d-fine

Roadmap to Zero-Carbon Combined Transport 2050

Investment needs to enable decarbonisation of inland freight transportation through zero-carbon combined transport

November 2022, on behalf of

UIRR
UNION INTERNATIONALE POUR LE TRANSPORT COMBINE RAIL-ROUTE

Contents

Acknowledgments

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Management Summary

The European Green Deal sets the overarching aim to make Europe the first carbon neutral continent on the planet. To get there, a carbon emission reduction by 55% has been agreed on until 2030 (on the 1990 base), while complete carbon neutrality is pledged by 2050 (the reduction target for the transport sector is 90 %) [1].

The Russian invasion of Ukraine and the ensuing war has added an additional objective beyond decarbonisation: a pronounced aim to boost energy efficiency. The use of energy generated on the continent came on top, as Europe must also reduce its dependency on external sources of fossil energy.

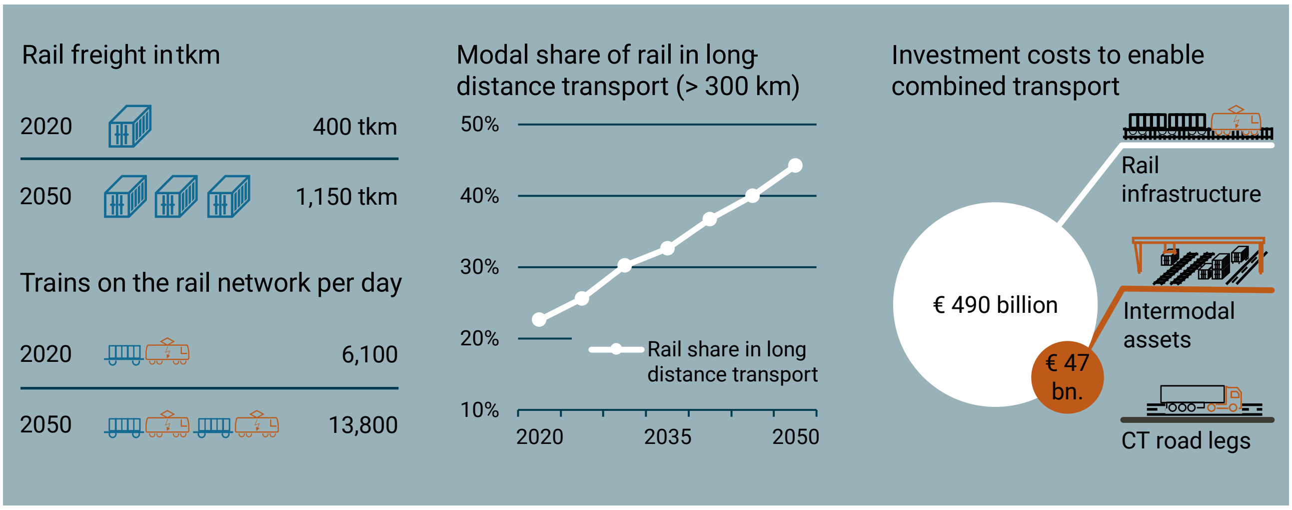
The need to boost energy efficiency while reducing emissions equally targets households, economic actors, and governments. The task in transportation, the sector whose share of Europe's carbon footprint grew significantly in the past years, promises to be particularly challenging.

In addition, it is expected that the transformation alongside growing transport demand will not interfere with the smooth functioning of society and the economy. The European Union projects a **27 % increase in freight transport by 2030 and 51 % by 2050** relative to 2020.

Various actors offered solutions. By today, two distinct alternatives seem to remain in the race: fuel cell electric vehicles propulsion based on green hydrogen and zero-carbon combined transport (ZCCT) using electric freight trains, electric transhipment and battery-powered trucks for the first and last mile connections all taking power directly from the electricity grid. The two have been compared in a recent study [2], which found that ZCCT is the substantially more energy efficient of the two.

In order to reap the benefits of ZCCT, a consistent and sustained shift from road to rail is needed. The **share of rail freight transport is projected to double until 2050**, with **combined transport filling 70 % of the freight trains**. In absolute numbers, this means that the **tonne-kilometres in rail freight transport are expected to triple by 2050 and combined transport will grow by 360 % over the coming 30 years.**

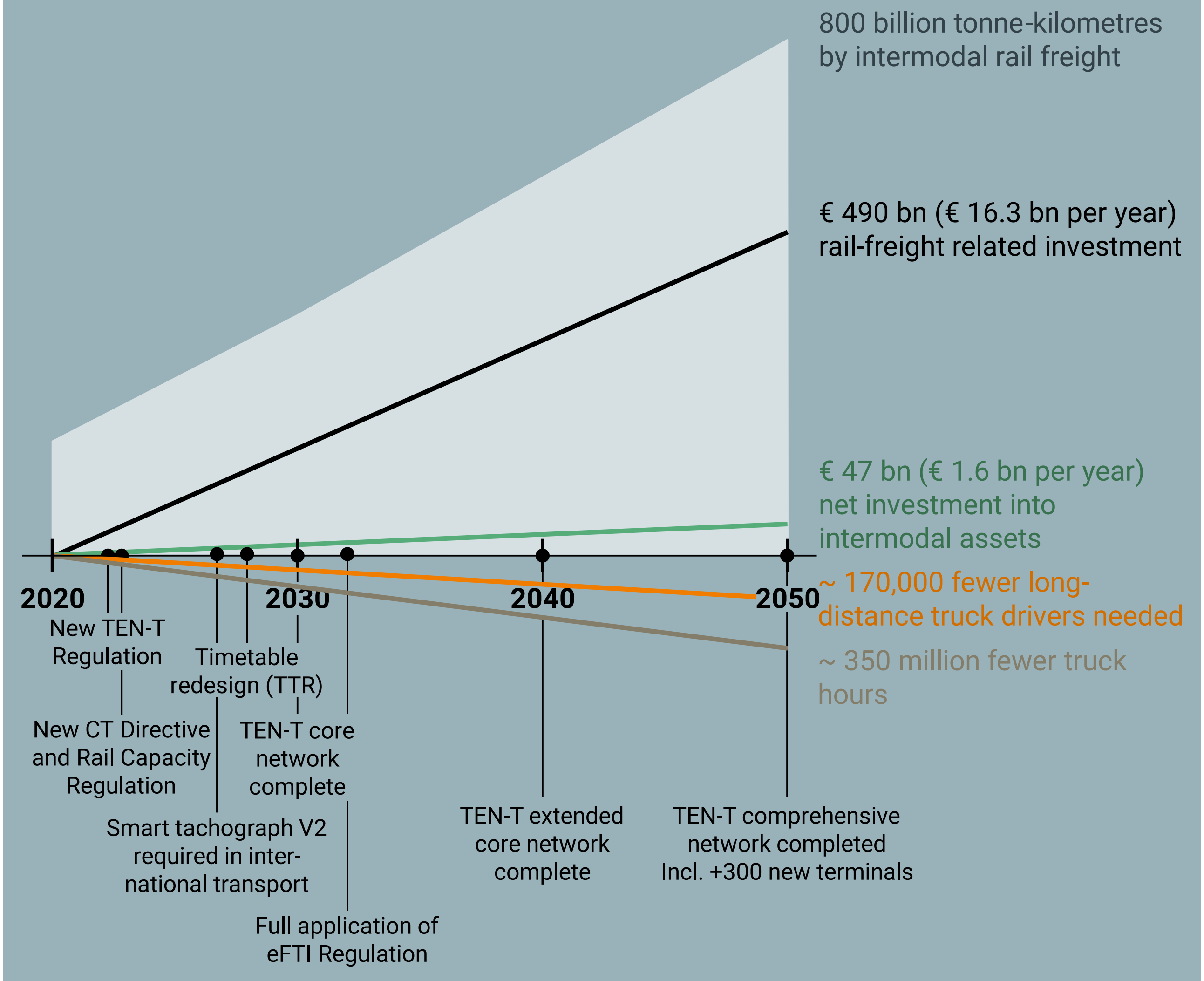
As a result of the increasing transport volumes on rail, the number of **freight trains is projected to double.**



The required capacity on the network can be met with the public investment of **€ 490 billion into the TEN-T rail infrastructure** (of which € 330 billion are already planned and € 160 billion are needed for elimination of bottlenecks) and about **€ 47 billion dominantly coming from private actors into transhipment terminals and other intermodal assets[1].**

Additional efforts are needed to implement digitalisation solutions, new operating processes, and an upgraded regulatory framework to enable decarbonisation and energy efficiency in inland freight transportation. The regulatory framework upgrades deemed essential include measures to level the playing field and a robust supportive recast of the Combined Transport Directive.

Roadmap to inland freight transport decarbonisation through zero-carbon combined transport 2020-2050



Reduced demand of truck hours and long -distance truck drivers is relative to the projected demand based on the EU Ref. Scenario without an accelerated shift to rail. The number of drivers is estimated based on truck hours assuming 2000 hours per year and driver. Legislative train schedule for the revision of the TEN-T Regulation ("departures") and the CT Directive ("departure before 07-2023"). Smart tachograph version 2 required in international transport from 21 August 2025 on. Final phase of TTR implementation is planned to start in Dec 2024, full application is assumed in the process of the rail capacity regulation. Obligation for MS authorities to accept digital freight information according to the eFTI Regulation is foreseen for August 2025, full application and wide use is estimated for mid 2030s. TEN-T standards are planned to be implemented in the core network by 2030, in the comprehensive network by 2050.

[1] This investment represents a lower boundary as additional investments can become necessary to further drive operational efficiency (e.g., through digitalisation) or avoid negative effects due to the higher infrastructure utilisation (e.g., noise protection measures).

Introduction

The European Commission announced ambitious climate goals, aiming to achieve carbon neutrality and a reduction of greenhouse gas emissions of 90 % for the transport sector by 2050 (compared to 1990) [1]. These goals are not comfortably achievable through an organic evolution of mode-specific technologies but require fundamental changes such as a significant shift of transport modes.

