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Reference and Pro Rail Scenarios for European Corridors to 2050

Working Paper 5 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral

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Executive Summary

Background. Transport, excluding international aviation and maritime shipping, comprised 21% of European GHG emissions in 2015 and where 23% above 1990 levels. In freight transport, 72% of GHG emissions were from road transport, where emissions from light duty vehicles declined due to consumption standards and less carbon intensive fuels. Heavy duty vehicles remain at constant emission rates related to transport activities to date. With this background it is most likely that we will fail to achieve the 40% GHG reduction targets for 2030 against 1990 levels across all economic sectors by a large margin. Thanks to transport, agriculture and other sectors which cannot adapt, the reduction achieved might be only 10%.

Given this background the research project LowCarb-RFC – Low Carbon Rail Freight Corridors for Europe, funded by the Stiftung Mercator Foundation and the European Climate Foundation between 2015 and 2018 explores ways to reduce freight transport's GHG emissions. The study looks at two busy European freight corridors. As standard measures to improve the freight sector have failed so far, we look at two extreme cases: massive shifts to rail and a de-carbonisation of trucking. This paper is part of a series of nine working papers and three summary reports exploring various aspects of this approach. The paper investigates options to massively improve rail freight competitiveness by investigating key drivers for mode shift and then by drafting a business-as-usual and a Pro Rail scenario to 2050. Related working papers discuss the feasibility of fundamental reforms in the rail sector, establish road transport scenarios and conduct an impact assessment for European corridors as well as for the German federal state of North Rhine-Westphalia.

Drivers for mode shift. In this working paper we have reviewed the key drivers for mode shift in freight transport along two of the major European rail freight corridors: RFC1: Rotterdam-Genoa and the western Part of RTC8: Antwerp-Warsaw. Using literature from railway undertakings, public institutions and the research community we could confirm the various forms of service quality, and secondly transportation costs as being the most relevant categories of drivers. However, new technologies and organisational structures together with supportive policy packages are indispensable for successful mode shift.

Scenario method. In this study we have reviewed detailed costs of road, rail, barge and intermodal transport with generalised, bulk and containerised cargo. For the cost categories infrastructure, vehicles, energy, labour and administration

2015 cost structures were analysed and projected to 2030 and 2050. The forecasts are partly based on existing studies, e.g. by the PRIMES or the ASTRA system dynamics models, transport sector statements and on an in-depth literature review.

In the **BAU scenario** we already see considerable cost efficiency gains to 2050 along the corridors, which are more larger for rail (-18%) than for road (-13%) and for IWT (-8%). This assumption is based on current observations of successes in re-structuring the sector. The enormous efficiency gains of the railway market that are still available will partly be utilised by measures which have already been implemented today. These are public subsidies, market opening, digitalisation, asset and labour management or the concentration on core markets.

In the BAU scenario road transport will from company mergers and the long-term independency from fossil fuels. While road freight rates are expected to decline by 17% towards 2050, the relative cost advantage of rail is still 26%.

The **Pro Rail** scenario is characterised by massive investments in rail capacity in the form of new infrastructure, but more importantly in high capacity and flexible train control and communications systems to ETCS / ERTMS level 3. With advanced asset and demand management platforms train, wagon and container space are filled close to system saturation. By these measures rail costs per ton kilometre are expected to decline by 59% to 2050 for general cargo.

Truck operations in the Pro Rail scenario are partly restricted and are subject to stricter social rules and much higher road charges. In total, truck operating costs are expected to climb up by 27% in 2050 relative to 2015. The relative cost advantage of rail therefore improves further to 81%.

- **Infrastructure** costs for rail are cut by half towards 2030 and decreased further to 2050 by public subsidies and economies of scale. For trucks we assume a tripling of infrastructure charges to cross-subsidise rail and IWT investments according to the Swiss model.
- **Rolling stock** related costs in rail freight decline massively due to modular wagon concepts, declining empty journeys, increased load rates, cross-border fleet management and longer productive life spans. Road haulage, in contrast, faces an increase in truck holding and operating costs due to stronger technical requirements and regulations.
- **Energy costs** show a less clear development. Energy prices are expected to rise towards 2030 and then fall slightly as more renewables come available. The extensive efficiency programmes in rail mean that energy costs fall by

35% in Pro Rail against 2015, while higher energy taxes in trucking cannot compensate for more efficiency of HGVs in the Pro Rail scenario.

