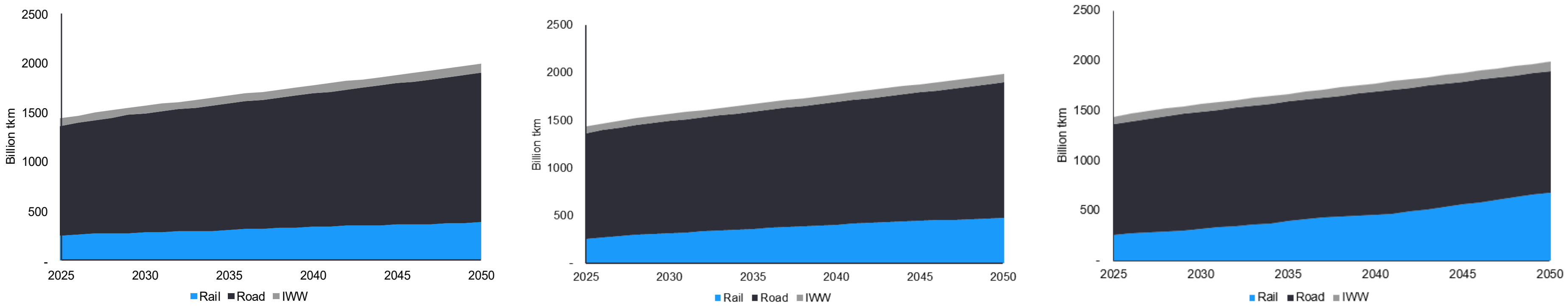

Figure 6: Freight demand for all modes in project scenarios (billion tkm)

[53] *See* Figure 13, Figure 14, Figure 15 *in the Annex for a detailed presentation of the evolution of traffic volumes.*

3.2 Environmental impact

The charts below (Figure 7) illustrate the impact of the project scenarios on CO_2 emissions and other external costs over the period.

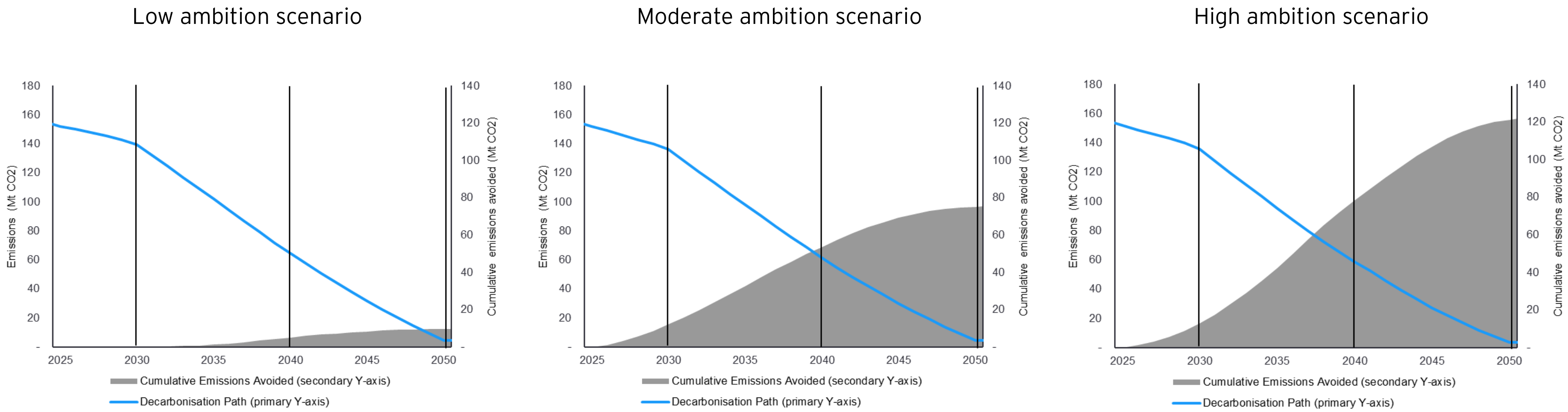

Figure 7: Impacts of the project scenarios on CO_2 emissions and other external costs

It highlights the substantial increase in cumulative emissions avoided over the 2025-2050 period in the three project scenarios. Specifically, cumulative emissions avoided (represented on the right y-axis) increase from 9,6 M t CO_2 in the low ambition scenario to 75,1 M t CO_2 in the under moderate ambition and 121,3 M t CO_2 in the high ambition scenario. The decarbonisation path (corresponding to the left y-axis) under the project scenarios is shown in blue.

Figure 8 provides an illustration of the resulting effects in terms of emission intensity[54] per mode in the high ambition scenario. It shows that the CO_2 emission intensity of road transport decreases from 112 gCO_2/tkm to 2,8 gCO_2/tkm between 2030 and 2050, as a result of the decarbonisation assumptions for road transport included in the baseline scenario. The CO_2 emission intensity from rail transport is very low between 2030 and 2050 and is also decreasing, although not zero by the end of the period[55].

[54] *The emission intensity presented in this section should not be confused with the CO_2 emission factors specified in section 2.3.5. In this section, the emission intensity corresponds to the overall emissions divided by the traffic volumes. As such, this metric depends on the evolution of the demand for transport.*

[55] *The remaining emissions for rail transport are essentially due to presence of a small proportion of non-electric trains at the end of the period. Even though the high ambition scenario includes the development of alternative fuels, this will still be associated with some CO_2 emissions (though they are much lower compared to diesel).*

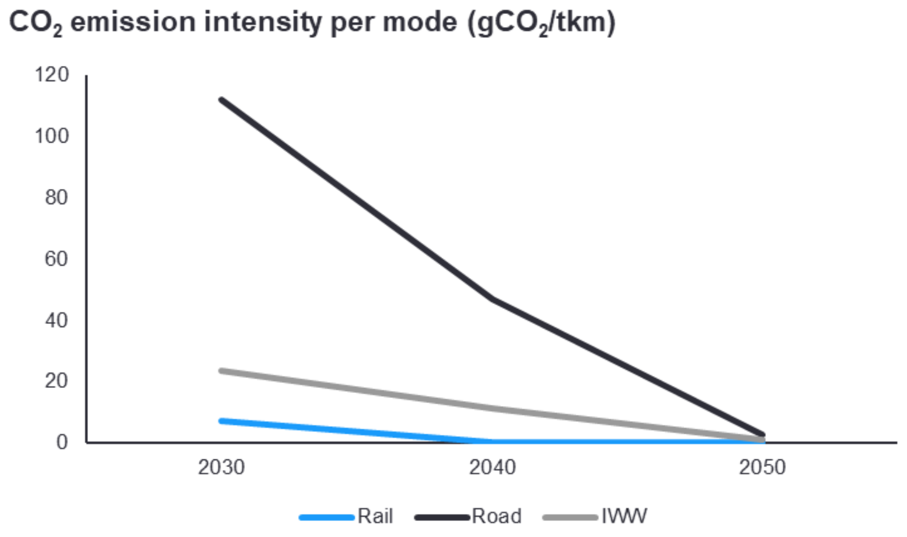

Figure 8: CO_2 emission intensity per mode in the high ambition scenario

While the difference in emissions between the baseline and project scenarios is significant, it remains relatively modest in this context. This is closely tied to these overall decarbonisation assumptions for all transport modes included into the analysis. Beyond the assumption on the decarbonisation of road and IWW transport incorporated in the baseline scenario, the model assumes indeed a substantial reduction in rail emissions in the baseline scenario (mainly through the development of PPAs to achieve net-zero well-to-tank emissions by 2040 for electric trains), thereby limiting the incremental impact of the proposed measures on CO_2 reduction.

3.3 Socio-economic impact

3.3.1 Societal benefits

Although the impact of the proposed measures on CO_2 emissions is relatively limited given the decarbonisation assumptions adopted in the baseline scenario, their effects on other external costs are substantial.

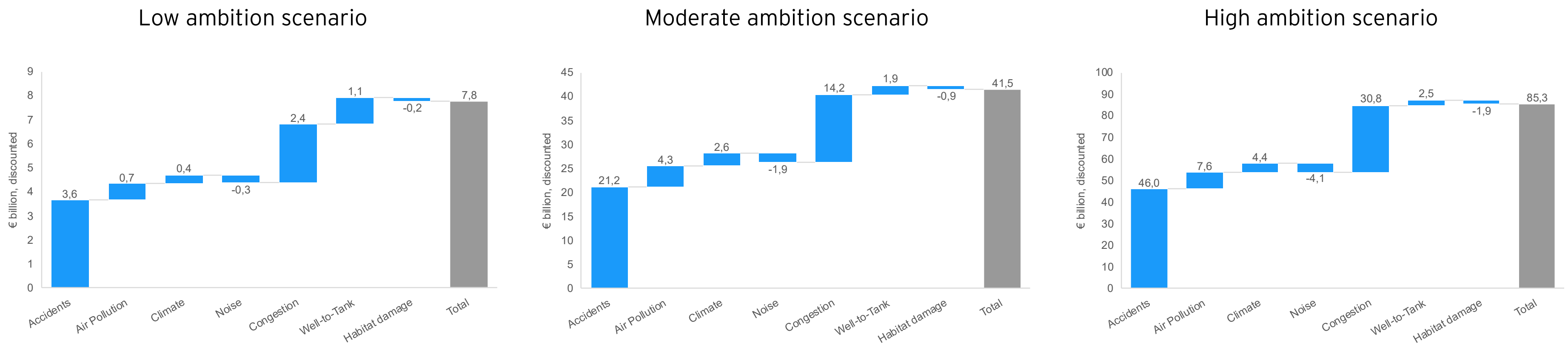

Figure 9: Reduction in externalities (€ billion, discounted)

As shown in the figures above (Figure 9), discounted external costs savings amount to € 8 bn in the low ambition scenario to € 85 bn in the high ambition scenario over the period. This cumulative reduction is largely driven by two key benefits of the modal shift from road to rail[56]:

- Reduction in transport accidents: with fewer vehicles on the road network, the frequency and severity of accidents decrease, leading to significant societal and economic savings.
- Alleviation of road congestion: the shift to rail reduces congestion on road networks, improving travel efficiency notably through a reduction in transport time.

This outcome is particularly important from a policy perspective. Indeed, even if the ambitious decarbonisation assumptions embedded in the baseline scenario for all transport modes were not fully realised, the measures assessed in this study would still deliver a notable impact of CO_2 emissions and very

[56] *The chart also indicates a relative increase in external effects related to noise and habitat damage. These negative effects of the development of rail transport, which are due to the fact that the rail mode generates relatively more noise nuisances and habitat damages, are largely offset by its positive effects.*

significant effect on external costs reductions. The multidimensional nature of these impacts reinforces the importance of evaluating the measures in a comprehensive manner, rather than through a single lens of CO_2 emissions reduction. By incorporating the range of externalities into the analysis, the study provides a comprehensive assessment of the expected positive effects of the development of rail transport within logistic chains in Europe. This should help to ground decision-making in a more holistic understanding of the expected benefits, allowing for more informed and balanced policies that not only support environmental goals but also enhance social welfare and economic efficiency. By taking all external costs into account, these outcomes make a strong case for fostering the development of rail transport into logistic chains in Europe.

3.3.2 Energy cost savings

As expected, the outcomes of the model highlight that, despite the projected growth in overall tkm over the period, total energy usage is decreasing significantly in the baseline scenario (see Figure 11). This is mainly due to the assumptions regarding the improvement of energy efficiency for road transport. As excepted, the energy savings are most pronounced in the project scenarios, driven in particular by the combination two key interrelated factors: the reduction in rail energy intensity resulting from the measures and the increase in rail modal share (as indicated in section 2.3.4, rail transport is more energy efficient than road transport). This reflects a significant improvement in overall energy intensity[57] in both the baseline and the project scenario. This evolution is presented in Figure 10, which also shows that the implementation of the measures (especially in the high ambition scenario represented by the figure) leads to a significant decrease of the energy intensity in comparison to the baseline.