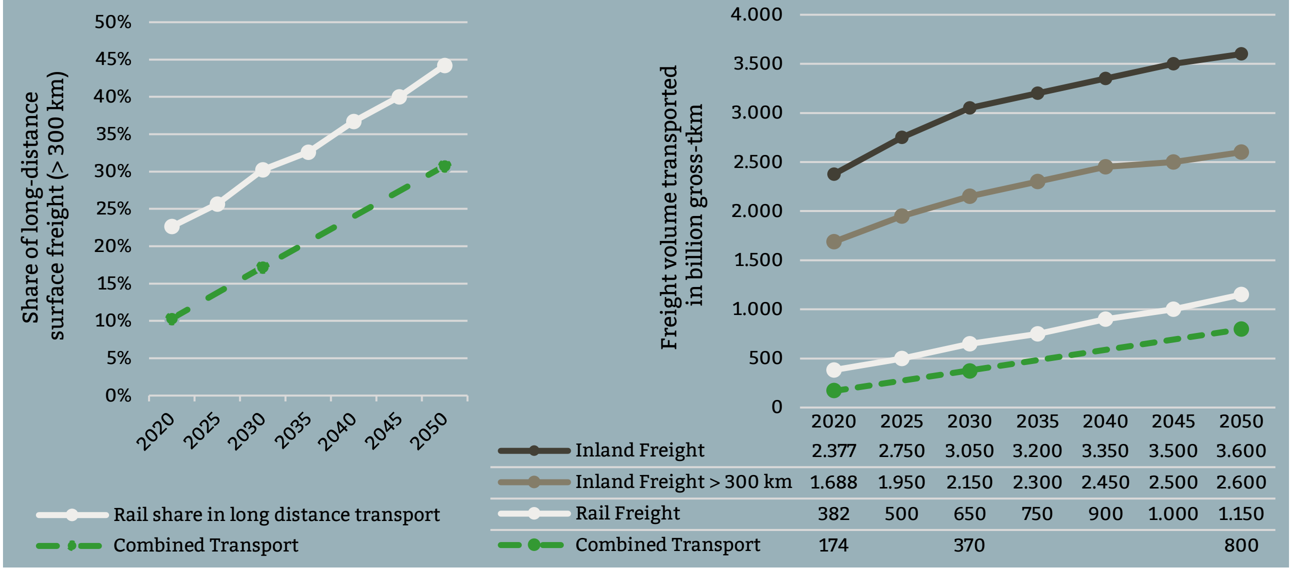
This study is part of a series highlighting the technical, regulatory and investment requirements to enable sustainable and even ZCCT. It was shown that contemporary door-to-door combined transport (CT) offers a CO_2 savings potential of up to 89 % compared to the Euro 6 diesel-powered trucking alternative. This is due to the fact that CT is significantly more energy efficient (up to 64 %), while it uses electric rail freight that is powered by electricity increasingly generated by renewable means [2]. Thus, modal shift has enormous potential to reduce emissions (25 million tonnes of CO_2 equivalents per percentage point of road transport shifted to rail [3]), and the technologies to enable even completely ZCCT already exist today [4].

The EU Reference Scenario projects an increase in freight transport in Europe of 27 % by 2030 and of 51 % by 2050 compared to 2020 [5] (*Table 1*, Figure 1). Together with an accelerating modal shift towards rail, this will pressure the existing rail and transhipment infrastructure.

This study analyses the projection of freight transport demand and investigates how the current infrastructures can cope with an increased shift towards sustainable means of transport – rail freight and CT. It is evaluated, to which extent infrastructure capacity can be increased through different intensive and extensive measures and a gap analysis indicates which measures and investments are needed.

The study is structured into four chapters. The first chapter models freight transport demand, rail freight, and CT volumes up to 2050 with a focus on EU decarbonisation objectives. Chapter 2 – 4 deal with capacity utilisation and planned improvements for rail and road infrastructure, as well as intermodal-specific technologies, respectively. The findings are summarised and conclusions are drawn in Chapter 5.

Figure 1: Projection of transported freight volumes in billion gross-tkm for surface freight, rail freight and CT. Projections based on the EU Reference Scenario for freight transport and own modelling.



	2020	2025	2030	2035	2040	2045	2050
Inland Freight	2.377	2.750	3.050	3.200	3.350	3.500	3.600
Inland Freight > 300 km	1.688	1.950	2.150	2.300	2.450	2.500	2.600
Rail Freight	382	500	650	750	900	1.000	1.150
Combined Transport	174		370				800

1. Demand for freight transport 2020-2050

Freight transport demand, especially by rail, will increase continuously in the coming years. Based on the EU Reference Scenario 2020 [5], the objectives of the rail sector [3], and the European Commission's Roadmap to a Single European Transport Area [6], rail freight transport will double by 2050 compared to 2020. One factor contributing to this is the growth of combined transport (CT), which can be assumed to increase in share from 43 % in 2018 to 70 % of total rail freight transport by 2050.

In consequence, the modal shift together with the increasing freight transport demand will result in the tripling of rail freight transport volumes in terms of tonne-kilometres by 2050 (relatively to 2020), while the number of intermodal consignments will grow by 360 % resulting in a growth of transport volumes on CT road legs and more transhipments in terminals.

1.1 Development of freight transport until 2050

The volume of surface[2] freight transport in Europe amounted to 2,377 billion gross-tonne-kilometres in 2020 [1]. Several independent studies[3] modelling the European[4] freight transport market project an increase of more than 50 % for surface freight by 2050.

Demand for surface freight transport is projected to increase

Europe has set itself ambitious climate targets in the Green Deal [7]. With the European Climate Law [8] and the "Fit for 55" policy package [1], the legislative basis has been established to deliver on the climate targets – a 55 % reduction of GHG emissions by 2030 compared to 1990 and climate neutrality by 2050. The EU Reference Scenario 2020 [5] will be used to provide a model for the freight transport development until 2050[5]. The modelling is calibrated based on historical data up to 2020 and projected transport volumes for the different modes among other social and economic indicators in steps of five years up to 2050.

EU- Reference Scenario 2020

The Reference Scenario 2020 relies on both carbon price signal extension to road transport and buildings as well as strong intensification of energy and transport policies with emission caps set in line with cost-effective contributions in each sector.

The EU Reference Scenario can be considered moderate compared to other models for freight transport demand, as it foresees a lower increase in transport volumes. However, it still projects an overall growth of 51 % in total freight transport volumes until 2050[6].

The projections presented in this work are a result from the interplay of a number of external impacts that are difficult to forecast and quantify, including demographics, ageing and urbanisation, development and breakthrough of technologies, relocation of industries and new

[2] Surface transport refers to the accumulated transport by road, rail, and IWW.
[3] These include: the OECD ITF Outlook 2021 [9], Fraunhofer ISI: Reference and Pro Rail Scenarios for European Corridors to 2050 [19], Capacity4Rail consortium: Requirements toward the freight system of 2030-2050 [10].
[4] European countries includes to the members of European Economic Area (consisting of EU27 countries plus Iceland, Liechtenstein and Norway) as well as Switzerland and European microstates. The ITF Transport Outlook additionally includes Turkey, Ukraine, Moldova, Serbia, Montenegro in the model for European freight transport.
[5] Meanwhile an adapted projection of freight transport that is in line with the Sustainable and Smart Mobility Strategy [12] and the "Fit for 55"-package [1] is available with the EU Green Deal Mix Scenario. However, as this differs only slightly from the EU Reference Scenario in terms of total freight volume and only models up to the year 2030, the EU Reference Scenario is chosen as basis for this work.
[6] The projections are based on data collected before the Covid-19 pandemic and the war in Ukraine. Emerging uncertainties are not considered an results may be skewed upwards.

production concepts, and the possible regionalisation of trade and the resulting flow of goods [9].

Several developments unique to Europe are caused by the change in type of cargo transported from bulk to manufactured goods. Components and finished products will make up more than half of the freight transport in 2050, while the transport of bulk cargo decreases [9, 10]. This shift will affect the transport techniques due to the decreasing cargo density. Intermodal loading units can hold any type of cargo carried in trucks today, which will subsequently lead to an increase of demand for intermodal transport.

OECD – High Ambition scenario

The ITF/OECD Transport Outlook Reshape scenario considers a strong set of decarbonisation policies with pro-active measures in response to environmental challenges in the transport sector and in support of the United Nations Sustainable Development Goals (UN SDGs).

Other forecasts for freight demand in Europe include the ITF Transport Outlook of 2021, which already included pandemic effects. The study projects a comparatively slower pace of growth until 2030 followed by a strong boom leading to a 120 % increase in freight volumes by 2050 compared to 2020.

Another method for projecting freight transport demand is based on its direct correlation with GDP growth, which has been observed over multiple decades [11]. From the latest GDP projection of the OECD Economic Outlook, a growth estimate for freight transport can be derived. Assuming that this development continues, the GDP projection until 2050 results in a growth in freight demand of 61 % [12].

The modelling and projection in the following chapters will, however, only be based on the EU Reference Scenario. The model was developed with a detailed and accurate representation of the conditions and circumstances in Europe[1] and is moreover in good agreement with GDP projections. Additionally, due to various sociodemographic effects that are particularly relevant for Europe (e.g., ageing of society, immigration policies), the moderate growth during the 2030 – 2050 period is considered more probable.

Table 1: Projections for surface[1] freight and rail transport volumes for 2030 and 2050. Increase relative to the base value of 2020 is given in brackets [5, 18, 21, 19].

	2020	2030		2050	
Freight volume in billion tonne-kilometres	2,377	3,000	(27 %)	3,600	(51 %)
Long distance freight >300 km in billion tonne-kilometres[7]	1,688	2,200	(29 %)	2,600	(54 %)
Rail freight modal share[8]	16 %	23 %		32 %	
Rail freight's long-distance modal share[9]	23 %	30 %		44 %	
Rail freight in billion tonne-kilometres	382	650	(69 %)	1,150	(201 %)
Rail freight in million tonnes	1,250	2,000	(61 %)	3,200	(161 %)
Intermodal rail share in total rail freight[10]	43 %	58 %		70 %	
Intermodal rail in billion tonne-kilometres	174	370	(114 %)	800	(361 %)

[7] Due to the non-distinction between short and long-distance freight transport in the EU Reference Scenario, the projections are based on the assumptions that the share of long- and short-distance road transport would stay constant in the baseline scenario and that the stronger shift to rail affects only long-distance road freight transport.
[8] The modelling of the share of rail transport is based on various recent European targets explained in Chapter 1.2.
[9] Long-distance freight transport refers to transport distances above 300 km.
[10] The modelling of the CT share is based on projections for transport volumes of different cargo types explained in Chapter 1.4.

1.2 Projection for modal split

The European Commission aims to achieve a more environment-friendly transport sector and backed this goal with a wide range of far-reaching regulatory measures. One of the Commission's objectives set out in the Sustainable and Smart Mobility Strategy, is to enable a fundamental change in modal share with setting a milestone of doubling rail freight until 2050 [13] – a goal that will already be achieved when projecting the rail freight transport volumes of the policy scenario for the European Green Deal Mix Scenario [14] to 2050 using the growth rates of the EU Reference Scenario.

The rail freight sector itself has set a more far-reaching goal. The members of the Rail Freight Forward[11] initiative committed themselves to an increase of rail modal share from 18 % in 2015 to 30 % by 2030. In this context, they addressed that more multimodal solutions and the required rail infrastructure are needed to achieve their goal [3].

The aforementioned ITF Transport Outlook also exceeds the goal of the Sustainable and Smart Mobility Strategy. This model projects the rail share in freight transport to increase to 23 % by 2030 and almost 30 % by 2050. Together with the very optimistic development of the overall transport market, this represents significantly more than a doubling of rail freight traffic by 2050. The study by the Capacity4Rail consortium[12] analysed that a rail share of 31 – 36 % would be necessary to achieve the European Commission's climate targets by 2050 [10].

Based on these aspects, a doubling of the rail share in freight transport from 16 % in 2020 to 32 % in 2050 is assumed for the modelling in this study, which is in line with the EU's climate targets [6] and still remains on the lower end of the rail freight share needed to achieve the climate objectives. This corresponds to a yearly increase in rail freight's market share by 0.5 percentage points and a 5 % annual growth rate for Combined Transport.

The analysis of long-distance transport (>300 km) [13] provides a realistic picture of the types of freight movements that are relevant for a shift to rail. In road freight transport, transhipments on long-distances are currently responsible for 60 % of transport [15]. Already today, rail accounts for 23 % of long-distance freight transport. It can be assumed that the change in the modal split toward rail is almost exclusively driven by the shift of long-distance transport from road to rail. For 2050, the modelling of this study results in the following modal split for long-distance transport: 44 % rail, 41 % road, and 15 % transport on inland waterways (IWW).