- **Labour costs** decline sharply in the rail sector due to massive automation and digitalisation. In the road sector this is less the case as automation here is restricted by law in the Pro Rail scenario.
- **Administrative costs** are among the major burdens of today's railways. The simplification of regulations, cooperation and digitalisation sees this burden shrink by 70% in rail freight, and by 20% in road haulage in the Pro Rail scenario against 2015.
- **Load factors** and occupancy rates of vehicles and infrastructures take a key role for the development of transport costs. Through new infrastructures, longer or shorter but high frequency trains and a unique high standard train control system, network throughput may double. Modular wagons, a central consignment management and the cooperative marketing of load space may add another 50% to rail network capacity related to net ton throughput.

The following table summarises the figures, including inland waterway transport. The values are averaged for a 300 km shipment of general cargo.

Table S1: Summary cost development by cost category and scenario

Cost category	Rail		Road		IWT	
	BAU	Pro Rail	BAU	Pro Rail	BAU	Pro Rail
Infrastructure	-20 %	-75 %	0 %	+200 %	0 %	0 %
Vehicle	-25 %	-60 %	+9 %	+52 %	0 %	-60 %
Energy	-12 %	-35 %	0 %	+15 %	-30 %	-30 %
Personnel	-42 %	-68 %	-20 %	+10 %	-30 %	-30 %
Administration	-25 %	-70 %	-20 %	-20 %	0 %	0 %
TOTAL	-18 %	-59 %	-13 %	33 %	-8 %	-37 %

Innovative technologies, new forms of organising rail businesses and capacity are indispensable for achieving these efficiency gains. These rely on a massive expansion of capacity and quality at the railways through new tracks, moving block train control, longer and / or faster trains and optimisation of wagon load space use. Investment costs may easily exceed 22 billion euros for the German networks alone. Related to the 50 billion tkm of additional traffic attracted to rail this is 0.80 €/Ct./tkm or roughly twice current track access charges. Political commitment and additional efficiency measures are thus needed

Key pre-conditions to these massive and unprecedented efficiency gains in the railway sector are external as well as internal developments: strong and coordinated political commitment, rapid implementation of capacity extension programmes and consequent structural reforms towards a lean management culture within the railway undertakings.

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Abbreviations

AT	Austria
BAU	Business-as-Usual
BE	Belgium
BG	Bulgaria
BGL	Bundesverband Güterkraftverkehr, Logistik und Entsorgung e.V.
BNetzA	Bundesnetzagentur (Federal Network Agency, Germany)
BUND	Bund für Umwelt- und Naturschutz Deutschland
BVWP	Bundesverkehrswegeplan
CER	Community of European Railways and Infrastructure Companies
CERRE	Centre on Regulation in Europe
CH	Switzerland
CO_2	Carbon dioxide
CT	Combined transport
CZ	Czech Republik
DB Cargo	Deutsche Bahn AG, Freight division
DB-Netz	Deutsche Bahn Netz AG
DE	Germany
DeStatis	Statistisches Bundesamt (Federal Statistical Office, Germany)
EC	European Commission
ECF	European Climate Foundation
ECM	Entities in Charge of Maintenance
ERRAC	European Rail Research Advisory Council
ERTMS	European rail traffic management system
ES	Spain
ETCS	European train control system
EU	European Union
FI	Finland
FR	France
GHG	Greenhouse gas
HGV	Heavy Goods Vehicle
HU	Hungary
IEA	International Energy Agency
IM	Infrastructure manager
IT	Italy
ITF	International Transport Forum
IWT	Inland waterway transport