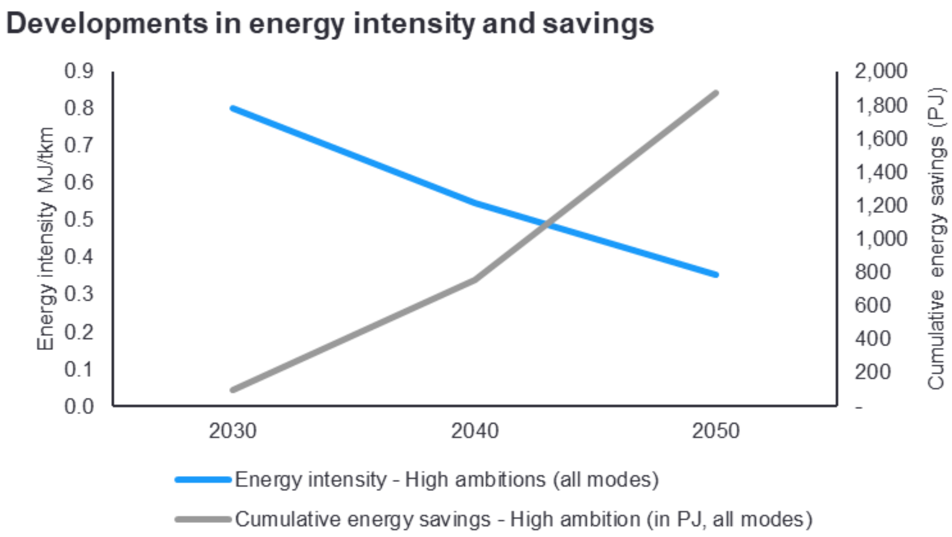

Figure 10: Evolution of energy intensity and cumulative energy savings in the high ambition scenario

[57] *This metric should not be confused with the unit values presented in section 2.3.4. It corresponds to the total volume of energy consumed divided by the total traffic, so its value is notably affected by the evolution of traffic composition over the period.*

In the high ambition scenario, the total energy intensity for the transport system would be 0,80 MJ/tkm in 2030, further decreasing to 0,55 MJ/tkm in 2040, and 0,35 MJ/tkm in 2050. In terms of energy savings, the high ambition scenario will generate energy savings of 96 PJ (petajoule[58]) by 2030, 753 PJ by 2040 and 1876 PJ by 2050.

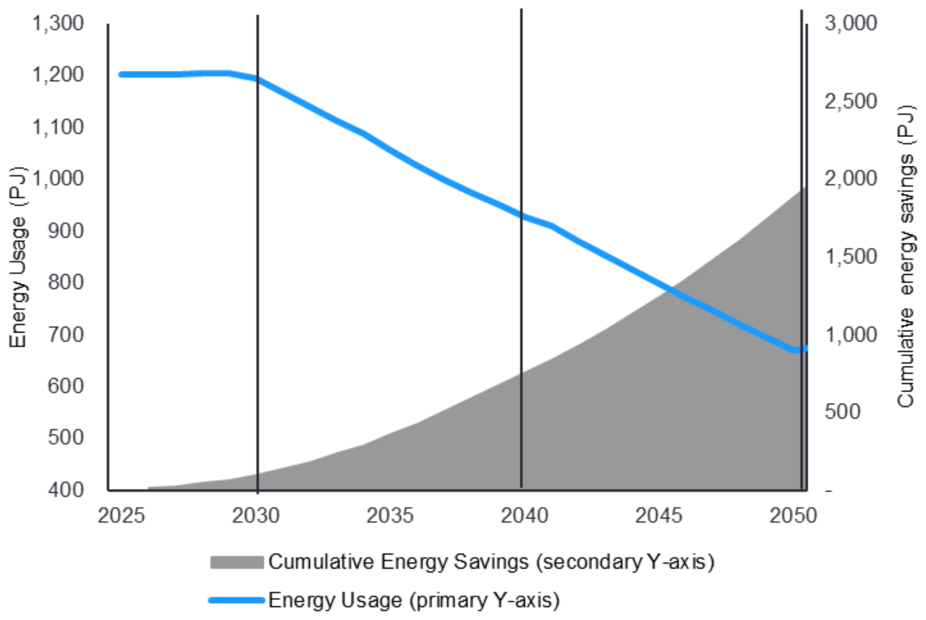

Figure 11: Evolution of energy usage and cumulative energy savings in the high ambition scenario

The reduction in energy consumption will also lead to significant cost savings for the European society. Applying the unit costs per MJ listed in Table 15, the high ambition scenario would generate €74 billion (discounted) in energy costs savings by 2060.

[58] *One petajoule equals 1 million MJ.*

3.3.3 Infrastructure maintenance

The last metric included in the model was the savings in terms of infrastructure maintenance costs. Figure 12 below illustrates the developments in infrastructure maintenance costs for the high ambition scenario. Overall, the costs are increasing due to the increase in demand, however, investing in rail and a more efficient logistics chain will lead to savings in infrastructure maintenance costs by approximately €6 billion (discounted) in the high ambition scenario over the period studied (2025-2060). Figure 12 below shows the development until 2050.

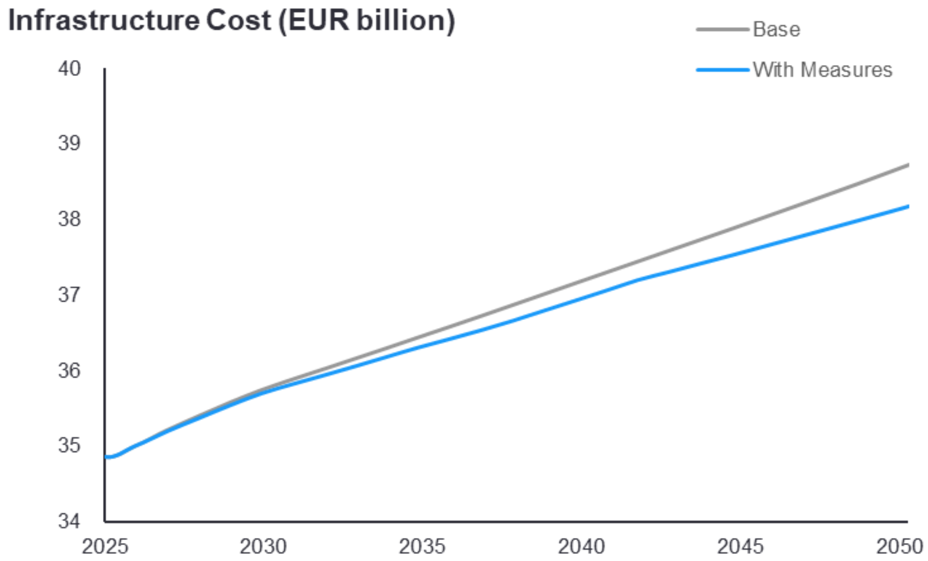

Figure 12: Infrastructure maintenance costs (discounted) - high ambition scenario

3.3.4 Net socio-economic impact

The reduction in external costs and the savings in expenditures on energy and infrastructure will lead to a positive net outcome for society. In fact, the Net Present Value is positive for all scenarios and all corridors, meaning that the benefits of monetised external costs always exceed the costs of deploying the measures. The total costs and benefits of the three scenarios are summarised in the table below:

M€ (discounted)	Costs	Benefits (savings)			NPV	B/C ratio
		Savings on external cost	Savings on energy	Savings on infrastructure maintenance		
Low ambition scenario	(408)	7 756	4 765	470	12 584	N/A
Moderate ambition scenario	(20 153)	41 479	31 133	2 759	55 417	3,7
High ambition scenario	(33 171)	85 309	74 172	5 996	132 306	5

Table 19: Costs and benefits in M€ (discounted) per scenario

For all scenarios, benefits mainly stem from energy savings, accidents avoided and decrease of congestion thanks to the modal shift from road to rail. The difference between scenarios is directly linked to the magnitude of the modal shift.

The low ambition scenario has relatively low costs, due to the fact it does not includes any infrastructure investments.

The total costs associated with the Moderate ambition scenario is estimated at € 20 bn (discounted). The largest costs arise from the deployment of ERTMS, DAC and the investments in intermodal terminals.

The total cost associated with the high ambition scenario is estimated at € 33 bn (discounted). The main costs stem from capital intensive measures such as the deployment of ERTMS, the adaptation of the infrastructure to accommodate longer trains and the deployment of DAC.

Implementing the measures will lead to significant cost savings for society. Specifically, the external cost reduction and energy costs savings lead to very important societal benefits. The high ambition scenario will generate €85 bn (discounted) in external cost savings, while at the same time saving €74 (discounted) bn in energy costs. This highlights the positive effects of the measures in addition to CO_2 reduction (see section 3.3.1).

The positive results of the CBA indicate that investing in the measures delineated in the project scenarios for the development of net-zero logistic chains is recommendable. In fact, the results mean that one Euro invested in railways will generate roughly 3,7 to 5,0 Euro of added value to society for the moderate and high ambition scenarios.

3.4 Wider economic impact

Investments in transport contribute further to society than reducing external costs, namely by creating additional jobs in the society as a whole. The assumption being that the investments made in railways by for example deploying DAC will generate employment not only in assembling and installing the couplers but also in other sectors like the manufacturing of fabricated metals or accounting[59]. By applying a job multiplier identified by the International Energy Agency (IEA) at 4,6 jobs created per million dollars invested[60], the investments made in logistics would create approximately 92 000 jobs in the moderate ambition scenario and 153 000 jobs in the high ambition scenario over the period under study.

The additional jobs created have not been accounted for in the CBA, as per the standard practice. The results of the multiplier should moreover be treated with very carefully, notably given the uncertainties on whether this reflects job creation of reallocation[61].

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[59] *CER (2014), The economic footprint of railway transport in Europe. Retrieved from: The_Economic_Footprint_-_web_-_final_final_30_Sept_0.pdf.*

[60] *IEA (2020), Employment multipliers for investment in the transport sector. Retrieved from: Employment multipliers for investment in the transport sector – Charts – Data & Statistics - IEA.*

[61] *OECD (2002), Impact of Transport Infrastructure Investment on Regional Development. Retrieved from: Impact of Transport Infrastructure Investment on Regional Development.*

4. Conclusion

This study provides critical insights on the potential of intermodal optimisation of freight transport to achieve more efficient and net-zero logistic chains in Europe. By analysing the interplay of rail, road, and inland waterway transport within logistic systems, the findings demonstrate the substantial potential of rail freight to deliver carbon reductions, while simultaneously ensuring economic efficiency and resilience. The scenarios evaluated reveal that targeted investments in rail freight can yield meaningful reductions in CO_2 emissions, thus highlighting the potential for better combinations and synergies of all transport modes to achieve net-zero logistics. **The study provides evidence that the high ambition scenario should be prioritised as it yields the most significant impacts.**

Three main policy implications can be drawn for the study:

- **Beyond emissions reductions, the analysis underscores the major socio-economic benefits of the high ambition scenario in particular,** notably because the set of measures considered strongly mitigate externalities, such as road congestion and accidents, and generate very significant energy savings. Despite the scale of investments required (€33 bn[62] for the five corridors), the cost-benefit analysis demonstrates that the socio-economic returns justify the effort, reinforcing the strategic importance of rail freight in the broader context of Europe's green transition. By integrating key enhancements such as increased train lengths, full deployment of ERTMS, harmonisation of operational rules, implementation of EU-Rail JU technical outputs, and significant investments in logistics hubs, the high ambition scenario provides a robust framework for achieving the highest level of carbon reduction as well as capacity exploitation and energy-efficiency across the logistic chain. It should be underlined that the outcomes are based on a high ambition scenario for road transport, ensuring that the model's results do not overestimate the impact of the measures considered in the project scenarios. Furthermore, the sensitivity analysis confirms that the positive outcomes remain robust even when key assumptions are altered, including the magnitude of the effects attributed to the measures or their associated costs.
- **Bundling measures and ensuring a whole network roll-out is critical to harness synergies and ensure maximum impact**. While measures such as investments in intermodal terminals or capacity management at the EU level deliver the highest individual benefits, the analysis makes a strong case for bundling measures together. While these specific measures provide strong individual returns, it is crucial to emphasise that these measures do not operate in isolation. Their full potential is best realised when combined with the other initiatives in the high ambition scenario. A critical factor in the success of the high ambition scenario is indeed the strong synergies between its measures, such as the combination of ERTMS with innovations like the Digital Automated Coupling (DAC), which enables higher speeds of freight trains, or the game changers included in the EU-Rail JU technical outputs, which can for example fully unlock the capacity-enhancing potential of ERTMS. Additionally, certain measures present a high degree of interdependency. As an example, the deployment of the DAC plays a crucial role in enabling longer freight trains and optimising operations including the EU wide implementation of common operational rules. The full deployment of ERTMS, when combined with the harmonisation of operational rules, significantly increases cross-border interoperability, reduces delays, and enhances overall network efficiency. Similarly, digital enablers, such as real-time data exchange and automated train operations, complement infrastructure investments by optimising traffic flow and improving asset utilisation. Furthermore, one of the key measures – investments in

[62] *This value is discounted.*

hubs and terminals — does not generate substantial socio-economic benefits on its own in this conventional cost-benefit assessment. Rather than providing immediate returns in isolation, it acts as an enabler, unlocking the full impact of other measures by facilitating the expected shift in freight flows and improving overall system efficiency. Without sufficient terminal capacity and optimised intermodal connections, the broader transformation towards net-zero logistic chains could be constrained, even if other measures were successfully implemented. As a result, while investments in terminals may not yield the highest standalone benefits, they remain a fundamental driver of net-zero logistics. Their role in enabling modal shift, enhancing network fluidity, and ensuring the effectiveness of operational improvements makes them a strategic priority. Given their systemic importance, there is a clear rationale for considering terminal infrastructure development as a core focus of public policy. Ensuring adequate public support and investment in this area will be essential to maximising the returns of the broader transition towards a more sustainable and efficient freight system. These interdependencies underscore the need for a comprehensive approach, where the full impact of each measure can only be realised when implemented together. A fragmented or partial implementation would fail to unlock the full benefits identified in the cost-benefit analysis, reinforcing the importance of a coordinated, high-impact strategy. Policymakers and industry stakeholders should therefore prioritise the deployment of these complementary measures to maximize the resilience, efficiency, and sustainability of Europe's freight transport network.