The "Transport 2050" plan of the European Commission published in 2011 called for 30% of road freight over 300km to be shifted to other modes like rail and waterborne transport by 2030, while 50% should be achieved until 2050 [16]. The 44% rail freight market share projected in this study – together with the inland waterway performance, promises to deliver the 50% objective.

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[11] Rail Freight Forward is an association of European rail freight companies, representing 90 % of the European rail freight market.
[12] Capacity for Rail (C4R) is a consortium that features rail freight companies, academies, and universities.
[13] Transports over 300 km are classified as long-distance freight transports. Eurostat data [14] on road freight transports by distance class is used and its distribution is assumed to be constant until 2050 (60 % long distance). In addition, it is assumed that every form of rail and IWW transport can be categorised as long-distance transport.

1.3 Projection of rail freight volume

A strong increase of rail freight volume arises from the general objective of increasing the market share of rail.

A tripling of rail freight tonne-kilometres is projected until 2050

A 70 % increase of rail transport volumes in tonne-kilometres is projected until 2030, while a tripling is anticipated until 2050 (relative to 2020, see *Table 1*).

The projections for transport volumes can also be translated into further characteristics that are relevant for estimating the capacity demand for rail infrastructure and terminals.

In 2021, the average distance for rail freight transport was 307 km[14] in Europe [17]. For the last decade, an annual increase in distance of 0.5 % can be observed [18]. Using this as a starting point, the average transport distance should develop towards 355 km in 2050. On this basis, the projection yields 2 billion tonnes of freight transported by rail in 2030 – an increase of 61 % compared to 2020. Until 2050, an increase by 160 % to 3.2 billion tonnes can be expected (*Table 1*).

Rail infrastructure for an additional 1,2 billion train-kilometres is needed until 2050

On average, today's freight trains carry a net payload of 555 gross tonnes [19, 18][15], which result in 2.2 million freight train journeys in 2020 (Table 2). The average cargo volume carried reflects the current composition of rail freight of conventional bulk cargo and containerised intermodal loads and the circumstance that conventional wagons typically travel empty nearly 50% of the time [20]. CT trains on average carry a payload of 658 tonnes per journey [19], the modelled increase of CT (see Chapter 1.4 for more details) is used to obtain a projection for the average payload per train. Building on this, the number of trains and train-kilometres have been derived.

For 2050, the projection yields 2.3 billion train-kilometres in freight transport corresponding to 14.7 thousand trains per day[16] – an increase of 140 % compared to 2020. Assuming an optimal utilisation of 740 m train length, the number of trains required is lowered to 13,800.

Table 2: Impact of the increase in freight volumes in rail and CT on infrastructure utilization. Increase relative to the base value of 2020 is given in brackets [1, 18, 21, 19].

	2020	2030		2050	
Rail freight traffic in number of trains per day	6,100	9,500	(+54 %)	14,700	(+140 %)
Rail freight traffic in million train-kilometres	700	1,100	(+62 %)	1,900	(+177 %)
Transported intermodal loading units (ILU) in millions	21.1	43.0	(+104 %)	84.5	(+301 %)
Freight on CT road-legs in billion tonne-kilometres	27	56	(+109 %)	120	(+350 %)

[14] The statistics on freight train journeys also include short distances, e.g., for shunting operations. Additionally, international trains may be counted as separate trains with a shorter distance in case of a change of the train number when crossing the border.
[15] The average gross payload per train is derived from statistical data for transported freight in tkm and reported train-km (Eurostat data for 2019) [17].
[16] No improvements in payload per train have been assumed for the projection of train numbers. Possible improvements are discussed in Chapter 2 of this study.

1.4 Development and projections for combined transport

Currently a change in the types of cargo carried in freight trains is ongoing. Volumes of manufactured goods are growing twice as fast as conventional bulk cargo [9, 22]. The goods in the fast-growing segments are typically transported in intermodal loading units (ILU).

Intermodal rail significantly contributes to rail freight transport

In 2018, intermodal rail transport accounted for 43 %[17] of rail freight tonne-kilometres [23] and with the accelerated growth in demand for CT, the share of intermodal rail within total rail freight is expected to increase further [9]. By 2030, intermodal rail will be responsible for up to 58% of rail freight tonne-kilometres (see *Table 1*). This forecast, based on historic trends, is in good agreement with the projection of CT's market share in the ITF Transport Outlook[18].

Considering the projected demand for CT, the share of intermodal rail is expected to reach 70 % of total rail freight by 2050. This figure is used for the modelling within the scope of this study.

1.5 Implications for the combined transport sector

With this increase in CT share, intermodal rail transport volumes are expected to more than double by 2030 (*Table 1*) and reach 800 billion tonne-kilometres in 2050, translating to an increase of 360 % compared to 2020. This growth of CT will impact multiple areas of the intermodal sector. Along with the number of trains, transhipment capacities and CT road legs around the transhipment terminals will expand dynamically.

Terminal capacity for transhipping 84.5 million intermodal consignments is needed

The required transhipment[19] capacity for CT is derived from the freight projections using an average weight per ILU[20] and an average cargo density. By 2030, transhipment capacity for 43 million consignments [21] will become necessary (Table 2). By 2050, the demand is expected to rise to 84.5 million consignments, an increase of 300 % compared to 2020.

Transport volumes on CT road legs are projected to triple

With the growth of CT, the demand for first and last-mile road legs within the catchment area of the terminals will also increase. An average road leg of 70 km[22] is assumed when modelling the anticipated growth in CT road legs. This results in a demand for the use of road infrastructure of 55 billion tonne-kilometres for 2030 and 120 billion tonne-kilometres for 2050 (Table 2). On the other hand, 420 billion

[17] Fraction of CT volume of total rail freight (in tkm).
[18] To determine the growth of CT share, the reported rail cargo types are classified as typically containerized or non-containerized goods.
[19] The terms handling and processing are used interchangeably.
[20] The average weight per TEU is derived from historical Eurostat data for rail freight transport in containers for the period from 2010 to 2020. The resulting average of 13.8 t/TEU is assumed to stay constant over time.
[21] The expected numbers of processed consignments in CT are based on the assumption of two transhipments in a typical CT transport chain.
[22] In unaccompanied CT, road legs are estimated to equate to 10 – 15 % [18] of the rail leg distance, which is 900 km for international CT within the EU [23]. Regarding UIRR members, 80 % of their services are unaccompanied CT. Distances in rail transport and CT rail legs are assumed to develop at the same rate as between 2010 and 2020 (annual growth of 0.5 %).

tonne-kilometres of long-distance trucking is projected to be eliminated by 2050 as a consequence of the increased shift to rail. When subtracting the additional 40 billion tonne-kilometres on CT road legs due to this shift, a net impact on the road infrastructure of minus 380 billion tonne-kilometres can be found (see Chapter 3.3 for details).

The growth of transport demand challenges the rail infrastructure

The increasing transport demand will pressure the existing rail and terminal infrastructure. The following chapters analyses to what extend the current and planned infrastructure and regulation are sufficient to accommodate the projected increases. In addition, it is derived which regulatory changes and investments are required to prepare the transport system in Europe for the challenges of the future.

2. Public investments into the rail infrastructure and the potential for capacity improvements

The rail sector can meet the challenges of increasing freight volumes with a relatively limited quantity of extensive expansion of infrastructure[23]. The implementation of various capacity improvements, most of which is already planned in the TEN-T programme, have the potential to unlock substantial additional infrastructure capacities. The required capacities can be created in combination with regulatory changes favourable to freight transport – underpinning that the rail freight sector is able to handle a rail freight modal share of 32 % (44% in terms of long-distance transport) in 2050.

2.1 Capabilities of the existing railway infrastructure

In 2020, approximately 2.2 million freight train journeys were performed on the European rail network (see Chapter 1.3), which corresponds to 690 million train-kilometres.

Freight transport makes up 20 % of the traffic on the rail network

Rail freight accounts for only 1 in 5 train-kilometres on the rail network in Europe [24]. In 2019, 18.2 thousand train-kilometres were recorded per line kilometre, with only 3.7 thousand train-kilometres attributable to freight trains. The level of utilisation varies greatly between countries[24]: The Netherlands (50 thousand train-km per line-km), Austria (31.4) or Denmark (30) recorded much higher utilisation rates than less densely populated Member States like Romania (6.6) or Greece (4.8) [24].

The utilisation of the existing rail network is already relatively high in several countries, and it must be assumed that existing capacities are extensively utilised under the current path allocation and traffic management scheme. Especially countries on the busiest rail freight corridor (Rhine-Alpine RFC), record utilisation rates above average (20,000 - 50,000 train-km per line-km). Data on trains crossing at least one border shows, that high utilisation rates are present (Table 3). In 2022, 677,600 border crossings of trains were recorded[25].

Revised TEN-T Goals

Among others, the TEN-T Goals include the finalisation of all 10 core TEN-T rail freight corridors, facilitation of use of 740-metre-long trains, P400 loading gauge and 22,5t axle load, as well as full electrification of the rail network and the implementation of the European Rail Traffic Management System (ERTMS).

Different indicators show that rail freight transport under the current path allocation system is close to its capacity limits

In rail transport, punctuality and infrastructure reserves are closely connected. When approaching the limit of capacity, actual transportation time becomes unstable [25] and punctuality declines.

The European Commission has set a punctuality target within its proposal for a revised TEN-T Guidelines Regulation [26]. According to which the average dwell time of freight trains crossing an internal EU border should not exceed 15 minutes by 2030, while at least 90 % of freight trains should arrive at their destination with a delay of less than 30 minutes [27].

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[23] Apart from construction to upgrade to TEN-T standards, the required capacity can be achieved without extensive construction through reallocation of passenger train paths.
[24] Differences also stem from geographical position and state of the infrastructure.
[25] Trains crossing borders can be used as an estimate for the number of trains and, thus, for line utilization. The numbers might be biased by double counting when using multiple corridors as well as by non-recording of domestic transport. Number of border crossings is not only influenced by utilization but also by the number of countries and respective borders on the corridor.

Table 3: Number of trains crossing at least one border on a TEN-T corridor in 2021 [67].

Corridor Name	Trains crossing a border	Corridor Name	Trains crossing a border
Rhine-Alpine	97,765	Orient-East Med	123,643
North Sea-Mediterranean	25,194	North Sea-Baltic	87,484
Scandinavian-Mediterranean	46,743	Rhine-Danube	102,970
Atlantic	14,931	Amber Rail Freight	30,639
Baltic Adriatic	88,618	*Alpine-Western Balkan*	16,404
Mediterranean	29,848	*Czech-Slovak*	13,409
Total			***677,600***

These targets are missed by far today. The present punctuality rate (arrival delayed by less than 30 minutes) in Europe reaches 60 % for domestic freight trains and 53 % for international freight trains – which means that only every second freight train arrives on time[26].

The congestion rate is another indicator showing that the capacity limits are currently being reached[27]. The share of railway lines classified as congested increased from 1040 km in 2015 to 2261 km in 2018 – the congested line kilometres have thus more than doubled in only 3 years [24]. The example of Germany shows that several important routes for freight transport are overloaded or have even been declared congested (Figure 2) – especially seaport hinterland routes. These routes need capacity enhancements to cope with the current and future increase in rail freight traffic instead of preventing the increase of rail share

2.2 Projection of capacity increases due to impacts of current legislative developments and regulatory undertakings

The European Commission announced the goal to complete the TEN-T core network by 2030 and the comprehensive network covering all European regions by 2040. Among construction and the achievement of standards for infrastructure, the policy objectives focus on application of new technologies and digital solutions [28]. Archiving the goals set in the TEN-T Guidelines Regulation (EU REG 1315/2013) in the core network by 2030 and the comprehensive network by 2050 is estimated to require investments at about € 1.5 trillion for all modes. Current investment plans show that 78.8 % of the TEN-T funding are used for rail projects [77]. The European Commission proposal for a revised TEN T Guidelines Regulation expands the policy objective of the TEN-T regulation. Among others, the core network standards are extended to the comprehensive network which is also expanded by additional sections with need for upgrade.