LowCarb-RFC	Low Carbon Rail Freight Corridors for Europe
NABU	Naturschutzbund Deutschland
NEE	Netzwerk Europäischer Eisenbahnen
NL	The Netherlands
NRW	North Rhine-Westphalia
NSB	North Sea Baltic (corridor)
PL	Poland
RALP	Rhine-Alpine (corridor)
RFC	Rail freight corridor
RU	Railway undertaking
SBB	Schweizer Bundesbahn
ScanMed	Scandinavian-Mediterranean Corridor
SNCB	Société nationale des chemins de fer belges
SNCF	Société nationale des chemins de fer français
SWL	Single wagon load transport
tkm	Ton kilometre
TPR	Department of Transport and Regional Economics (at the University of Antwerp)
TRT	Trasporti e Territorio
UBA	Umweltbundesamt
UIC	International Union of Railways
UNECE	United Nations Economic Commission for Europe
VCD	Verkehrsclub Deutschland
VDV	Verband deutscher Verkehrsunternehmen e.V.
vkm	Vehicle kilometre
WWF	World Wildlife Fund

1 Introduction

1.1 Context: The LowCarb-RFC project

This publication is one of three summary reports of work performed within the study “Low Carbon Rail Freight Corridors for Europe” (LowCarb-RFC). The Study is co-funded by the Stiftung Mercator Foundation and the European Climate Fund over a three-year period from September 2015 to November 2018 and is carried out by the Fraunhofer Institutes for Systems and Innovation Research (ISI, Karlsruhe) and for Logistics and Material Flows (IML, Dortmund), INFRAS (Zurich), TPR at the University of Antwerp and M-FIVE GmbH (Karlsruhe).

The LowCarb-RFC study concentrates on long-distance freight transport along major European corridors as this sector is among the most steadily growing sources of greenhouse gas emissions in Europe, and which is most difficult to address by renewable energies and other standard climate mitigation measures in transport. Starting from the classical suite of approaches avoid, shift and improve the LowCarb-RFC methodology concentrates on mode shift to rail and mitigation measures in all freight modes along the two major transport corridors crossing Germany: Rhine Alpine (RALP) from the Benelux countries to Northern Italy and North-Sea-Baltic (NSB) from Benelux via Poland to the Baltic States. Besides major European strategies the project concentrates on the implications for transport policy at the intersection of these two corridors, which is the German Federal State of North-Rhine Westphalia (NRW). The project focuses on rail as a readily available alternative to carry large quantities of goods along busy routes by electric power, and thus potentially in a carbon neutral way. Within this setting, the project pursues three streams of investigation:

- **Stream 1: Railway Reforms**. This thematic area responds to the idea of rail freight as a strong pillar of climate mitigation policy. It considers the slow pace of climate mitigation in the freight transport sector and asks the question how regulatory frameworks, company change management processes or new business models can accelerate them.
- **Stream 2: European Scenarios and Impacts**. For rail, road and waterway transport along the two corridors, cost and quality scenarios are established and their impact on modal split, investment needs and sustainability are modelled. This stream is the analytical core of the study and shall provide the basis for the subsequent analysis of pathways of interventions.
- **Stream 3: Case Study NRW**. This step eventually breaks down the transport scenarios and intervention pathways to the local conditions in NRW and looks

at the implications for investments or de-investments in certain infrastructures, jobs, economic prosperity and the environment.

1.2 Purpose of this working paper

Human contribution to climate change is among the biggest foreseeable threats to nature and our civilisation. Transport, excluding international aviation and maritime shipping, made 21% of European GHG emissions in 2015 and where 23% above 1990 levels. In particular freight transport, 72% of GHG emissions were from road transport, where light vehicles declined in average emissions due to consumption standards and less carbon intensive fuels. Only truck transport remains at constant emission rates related to transport activities to date. Behind that background it is most likely that we will vastly miss the 40% GHG reduction targets for 2030 against 1990 levels across all economic sectors. Thanks to transport, agriculture and other rigid economic branches only 10% reduction might be realised.