- **Technology supports the optimisation of network capacity**, without the need for extensive infrastructure investments as well as the pre-deployment activities of system innovations, such as DAC. In this regard, EU-Rail JU is playing a key role in driving forward innovation to accelerate the transformation or rail freight and optimise its integration across logistic chains.

A corollary outcome of the study is to highlight that **better integration of rail within logistic chains generates substantial cost savings** across four key dimensions. First, it significantly reduces the cost of road decarbonisation by shifting freight from road to rail, thereby lessening the need for costly measures to curb emissions from road transport. Second, the superior energy efficiency of rail leads to a marked reduction in overall energy consumption, while also mitigating exposure to energy price volatility. Third, by alleviating pressure on road infrastructure, rail freight reduces the need for costly road expansions and maintenance, generating substantial infrastructure savings. Lastly, the improved efficiency and capacity utilisation of rail networks contribute to lower overall transport costs, enhancing the competitiveness of freight transport while supporting long-term economic and environmental objectives. Table 20 provides the main savings (cumulative and discounted) for the key metrics examined in the study in the high ambition scenario.

Metric	2030	2040	2050	Total[63]
Emissions saved (M t CO_2e)	13	78	121	134
Energy cost savings (€ M)	1 459	17 490	43 110	74 172
Infrastructure maintenance savings (€ M)	99	1 316	3 483	5 996
External cost savings (€ M)	1 915	22 769	52 503	85 309
NPV (€ M)	N/A	N/A	N/A	132 306

Table 20: Main results - High ambition scenario (discounted)

How these investments will be financed is, of course, critical. Several key elements should be highlighted in this regard. First, the introduction of the ETS2 is expected to generate significant revenues that could be leveraged to support infrastructure projects aimed at enhancing the efficiency and competitiveness of freight logistic systems. Moreover, the overall enhancement of logistics chains efficiency can act as a catalyst for private investment, particularly in logistics hubs (including seaports in particular), urban nodes, intermodal terminals, and digital infrastructure. Public funding can play a crucial role in de-risking these investments, either through public-private partnerships (PPPs) or targeted co-financing schemes that attract private capital. By improving infrastructure reliability and efficiency, well-designed public investments can stimulate additional private commitments, helping to bridge the funding gap for necessary upgrades.

All in all, the findings also underscore rail freight's contribution to enhancing Europe's industrial competitiveness. The development of rail freight not only supports decarbonisation but also enhances the overall efficiency of the transport system, which will benefit to other transport modes, particularly road. By improving the performance of logistic chains, it will indeed help optimise freight flows, reducing inefficiencies resulting from empty truck runs or road congestion for example. At the same time, optimisations of freight transportation, on long distances especially, can help reduce the decarbonisation cost the ETS will impress on road over time. This represents a glaring example of how to decarbonise while gaining competitiveness, by driving down logistical costs and fostering more sustainable and resilient supply chains. For these reasons, the measures evaluated in this study fully align with the ambitions of the EU's Clean Industrial Deal as well as the Sustainable and Smart Mobility Strategy. **This dual role — decarbonisation and competitiveness — positions rail freight as a cornerstone of sustainable economic development**. Supported by robust data collection efforts and rigorous analysis, this study provides a compelling case for integrating rail freight at the heart of Europe's industrial strategies to drive both environmental and economic progress.

[63] *The values provided in this column are calculated for the entire period covered by the CBA, which extends until 2060 (see section 2.3.6).*

Drawing on the outcomes of the study, a set of key recommendations can be derived to drive the transition towards more sustainable and efficient logistic chains which, in turn, should contribute to strengthening the competitiveness of the European industry. These recommendations, presented in the box below, aim to provide actionable measures to unlock the full potential of the high ambition scenario. It should be highlighted that the development of the high ambition scenario should also significantly strengthen the capacity to meet evolving military mobility requirements.

Key recommendations

The report highlights that the high ambition scenario should be prioritised. Unlocking its full potential will require careful strategic planning and coordination, with the ultimate goal of fully contributing to the Clean Industrial Deal as well as the Sustainable and Smart Mobility Strategy. A holistic vision is needed, not only for rail freight but for the entire transport system, ensuring that these measures are embedded within a broader strategy which fully supports Europe's transition towards a more sustainable and competitive economy. While some of the actions identified in the study are already underway, they must be integrated into a more comprehensive strategic framework to advance this agenda effectively.

Such framework should, in particular, focus on the following priorities:

- Strategic planning:
  - Develop a **strategic roadmap** defining clear priorities, possible regulatory changes, quantified targets, timeline and responsibilities to advance this agenda forward. Such roadmap should notably facilitate a coordinated technology deployment.
- Infrastructure and capacity management:
  - **Drive forward the innovation agenda** to optimise network capacity and foster the integration of rail freight transport across logistic chains.
  - **Accelerate the set-up of Net-Zero multimodal hubs** across the EU corridors and according to Member States' specific needs (which should be delineated as per the national action plans for the development of a multimodal freight terminal network that have to elaborated by July 2027[9]).
  - Ensure **appropriate last mile connectivity** of hubs, intermodal terminals, urban nodes and seaports.
  - Unlock cross-country rail infrastructure capacity management, to enable its best use, especially over long distances.
- Funding:
  - **Exploit synergies of interest between the public and private sectors** to drive investments funding, particularly given the significant potential in dual-use (military-commercial) infrastructure. This approach, which should be developed in line with hubs' specialisation trends and the associated value chains' transformation, holds significant promise for effectively addressing the challenges of last-mile connectivity in particular.
  - Provide, notably through appropriate incentives, **encouraging market conditions for private investments** in net-zero optimised business models.
  - **Leverage revenue from the Emissions Trading System 2** to support targeted investments in the development of net-zero logistic chains.
- Stakeholder engagement:
  - Keep **engaging with stakeholders** to ensure that these developments align with market needs and operational realities. Engaging the relevant actors across the different modes will be essential to successfully implementing the necessary transformations.

It is worth noting that further research could deepen the analysis in several key areas:

- **Infrastructure and investment priorities.** A more detailed assessment of the necessary infrastructure upgrades and technological investments, would help building a structured roadmap for policy and industry stakeholders. While this study has necessarily adopted a relatively macro perspective, a more granular analysis at the micro level would be useful to examine the details of flows across logistic chains and associated investment needs or required transformations.
- **Market dynamics and supply chain integration.** A deeper analysis of demand-side factors, including evolving logistics trends and strategies and shipper preferences would help refine strategies for integrating rail freight more effectively into European and global supply chains. Additionally, a market-segment-level analysis would provide valuable insights into the specific dynamics of different freight categories, identifying how their evolution can shape the future role of logistic chains. The transition towards Net-Zero will inevitably drive changes in the structure of freight traffic, modifying existing segments and fostering the emergence of new ones, such as carbon capture and transport. Understanding these shifts will be essential to anticipating future infrastructure and service needs.
- **Passenger-freight interdependencies and capacity trade-offs.** One limitation of this study is its exclusive focus on freight transport, without considering the broader implications of passenger services. While the analysis evaluates the impact of various measures to optimise freight integration within logistics chains, a significant share of the constraints on freight development stems from capacity trade-offs between passenger and freight operations, especially for rail transport. Integrating this dimension into the analysis would provide a more comprehensive understanding of the bottlenecks and trade-offs at play. As for rail transport in particular, this would require examining governance structures and public policy choices regarding the allocation of network capacity, as infrastructure prioritisation, slot allocation mechanisms, and funding schemes often favor passenger services, limiting the expansion of rail freight. Addressing these barriers requires a more integrated approach to capacity planning, including dynamic scheduling, dedicated freight corridors, and revised regulatory frameworks to ensure a more balanced use of the rail network.
- **Synergies between measures.** A more detailed analysis of the interactions between different measures could contribute to improve the proposed scenarios and maximise their outcomes. By integrating these synergies into the evaluation models, decision-makers could develop more effective strategies tailored to the actual needs of industry stakeholders.
- **Strategic linkages with urban nodes and ports.** The strategy for developing more efficient and net-zero logistic chains should take into account the strong interlinkages with urban nodes and ports as there are critical components of good flows. This integration is critical for optimising good flows, reducing emissions and ensuring a transition to a sustainable and competitive transport system. While the study lays the groundwork for this analysis, it appears important to dedicate efforts on this question to complete and refine the policy recommendations derived from this report.

Beyond these questions, the study also paves the way for the market analysis on multimodal freight terminals and the action plans for the development of a multimodal freight terminal network that Member States have to develop by 19 July 2027, as outlined in Regulation (EU) 2024/1679[64].

[64] *Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on Union guidelines for the development of the trans-European transport network, amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and repealing Regulation (EU) No 1315/2013.*

This study necessarily invites a forward-looking reflection on the future of logistic chains and their transition to net zero. Several key developments could reshape freight flows and the balance between transport modes, starting with road congestion. As urbanisation and e-commerce demand grow, road infrastructure faces increasing saturation constraints, leading to higher transport costs, delays, and uncertainty for businesses. Congestion also reduces the predictability of delivery times, which is critical for just-in-time logistics. In response, supply chains may adapt by diversifying transport options, with a stronger emphasis on intermodal solutions that optimise the combination of road, rail, and inland waterways. This shift would require investments in transshipment hubs and more flexible logistics strategies to maintain efficiency across modes.

Another major factor is the potential disruption of global supply chains due to rising geopolitical tensions. The resulting uncertainties could indeed push businesses to reassess their transport networks. More regionalised supply chains may emerge, reducing reliance on long-haul maritime routes and increasing the role of rail and short-sea shipping in intra-continental freight movements. This reconfiguration could lead to new trade corridors, requiring better coordination between different transport modes to ensure resilience and flexibility in freight logistics. In addition, the ongoing trend of investing in military mobility infrastructure could be further accelerated by this evolving geopolitical landscape. Since 2017, initiatives such as the EU's Military Mobility Action Plans have sought to streamline cross-border transport for military assets, improve transport infrastructure capacity, and enhance resilience against disruptions. The latest iterations of these plans emphasise upgrading road and rail corridors to handle greater weight and size requirements, digitalising administrative procedures, and reinforcing cybersecurity in transport networks. As geopolitical instability increases, these investments are likely to expand further, creating additional freight capacity that could indirectly benefit civilian supply chains. In particular, infrastructure upgrades aimed at military readiness -such as reinforcing bridges, expanding rail capacity, and harmonizing cross-border regulations- could have spillover effects on commercial freight operations. Dual-use transport corridors, initially designed to ensure rapid deployment of military equipment, could also improve the efficiency and reliability of freight movements across Europe.

Technological advancements, particularly in artificial intelligence, are also set to transform supply chain dynamics. AI-driven route optimisation can improve modal selection in real-time, allowing logistics operators to adjust transport plans based on congestion, costs, and emissions. Automated transport systems, including self-driving trucks and automated rail operations, may alter the cost structures and competitiveness of different modes, potentially leading to a rebalancing of modal shares. Digital platforms integrating predictive analytics will further enhance the adaptability of supply chains, enabling more efficient and dynamic freight capacity allocation.