Pledged investments have to be made in time

The analysis accompanying the impact assessment for the revision proposal of the TEN-T Guidelines Regulation concluded, that the original investment goals and regulatory measures are not sufficient for

[26] Additionally, approx. 11 % of international freight services are cancelled.
[27] The threshold for declaration of routes as congested varies for different countries. In general, a route is declared congested according to Article 47.1 of Directive 2012/34/EU when it is not possible to satisfy the requests after coordination and consultation [65].

achieving the Sustainable and Smart Mobility Strategy objectives [29]. The assessment focused on the removal of bottlenecks and estimates additional costs of € 16.4 billion per year, which represents an increase of 33 % of annual investments [27].

The transformation of the rail infrastructure to comply with the TEN-T technical standards on the comprehensive network is a major cost factor accounting for 78 % of the additional costs. However, these investments include measures that are specific to passenger transport such as the introduction of a minimum line speed of 160 km/h for the passenger core network, which is estimated to contribute 31 % (€ 5 billion per year) of additional spending.

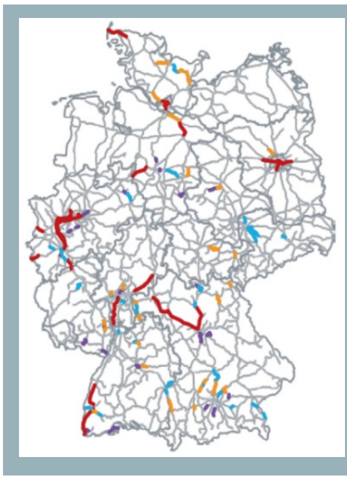

Figure 2: Map of the capacity utilisation on the German rail network. Congested segments are marked in red. Tracks with a load factor of over 125 % are shown in purple, with 115 – 125 % in orange and with 108 – 115 % in blue. Other tracks of the network are shown in grey [66].

Implementation of the TEN-T standards has the potential to significantly increase infrastructure capacity

The existing railway infrastructure still offers capacity reserves, which can be exploited through infrastructure management techniques within the framework of TEN-T by 2050 (Table 4).

Improving the signalling system and the traffic management system will increase line capacity. The introduction of the European Rail Traffic Management System (ERTMS) has the potential to increase capacity by up to 25 % [30]. Combined with reduced signalling block lengths, the overall capacity impact can be increased to 37 % [31]. Improving traffic management to enable a steady speed of 100 km/h for freight trains offers the possibility of increasing line capacity by up to 66 % [32].

The introduction of P400 provides the opportunity to use high-capacity intermodal loading units, like high cube pallet-wide European containers or semi-trailers [33]. P400 will allow transportation of these units on the entire TEN-T network, enabling rail operators to fill their trains more efficiently, as they will enable higher transport volumes for low density cargo [32]. These effects will have a measurable capacity impact and will increase the ability of the network to accommodate the projected modal shift.

Table 4: Possible measures to increase capacity within the existing rail infrastructure.

Description	Current situation	Potential for improvement
European rail traffic management system (ERTMS) [27, 30, 32, 34, 35, 3]		
ERTMS is the system of standards for management and interoperation of signalling for railways. It consists of two main subsystems, namely the European Train Control System (ETCS) and the Global System for Mobile Communication for Railways (GSM-R). Three different levels[28] of ERTMS application exist.	▪ 52 % of entire TEN-T network[29] needs to be upgraded ▪ 46 % of all new trains are already equipped ▪ 0.17 million €/km (for L-2[28]) ▪ **Cost for the TEN-T network in total: € 30 billion**	▪ Line capacity increase of 5 %[30]-15 % with ERTMS L-2 on already optimised block sections ▪ **25 % increase in line capacity with L-2[31]**
P400 gauge [23, 33, 36]		
The P400 reference is the used standard of measurement for semi-trailers loaded on a pocket wagon. It allows for a maximum height of 4 metres, at which a semi-trailer can be transported by rail[32]. Currently, semi-trailers account for 25 % of CT.	▪ 52 % of the TEN-T network needs to be upgraded, 75 % of all upgrades in Spain, France and Italy ▪ **Cost for the TEN-T network in total: € 5.1 billion**	▪ Increased ability to shift long-distance road transport to rail, due to the better usability of high-capacity loading units
100 km/h average speed [27, 32]		
Currently, the average speed of freight trains is about 55 km/h. With a block length of 3,000 metres, the maximum throughput through a line section is 12 trains per hour.	▪ 34 % of the total TEN-T network needs to be upgraded ▪ **Cost for the TEN-T network in total: € 48.9 billion**	▪ Maximum line capacity increases to 20 trains per hour ▪ **66 % increase of maximum trains per line[33]**
Electrification [24, 37, 38]		
Although largely electrified, the rail network is interspersed with sections lacking electrification. Eliminating these would reduce the need for change of locomotives and increase capacity.[34]	▪ 89 % of TEN-T core network electrified ▪ € 0.7 – 1.2 million/km ▪ **Cost for the TEN-T network in total: € 92.4 billion**	▪ In the report "The Future of Rail" the international energy agency assessed that electrified lines carry twice as many tonne-kilometres compared to non-electric ones
Optimal usage of maximum train weight and length [27, 20, 2]		
Currently, trains transport on average about 555 tonnes of payload. In a fully developed TEN-T network, the potential of long trains with a length of 740 m and a train weight of 2,000 t (22.5 t axle load), can be better be exploited.	▪ 34 % of the total TEN-T network needs to be upgraded ▪ **Cost for the TEN-T network in total (740-m-long trains): € 0.8 billion; (22.5 t axle load): € 150 billion**	▪ Full exploitation of **740 m-long trains** without improved load factor[35]: **13 % increase** ▪ Maximum capacity utilization of a **740 m-long train at 2,000 t[36]: 60 % increase**.

[28] L-1 is designed as an add-on for conventional lines equipped with line-side signals and train detectors. In contrast, L-2 does not require line-side signals. The movement authority communication occurs directly to the on-board unit using a GSM-R. Continuous communication in L-2 allows the train to reach its optimum or maximum speed while maintaining a safe braking distance. The conceptual stage L-3 is based on moving block technology instead of classic operation in fixed intervals to continuously allow the train to monitor its own position and to achieve continuous line-clear authorisation.
[29] Entire network refers to the combined TEN-T core and comprehensive network.
[30] For double track lines.
[31] Combined with shorter block length the impact of ERTMS L-2 increases to 37 %, implementing ERTMS L-3 with floating blocks offers capacity increase of 42 % – 50 % [31, 30].
[32] This limit is set from the base of the wagon to the top of the semi-trailer.
[33] Higher speed can also be the result of block signalling due to ERTMS, which reduces the individual effects.
[34] Interoperability issues can occur between different voltages used on national networks. Adjustment of traction of international trains to voltages among 750V, 1.5 kV, 3 kV, 15 kV, and 25 kV is necessary.
[35] Modelled 740 m-long train under the assumption that empty trip factors and the share of semi-trailers and containers [18] stays constant for the period up to 2050. Capacity increases stem from the higher payload of this average 740 m-long train (679 t) compared to the average projected payload (603 t).

Exploiting a maximum allowed train length of 740m and the maximum gross weight of trains at 2,000 t holds further potential. Compared to the current average payload per train, optimal utilisation would increase the payload by up to 60 %[36]. However, beforehand infrastructural preconditions (740m train length, 22,5t axle load) for the use of optimal trains have to be established within the framework of TEN-T.

More efficient timetabling is needed to enable better capacity utilisation

The current timetabling system lacks efficient path allocation[37], since almost 80 % of freight train path requests have to be repeatedly modified [39]. A major redesign of the current timetabling regime is under way with the Timetable Redesign Project (TTR). The rail sector expects the TTR to increase flexibility and deliver higher quality train paths. Additionally, measures are planned to be implemented to increase the efficiency and reliability of timetables [40].

The investment including also IT-infrastructure accumulates to € 1 billion while the potential benefit is estimated to € 1.5 to € 2 billion per year [41, 39]. RNE reports, that through the measures of TTR, capacity gains of 15 % are possible [41].

2.3 Gap assessment – capacity projection compared to the freight demand growth

In combination, the capacity of the existing railway infrastructure can potentially be improved to a significant extent through measures allowing for a higher number of trains running per hour, as well as enabling higher payloads and volume utilisation of trains (Table 5). It is highly advisable to initiate these measures in order to bridge the gap between infrastructural capabilities and projected freight volumes. Most capacity improvements are interdependent, which could reduce the total combined effect of the named measures. To compensate for reduced effects, additional solutions that include extensive work on the rail network and regulatory changes are discussed in the following.

Socio-economic cost-benefit analysis could serve as a good basis for prioritising investments in the railway infrastructure. The proposal for the revision of the TEN-T Guidelines Regulation contains this tool.

2.4 Regulatory changes needed to enable rail freight growth

The proposal for the revision of the TEN-T Guidelines Regulation is a first step in making the rail sector ready for the objectives set in the European Union. Additional measures together with regulatory changes are needed to provide a resilient rail network in 2050. The regulatory framework upgrades deemed essential include measures to level the playing field and a robust supportive recast of the Combined Transport Directive.

[36] The optimally utilised CT-train (740 m, 2,000 t, no empty wagons) considers the average share of semi-trailers and containers [18]. The resulting increase in payload is relative to the projected payload for 2050 considering the development of CT share

[37] An important issue is that railway undertakings are currently required to book train paths 8 to 20 months in advance, which leads to leads to overbooking to obtain sufficient flexibility. In this way, bookings often have to be adjusted and the remaining capacity is needed for last-minute changes [39].

Table 5: Measures for capacity improvement in rail transport (in number of trains) and assessment of cost. The improvements are expressed in percentages compared to non-TEN-T compliant infrastructure.

Number of trains per year (in thousand)	*EU Reference Scenario and own calculation*		
2020	6,100 trains per day		
2030	9,500 trains per day (54 % increase relative to 2020)		
2050	14,700 trains per day [13,800 if 740m overall possible] (140 % increase relative to 2020)		
Capacity improvement	**Increase in capacity**	**Calculated cost (in billion €)**	**Status of implementation**
Improvements for train capacity			
P400 gauge	---	**5**	48 %
740m avg. trains	**13 %**	**1**	43 %
Optimal capacity usage (length and weight)	**41 %**	**150**	81 %
Improvements for track capacity			
ERTMS (ETCS level 2)	**25 %**	**30**	48 %
Increased avg. speed (100 km/h)	**66 %**	**49**	66 %
Electrification	---	**92**	80 %
Timetable redesign (TTR)	**15 %**	**1**	---
Gap assessment for 2050			
Cumulated capacity improvements[38]	**<150 %**	**328**	---

Upgrading single track lines can reduce bottlenecks, especially when routes are blocked

Expanding bypass tracks and establishing double tracks – as advised by TEN-T [28] – can help to eliminate bottlenecks. As of today, 128 thousand kilometres (60 %)[39] of the TEN-T network were still single tracks [18]. Upgrading these to double tracks increases the maximum number of trains from 3 to 20 trains per hour with similar timetable speed or to 10 trains per hour on lines with heterogeneous traffic[40] [32]. Upgrading single tracks and expanding sidings can thus offer additional double-digit percentage improvements in capacity. This option becomes particularly important when lines become blocked, as it allows overtaking instead of a total stop of operations.