This paper feeds into Stream 2 of the LowCarb-RFC study. It seeks to construct a Business-as-Usual scenario and a more ambitious Pro Rail scenario for freight transport along two major European rail freight corridors: RFC 1 (Rhine-Alpine) from the Dutch seaports to northern Italy and RFC 8 (North Sea-Baltic) from the Belgium seaports to Poland. The main focus of the scenarios is on the railways, but for a complete picture road haulage and inland navigation are considered as well.

- **Business-as-Usual**: This reference scenario assumes that current economic, technological and organisational trends in the transport sectors carry on to 2050. These include cost cuts and efficiency gains in the rail and inland waterway (IWT) sectors, moderate energy price increases, labour market trends, ongoing moderate automation, etc. The assumptions taken in the BAU case are non-disruptive and are slightly in favour on rail and IWT. Accordingly, the outcome should be broadly in line with current transport market projections with a focus on sustainability.

  Pro Rail. This scenario portrays modernisation and efficiency development in the European rail freight market. All quality and efficiency enhancing technologies and organisational structures conceivable are exploited to their full extent. In parts this means a complete reconstruction of the rail freight business, at least along the major corridors, compared to the sector's current structure. What remains is the concept of electric powered trains on tracks. Full digitalisation and automation of infrastructures, rolling stock and operations, active marketing and new forms of cooperation and business models will drive down unit costs of the railways considerably. At the same time, trucking will be subject to additional sustainability charges, new road construction will nearly come to a halt, the labour market is considered to remain restrictive and autonomous driving will be restricted. The Pro Rail scenario describes a future in which all options for strengthening and modernising the rail freight sector along the major corridors are realised to their full extent. Realising such profound cuts in costs and improvements in infrastructure availability and service levels requires fundamental changes in organisational structures, policy priorities and business models. Who the new players in European rail freight transport are and what disruptive business models for the sector might look like are left open in the scenarios.

Summary Report 1 (Petry et al., 2018) of the LowCarb-RFC project discusses the options and the difficulties with structural reforms of such dimensions in large organisations. Having this in mind, the Pro Rail scenario drafted here is more to be understood as a target for a road mapping process in the freight transport sector rather than as the sketch of a likely future. While we are aware of the fact that the Pro Rail scenario is unrealistic, the LowCarb-RFC study explores the limits of how far rail can contribute to achieving the -60% GHG reduction target for transport in 2050 compared to 2005 levels as postulated by the EC Transport White Paper of 2011.

Structure of the paper:

- Chapter 2 reviews drivers and barriers to mode shift by looking at scientific studies, rail sector publications and policy statements. This overview informs the subsequent elaboration of future scenarios for rail, road, IWT and intermodal services.
- Chapter 3 then introduces the main part of the paper by presenting the scenario philosophy and by reviewing selected current trends. The scenario narratives are then presented for the Business-as-Usual and the Pro Rail case in Chapter 4.
- In the subsequent Chapter 5 we delve into the economic consequences of the scenario's narratives. We apply the generalised cost approach along the rail sector elements. These feed into the TPR Chain Model for the transport impact assessment. Insofar, Chapter 5 is the most important part of this data.
- Chapter 6 looks at performance indicators for the scenarios, including transit times, reliability, quality and information. Chapter 7 provides some ideas of an implementation plan and provides an insight into how future investment plans might be implemented.
- Chapter 8 finally summarises the main statements in the Working Paper and gives an outlook of what they might mean for mode shift from road to rail.