Finally, adapting to climate change will require long-term planning to ensure the resilience of supply chains. Extreme weather events and stricter emissions regulations will disrupt existing transport networks, making infrastructure planning a critical issue for both businesses and policymakers. Decisions on transport investments will need to account for climate risks, ensuring that freight corridors remain operational and efficient despite changing environmental conditions.

5. Annex

5.1 List of measures

The following section expands on the measures outlined in section 2.4.2. The definition of these scenarios resulted from iterations with the group of academic experts and steering committee. It is important to note that the scenarios are cumulative in nature, with each successive scenario building upon the measures introduced in the previous one[65]. Moreover, it has to be noted that the effects presented per measures are individual impacts that do not account for the synergies across measures.

The definition of the different parameters, including the starting date and the phasing of the measures, results mainly from the literature review conducted by EY-Parthenon, previous studies conducted by EY-Parthenon and Blue Arches, experts' interviews, ad hoc estimations as well as interactions with the Steering Committee.

To refine the value assigned to each corridor in terms of modal shift (when relevant), the initial estimated values were slightly adjusted using a scoring method. To this end, a score was assigned to each corridor based on four KPIs defined by the PRIME Benchmarking report (2022)[66]:

- Density of the network (limiting factor to the modal shift).
- Starting point in terms of modal share (limiting factor in situations where rail transport has already a relatively higher modal share).
- Track access charges (limiting factor).
- Train punctuality (limiting factor).

Building on the scores obtained, the following factors have been applied to initial values of the modal shift or increase in demand:

- North-Sea-Rhine Mediterranean: initial value x 1,1
- Scandinavian-Mediterranean: initial value x 0,9
- Baltic-Adriatic: initial value x 1,1
- Mediterranean: value unchanged
- Western Balkans – Eastern Mediterranean: initial value x 0,9

[65] *Naturally, when a measure appears in two different scenarios (with different levels of deployment), their effects and costs are not counted twice. Only the costs and impact of the most ambitious level of deployment is taken into account.*

[66] *PRIME (2022), Benchmarking report. Retrieved from: https://wikis.ec.europa.eu/download/attachments/44167372/PRIME%20External%20Report%202021.pdf?version=2&modificationDate=1687506392630&api=v2.*

5.1.1 Low ambition scenario

5.1.1.1 Moderate improvement of operational rules

This measure, focusing on the harmonisation of operational rules for railways at the EU level, addresses one of the barriers to the efficiency of cross-border rail freight operations. Fragmented national rules currently result in divergences that create delays, additional administrative burdens, and technical incompatibilities at borders. By harmonising these rules, the measure aims to reduce these obstacles and streamline processes, fostering greater interoperability and efficiency across the European rail network.

A major benefit of harmonisation lies in its potential to reduce cross-border dwelling times, which are a significant source of delays in freight logistics. National-level discrepancies often necessitate time-intensive safety checks, documentation reviews, and technical adaptations, limiting rail's competitiveness against road transport[67]. Harmonising operational frameworks will minimise these inefficiencies, improving the reliability and speed of rail freight services. This, in turn, enhances rail's attractiveness for shippers, contributing to a modal shift to rail.

To estimate the potential modal shift, the analysis relies on data provided by RNE on dwelling times at borders for each corridor. Using corridor distance data and an assumption about the average speed of freight trains[68], the impact of reduced dwelling times on overall average speed can be calculated. In the low ambition scenario, which assumes moderate improvements in operational rules, dwelling times were estimated to decrease by 15%. For the high ambition scenario, representing full harmonisation of operational rules, a 30% reduction in dwelling times was assumed. It is to be underlined that other factors contribute to dwelling times, including some which depend on the railway undertakings and their operational planning. The deployment of ERTMS also contributes to reducing dwelling times, and these effects are accounted for separately under the corresponding measure.

The estimated increase in average speed for each corridor was then used to calculate the corresponding modal shift, applying modal shift elasticities to transport time identified from the literature[69,70]. This resulted in differentiated modal shift outcomes by corridor, reflecting the specific characteristics of each route.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to the total demand and the values have been adjusted according to the scoring method):
    - Baltic-Adriatic Corridor: 2,0%
    - Scandinavian-Mediterranean Corridor: 0,1%
    - North Sea – Rhine – Mediterranean Corridor: 0,8%

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[67] *More information can be found in the Rail Technical Operational Issues Logbook and related assessments of the issues' impact on railways:*
- *Panteia et al. (2022), Technical support for the interoperability Issues Logbook. Methodology for cost benefit analysis of the solutions and pilot projects and impacts estimation. Retrieved from: https://transport.ec.europa.eu/document/download/81d92b8b-a71f-4341-b9fd-872d5cdd10ba_en?filename=ILB_Final_Economic_report.pdf;*
- *And ERA (2022), Cross-border Rail Transport Potential. Retrieved from: Report - Cross-border Rail Transport Potential.*

[68] *It is assumed to be 40 km/h based on an average speed of pre-allocated paths across all RNE corridors.*

[69] *ITF (2022), Mode Choice in Freight Transport. Retrieved from: https://www.itf-oecd.org/sites/default/files/docs/mode-choice-freight-transport.pdf.*

[70] *The value selected for the modal shift elasticity to travel time is 0,8.*

    - Mediterranean: 1,3%
    - Western Balkans – Eastern Mediterranean: 2,0%

- **Implementation year**[71]: 2035
- **Phasing**[72]: 5 years
- **Cost of introduction per corridor**: € 4M. The only available estimate is offered by the ERA impact assessment on the TSI OPE revision[73]. Accordingly, a one-off cost of €20 million is assumed for the entire railway ecosystem (railway undertakings, infrastructure managers and national safety authorities). This cost has been split evenly across the 5 corridors as operational rules would have to be harmonised at EU-level to be effective.

5.1.1.2 Alternative fuels – limited migration

The European Association of Rail Rolling Stock Lessors (AERRL) estimates that 50% of the locomotive fleet, mainly in freight (13 350 locomotives), run on diesel. Most of these vehicles are shunting locomotives (10 500), used in shunting yards throughout Europe. But AERRL estimates that there are still 2 850 main line locomotives running on diesel[74].

This measure focuses on alternative solutions for main line locomotives. There are several solutions explored today to reduce greenhouse gas (GHG) emissions and air pollution beyond electrification: HVO (Hydrotreated Vegetable Oil), hydrogen or battery / electric trains. All these solutions have their pros and cons, and are adapted to different situations:

- HVO can be used by the existing fleet of diesel trains with no or little investments, but the GHG emissions are still relatively high compared to hydrogen and battery / electric trains.
- Hydrogen offers very good autonomy and entails very low emissions, but the rolling stock is today more expensive than a diesel locomotive (€ 5,5 M vs. € 4 M). Moreover, there is a challenge related to the storage of hydrogen, which might require a tender behind the locomotive, meaning one less wagon for long trains.
- Battery / electric trains are expected to be less expensive than hydrogen trains (in-between diesel and hydrogen trains), have very low emissions, but little autonomy. They could be used when only a small part of a trip is not electrified (less than 50 km), for example for the "last mile".

Alternative fuels, especially biofuels, can offer prominent improvements in CO_2 emissions per train-kilometre compared to diesel. The average values for a 1000-tons freight train are the following[75]:

- Diesel: 23 571 gCO_2/train-km.
- Biofuels: 2 226 gCO_2/train-km, representing over a 90% reduction compared to diesel use.
- Hydrogen: 34 gCO_2/train-km, achieving near-zero emissions.

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[71] The implementation year indicates the date from which the measure is expected to be fully implemented.
[72] The phasing refers to the time required for the measure to take full effect after is implementation. A gradual effect is therefore accounted for in the model for each measure.
[73] ERA (2018), Full Impact Assessment – TSI OPE Revision. Retrieved from: ERA.
[74] Railtech (2023), Over half of EU locomotives still run on diesel: the road to net zero. Retrieved from: https://www.railtech.com/rolling-stock/2023/05/09/over-50-of-eu-locomotives-still-run-on-diesel-the-road-to-net-zero/.
[75] Calculations carried out by Blue Arches in the context of EIB (2022). Analyse du marché et étude de faisabilité d'un déploiement de solutions de propulsion alternatives dans le ferroviaire en Tunisie.

- Battery-electric: 123 gCO_2/train-km, also approaching zero emissions.

For the low ambition scenario, a 100% market share has been allocated to biodiesel.

Lastly, a transition to alternative fuels could reduce the costs for railway operators by limiting the need for additional locomotives at ports/terminals. In turn, this would reduce the costs of rail transport and induce an increase in demand for rail freight.

The values of the parameters selected in the model for the measure are as follows:

- **CO_2 emissions:** 2 226 gCO_2 / train-km[76]
- **Modal shift** (the percentage increase is applied to the total demand)**:**
    - Baltic-Adriatic Corridor: 0,9%
    - Scandinavian-Mediterranean Corridor: 0,8%
    - North Sea – Rhine – Mediterranean Corridor: 0,9%
    - Mediterranean: 0,8%
    - Western Balkans – Eastern Mediterranean: 0,8%
- **Implementation year**: it is considered that the uptake of these new solutions will start in 2030.
- **Phasing:** these new solutions will be deployed progressively in Europe, through the replacement of existing fleet. As the life duration of a vehicle is 30 years, it is estimated that the average age of the fleet today is 15 years old, and that the measure can be deployed in 15 years.
- **Cost of introduction per corridor**: the cost of introduction per locomotive is considered as an extra cost of € 0,75 M. As there are 2 850 main line locomotives to be equipped, it represents a total cost of € 2 136 M for the complete implementation (under the high ambition scenario). The cost for each corridor is determined based on its traffic relative to the total traffic across Europe.
    - Baltic-Adriatic Corridor: € 40 M
    - Scandinavian-Mediterranean Corridor: € 83 M
    - North Sea – Rhine – Mediterranean Corridor: € 89M
    - Mediterranean: € 26M
    - Western Balkans – Eastern Mediterranean: € 41M

For the low scenario 20% of this cost is expected to be incurred.

[76] *This value has been converted in tkm in the model, using an assumption on the average weight of freight trains.*

5.1.2 Moderate ambition scenario

5.1.2.1 DAC deployment [77]

European rail freight is facing three principal challenges: productivity, quality and rail network capacity. One of the main causes is how freight trains are operated and handled. Shunting and train preparation are characterised by manual interventions and, generally speaking, rail freight is insufficiently digitalised and automated, which causes inefficiencies and (transport) time losses.

To address this challenge, a new technical solution for wagons and locomotives has been proposed by the sector: the "Digital Automatic Coupling" (DAC). DAC enables the rapid mechanical (un) coupling of wagons and locomotives, as well as that of digital communication and energy supply throughout the train. Many perceive DAC as the technology of choice to enable rail freight automation and overcome rail capacity issues, to offer more attractive services to customers, to increase rail freight quality and to decrease operating costs.

This new digital solution will also substantially increase worker's safety by automating manual processes. In addition, better working conditions will improve the attractiveness of the rail sector for workers. Finally, DAC will also be an enabler for the digitalisation of rail freight transport through the development of new digital services.

A cost benefit analysis of DAC deployment has been published in 2023[77], testing four "technical packages" of DAC with additional components:

- The first "tech package" only considers DAC 4 (automated coupling) and the associated communication system.
- The second "tech package" corresponds to DAC 5 (automated coupling and uncoupling).
- The third "tech package" considers an automated brake test device on top of tech package 2.
- The fourth "tech package" considers all the components from tech package 3 plus equipment required for automated wagon inspection on the wagon and for automated parking brake. It can be seen as the upper bond of the potential effect of DAC with the functionalities identified and quantified today.

Overall, all scenarios have a very good result from a societal perspective, with IRR and B/C ratios ranging from 11% to 19% and from 1,9 to 28 respectively. The CBA also concluded that the most robust upper bound to be considered was the tech package 3, with automated brake test.

However, railway operators typically apply at a maximum a time window of 10 years for investment decisions. In this period, the CBA shows that the benefit cost ratio does not pass 1, due to the high upfront investment costs and the delayed materialisation of benefits. Moreover, half of the benefits are relative socio-economic benefits that follow from a greater shift from road to rail transport: these benefits will not be fully captured by railway undertakings, wagon leasing companies and ROSCOs. At the same time, the large societal benefits provide a strong rationale for public support for DAC.