Total costs for upgrading single tracks to double tracks are estimated to € 6.2 million per kilometre [35]. Consequentially, upgrading the TEN-T network to comply with this standard would require a total investment of € 795 billion. However, since freight transport is only responsible for only 20 % of infrastructure utilisation, only 20 % of the total costs

[38] The cumulative capacity gain represents an upper limit under the assumption that no correlation exists between the individual measures and that capacity increases at train level lead to a reduction in the number of trains, and to the same extent reduce the utilisation of lines.
[39] Germany for 2021 due to missing data for 2020.
[40] Line capacity is lower on mixed tracks used by slow trains (freight, regional) and express trains due to missing options for overtaking [31]. This bottleneck can be addressed by extension of additional tracks for overtaking.

should be assigned to the freight sector[41]. Resulting in an investment need related to freight transport of € 160 billion until 2050.

Redesignating some passenger trains paths to freight can help to close the capacity gap

The capacity gains of the various measures discussed above cannot be expected to add up. Several actions will only yield an improvement but not the optimal state (e.g., average speed of 100 km/h for freight trains, exploitation of maximum length and weight). In case only a 60 % overall capacity gain could be achieved by 2050, a gap to the needed 80 % would remain.

Further selected instruments allowing for higher capacity utilisation	• **Joining two 740-meter-long trains**, with two locomotives, to pass through congested lines as a single 1480 m train require only 20 % more network capacity while carrying twice the payload on a single train path [64]. • **Alignment of voltage and frequency for traction** along with harmonisation of multi-system locomotives can help to reduce delays when crossing borders by not requiring a change of locomotives. Costs per kilometre for electrification of existing lines are estimated at € 0.6 million, changing existing electrification could thus account for similar costs [35].

One option to close this gap, could be to employ a socio-economic cost-benefit analysis to reallocate certain train paths from low utilisation passenger trains to freight transport. Considering the 80:20 ratio for the use of the rail network, each percentage point of passenger train-kilometres reallocated for freight transport would result in a capacity increase for freight by 4 percentage points[42].

Dedicated freight lines and extended bypass options allow to double capacity in highly congested areas

Speed differences of passenger and freight trains on mixed lines are one of the largest factors reducing track capacity for rail freight on the infrastructure today [22]. Freight trains are often required to stop to let passenger trains overtake. Dedicated freight tracks along major corridors and bypass routes around major urban cities could help solving this problem, as this allows up to doubling the number of circulating trains [10]. Construction costs for new lines are assessed at approx. € 8.2 million per kilometre [35]. Nevertheless, when considering extensive infrastructure expansion, e.g., for dedicated freight lines, the long construction time for new rail tracks [42] should be taken into account.

[41] Note that tracks for single usage by freight as well as passenger transport exists. However, a huge majority of lines are for mixed use [42].
[42] If this measure was taken, the costs of line upgrades attributed to freight transport would also need to be increased by € 7.95 billion.

2.5 Investment assessment for ensuring a resilient rail network

The rail infrastructure can meet the challenge of tripled freight volumes through the measures set out in the Commission's proposal for the revision of the TEN-T Guidelines Regulation [26] and additional upgrading measures discussed in this chapter.

Additional investments of € 490 billion are needed to achieve full compliance with the proposal for a revised TEN-T Guidelines Regulation and provide the infrastructure to enable a modal shift to 32% rail (44% in terms of long-distance transport above 300 km). This implies that additional investment of € 17.4 billion per year into the rail network is required, with is about 40% over today's levels. The largest expenses relate to upgrading the existing infrastructure to allow more efficient trains (€ 151 billion), electrification of the current infrastructure (€ 92 billion), and the development of a more resilient rail network by upgrading single tracks to double tracks (€ 160 billion).

The next chapter will therefore investigate the current investment plans into road infrastructure and analyse potential savings that result from the shift towards rail.

3. Investment plans for road infrastructure and road capacity utilisation

The proposal for the revision of the TEN T Guidelines Regulation is based on projections for freight transport that assume a rail share in freight transport of 21 % for 2050. It has already been shown that the rail infrastructure would be capable of handling a rail share of 32 %, if the foreseen TEN-T measures are delivered. Through an increase in CT, a substantial portion of the cargo that is presently carried in trucks can be shifted to rail, resulting in a significant reduction of the projected transport volume on road by 420 billion tonne-kilometres compared to the TEN-T base scenario in 2050. At the same time, transport volumes related to CT road-legs will increase to 120 billion tonne-kilometres.

3.1 European road network utilisation and congestion

Based on the 2019 TEN-T Performance Report [43], the road network consists of motorways (85 %) with more than two lanes (77 %) that connect urban areas (91 %). Annual average daily traffic flow (AADT[43]) on most of the network (52 %) is less than 20,000 vehicles per day, while 6 % of the network have an AADT of more than 80,000 vehicles per day. A major part consists of passenger car traffic. About 30 % of road utilisation in the core network stems from heavy goods traffic[44]. This share has remained constant over the last 10 years.

Figure 3: Map of the AADT on the European road network. Roads utilised by more than 100 thousand vehicles per days are marked in purple, 80-100 thousand in red, 40-80 thousand in orange, 20-40 thousand in yellow, and under 20 thousand in green. Roads without data are presented in grey [43].

For two-lane motorway sections outside of urban areas, a vehicle throughput of 18,000 vehicles per day was identified as a threshold for free traffic flow [44]; motorways with 2x3 lanes help to increase the average capacity to 31,000-52,000 vehicles per day [45]. This high AADT limits imply that nearly 50 % of traffic could already be handled by two-lane motorways, while 2x3 lane motorways are able to compensate for higher traffic flows in areas with higher utilisation. Consequently, free traffic flow should be possible in terms of capacity utilisation in most cases. Also, the average daily traffic flow shown in Figure 3 exceeds average utilisation only exceptionally. However, most congestion is related to traffic patterns and traffic-jam influencing events, such as

[43] AADT is calculated as total volume of vehicle traffic for one year divided by 365 days.
[44] Goods vehicles weighing in excess of 3.5 tonnes.

traffic incidents, construction work, weather [46], peak hours in urbanised areas [47, 48], or seasonal variability [48] that raise the vehicle flow or limit the capacity in the short term[45].

3.2 Planned investments into the road infrastructure

In contrast to the implementation status of the TEN-T railway lines (Table 5), the completion rate of the TEN-T road network ranges from 70 % to almost 100 %. This high level was achieved thanks to € 78 billion of funding from the European Union[46]. One third was allocated to projects outside of the TEN-T core network[47] [49], € 17.8 billion was attributed to construction of new roads (2,000 km) of which 50 % are outside the core network. Presently, the reconstruction of 770 km of roads and capacity improvements for the TEN-T road sections is planned [43].

Focus on the maintenance of existing road infrastructure is required

With TEN-T, the length and capacity of roads in every EU Member State increased. At the same time national maintenance budgets have steadily declined [49]. In their 2020 report, the European Court of Auditors states that the Member States do not devote adequate resources to the required maintenance and upkeep, putting the condition of the core road network at risk in the medium- to long-term [49].

The TEN-T revision concluded that improvements are necessary, mainly to reduce the number of accidents due to the insufficient safety and operational reliability of the TEN-T road infrastructure. Safety-related upgrades are needed on a length of 4,477 km (7.2 % of the comprehensive network) at an annual cost of € 693 million between 2025 and 2040[48] (€ 10.4 billion in total) to reduce road traffic fatalities. The assessment concluded that the investments would help to decrease the fatality rate by 1.2 % compared to a scenario assuming no further upgrades beyond those planned within the original TEN-T policy [27, 29]

3.3 Road infrastructure usage and costs related to combined transport

Road freight transport associated with CT road legs will reach 120 billion tonne-kilometres in 2050. Of these, 40 billion tonne-kilometres are directly related to the modal shift towards rail exceeding the growth projected by the EU Reference Scenario. At the same time, due to this shift long-distance road freight transport will be reduced by 420 billion tonne-kilometres per year in and after 2050. This transport volume corresponds to 30 % of total long-distance road transport projected in 2050. Translated into utilization of trucks, this implies that at least 450 million truck hours less per year are required compared to the EU Reference Scenario[49]. On the other hand, the increase in road haulage due to first and last leg in CT can be assumed to account for about 100 million truck hours[50]. Because of the lower speed and additional

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[45] Short term congestion is estimated to account for a loss of 1 % of GDP [49].
[46] Besides grants, the EU supports development of the road network through financial instruments such as loans and guarantees to attract private investments.
[47] Comprehensive TEN-T network as well as non-TEN-T roads.
[48] Funding for investments into road infrastructure shall be secured through EU funds (55 %), the private sector (5 %), toll revenues (15 %) and further national funds (25 %).
[49] Calculation of truck hours assuming average parameters for long-haul trucking: weight per journey of 14.33 t [2], speed of 65 km/h [51].
[50] Calculation of truck hours assuming average parameters for CT: weight per journey of 15.85 t [2], speed of 25 km/h [51].

factors like, e.g., dwell time in terminals and a higher frequency of loading and unloading operations, the net reduction of road transport volumes does not lead to a proportional reduction of truck hours. Nevertheless, the shift to rail coupled with the parallel growth of CT can achieve a net reduction in truck demand of 350 million truck hours. Considering infrastructure utilization costs, the net reduction of transport volumes on road would also translate into less demand for investment into construction, upgrading, and maintenance of road infrastructure [50]. In addition, the regional nature and relatively low speed of trucks operating on the first and last leg in CT, result in a reduced wear and tear on the road infrastructure[51] [51].

Regarding vehicles, the net reduction of truck hours for the modelled higher rail share in long distance freight transport also implies a reduced demand for investment into trucks compared to the modelling of the EU Reference Scenario. While vehicles currently used in long-haul trucking are equally suitable for CT road legs, the introduction of more sustainable subsidies like BEV trucks in fleet renewal and transformation becomes also easier. The reason for this is, that CT road legs offer good possibilities for integration of charging cycles because of their characteristics (short distances, more frequent stops for loading and unloading). This is not only worthwhile in terms of sustainability, but also in terms of investments. Current projections for the total costs of ownership (TCO) of EURO 6 diesel trucks compared to BEV trucks indicate, that the latter will overtake and be the cheaper option before 2030 in all European countries [4]. The possibility to employ trucks of a regional configuration offers another potential to decrease investment needs due to lower purchase prices by about 10 %.

In contrast, the demand for container chassis and loading units will increase. In 2017, only 9.5 % of the registered 240,000 semi-trailers were container chassis [52]. When considering that these travel on average 100,000 km per year[52], it becomes obvious, that not all but about half of them are required to handle the current transport volumes on road legs in rail-road CT [52]. With an increase of CT transport volumes by the factor of up to 3.5, the fleet of container chassis used in CT needs to increase from 12,000 to 60,000 – resulting in the need for private investments of € 480 million[53].

Effectively, there are investment needs in road infrastructure as well, however, these are outweighed in the net perspective as a consequence of the higher share of rail freight compared to the EU reference scenario. Maintenance expenses foreseen for road infrastructure can, thus, be redirected towards other modes.