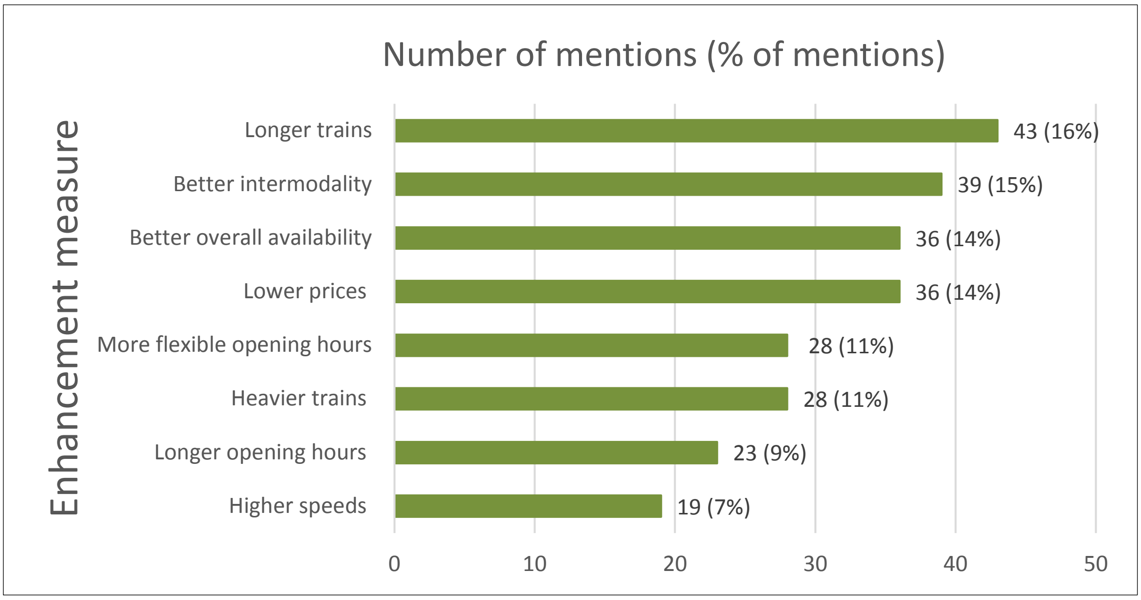
2 Review of Drivers for Rail Freight Volumes

Since the first road and rail market reforms in Europe in the early 1990s mode shift to rail has been a corner stone of transport policy. Despite massive financial contributions to the railways, however, their mode share in fright transport was declining or at best stable in some countries. The reasons behind this failure of transport policy have been discussed in Working Paper 1 of the LowCarb-RFC project. Assuming that the railways play an important role in mitigating climate gas emissions from freight transport, the decisive question now is what helps, i.e. which factors drive their market success.

The aim of this section is to identify the most relevant drivers for rail freight market shares on major European freight corridors, namely the Rhine-Alpine (RALP) and the North-Sea-Baltic (NSB) corridors connecting the North Sea ports in Belgium and the Netherlands to Northern Italy and Poland. The discussion on drivers (or success factors) is closely linked to the debate on barriers or limiting factors to rail freight market growth. In most cases both constitute different activity levels of the same field of action. In this paper we take a positive perspective by arguing how to remove barriers instead of elaborating on their severity.

A first indication of drivers for the freight railways' market success is provided by the EC corridor studies. A poll amongst rail freight stakeholder's active in the Scandinavian – Mediterranean corridor (ScanMed) reveals a mixture of efficiency (lower prices, longer and heavier trains, etc.) and user friendliness (flexibility, availability, etc.).

Figure 1: Stakeholder consultation on drivers for rail freight success in the ScanMed corridor



Source: ETC et al. (2014)

The first three sections go through key publications in the field since 2010, which is basically around and after the issuing of the 2011 EC White Paper on a transport roadmap for 2050. We sorted the study by main authors, which is scientific studies, industry roadmaps and policy papers. Of course there is considerable overlap as studies written by research institutes or consultancies maybe be commissioned by industry bodies. For transparency we thus provide authors and clients of the studies in all cases.

2.1 Scientific studies

AECOM, 2016 to the Department for Transport (DfT): Future Potential for Modal Shift in the UK Rail Freight Market (Allan et al., 2016). Requested by the UK Department for Transport (DfT) Allan et al. (2016) have compiled a market and modelling study on options to improve rail market share and lower greenhouse gas (GHG) emissions along selected UK freight corridors. In dialogue with rail stakeholders the study confirms the commonly cited drivers for rail market success: infrastructure capacity, low costs, flexibility, awareness & attitudes and skills & training.

By looking at current rail shares and growth potentials the following key markets for rail freight growth are identified: Ports and domestic intermodal transport, construction, channel tunnel traffic, express and parcels services, and automotive.