It is worth noting that this measure is strongly related to ERTMS deployment. DAC is indeed providing the train integrity functionality for freight trains which is required to reap the full benefits of moving blocks with ERTMS level 2. As mentioned in section 2.4.2, this interdependency is already accounted for in the model as the two measures are combined in both the moderate and high ambition scenario.

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[77] *All content in this section, including numerical values, is based on INECO, EY (2023). Digital Automatic Coupling – cost benefit analysis. Retrieved from: https://projects.shift2rail.org/s2r_ip5_n.aspx?p=6%20EU-DAC.*

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to the total demand and the values have been adjusted according to the scoring method):
  - Baltic-Adriatic Corridor: 4,2%
  - Scandinavian-Mediterranean Corridor: 3,4%
  - North Sea – Rhine – Mediterranean Corridor: 4,2%
  - Mediterranean: 3,8%
  - Western Balkans – Eastern Mediterranean: 3,4%
- **Implementation year: 2030**
- **Phasing:** 5 years
- **Cost of introduction per corridor**[78]:
  - Baltic-Adriatic Corridor: € 1.219 M
  - Scandinavian-Mediterranean Corridor: € 2.528 M
  - North Sea – Rhine – Mediterranean Corridor: € 2.694M
  - Mediterranean: € 795 M
  - Western Balkans – Eastern Mediterranean: € 1.233 M

5.1.2.2 Capacity management at EU-level

The measure follows what is delineated under Policy Option 3 of the Impact Assessment accompanying the Proposal for a Regulation of the European Parliament and of the Council on the use of railway infrastructure capacity in the single European railway area[79], amending Directive 2012/34/EU and repealing Regulation (EU) No 913/2010. This policy focuses on improving capacity management at the EU level, aiming to harmonise the processes for rail capacity allocation, particularly for cross-border freight services. The goal is to optimise the use of rail infrastructure across Europe by introducing new rules and procedures for capacity planning, enhancing coordination between infrastructure managers, regulatory bodies, and freight operators. These changes are intended to streamline the management of rail capacity and improve the reliability and efficiency of rail freight services, ultimately contributing to the EU's sustainability and decarbonisation goals.

According to the Impact Assessment, the modal shift impact for the entire network is estimated to be 2,7% by 2030, 3,6% by 2040, and 4% by 2050. This reflects the expected shift from road to rail freight due to the improved efficiency and competitiveness of rail services, resulting from better capacity management and cross-border coordination. These improvements are expected to reduce delays and optimise the use of existing infrastructure, making rail a more attractive option for freight transport.

The Impact Assessment also estimates the total cost of this measure to be roughly € 2 bn for all stakeholders across the EU. In the model, this cost is split evenly across the various corridors, as

[78] The cost for each corridor is determined based on its traffic relative to the total traffic across Europe.
[79] European Commission (2023). Proposal for a Regulation of the European Parliament and of the Council on the use of railway infrastructure capacity in the single European railway area, amending Directive 2012/34/EU and repealing Regulation (EU) No 913/2010. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52023SC0443.

the capacity management system would need to be implemented at the EU level to be effective. The main costs identified are related to the development and deployment of IT systems for managing rail capacity, which are essential to ensure seamless coordination and real-time data sharing across borders.

At the time of publication of this report, the proposed Regulation was still under negotiations Consequently, the final outcome of those negotiations and the final adopted Regulation may result in different parameters than the ones below. The values of the parameters have been chosen as they represent the preferred policy option of the European Commission impact assessment and thus the most certain estimation of the future impact of the Regulation.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to the total demand): 2,7% by 2030, 3,6% by 2040 and 4% by 2050 (the values per corridor used in the model have been weighted according to the scoring method)
- **Implementation year**: 2026
- **Phasing:** 3 years
- **Cost of introduction per corridor**: € 400 M

5.1.2.3 Alternative fuels – moderate migration

For a full description, see section 5.1.1.2. For the moderate scenario, the split between biodiesel, hydrogen and battery powered traction has been assumed to be 60%, 20% and 20% respectively by 2050.

The values of the parameters selected in the model for the measure are as follows:

- **CO_2 emissions:** 1 367 to 2 226 gCO_2 / train-km[80]
- **Modal shift (**the percentage increase is applied to the total demand**):**
    - Baltic-Adriatic Corridor: 2,3%
    - Scandinavian-Mediterranean Corridor: 1,9%
    - North Sea – Rhine – Mediterranean Corridor: 2,3%
    - Mediterranean: 2,1%
    - Western Balkans – Eastern Mediterranean: 1,9%
- **Implementation year**: it is considered that the uptake of these new solutions will start in 2030.
- **Phasing:** these new solutions will be deployed progressively in Europe, through the replacement of existing fleet. As the life duration of a vehicle is 30 years, it is estimated that the average age of the fleet today is 15 years old, and that the measure can be deployed in 15 years.
- **Cost of introduction per corridor**: the cost of introduction per locomotive is considered as an extra cost of € 0,75 M. As there are 2 850 main line locomotives to be equipped, it represents a total cost of € 2136 M for the complete implementation (under the high scenario). The cost for each corridor is determined based on its traffic relative to the total traffic across Europe.
    - Baltic-Adriatic Corridor: € 100 M

[80] *This value has been converted in tkm in the model, using an assumption on the average weight of freight trains.*

- Scandinavian-Mediterranean Corridor: € 208 M
- North Sea – Rhine – Mediterranean Corridor: € 221M
- Mediterranean: € 65M
- Western Balkans – Eastern Mediterranean: € 101M

For the moderate scenario 50% of this cost is expected to be incurred.

5.1.2.4 Moderate deployment of ERTMS[81]

Fragmentation in European rail traffic management systems leads to inefficiencies, safety concerns, and delays –particularly at borders– due to incompatible national signalling and communication systems.

To address this challenge, the EU has developed the European Rail Traffic Management System (ERTMS), combining the European Train Control System (ETCS) for signalling with the GSM-R communication network. This solution aims to standardise rail traffic management across Europe, improving safety, enhancing network efficiency, and advancing the digitalisation of rail systems by optimising train frequency and infrastructure use, particularly for freight.

ERTMS is expected to yield several key benefits:

- Enhanced safety: the modernisation of train control systems aims to reduce accidents and enhance overall rail safety.
- Increased network capacity: implementing ERTMS Level 2 could improve train frequencies and optimise existing rail infrastructure usage, especially for freight.
- Improved interoperability: as a standardised system, ERTMS facilitates seamless operations across various national rail networks, enhancing cross-border connectivity.

The measure considered in scenario focuses on the deployment of ERTMS on the Core Network. As highlighted above, this measure is strongly related to DAC deployment, reason why both measures are combined in the moderate and high ambition scenario.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to the rail demand only and the values have been adjusted according to the scoring method):
    - Baltic-Adriatic Corridor: 5,5%
    - Scandinavian-Mediterranean Corridor: 4,5%
    - North Sea – Rhine – Mediterranean Corridor: 5,5%
    - Mediterranean: 5,0%
    - Western Balkans – Eastern Mediterranean: 4,5%
- **Implementation year:** 2030
- **Phasing**: 5 years

[81] *The data and information provided here comes from the work of the "Deployment Management Team" under the contract "Technical support for the deployment of ERTMS and digital improvements to the Single European Rail Area".*

- **Cost of introduction per corridor**[82]**:**
  - Baltic-Adriatic Corridor: € 1.427M
  - Scandinavian-Mediterranean Corridor: € 2.959M
  - North Sea – Rhine – Mediterranean Corridor: € 3.153M
  - Mediterranean: € 930M
  - Western Balkans – Eastern Mediterranean: € 1.443M

5.1.2.5 Moderate investments in multimodal terminals to foster intermodality

This measure encompasses strategic investments in intermodal loading and unloading capabilities aimed at significantly boosting freight handling capacity. By facilitating greater volumes of freight traffic, these investments are designed to support the growing demand for multimodal transport solutions. Investments to foster intermodality prioritise the practical enhancement of transport mode integration, emphasising cost-effective and targeted improvements over large-scale infrastructure developments. The FERRMED study (2023)[83] proposes constructing 425 new intermodal terminals and upgrading existing ones. These are designed for rapid, efficient handling of semi-trailers, containers, and swap bodies, thus facilitating multimodal transport. It corresponds, according to the study, to the investments required to achieve a 30% modal share of rail freight, which aligns with the share estimated the high ambition scenario[84].

The moderate ambition scenario envisions 50% of these investments being carried out[85], which will result in the partial realisation of the infrastructure improvements outlined above across the selected corridors.

Unlike other measures, this measure does not project a change in rail transport demand itself. Its main objective is rather to enable the modal shift associated with the moderate and high ambition scenarios to happen.

The values of the parameters selected in the model for this measure are as follows:

- **Implementation year:** 2035
- **Phasing:** 15 years
- **Cost of introduction per corridor**[86]**:**
  - Baltic-Adriatic Corridor: € 545M
  - Scandinavian-Mediterranean Corridor: € 1.131 M
  - North Sea – Rhine – Mediterranean Corridor: € 1.205M
  - Mediterranean: € 356M
  - Western Balkans – Eastern Mediterranean: € 551M

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[82] *The cost for each corridor is determined based on its traffic relative to the total traffic across Europe.*

[83] *FERRMED (2023), Study of Traffic and Modal Shift Optimisation in the EU. FERRMED A.S.B.L. Retrieved from: https://ferrmed.com/wp-content/uploads/2023/11/FERRMED_study_291123.pdf.*

[84] *The FERMMED report covers a broader scope as it goes beyond the five selected corridors. However, since these corridors represent a high portion of rail traffic and concentrate a very substantial part of the investment needs, the investment amounts proposed in the FERRMED report seem to constitute a satisfactory proxy for the needs of this study.*

[85] *The total cost amounts to € 11,6 bn so the value of € 5,8 bn has been used for this measure.*

[86] *The costs for each corridor were calculated by allocating half of the total cost from the FERRMED study based on the traffic proportion of each corridor relative to the overall traffic within the EU.*

5.1.3 High ambition scenario

5.1.3.1 Increasing train length

This measure, which involves the necessary upgrades and adjustments to enable freight trains up to 740 meters in length to operate efficiently across key corridors. Achieving this requires significant infrastructure modifications, such as extending sidings, adapting track layouts, and upgrading stations to handle longer trains. Operational adjustments, including timetable reconfigurations and specialised staff training, are equally critical for seamless implementation.

Many rail corridors do not have the infrastructure (including logistic hubs) required to accommodate 740-meter trains. As an example, across the rail freight corridor Rhine-Alpine, the average train lengths were approximately 480 meters for block trains and 530 meters for intermodal services in 2018 (TRT Trasporti e Territorio, 2019)[87].