Well maintained road infrastructure is also needed for CT to function. However, the focus is shifted from the main supra-regional or even international transport axes to the regional road network within the proximity of transhipment terminals [43]. The capacity and investment analysis of these is the topic of the next chapter.

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[51] This effect can be diminished due to higher weight of batteries for BEV trucks. However, BEV trucks operating on CT road legs do not require the range provided by current BEV truck models. Thus, battery capacity and weight could be reduced [4].
[52] Based on expert interviews [33]. The industry composition and the involvement of CT operators is unclear. For usage in CT, rather lower annual mileages are to be expected [81].
[53] Average price of €10,000 for new container chassis is assumed [33]. Costs for additional tractor units are not factored in since they would also be required without an increased shift to rail. However, compared to the transport projection in the EU Reference Scenario, the net effect of less road transport should also result in net less required tractor units.

4. Investment needs for intermodal assets

To be able to handle the projected volume of intermodal consignments, major increases in terminal capacity are required, as the number of expected transhipments in rail-road CT should reach about 84 million in 2050. To this end, upgrading of existing terminals and the construction of additional ones is required to establish the necessary transhipment capacities. The costs for these measures are estimated with € 47 billion until the year 2050 (about € 1,6 billion annually).

4.1 Capacity and utilisation of current intermodal infrastructure

A recent study on transhipment technologies for intermodal transport on behalf of the European Commission concluded that around 850 terminals for transhipment to rail (around 1,000 when including all types of intermodal terminals) exist in EU-27 and Switzerland [36]. Of these, 212 rail-road terminals are located directly alongside the TEN-T core network corridors and offer each a capacity for processing more than 40 thousand consignments per year[54] [27] (Figure 4).

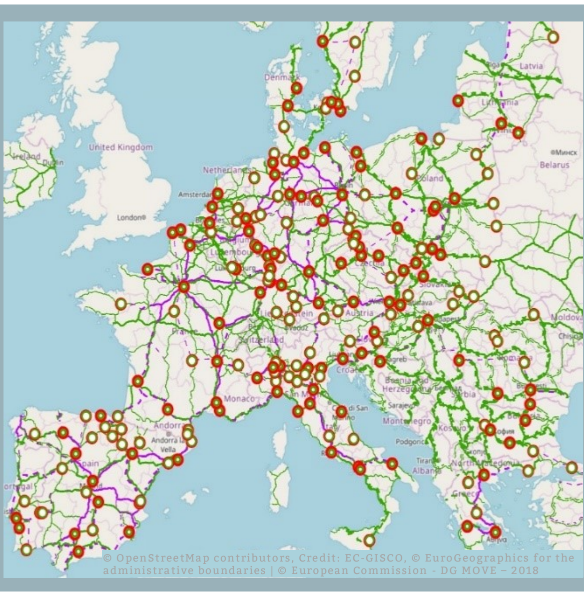

Figure 4: Map of the TEN-T rail network and terminal distribution. Terminals on the core network are marked in green-red, terminals on the comprehensive network are marked in white-red. High speed rail tracks are marked in purple, all other rail tracks are marked in green [70].

850 rail-road terminals provide total transhipment capacity for 66 million consignments per year

Following a bottom-up approach based on the available handling equipment per terminal[55], the referenced study identified a current transhipment capacity of 261 million consignments per year for the terminal network. This implies that each terminal would on average have a capacity for processing 250,000 consignments. This can be considered as a theoretical upper limit that likely overestimates the actual capacity due to several limitations[56].

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[54] For 2021, UIRR reported statics for 124 terminals managed by members companies.
[55] Assuming that all terminal equipment is in use.
[56] There are several limitations to this estimate. Only for about 500 terminals exists information on handling equipment. For terminals without information an average capacity was assumed. It is likely that the number of active terminals is smaller. Since RFP data might more likely be available for larger terminals, capacities of small terminals might be overestimated. Only two handlings per consignment were assumed, while realistic numbers might be higher and, thus, reducing the actual processing capacity.

Consequently, in this study a top-down approach is applied for the assessment of actual capacities. Following the approach used for the impact assessment for the TEN-T regulation [27], the terminals are classified into categories of transhipment capacity based on the offered equipment. For the 40 % of terminals without gantry equipment or for which no information on the available transhipment equipment is available [36], an average capacity of 40 thousand consignments per year is assumed. However, also terminals without gantry cranes may be capable of processing more than 100,000 consignments annually[57].

The remaining terminals are categorised as follows: 30 % of the terminals are medium sized (40 – 100 thousand consignments transhipped), 21 % are large (100 – 150 thousand consignments), and 9 % mega-hubs (> 150 thousand consignments) [27][58]. Assuming these shares and average processing capacities within each size category[59] results in a projected transhipment capacity of 73 million intermodal consignments throughout the entire European terminal network.

Further considerations need to be made regarding terminal capacities:

- besides handling capacities also throughput at the entrance gate and through the storage yard can pose the upper limit for terminal capacities. An analysis for the Baltic Sea region found storage throughput (50 %) and handling equipment throughput (40 %) to be the most common limiting factor [53].
- a practical capacity limit can be assumed to be reached at 80% of the nominal capacity [54, 55].
- besides publicly accessible terminals, terminals exclusively servicing the needs of their owners exist. For the Baltic Sea Region, about 25 % of terminals are of restricted access [53]. Statistics on transhipments in these terminals is not provided. However, it can be assumed that these account for single-digit percentages of all transhipment in Europe.

The number of transhipped consignments depends on many factors

The 124 UIRR member terminals processed 7.5 million consignments in 2021 [19]. On average, these terminals operated 3.3 cranes, each handling around 18.4 thousand transhipments – resulting in 60,000 consignments on average per terminal per year. This is in line with the average utilisation of 54 % assessed for terminals in the Baltic Sea Region [51]. However, capacity utilisation is highly variable depending on the region where a terminal is located and its architecture.

The current terminal infrastructure might not be enough to facilitate the transhipment of 85 million consignments in 2050

The modelling in this study projects a need for up to 85 million transhipments per year by 2050 (see Table 2). In the absence of substantial productivity improvements, the current terminal infrastructure would see a utilisation of 155 %. Implying that each terminal would unrealistically need to handle 100 thousand consignments.

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[57] Examples exist among the UIRR members [81].
[58] For the Baltic Sea Region, a distribution of 32 % small, 23 % medium, and 45 % large terminals is assumed. This shift might result from the fact that the sample of 152 terminals included 90 sea terminals, biasing the distribution towards larger terminals.
[59] Mega hubs are considered to handle up to 250,000 consignments per year [26].

4.2 Improvements to the terminal infrastructure

To establish a comprehensive terminal network, the overall transhipment capacity would need to increase by up to 50 % until 2050. Thus, measures to increase capacity within the existing infrastructure, upgrades of existing terminals, and the construction of new terminals are needed.

The proposed revision of the TEN-T Guidelines Regulation defines measures offering capacity gains within the existing infrastructure

With the EU's 2021 Connecting Europe Facility (CEF) call for proposals, a program was launched for upgrading rail-road terminals on the TEN-T network with a total volume of € 350 million.

According to the proposed revision of the TEN-T Guidelines Regulation, terminals are obliged to accommodate 740 m long trains complying with the P400 loading gauge as well as to process of all types of consignments and allow for rail-to-rail transhipment by 2030. It is intended to introduce the TEN-T standards also for the last mile rail infrastructure into the terminals, to promote the digitalisation of terminals, and to install infrastructure for alternative fuels at all terminals. These measures allow for cost and time reductions and the combined costs for upgrading to these standards are estimated at € 15.5 billion (Table 6).

Table 6: Improvements for terminal infrastructure planned within TEN-T, their costs and assessed improvement of costs or processing time [10, 27].

Terminal improvements	Cost/time reduction	Cost per terminal (in million €)	Total cost (in billion €)	Improvement area
Operating all types of ILUs[60]	5 %	15	2	Overall
Rail-to-rail transhipment[61]	NA[62]	25	3.7	Handling
Extension of tracks under the crane to handle 740 m trains	5 %	15	3.2	Handling
TEN-T standards on last mile	5 %	10 – 25	3.6	Overall
Digitised terminal	2 %[63]	8.9	1.9	Overall
Alternative fuel infrastructure	NA	0.3	0.06	Overall
Terminals with horizontal transhipment (e.g., CargoBeamer / Modalohr)	50 %[64]	35 / 30	2	Handling
Total upgrade costs			€ 15.5	

[60] Currently 90 % of European CT terminals accept both ISO containers and continental containers, 25 % of them accept swap bodies, and 0.3 % accept non-craneable semi-trailers.
[61] For medium-sized terminals, an additional gantry crane and additional reach stackers are required, for large terminals 2-3 gantry cranes and 2-3 processing tracks are necessary to enable rail-to-rail handling. Efficient handling of 740 m trains requires at least two gantry cranes in addition to a pathway between the tracks and storage areas [26].
[62] Rail-to-rail shipment offers the opportunity to replace shunting processes on route, because consignments are transhipped instead of moved through shunting operations.
[63] Even though digital terminals themselves provide time savings of only 2 %, they are the prerequisite for several digital tools that allow for large terminal productivity increases.
[64] Horizontal terminals allow efficient handling of non-craneable semi-trailers [10]. The latter account for about 90 % of all semi-trailers [71]. An average CargoBeamer terminal can handle 130,000 semi-trailers per year (when upgraded: 260,000) [73].

Increasing the reliability of rail infrastructure is crucial for terminal productivity

The capacity utilisation of lines and terminals are strongly interdependent. Currently, one of the biggest obstacles to efficient use of terminals are unreliable timetables and the lack of punctuality of freight trains. Most punctuality problems in terminals can be traced back to delayed trains for which the reason is to be found in the railway system [55]. By addressing this issue through, for instance, the TTR [37], it becomes possible to increase terminal capacity by double-digit percentages through less delays and accurate estimation of arrival times [56, 57].

As of today, most terminals lack information on the type of cargo (e.g., hazardous materials) and the arrangement, status, and delay of incoming trains as well as on exact times when units are to be picked up [55]. In the CT sector, efforts are being made to address these problems through the implementation of a European open digital CT service platform [58] and the harmonisation of digital processes – for the electronical European cleaning document (eECD), the electronic freight documents (eFTI), and the electronical estimated time of arrival (ELETA, [57]). This is planned to be combined with a central platform for international time tabling and train path management. Projects like Q-ELETA[65] will offer a comprehensive quality management system[66] and improve the accuracy of the estimated time of arrival [40]. Increased operational efficiency on rail and in terminals will provide cost saving opportunities and facilitate efficient CT chains. Streamlining of processes and fostering the digital transformation of terminals is thus of value for achieving higher operational efficiency. This can be incentivised by regulatory measures and dedicated investment programmes.

Transhipment capacity can be increased by the use of photogates with OCR capability

Besides installation of additional traffic lanes, overall transhipment capacity can mainly be improved through digitalised solutions, e.g., systems for truck arrival prenotification and optical character recognition (OCR) gates on both the road- and the rail side of terminals [53]. OCR gates allow to automatically process arriving vehicles, whether road or on rail – one of the most urgent improvements according to rail terminal operators [59].

Their costs are estimated to € 310,000[67] per terminal, while reducing handling hours per train by 22 %. Retrofitting all terminals limited by gate capacity (15 %) with OCR gates would require a total investment of € 40 million.