To gain growth in these markets 27 interventions in the following areas are proposed: Investment and Infrastructure Schemes, Innovation and New Systems, Promotion, Marketing and Engagement, Facilitation and Funding, Regulatory Intervention, Further Studies, and Skills Access and Promotion. By far the largest impact of these interventions is assumed for domestic container transport, shifting 28.1 out of 41.0 billion tkm (all commodities) of truck traffic to rail.

These interventions are prioritised and have feasibility and cost qualifiers assigned to them. By their implementation it is estimated that GHG emissions from trucking can be reduced to 19% by shift from road to rail. The most powerful measure to save GHG emissions, however, is electrification of the corridors, as diesel traction still accounts for 93% in rail freight in the UK.

BESTFACT, 2015: Best Practice Factory for Freight Transport (Permala and Eckhardt, 2015). The objective of BESTFACT is to develop, disseminate and enhance the utilisation of best practices and innovations in freight transport that contribute to meeting European transport policy objectives with regard to competitiveness and environmental impact. (Permala and Eckhardt, 2015). The project serves three clusters:

- Urban Freight;
- Green Logistics & Co-modality;
- eFreight.

58 projects were analysed in cluster 2. The most important gap to more sustainable freight transport to be bridged is economic viability of the projects. New solutions will only be adopted by businesses with a strong economic case even under difficult conditions. Motorways of the sea and new intermodal solutions offer the potential for modal shift, but they need address flexibility and reliability. Finally, an EU-wide approach to mode shift policies is missing. Express rail with 140 km/h is comparable to road along entire corridors. For eFreight automation and delivery optimisation tool are favoured to speed up logistics processes and to maximise their reliability.

EC (2014): Rhine-Alpine core network corridor study. For all eight core network corridors the European Commission (EC) has issued specific studies in 2014. Among reviews project implementation against plan for the transport modes, the reports contain market studies looking at demand, supply and future prospects in passenger and rail transport quality and sustainability. The Rhine-Alpine CNC study modelled future mode shares in freight transport by implementing the following measures for a seamless rail network:

- Rail cost reduction through (1) removal of border stops, (2) electrification of the entire European rail network, (3) unique UIC gauge and (4) unique 740m train length;
- Rail network capacity increase through (1) ERTMS full deployment, (2) additional double track lines and (3) unique 22.5 t axle load (no effect);
- Increased road costs through (1) HGV charging and (2) stricter social rules;

Together with come additional measures for shipping the model calculations found an increase of rail volumes by 10% against a decline in road volumes by just 2% in 2050.

CERRE Policy Paper 2014: Development of Rail Freight in Europe. By pulling together a number of key experts in the European rail market the Centre on Regulation in Europe (CERRE) has issued a policy paper on the key aspects of regulation for the success of European rail freight industries (Crozet et al., 2014). Key message of the paper is that the form of regulation of the European railway sector is less decisive for its development than the resulting environment of non-discrimination, cooperation and fair regulatory and pricing rules among market players. In some cases, e.g. single wagon load, large dominating carriers may be superior to a fragmented landscape of small companies.

Core drivers for a successful rail market considered by the study include

- external economic conditions, i.e. market growth,
- low generalised costs, including prices, speeds and handling,
- Reliability and service quality,
- Accessibility to networks and terminals for all rail undertakings and
- provision of customer tailored products: costs;

The study recommends further rail de-regulation, road regulation, fair charging and taxation regimes by policy. National and international policy makers shall further seek for ways to foster cooperation and non-discrimination in intra-modal competition. The RU shall address key markets, namely automotive and combined transport and shall provide high quality (mainly international) train paths.

PLATINA2, 2014: Platform for the implementation of NAIADES II (Lambrechts & Dasburg-Tromp, 2014). The PLATINA2 project (Lambrechts and Dasburg-Tromp, 2014) is a coordination and support action co-funded by the EC's FP7 with the mandate to support NAIDES II funding programme 2013-2020 for inland waterway transport. The stakeholder dialogue in the PLATINA-2 project is informed by a review on existing studies and practice cases on drivers and instruments for strengthening mode shift to cleaner modes, namely inland waterway transport (IWT) and heavy rail. Both sources of information lead to a rather clear picture of mode shift drivers:

- Transport costs from door-to-door constitutes the most relevant driver.
- Other characteristics of logistics chains are also highly relevant, but can be balanced out by shippers: reliability, transit time, flexibility and safety.