Implementing this measure will increase the efficiency of rail freight by enabling a higher volume of goods to be transported per service, reducing operational costs, and enhancing the competitiveness of rail transport compared to road freight, encouraging a shift from road to rail. More precisely, the anticipated effect on modal shift stems for three main factors:

- Enhanced cost-competitiveness: increasing train lengths significantly lowers the cost per ton-kilometre transported, improving rail freight's economic appeal relative to road freight. By enabling 740-meter trains, rail operating costs could decrease by 12–20%, translating to a reduction of 9–12% in door-to-door shipping prices for intermodal services (TRT Trasporti e Territorio, 2019).
- Multimodal synergies: by enabling the operation of longer trains, rail becomes a more integral part of multimodal logistics chains. Its enhanced capacity to handle larger shipments improves efficiency and strengthens rail's role in supporting intermodal freight, where seamless integration with other transport modes is crucial. This measure contributes to a more cohesive and sustainable logistics network.
- Addressing shipper priorities: cost, reliability, and capacity are the key factors influencing modal choice for shippers. Increasing train lengths addresses these priorities directly, making rail freight a more competitive and attractive alternative to road transport. This measure not only enhances rail's economic appeal but also aligns with shippers' growing focus on sustainability and efficiency.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift**[88] (the percentage increase is applied to the total demand and the values have been adjusted according to the scoring method):
    - Baltic-Adriatic Corridor: 2,9%
    - Scandinavian-Mediterranean Corridor: 2,3%
    - North Sea – Rhine – Mediterranean Corridor: 2,9%

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[87] *TRT Trasporti e Territorio (2019). Transport Market Study: "Quantification of modal shift potential on the Rail Freight Corridor Rhine-Alpine". Retrieved from: https://www.corridor-rhine-alpine.eu/files/downloads/others/Transport%20Market%20Study%202018.pdf.*

[88] *Due to the absence of data, the modal shift applied to all corridors is based on the evaluation done for the rail freight corridor Rhine-Alpine in 2019. Source: TRT Trasporti e Territorio (2019). Transport Market Study: "Quantification of modal shift potential on the Rail Freight Corridor Rhine-Alpine". Retrieved from https://www.corridor-rhine-alpine.eu/files/downloads/others/Transport%20Market%20Study%202018.pdf. The value chosen (2,6%) comes from the "base scenario," which is a conservative approach.*

- Mediterranean: 2,6%
- Western Balkans – Eastern Mediterranean: 2,3%

- **Implementation year**: 2035
- **Phasing**: 15 years
- **Cost of introduction per corridor**: € 3100 M[89]

5.1.3.2 Full deployment of ERTMS[90]

The measure is an extension of the measure described in section 5.1.2.4, which is focusing on the Core Network corridors. In this new measure, the deployment of ERTMS is considered on the Comprehensive Network and also at national level when foreseen in the National Implementation Plans from Member States. As mentioned above, this measure is strongly related to DAC deployment, reason why both measures are combined in the moderate and high ambition scenario.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to rail demand only. The chosen values are aligned with the ambitious scenario from the ERTMS business case analysis[91]. They have been adjusted according to the scoring method):
  - Baltic-Adriatic Corridor: 7,7%
  - Scandinavian-Mediterranean Corridor: 6,3%
  - North Sea – Rhine – Mediterranean Corridor: 7,7%
  - Mediterranean: 7,0%
  - Western Balkans – Eastern Mediterranean: 6,3%
- **Implementation year**[92]:
  - Baltic-Adriatic Corridor: 2037
  - Scandinavian-Mediterranean Corridor: 2037
  - North Sea – Rhine – Mediterranean Corridor: 2040
  - Mediterranean: 2035
  - Western Balkans – Eastern Mediterranean: 2035
- **Phasing**: 15 years

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[89] *In the absence of data, the investment amount used for this measure is the one estimated for the rail freight corridor North Sea-Baltic in 2020. Source: Tplan consulting, HaCon, Railistics (2020). Study on Capacity Improvement of the Rail Freight Corridor North Sea-Baltic. Retrieved from: https://rfc8.eu/files/public/Downloads_STUDIES/RFC_NSB_SCI_Final_Report_2020.pdf.*

[90] *As for the moderate ambition scenario, the data and information provided here comes from the work undertaken by "Deployment Management Team" under the contract "Technical support for the deployment of ERTMS and digital improvements to the Single European Rail Area".*

[91] *European Commission: Directorate-General for Mobility and Transport, ERTMS business case on the 9 core network corridors – Second release, Publications Office, 2019, https://data.europa.eu/doi/10.2832/813655.*

[92] *To determine the implementation years for the ERTMS measures, EY compiled a list of Member States that each corridor traverses. This was then combined with the ERTMS deployment dates from the relevant National Implementation Plans for both the core and comprehensive networks to determine the implementation date foreach corridor.*

- **Cost of introduction per corridor**[93]:
    - Baltic-Adriatic Corridor: € 1.314 M
    - Scandinavian-Mediterranean Corridor: € 2.725 M
    - North Sea – Rhine – Mediterranean Corridor: € 2.904 M
    - Mediterranean: € 857 M
    - Western Balkans – Eastern Mediterranean: € 1329 M

5.1.3.3 Full harmonisation of operational rules

The measure is presented in the context of the low ambition scenario, where its main features are outlined. For the high ambition scenario, corresponding to full harmonisation of operational rules, the assumption is that dwelling times at borders would be reduced by 30%, reflecting the greater efficiency gains achievable under this measure.

The values of the parameters selected in the model for the measure are as follows:

- **Modal shift** (the percentage increase is applied to the total demand and the values have been adjusted according to the scoring method):
    - Baltic-Adriatic Corridor: 4,0%
    - Scandinavian-Mediterranean Corridor: 0,2%
    - North Sea – Rhine – Mediterranean Corridor: 1,5%
    - Mediterranean: 2,7%
    - Western Balkans – Eastern Mediterranean: 3,9%
- **Implementation year: 2035**
- **Phasing:** 5 years
- **Cost of introduction per corridor**: €4 M per corridor (total €20 million). Same as in the moderate harmonisation of operational rules.

5.1.3.4 Full deployment of EU-Rail JU technical outputs

This measure focuses on integrating innovations from the Europe's Rail[94] innovation programme to support the modernisation and development of the rail freight sector. These innovations include advancements in digital technologies, such as the digitalisation and automation of freight rolling stock (such as automatic train operation) or enhanced traffic management and control systems. These technologies are designed to optimise the operational performance of single-wagon, block, and combined freight systems, thereby addressing key inefficiencies in rail freight. Detailed descriptions of the innovations and their expected impacts can be found in the report developed by

[93] *As for the moderate ambition scenario, the cost for each corridor is determined based on its traffic relative to the total traffic across Europe.*
[94] *Formerly known as Shift2Rail (S2R).*

EY for the EU-Rail Joint Undertaking[95].The modelling assumptions for this study are drawn directly from the findings delineated in this report[96]. The expected impact of these innovations is an increase in the overall demand for rail freight services, by improving the operational efficiency and capacity of rail freight. The technologies included within this measure are expected to further boost some of the other measures such as ERTMS deployment. The game changers can for example fully unlock the capacity-enhancing potential of ERTMS.

The overall estimated impact on rail freight demand for the full deployment of these innovation is projected to be a 25% increase. These assumptions reflect the scaling of expected benefits based on the level of implementation and adoption of these technologies.

The report mentioned above estimates the total cost of this measure to be roughly € 4,3 bn for all stakeholders across the EU. As for the measure related to capacity management, this cost is split evenly across the various corridors, as the EU-Rail technical outputs would need to be implemented at the EU level to be effective.

The values of the parameters selected in the model for this measure are as follows:

- **Modal shift** (the percentage increase is applied to rail demand only and the values have been adjusted according to the scoring method):
  - Baltic-Adriatic Corridor: 27,5%
  - Scandinavian-Mediterranean Corridor: 22,5%
  - North Sea – Rhine – Mediterranean Corridor: 27,5%
  - Mediterranean: 25,0%
  - Western Balkans – Eastern Mediterranean: 22,5%
- **Implementation year**: 2028
- **Phasing**: 15 years
- **Cost of introduction per corridor**: € 840 M

5.1.3.5 Major investments in multimodal terminals to foster intermodality

The high ambition scenario of this measure builds upon the moderate scenario (see 5.1.2.5) by planning for the full implementation of the new intermodal terminals proposed by the FERRMED study, rather than half of the investment effort in the moderate scenario.

The values of the parameters selected in the model for the measure are as follows:

- **Implementation year**: 2035
- **Phasing**: 15 years
- **Cost of introduction per corridor**[97]:
  - Baltic-Adriatic Corridor: € 1.091 M

[95] *EY (2023), Strategic support to the Shift2Rail Joint Undertaking | S2R.19. OP.02 - LOT 1 Strategy Advice - I.3 Work to support with a cost-benefit analysis the definition of migration paths for the implementation of S2R selected innovations on the European network. Retrieved from: https://rail-research.europa.eu/wp-content/uploads/2023/01/S2R-I4-V2-Final-report-2022-11-03_clean_.pdf.*

[96] *This includes the assumptions on the introduction year, timing and the cost of implementation.*

[97] *As for the moderate ambition scenario, the costs for each corridor were calculated by allocating the total cost from the FERRMED study (€ 11,6 bn) based on the traffic proportion of each corridor relative to the overall traffic within the EU.*

- Scandinavian-Mediterranean Corridor: € 2.262 M
- North Sea – Rhine – Mediterranean Corridor: € 2.410 M
- Mediterranean: € 711 M
- Western Balkans – Eastern Mediterranean: € 1.103 M

5.1.3.6 Alternative fuels – strong migration

For a full description of the alternative fuels measure, see section 5.1.1.2. For the high scenario, the split between biodiesel, hydrogen and battery powered traction has been assumed to be 20%, 40% and 40% respectively by 2050.

The values of the parameters selected in the model for the measure are as follows:

- **CO_2 emissions:** 508 to 2 226 gCO_2 / train-km[98]
- **Modal shift** (the percentage increase is applied to the total demand)**:**
  - Baltic-Adriatic Corridor: 4,6%
  - Scandinavian-Mediterranean Corridor: 3,8%
  - North Sea – Rhine – Mediterranean Corridor: 4,6%
  - Mediterranean: 4,2%
  - Western Balkans – Eastern Mediterranean: 3,8%
- **Implementation year:** it is considered that the uptake of these new solutions will start in 2030
- **Phasing:** these new solutions will be deployed progressively in Europe, through the replacement of existing fleet. As the life duration of a vehicle is 30 years, it is estimated that the average age of the fleet today is 15 years old, and that the measure can be deployed in 15 years.
- **Cost of introduction per corridor**: the cost of introduction per locomotive is considered as an extra cost of € 0,75 M. As there are 2 850 main line locomotives to be equipped, it represents a total cost of € 2136 M. The cost for each corridor is determined based on its traffic relative to the total traffic across Europe.
  - Baltic-Adriatic Corridor: € 200 M
  - Scandinavian-Mediterranean Corridor: € 415 M
  - North Sea – Rhine – Mediterranean Corridor: € 443M
  - Mediterranean: € 131M
  - Western Balkans – Eastern Mediterranean: € 203M

[98] *This value has been converted in tkm in the model, using an assumption on the average weight of freight trains.*

5.2 Sensitivity analysis

To test the robustness of the outcomes, a sensitivity analysis was carried out. It was conducted by changing four main assumptions:

- Limiting the effect of the measures to 70% of the value considered in the main model.
- Increasing the measures‘ introduction costs by 30%.

The tables below present the outcomes of different tests undertaken[99] (Table 23 presents the results of the main model for comparison purposes):

- Table 21: implementation costs increased by 30% and measures at 70% of the intensity considered in the main model.
- Table 22: implementation costs increased by 30% and intensity of the measures unchanged.

The results highlight that even in a situation where the intensity of the measures is reduced to 70% of their value use in the modal and a 30% increase of the implementation cost is introduced, the CBA would still be positive with an NPV of €76 bn (discounted) in the high ambition scenario.

KPI	Unit	Base			Low			Moderate			High		
		2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Rail Modal share	%	18%	18%	18%	18%	19%	19%	19%	21%	22%	20%	24%	29%
Rail demand	**Billion tkm**	281	320	360	282	333	376	303	377	439	308	420	587
Energy cost	**€ billion**	€ 52	€ 48	€ 51	€ 53	€ 49	€ 53	€ 52	€ 47	€ 51	€ 52	€ 46	€ 47
CAPEX	**€ billion**				€ 0,750			€ 33			€ 65		
CO_2 emissions	**Million tCO_2e**	140	65	5	140	65	5	137	63	4	137	61	4
Energy usage	**Million GJ**	1226	1010	806	1228	1013	819	1210	983	784	1204	951	710
NPV	**€ billion**				€ 9			€ 28			€ 76		

[99] *The tables present the value for each specific year. The CAPEX and NPV are for the entire period covered by the CBA, CBA which extends until 2060 (see section 2.3.6). It should be noted that the NPV value presented in the table are discounted while the CAPEX values presented are undiscounted.*

Table 21: Results with implementation costs increased by 30% and measures at 70% intensity

KPI	Unit	Base			Low			Moderate			High		
		2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Rail modal share	%	18%	18%	18%	18%	19%	19%	20%	23%	24%	**20%**	**26%**	**34%**
Rail demand	**Billion tkm**	281	320	360	282	338	383	313	401	473	**319**	**459**	**684**
Energy cost	**€ billion**	€ 52	€ 48	€ 51	€ 53	€ 49	€ 53	€ 52	€ 47	€ 50	**€ 51**	**€ 45**	**€ 45**
CAPEX	**€ billion**				€ 0,750			€ 33			€ 65		
CO_2 emissions	**Million tCO_2e**	140	65	5	140	65	5	136	61	4	**136**	**59**	**4**
Energy usage	**Million GJ**	1226	1010	806	1228	1010	816	1202	931	658	**1195**	**928**	**670**
NPV	**€ billion**				€ 13			€ 49			€ 122		

Table 22: Results with implementation costs increased by 30% and intensity of the measures unchanged

KPI	Unit	Base			Low			Moderate			High		
		2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Rail modal share	%	18%	18%	18%	**18%**	**19%**	**19%**	**20%**	**23%**	**24%**	**20%**	**26%**	**34%**
Rail demand	**Billion tkm**	281	320	360	**282**	**338**	**383**	**313**	**401**	**473**	**319**	**459**	**684**
Energy cost	**€ billion**	€ 52	€ 48	€ 51	**€ 53**	**€ 49**	**€ 53**	**€ 52**	**€ 47**	**€ 50**	**€ 51**	**€ 45**	**€ 45**
CAPEX	**€ billion**				€ 0,577			€ 26			**€ 50**		

KPI	Unit	Base			Low			Moderate			High		
		2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
CO_2 emissions	Million tCO_2e	140	65	5	140	64	5	136	62	4	136	59	4
Energy usage	Million GJ	1226	1010	806	1228	1010	816	1202	969	771	1195	928	670
NPV	€ billion				€ 13			€ 55			€ 132		

Table 23: Comparative results of the impact of the high impact scenario

5.3 Detailed outcomes of the model on the demand evolution across scenarios

Figure 13, Figure 14 and Figure 15 illustrate the evolution of the demand for road and rail transport and indicate the demand values for the three key milestones considered in this study: 2030, 2040, and 2050. They allow for a comparison of demand trends by mode for each scenario against the baseline scenario. As expected, the implementation of the measures results in an increase in rail freight demand compared to the baseline scenario (and the effect is stronger as the scenario becomes more ambitious). Conversely, road transport experiences a relative decrease in demand compared to the baseline, whose magnitude is proportional to the ambition of the scenario.