Mathematical optimisation can increase efficiency by up to 7 %

Data-based optimisation of storage handling – especially at peak times – offer large productivity gains by reducing the number of handlings to reshuffle containers. The optimal heuristics depend on terminal characteristics and allow to reduce total operational costs by up to 7 % with respect to generic algorithms [60].

[65] Within the EDICT project, algorithms and potentially advanced AI methods for delay identification and classification are developed to improve quality and punctuality of CT services. Integration with the ETA information is in scope.
[66] A Europe-wide train identification system that works across borders is a prerequisite for the exchange of ETA, train running and train composition information to track trains from origin to destination. This is defined in the TAF/TAP TSI [40].
[67] One gate is needed for the road and for the rail entrance. Annual maintenance costs lead to increased terminal operating costs of €5 thousand per year.

Physical extension of terminals is planned along large parts of the network

Until 2030, every fourth intermodal terminal in the TEN-T core network will undergo capacity related construction works[68], implying that additional extension works can be expected until 2050. Consequently, about 60 % of the current terminals will likely face an upgrade until 2050.

Estimating an average capacity improvement unlocked by these upgrades is hampered by the fact, that the impact is only reported for a small fraction of these projects. A recent evaluation of transhipment technologies for intermodal transport analysed several terminal upgrade projects which were performed within the CEF framework. For 10 of these, information on capacity improvement is provided and ranges between 14 % and 117 % [36]. Corresponding costs also vary highly due to the different project sizes[69] – the average of € 50 million should thus be interpreted with caution. A rough calculation yields that approximately the capacity for processing 4,200 consignments is generated per million invested in terminal upgrades. It can, thus, be estimated that each 10% overall increase in transhipment capacity would costs about € 2.4 billion[70].

4.3 Additional terminal infrastructure and a comprehensive network of intermodal terminals

In addition to the overall processing capacity of the terminals, the distribution of these terminals across Europe is also crucial to enable efficient CT services with reasonably short road legs. This ensures that the advantages of CT regarding energy efficiency and also costs for long distances can be fully exploited[71]. Currently the distance between rail-road terminals is well above 300 km in many regions throughout the TEN-T network, which limits the availability of multimodal transport in these regions [27]. For this very reason, current network connectivity in terms of intermodal terminals was identified as insufficient within the proposal for the revision of the TEN-T policy. To achieve a network of terminals with less than 200km distance from each other[72], the construction of at least 300 new terminals along the comprehensive network was found to be necessary[73] [27]. With average construction cost of € 47 million per terminal [61], the total investment for the entire network accumulates to € 14 billion.

This addresses deficiencies in terminal infrastructure but does not consider unevenly distributed cargo density. Additional terminals may be needed to accommodate the projected growth of CT while allowing for efficient CT road leg distances of 70 km or less [36]. Thus, every indus-

[68] An assessment for Austria and its bordering regions found the extension rate to be even higher. In total 19 out of the 28 investigated terminals have been extended in the last 5 years or their extension is already planned [73].
[69] Some terminal improvements provide capacity gains for less than additional 10,000 TEU per year while others unlock capacities for over one million additional TEU per year.
[70] Assuming constant conversion rates of 1.53 TEU per average consignment.
[71] Although making up only 15 % of transport distance, road legs account for 40 % of the transport costs in CT [3].
[72] Another assessment proposed that at least one terminal per transhipment technique should be available every 850 km. In this case, the construction of 169 new terminals with a total investment of € 2,6 billion would be needed [36].
[73] Each urban node (> 100,000 inhabitants) should have at least one average size terminal, with a capacity for processing 120,000 consignments. In addition, one additional hub per 500,000 inhabitants should be build.

trial location and central city should be provided with sufficient terminal infrastructure within this distance. In more densely populated areas and near the busiest railway lines, even higher densities may be needed to meet capacity requirements in 2050. A recent study indicates, that since transport flows are significantly higher between European logistics hubs, investments should concentrate on these sections of the core network that concentrate 65 % of the total land freight transport. As a consequence of their bottom-up analysis of terminal capacities, the authors indicate that about 400 new terminals and new pass-through concepts for terminals may be required[74] [62].

4.4 Impact on railway rolling stock

In the context of the impact assessment of the revision of the Noise TSI, a comprehensive survey of the wagon fleet in Europe[75] was conducted. While the total wagon fleet is assessed at 630,000 wagons for 2017 [63], about 64,000 intermodal wagons especially designed for CT[76] were reported for the same year [64]. Within the last 10 years, this fleet has increased by only 15 % and is expected to increase annually by 1 % until 2025.

Due to the increase in rail and CT traffic, the current fleet of rolling stock needs to be used more efficiently and expanded until 2050. Without any form of efficiency improvement, the current fleet would have to increase by approximately the same factor as the number of trains, while the share of CT wagons would need to rise disproportionately to accommodate for the projected CT share of 70 %. This would imply an increase of the total rail wagon fleet from 630,000 to 1.45 million of which at least 235,000 should be suitable for CT. This implies investment needs into intermodal wagons of € 12 billion until 2050 (€ 0.4 billion per year)[77].

The considerations regarding CT wagons can be transferred almost identically to the demand for and the use of ILUs. By 2050, the number of handlings per year will quadruple. Accordingly, it must be assumed that the demand for ILUs will also rise sharply. Only more efficient use (e.g., through reduced storage times and avoidance of empty redistribution) will presumably not be sufficient to cover the additional demand, so that investment into further ILUs becomes necessary.

4.5 Qualitative gap analysis and investment assessment

The strong increase in CT poses a challenge for the existing terminal infrastructure, which will be confronted with a tripling of the number of consignments by 2050. However, various measures exist to increase capacity that can be implemented by 2050. By improving the current terminal infrastructure (17 %), introducing digital tools (~20 %), increasing transhipment efficiency (7 %), upgrading existing terminals, and construction of additional terminals (35 %), the current European intermodal transhipment capacity can be increased – from the current

[74] The gap analysis for terminal capacities included different scenarios for operating hours. Capacity varies significantly between these scenarios and operating schedules are not uniform among all terminals in the network impacting the resulting gap assessment.
[75] Europe includes EU27 plus UK, CH, NO, EE, LV, LT
[76] In addition to the intermodal fleet presumably not more than 50,000 standard rail freight wagons can also be used for CT services.
[77] Assuming a purchase price of 70,000 per wagon [83].

level of about 72 million consignments to more than 100 million in 2050. The implementation of these improvements requires investments in terminal infrastructure totalling € 35 billion and another € 12 billion in further intermodal assets.

Although this study assumes 105 % higher transport volumes by rail in tonne-kilometres compared to the underlying modelling for the proposal for the TEN-T Regulation Guidelines revision, it could show, that no additional terminals beyond the ones planned within TEN-T are required. The capacity to accommodate the projected freight volumes is expected to be achieved by the measures panned within the TEN-T framework. Necessity for additional terminals beyond the proposed 300 new ones within the TEN-T revision proposal could arise from strong concentration of transhipment demand at industrial nodes.

5. Conclusions

Until 2050, the European Union aims to reach climate neutrality overall and defined the target for the transport sector to reduce of greenhouse gas emission by 90 % (compared to 1990). Door-to-door CT can help to achieve this target as it offers a CO_2 saving potential of up to 89 % compared to road transport. Even for zero-carbon CT, the necessary technologies are already available today.

This study investigates how the existing infrastructure can accommodate the projected increase in freight volumes together with the shift towards zero-carbon modes of transport and what investment and accompanying measures are needed in order to promote zero carbon door-to-door CT.

5.1 Projections for freight transport, upcoming capacity bottlenecks, and possible improvements

The EU Reference Scenario projects an increase in freight transport volumes in Europe of 27 % by 2030 and of 51 % by 2050 – compared to 2020.

In accordance with the objectives of the rail sector and the European Commission's Roadmap to a Single European Transport Area, it is assumed that a doubling of the share of rail freight can be achieved by 2050, resulting in a tripling of the tonne-kilometre performance of freight trains. This increase is essentially driven by the growth of CT, which can be expected to reach a share of 70 % of total European rail freight transport in tonne-kilometres by 2050.

The current railway and intermodal terminal infrastructure would not be able to accommodate this increase. However, for the transport modes involved in CT various measures exist to allow for capacity increases within the existing infrastructure – and, in combination, to meet demand.

By achieving the TEN-T standards for rail infrastructure, substantial capacity reserves can be used. With regard to intermodal transhipment, the modernization of the existing infrastructure, and an increase in terminal density are of decisive importance in order to enable effective CT transport chains throughout Europe. The assessment undertaken as part of the TEN-T revision process indicates that approximately 300 additional terminals will be needed to establish a resilient, comprehensive network. However, the resulting terminal infrastructure should also provide the necessary capacity reserves to accommodate higher utilization due to a higher modal share of rail by 2050.

5.2 Investment assessment for a resilient infrastructure for rail and combined transport sector

This study considered and analysed measures included in the original TEN-T Regulation Guideline, as well as measures that go beyond those. The investment costs for these measures are estimated to € 537 billion until 2050 – breaking down into € 490 billion for rail infrastructure and € 47 billion for extension and upgrade of intermodal assets. To a large extent, these measures were identified as necessary in the proposal for a revised TEN-T Guideline Regulation, thus, the majority of investment costs were also indicated within the revision.

Table 7: Summary of demand development, possibilities to increase infrastructure capacity, and corresponding additional investment needs.

	Projected demand increase until 2050		Effect of measures to increase capacity	Total investment needs (in billion)
Rail infrastructure	+140 %	in trains per day	> 150 %	€ 490
Road leg infrastructure	+350 %	in tonne-kilometres	--	net positive[78]
Intermodal assets	+220 %	in transhipments	> 100 %	€ 47

At the same time, the projected rail share of 32 % in freight transport (44 % in long-distance transport) together with an intensive usage of CT (70 % share of intermodal rail in total rail freight transport) offers potential for cost savings in the road transport sector due to the net reduction of truck hours and road infrastructure costs[79].

Technically, zero-carbon combined transport is already possible today. In order to achieve widespread implementation and to meet the European climate targets for the transport sector, investments in infrastructure for rail, transhipment and short-distance road haulage are necessary over the next years which should be accompanied by supporting political and regulatory measures.

[78] No concrete sum is given here, as it is a net saving compared to the assessment of required costs based on the freight demand projection of the EU Reference Scenario.
[79] Other external effects include reduced congestion of roads and higher energy efficiency in transport.

References

[1] COMMUNICATION FROM THE COMMISSION, “'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality,” vol. COM(2021) 550 final, 2021.

[2] d-fine GmbH, "Combined Transport: carbon footprint and energy efficiency," 2021. [Online]. Available: https://www.uirr.com/en/media-centre/leaflet-and-studies/mediacentre/2102-comparative-study-on-co2-emissions-in-door-to-door-ct-d-fine.html. [Accessed 11 11 2022].

[3] Rail Freight Forward, “30 by 2030: Rail Freight strategy to boost modal shift,” 2018.

[4] d-fine GmbH, “Zero-Carbon Combined Transport: Technology and efficiency analysis of zero-carbon road-rail combined transport,” 2022. [Online]. Available: https://www.uirr.com/en/media-centre/leaflet-and-studies/mediacentre/2236-zero-carbon-combined-transport-study-by-d-fine-.html. [Accessed 22 11 2022].

[5] European Commission, Directorate-General for Climate Action, Directorate-General for Energy, Directorate-General for Mobility and Transport, De Vita A., Capros P., Paroussos L., Fragkiadakis K., Karkatsoulis P., Höglund-Isaksson L., "EU reference scenario 2020 : energy, transport and GHG emissions : trends to 2050.," 16 07 2021. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/96c2ca82-e85e-11eb-93a8-01aa75ed71a1/language-en/format-PDF/source-219903975. [Accessed 22 11 2022].

[6] European Commission - DG-Move, “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system,” EUROPEAN COMMISSION, Brussels, 2011.

[7] European Commission, "The European Green Deal," *COM(2019) 640,* 2019.

[8] REGULATION (EU) 2021/1119 OF THE EUROPEAN PARLIAMENT, "European Climate Law," *Official Journal of the European Union,* no. 2021/1119, 2021.

[9] ITF, “ITF Transport Outlook 2021,” OECD Publishing, Paris, 2021.

[10] CAPACITY4RAIL, “Requirements toward the freight system of 2030-2050,” 2018.

[11] eurostat, “Volume of freight transport relative to GDP,” 20 04 2022. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/product/view/TRAN_HV_FRTRA?lang=en . [Accessed 01 11 2022].

[12] OECD, “Economic Outlook No 109 - October 2021 - Long-term baseline projections,” 2022.

[13] European Commission, “Sustainable and Smart Mobility Strategy,” European Commission, 2020.

[14] European Commission, “European Green Deal: PRIMES Model for 'Fit for 55' MIX scenario,” European Commission, 2021.

[15] eurostat, “Annual road freight transport by distance class with breakdown by type of goods,” 14 10 2022. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/ROAD_GO_TA_DCTG__custom_3741697/default/table. [Accessed 02 11 2022].

[16] European Commission, “Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions,” Brussels, 2011.

[17] UIC, “Railway Statistics 2021,” UIC, Paris, 2022.

[18] eurostat, “Freight transport statistics - Goods transport,” 2020. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/ttr00006/default/table?lang=en. [Accessed 05 09 2022].

[19] UIRR, “UIRR Report 2021-22: European Road-Rail Combined Transport,” Brussels, 2022.

[20] Fraunhofer ISI, “Reference and Pro Rail Scenarios for European Corridors to 2050,” *Working Paper Sustainability and Innovation,* no. 5, 2018.

[21] eurostat, “Freight transport statistics - modal split,” 7 7 2021. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/product/view/TRAN_HV_FRMOD?lang=en. [Accessed 22 11 2022].

[22] KombiConsult GmbH, Intermodality Ltd, PLANCO Consulting GmbH,Gruppo CLAS S.p.A., “Analysis of the EU Combined Transport,” European Commission, Frankfurt, 2015.

[23] UIC, “2020 Report on Combined Transport in Europe,” International Union of Railways, 2022.

[24] European Commission, “Seventh monitoring report on the development of the rail market under Article 15(4) of Directive 2012/34/EU of the European Parliament and of the Council,” Brussels, 2021.

[25] J. Doppelbauer, Interviewee, *A high-Performance European Railway infrastructure for Combined Transport.* [Interview]. 19 May 2022.

[26] European Commission, “Proposal for a Regulation on Union guidelines for the development of the trans-European transport network,” 2021.

[27] European Commission, “IMPACT ASSESSMENT REPORT: REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Union guidelines for the development of the trans-European transport network, amending Regulation (EU) 2021/1153 and Regulation (EU) No 913/2010,” 2021.

[28] European Parliament, European Council, “REGULATION (EU) No 1315/2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU,” 2013.

[29] W. Schade, C. de Stasio, D. Bielanska, F. Fermi, M. Himmelsbach, N. Lindberg and S. Maffii, "Analysis accompanying the Impact Assessment for the revision of Regulation (EU) N° 1315/2013 – FINAL REPORT," Karlsruhe, Milano, 2021.

[30] UNIFE, "Position Paper on the Revision of the TEN-T Regulation," 2022.

[31] V. Ranjbar, N. O. Olsson and H. Sipilä, "Impact of signalling system on capacity – Comparing legacy ATC, ETCS level 2 and ETCS hybrid level 3 systems,," *Journal of Rail Transport Planning & Management,* no. 23, 2022.

[32] B.-L. Nelldal, "Line capacity and train capacity for future rail freight corridors," KTH Royal Institute of Technology, Stockholm, 2017.

[33] UIRR , "Intermodal: the increasing importance of P400," 04 25 2021. [Online]. Available: https://www.uirr.com/news/mediacentre/1846-intermodal-the-increasing-importance-of-p400.html. [Accessed 15 09 2022].

[34] European Commission, "ERTMS: Work Plan of the European Coordinator," 2020.

[35] PricewaterhouseCoopers, "Assessment of unit costs (standard prices) of rail projects (CAPital EXpenditure)," European Commission, Brussels, 2018.

[36] PricewaterhouseCoopers; KombiCunsult, "Comparative evaluation of transhipment technologies for intermodal transport and their cost," European Commission, Brussels, 2022.

[37] International Energy Agency, "The Future of Rail: Opportunities for energy and the environment," 2019.

[38] European Commission, European Parliament, European Council, European Economic and Social Committee, Committee of the Regions, "Progress report on implementation of the TEN-T network in 2016-2017," European Commission, Brussels, 2020.

[39] RNE; TTR; FTE, "TIMETABLING AND CAPACITY REDESIGN (TTR) - Overall Presentation," 2019.

[40] CER; UIC; UIRR; CEFIC;, "Sector Statement on Rail Freight Corridors Follow-up," 2020.

[41] Mobility Consulting, "Redesign of the International Timetabling Process (TTR) Business Case - Draft," TTR Steering Committee, 2019.

[42] European Court of Auditors, " Rail freight transport in the EU: Still not on the right track," 2016.

[43] CEDR, "Trans-European Road Network, TEN-T (Roads): 2019 Performance Report," 2020.

[44] M. G. Romana and D. Hernando, "Obtaining a maximum AADT sustained by two-lane roads: an application to the Madrid region in Spain," *Transportation Research Procedia,* vol. 14, pp. 3209-3217, 2016.

[45] Louis Berger S.A. , "Transport Infrastructure Regional Study (TIRS) in the Balkans / Final Report - APPENDIX 5," ITF, 2002.

[46] G. Cookson, "Europe's Traffic Hotspots - Measuring the impact of congestion in Europe," INRIX Research, 2016.

[47] P. Christidis and J. N. Ibáñez Rivas, "Measuring road congestion," European Commission, 2012.

[48] C. Janusz, O. Krzysztof and M. Tracz, "Variability of Capacity and Traffic Performance at Urban and Rural Signalised Intersections,," *Transportation Research Procedia,* vol. 15, pp. 87-99, 2016.

[49] European Court of Auditors, "The EU core road network: shorter travel times but network not yet fully functional," 2020.

[50] R. Monden, K. El Beyrouty, M. Gatto, H. Kramer, L. v. Wijngaarden, A. Schroten, M. Brambilla, V. Lambla, F. Trosky, S. Amaral, M. Killer, D. Bertschmann and S. Maffii, "Overview of transport infrastructure expenditures and costs," European Commission, Brussels, 2019.

[51] R. Vaiana, G. Capiluppi, V. Gallelli, T. Iuele and V. Minani, "Pavement Surface Performances Evolution: an Experimental Application," *Procedia - Social and Behavioral Sciences,* vol. 53, pp. 1149-1160, 2012.

[52] IDIADA; TML; TUG, "Bodies and trailers – development of CO2 emissions determination procedure," 2018.

[53] M. Bielenia, A. Borodo, G. T. Cirella, E. Czermański, T. Czuba, J. Jankiewicz, A. Oniszczuk-Jastrząbek, M. Sidorowicz and B. Wiśnicki, "COMBINED TRANSPORT TERMINALS BENCHMARK ANALYSIS," COMBINE, 2020.

[54] Kessel + Partner Transport Consultants, KombiConsult GmbH, "Study On Infrastructure Capacity Reserves For Combined Transport By 2015," UIC, Freiburg/Frankfurt am Main/Paris, 2004.

[55] A. Huelsz Prince, "Capacity factors in intermodal road-rail terminals," Gothenburg, 2015.

[56] Hacon Ingenieurgesellschaft mbH; To70 B.V, "Performance Indicators & Expected Benefits," Hannover, The Hague, 2021.

[57] UIRR, "Electronic exchange of ETA information - Project objectives and consortium," [Online]. Available: https://www.uirr.com/en/projects/ongoing/item/21-electronic-exchange-of-eta-information/34-ongoing.html. [Accessed 22 11 2022].

[58] UIRR, "MORE EFFICIENCY THROUGH DIGITALISATION IN COMBINED TRANSPORT," in *18th Florence Rail Forum*, Florence , 2019.

[59] CAPACITY4Rail, "Rail Freight Systems of the Future (Final)," 2017.

[60] C. Colombaroni, G. Fusco, N. Isaenko and L. Quadrifoglio, "Optimization of container operations at inland intermodal terminals," in *2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, Naples, 2017.

[61] B. Wiegmans and B. Behdani, “A review and analysis of the investment in, and cost structure of, intermodal rail terminals,” *Transport Reviews,* vol. 38, no. 1, pp. 33-51, 2018.

[62] FERRMED, “Presentation of the final results of the FERRMED study of traffic and modal shift optimsation in the EU,” in *Eurasian Connectivity and industrial Cooperation Forum (Europe)*, Brussels, 2022.

[63] ERA, Full Impact Assessment - Revision of the Noise TSl: Application of NOI TSI requirements to existing freight wagons, European Union Agency for Railways, 2018.

[64] UIC, “2018 Report on Combined Transport in Europe,” International Union of Railways, 2018.

[65] Independent Regulators’ Group – Rail, “A survey of congested infrastructure, priority criteria and capacity charges in Europe,” *IRG-Rail* , vol. 4, no. 19, 2019.

[66] Deutsche Bahn AG, “Leistungs- und Finanzierungsvereinbarung: Infrastrukturzustands- und -entwicklungsbericht 2020,” 2021.

[67] RailNetEurope, “RFC KPIS,” [Online]. Available: https://rne.eu/rail-freight-corridors/rfc-kpis/. [Accessed 23 09 2022].

[68] European Commission - DG-Move, “TENtec Viewer,” 7 6 2022. [Online]. Available: https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html. [Accessed 04 10 2022].

[69] BDI, “Climate Giant in Chains – Combined Road/Rail Transport,” Industrie-Förderung Gesellschaft, Berlin, 2022.

[70] J. Schrampf, P. Weiss, N. Sedlacek and I. Steinacher, “Terminalkonzept 2022,” Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, Vienna, 2022.

[71] U. Expert, Interviewee, *Discussion on Combined Transport.* [Interview]. 11 2022.

[72] CAPACITY4RAIL, “Parameters for capacity and costs of freight trains in Sweden including Business cases and validation of new freight wagons,” KTH, 2017.

[73] CargoBeamer, “CargoBeamer opens terminal in Calais,” 12 July 2021. [Online]. Available: https://www.cargobeamer.com/news/cargobeamer-opens-terminal-in-calais.html. [Accessed 18 10 2022].

[74] European Commission - CORDIS, “Shifting to rail via longer freight trains,” 6 October 2015. [Online]. Available: https://cordis.europa.eu/article/id/91132-shifting-to-rail-via-longer-freight-trains. [Accessed 19 10 2022].

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