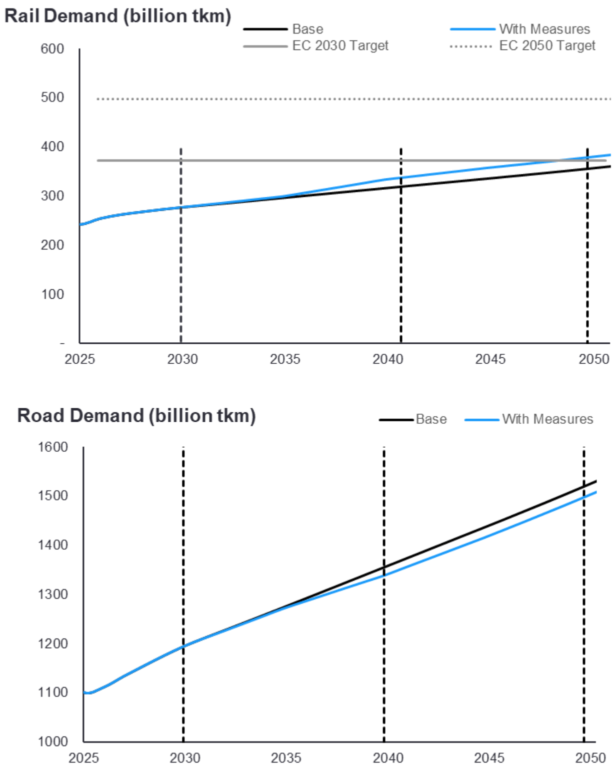

Figure 13: Freight demand for rail and road transport in the low ambition scenario

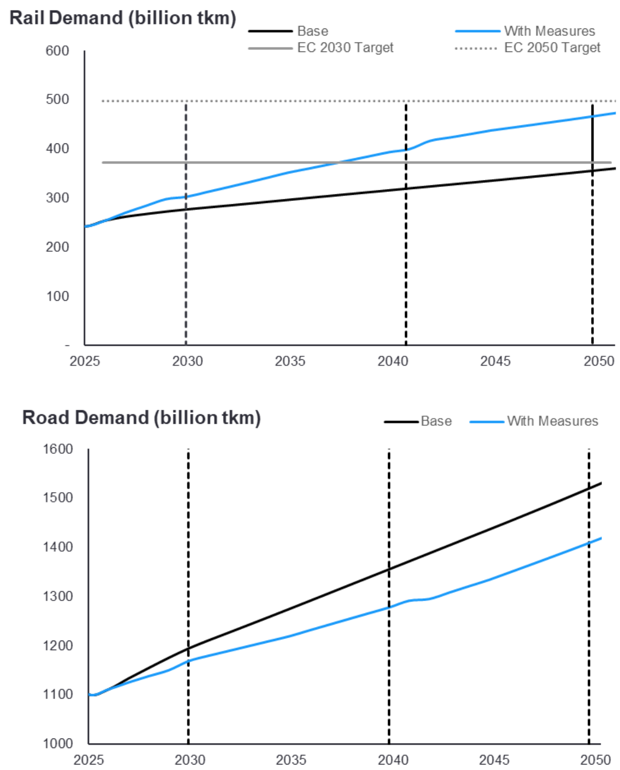

Figure 14: Freight demand for rail and road transport in the moderate ambition scenario

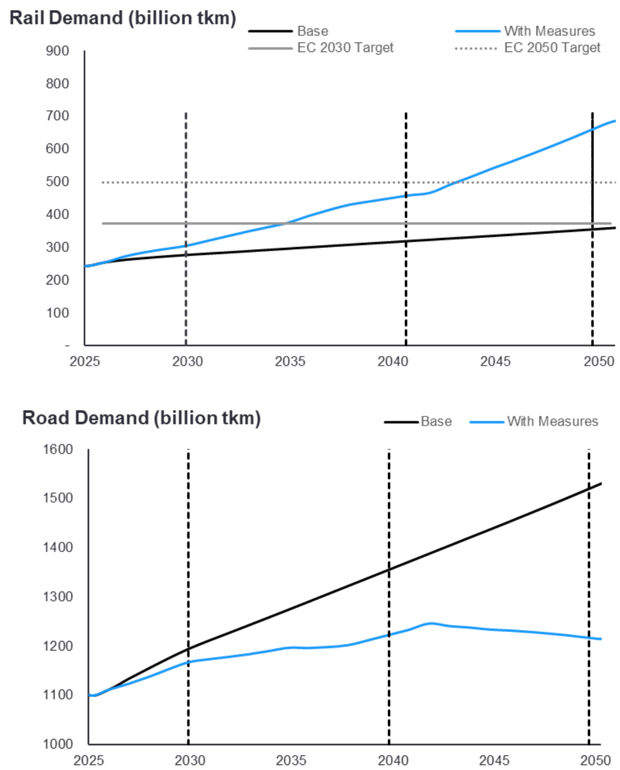

Figure 15: Freight demand for rail and road transport in the high ambition scenario

Figures relating to the evolution of modal shares are presented in the following charts (Figure 16, Figure 17 and Figure 18). It shows that in the low ambition scenario, the rail modal share increases to 19% in 2040 and remains largely unchanged until 2050. In the moderate scenario modal share for rail in the period 2030-2050 grows from 20% to 24%, while in the high ambition scenario, it rises from 20% to 34%[100]. Two points are worth underlining:

- The value taken by modal shares in the high ambition scenario for 2050 aligns with EU's ambitions on the development of rail freight in Europe as defined in the Sustainable and Smart Mobility Strategy.
- As described in section 2, the scale of modal shift is constrained by three factors introduced in the model: capacity limitations included in the low and moderate ambition scenarios, capacity constraints arising from upcoming infrastructure works in most of Europe which are assumed to be applicable until 2040 whereafter this constraint is lifted, and the consideration that modal shift applies only to road traffic over distances greater than 300 km.

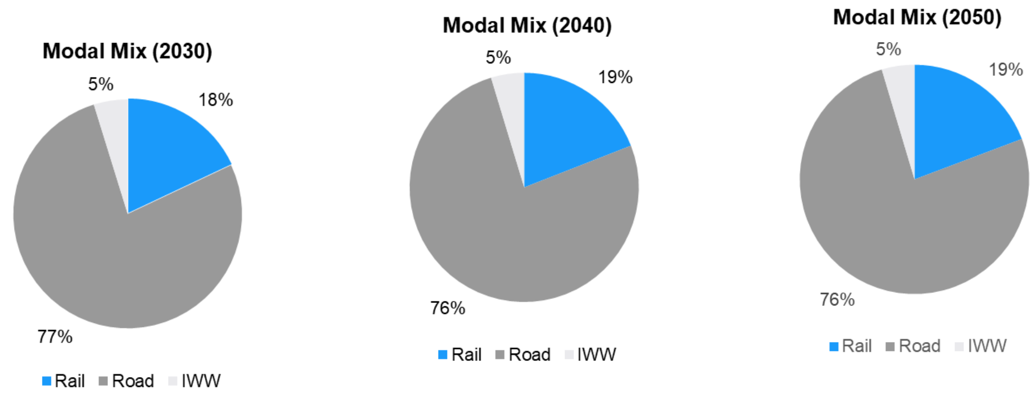

Figure 16: Evolution of modal shares in the low ambition scenario

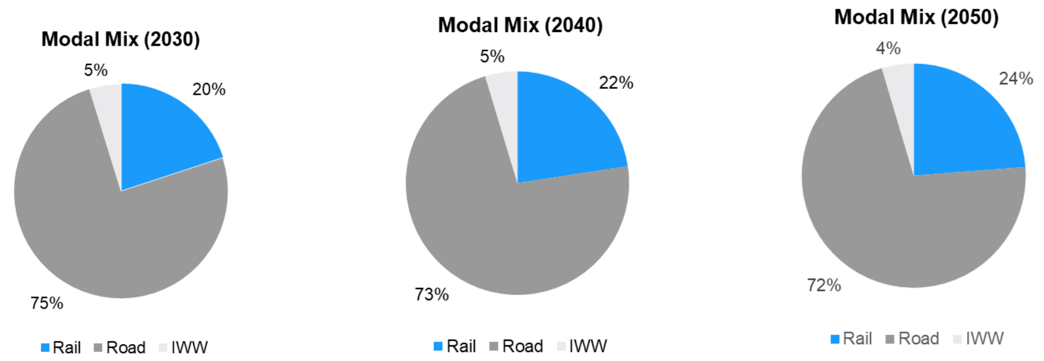

Figure 17: Evolution of modal shares in the moderate ambition scenario

[100] *The different values of the modal share for 2030 are explained by the fact that the implementation of certain measures occur prior to that year (e.g. deployment of EU-Rail technical outputs).*

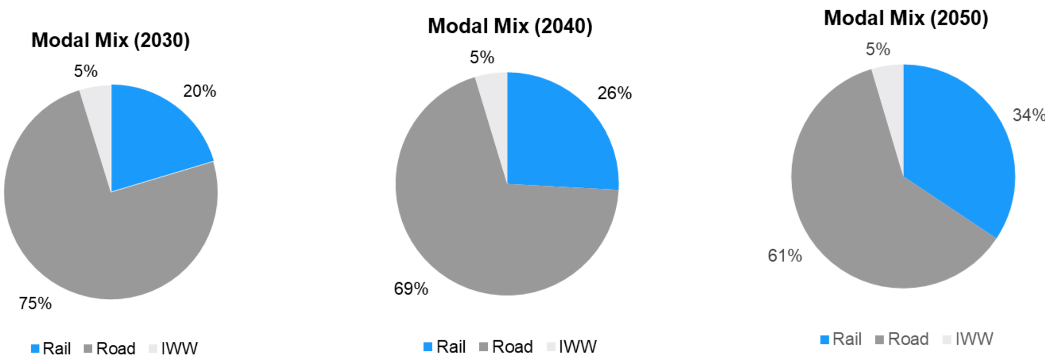

Figure 18: Evolution of modal shares in the high ambition scenario

5.4 Data collection exercise

A key challenge of the study has consisted in gathering the detailed data necessary for model development. The definition of the methodological framework with the group of academic experts and the Steering Committee has allowed for a fairly precise identification of the type of data needed to enable the modelling exercise. This included, in particular, data related to:

- Traffic (in tkm).
- Impact of measures on modal shift or CO_2 emissions.
- Measures' implementation cost.
- Capacity constraints.
- Transport externalities
- Evolution of energy intensity.
- Hubs, terminals and ports located along the corridors.

One of the main challenges was to gather recent data on traffic volumes at corridor level. Thanks to the collaboration with Rail Net Europe, very detailed data has been collected by corridor for the years 2023 and 2024, which has constituted a valuable contribution to the robustness of the estimates.

Regarding the impact of the selected measures on modal shift or CO_2 emissions, EY-Parthenon conducted an extensive literature review, complemented by exchanges with the academic expert group and stakeholders.

To gain a qualitative understanding of the issues facing both the corridors and the hinterland terminals and seaports, a series of targeted interviews and consultations were conducted. The stakeholders consulted included railway undertakings, infrastructure managers, seaports and intermodal ports. The consultations provided valuable insights on capacity constraints (present and future), the measures included in the study and the main assumptions underlying the model.

Data was collected from various sources, including but not limited to: Eurostat, Rail Net Europe's Corridor Information Platform, TEN-T Corridor studies, European Commission's Impact Assessments, the OECD, peer-reviewed academic articles, as well as industry reports and studies. A list of key data sources and references is provided in Table 24 below.

Data	Application	Source
TEN-T Corridor Reports	Demand assessment and market analysis	EC (2024), *Trans-European Transport Network (TEN-T)*. Retrieved from: [*EC (2024), Trans-European Transport Network (TEN-T).*]
RNE – RFC Reports	Demand assessment, market analysis	Rail Net Europe (2024), *RIS* Retrieved from: [Rail Net Europe (2024), RIS]

Data	Application	Source
RNE - Databases on trafic volumes per corrirdor	Demand assessment	N.a.
FERRMED Study of Traffic and Modal Shift Optimisation	Capacity assessment	FERRMED (2024). *Study of traffic and modal shift optimisation.* Retrieved from: Study of traffic and modal shift optimisation
Eurostat data	Demand assessment	Eurostat (2024), *various datasets.* Retrieved from: https://ec.europa.eu/eurostat
OECD data	Demand assessment	OECD (2024), *various datasets*. Retrieved from: https://www.oecd.org/en/data.html
CE Delft Handbook on External Costs of Transport	CBA	EC (2019) *Handbook on the external costs of transport - Publications Office of the EU* Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1
ERTMS	Measures	Ineco, EY (2019), *ERTMS Business Case on Nine Core Corridors.* Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/995e2d1b-9950-11e9-9d01-01aa75ed71a1/language-en
DAC	Measures	European Commission (2023). DAC CBA Report on Maritime Ports
Alternative fuels propulsion	Measures	EY (2022). Report on Market Analysis & Feasibility for Alternative Fuels in Railway
Capacity management	Measures	EC (2023). *Impact assessment for the proposal on the use of railway infrastructure capacity in the single European railway area.* Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52023SC0443

Data	Application	Source
Increased train length	Measures	TRT Trasporti e Territorio, (2019) "*Quantification of modal shift potential on the Rail Freight Corridor Rhine-Alpine*" Retrieved from: https://www.corridor-rhine-alpine.eu/files/downloads/others/Transport Market Study 2018.pdf
Europe's Rail JU technical outputs	Measures	EU-Rail (2023). Work to support with a cost-benefit analysis the definition of migration paths for the implementation of S2R selected innovations on the European network. Retrieved from: https://rail-research.europa.eu/publications/final-report-work-to-support-with-a-cost-benefit-analysis-the-definition-of-migration-paths-for-the-implementation-of-s2r-selected-innovations-on-the-european-network/
Introduction of ETS for transport	Measures	Dahl, C.A. (2012). *Measuring global gasoline and diesel price and income elasticities*. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0301421510008797 Luke Haywood and Michael Jakob (Transport Policy 139 (2023) 99–108), *The role of the emissions trading scheme 2 in the policy mix to decarbonize road transport in the European Union*. Retrieved from: https://trid.trb.org/view/2195213
Harmonisation of operational rules	Measures	ERA (2012), *Full Impact Assessment – TSI OPE Revision*. Retrieved from: ERA.europa.eu
Intermodal (un-) loading solutions	Measures	FERRMED (2024). *Study of traffic and modal shift optimisation*. Retrieved from: https://ferrmed.com/study-of-traffic-and-modal-shift-optimisation/
	Emissions assumptions – energy mix	International Energy Agency (2024). *World Energy Outlook 2024*. Retrieved from World Energy Outlook 2024 – Analysis - IEA
	Emissions assumptions - road transport	EC (2024). Regulation (EU) 2024/1610 - as regards strengthening the CO_2 emission performance standards for new heavy-duty vehicles and integrating reporting obligations. Retrieved from: Regulation - EU - 2024/1610 - EN - EUR-Lex

Data	Application	Source
	Emissions assumptions - road transport	IRU (2023), *IRU Green Compact Research Study: Europe Executive Summary*. Retrieved from: *IRU Green Compact – Research Study: Europe - General information | IRU | World Road Transport Organisation*
	Emissions assumptions – IWW	European Commission (2021), *NAIADES III: Boosting future-proof European inland waterway transport*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0324&from=EN
	Emissions assumptions – IWW	CCNR (2021), *Study on financing the energy transition towards a zero-emission european IWT sector*. Retrieved from: *Final_overall_study_report.pdf*

Table 24: Key data sources

5.5 Selected corridors

5.5.1 Societal Scandinavian-Mediterranean Corridor

The Scandinavian-Mediterranean Corridor, is a vital artery for trade and freight transport in Europe, stretching from the northern reaches of Finland and Sweden down to the southern tips of Italy and the Mediterranean. This corridor traverses key countries such as Denmark, Germany, and Austria, linking economically powerful regions through its 7,527 kilometres of railway tracks. A notable segment of this network is the railway line between Verona and München, which spans 435 kilometres and involves coordination between three countries and three infrastructure managers. This line is particularly significant as it is one of the most heavily circulated freight corridors in Europe, serving a variety of trade lanes and reflecting the strategic importance of the corridor for transalpine transport.

Despite political intentions and efforts to promote rail transport, the modal share of rail in transalpine freight traffic has not seen a significant increase over the past 20 years, remaining at about 30% in 2019. This stagnation comes despite the clear advantages of rail in terms of sustainability and efficiency for long distances. The goods transported along this corridor are diverse, but machinery and transport equipment, as well as crude and manufactured materials, represent the highest shares of traffic. These commodities reflect the industrial and productive nature of the regions served by the Scan-Med Corridor.

Furthermore, the Corridor encompasses some of the main European ports, such as Hamburg, as well as ports at the northern and southern extremities of Europe, reinforcing its role as a link between north and south EU markets. Around 35 terminals are connected to this corridor, including combined rail-road facilities, like those in Hamburg and Bologna, as well as major seaports such as Hamburg, Bremerhaven, and Gioia Tauro.

5.5.2 Baltic-Adriatic Corridor

The Baltic-Adriatic Corridor serves as a major trans-European axis, extending from the Polish Baltic Sea ports in the north to the Slovenian and Italian ports by the Adriatic Sea. This corridor brings together over 10,000 kilometres of railway tracks, of which 5,200 kilometres are part of the Rhine-Alpine RFC5 (Rail Freight Corridor 5). Along this route, 12 seaports, 5 inland waterway (IWW) ports, and 28 rail-road terminals form a dense grid of multimodal connections.

In 2018, the modal share of rail transport along this corridor was 33%, with a higher share of 45% for distances ranging from 400 to 900 kilometres, highlighting a significant reliance on rail for mid-range transport. Despite this, there has been a downward trend in rail's modal share over the past decade, and as of 2014, the corridor's rail capacity was not being fully utilised. This underutilisation suggests that there is ample room for growth and efficiency improvements within the corridor's rail services. Freight rail transport is serving the mining and quarrying activities in Southern Poland and Czechia, as well as the important industrial manufacturing activities present in the corridor's catchment area[101].

A notable 82% of the rail traffic consists of block trains or single wagonload (SWL) traffic, underscoring the corridor's role in facilitating bulk transport and serving the industrial activities in the region. The Baltic-Adriatic Corridor also encompasses key Central European countries such as Poland, Czechia, Slovakia, and Slovenia, and includes major ports like Gdansk, Szczecin, and Trieste[102].

5.5.3 North Sea – Rhine – Mediterranean Corridor

The North Sea – Rhine – Mediterranean Corridor is a pivotal axis in the European transport network, connecting the North Sea ports of Belgium and the Netherlands with the Mediterranean hub of Genoa and running through Switzerland. This corridor stands out in the European Union for having the largest share of non-road transport: approximately 50% of the annual freight volumes, which equates to 138 bn tkm, are transported via waterways, while rail transport represents 16% of the modal share. Road transport, limited by stringent Swiss regulations designed to restrict freight traffic on roads, accounts for the remaining 34%. This distribution underscores the corridor's reliance on sustainable transport modes and highlights the potential for further modal shift from road to rail or waterborne transport.

Container transport, which represents 9% of the total freight on the Rhine between Basel and the German-Dutch border, has seen a substantial increase of 27% from 2009 to 2017. This growth indicates a rising trend in containerisation, which could drive further development in intermodal solutions along the corridor. The corridor's inclusion of major European ports such as Genoa, Antwerp, Rotterdam, and Duisburg not only facilitates international trade but also strengthens the economic ties between the northern and southern regions of the continent. With a relatively low mode share for road transport, the North Sea – Rhine – Mediterranean Corridor exemplifies the potential for a more sustainable and integrated European freight transport system, where investment in rail capacity and waterborne infrastructure could further shift the balance towards

[101] *European Commission (2014), Baltic-Adriatic Core Network Corridor Study – Final Report. Retrieved from: https://transport.ec.europa.eu/document/download/c51d4047-214b-420d-a331-2eccca68ba5_en?filename=baltic-adriatic_study.pdf;*
and Tplan Consulting (2020) Transport Market Study of the Rail Freight Corridor Baltic-Adriatic 2020 Update. Retrieved from: https://www.rfc5.eu/studies/.

[102] *Tplan Consulting (2020) Transport Market Study of the Rail Freight Corridor Baltic-Adriatic 2020 Update. Retrieved from: https://www.rfc5.eu/studies/.*

more sustainable logistic chains.

5.5.4 Mediterranean

The Mediterranean Rail Freight Corridor (Med RFC) connects ports in the southwestern Mediterranean region to the centre of the EU. It follows the coastlines of Spain and France, crosses the Alps, and continues through northern Italy, Slovenia, Croatia, and Hungary up to the Ukrainian border. The main branches of the Corridor include Almería – Valencia / Algeciras / Madrid – Zaragoza / Barcelona – Marseille – Lyon – Torino – Milano – Verona – Padova / Venezia – Trieste / Koper – Ljubljana/Rijeka – Zagreb – Budapest – Zahony (Hungarian-Ukrainian border). The Med RFC covers more than 7,000 km and includes 9 seaports as well as roughly 90 terminals, making it one of the most interconnected corridors in Europe.

In 2016, the Mediterranean Rail Freight Corridor's market area represented a global traffic volume of international freight transport by all modes of 185 million tons. The distribution of this traffic was as follows: 78% by road, 11% by rail (21 million tons), and 11% by short sea services. The rail share for international freight transport in the Med RFC market area is relatively low compared to other long-distance flows across Europe, especially in the north-south direction. This low rail share can be attributed to several factors, including the competitiveness of short sea services, the structure of the traffic, and remaining technical bottlenecks on rail infrastructure such as track gauge differences with Spain, severe ramps across the Alps at border crossings, train length limitations, and lack of interoperability[103].

5.5.5 Western Balkans – Eastern Mediterranean

The Western Balkans - Eastern Mediterranean (WBEM) Corridor is a vital freight transport route that connects central European Member States with the ports of the Adriatic and East Mediterranean Seas through the Western Balkans. This corridor spans eight EU Member States—Austria, Slovenia, Croatia, Hungary, Bulgaria, Greece, Cyprus, and Italy—as well as Serbia, Bosnia and Herzegovina, Montenegro, Kosovo, Albania, and North Macedonia. It links all capital cities along its path, except Vienna and Rome, and integrates segments of the former Orient/East-Med corridor. The WBEM Corridor is multimodal, enhancing the movement of goods across road, rail, and maritime transport, thereby playing a key role in facilitating trade and economic integration in the region[104].

[103] *PWC (2020). 2020 Update of the Transport Market Study along the Mediterranean Rail Freight Corridor (Med RFC) (Version 3.0).*

[104] *EC Mobility and Transport. (n.d.). Western Balkans - Eastern Mediterranean corridor. Retrieved from: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-wnetwork-ten-t/western-balkans-eastern-mediterranean-corridor_en Retrie ved from: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/western-balkans-eastern-mediterranean-corridor_en*

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