Demonstration cases to build up experience with non-road modes and strategy building for medium- to long term planning are relevant for initiating deviations from well-known logistics patterns. The PLATIINA-2 project does not provide market forecasts or estimates on the effectiveness of these drivers.

CE-Delft / TRT (2011) for CER: Drivers for rail mode shift. On behalf of the Community of European Railways and Infrastructure companies (CER) CE Delft and TRT **(de Boer et al., 2011)** summarise the discussion on drivers for mode shift on European level for the year 2008. For the analysis of drivers for rail market success the perspectives of users, suppliers and the society were taken. For each of these interest groups different sets of divers (or barriers) are formulated:

- User perspective: costs (inventory, handling, transport), time (transport speed, lead time, just in time), quality (flexibility, information/traceability, transparency/simplicity, security) and cargo (physical characteristics, transport requirements);
- Supplier perspective: Service and network (frequency, destinations, service orientation, price), infrastructure (terminals, interoperability, capacity);
- Societal perspective: accessibility (congestion, safety), environment (air pollutant-, GHG- and noise emissions) costs (social internal and external costs).

These drivers are not prioritised in the study, as the priorities may vary considerably along different transport markets and between elements of transport chains. However, in most cases costs to the user, followed by time and quality performance, dominate mode choice decisions. The study suggests to distinguish between three basic transport markets:

The study names three major gaps between demand and supply for rail:

- Balance of market power due to capital intensity of rail: puts even large customers in weak negotiating positions.
- Insufficient rail offer: low network density; discontinued direct rail access of shippers. Result: RU weak in key supply side factors:
  (1) frequency, speed and reliability;

(2) offers also for small volumes;
(3) door-to-door services;
(4) fast and easy contracting;
(5) Value-added services (tracking & tracing, packaging, stock management);
(6) conditioned (... and supervised / connected) containers;
(7) competitive and transparent prices.

- Lack of readability and communication of rail tariffs and services. → Simplicity of the system to the user (as is provided by road haulage).

Growing environmental awareness and congestion avoidance constitute additional elements of forwarders' mode choice decisions, but are not considered very strong yet.

AEA, CE Delft & TNO 2012 for EC: GHG Routes to 2050 (Skinner et al., 2012). In preparation to the 2011 EC White Paper Skinner et al. (2012) provided a study on options for reducing transport's GHG emissions by 60% from 2010 to 2050. For this purpose the SULTAN model was developed. The model assumed two alternative Business-as-Usual (BAU) cases (projection for past volumes and saturation with constant per capita passenger and freight trip rates) and five fields of activity. Applied one after another the SULTAN model finds the following cumulative GHG-Emission reductions by 2050:

- Use of biofuels to de-carbonise fuels: -9%;
- Other measures to de-carbonise transport fuels and energies: -20%;
- Spatial planning, more efficient organisation of the transport sector use: -9%;
- Economic instruments and all other measures: -21%.

These figures include maritime shipping, contributing around 25% to overall transport GHG emissions in Europe. Re-organizing freight intermodality without any complementary instrument is reported to gain at maximum 5% of annual emissions. The strongest GHG reduction is assumed for spatial planning measures with -10%. Without accompanying economic and regulatory measures the study warns that rebound effect through cheaper transport energy or freed capacity due to mode shift and efficiency measures could eat up the positive effects of the original technologies and policies.

Holzhey (2010) for UBA: Rail Freight Transport 2025/2030. On behalf of the German Federal Environment Agency (UBA) Holzhey (2010) develop a concept how rail can accommodate an increase in rail freight from 95 billion tkm in 2009 to 213 billion tkm in 2025/2030. After recovering from the world economic crisis and utilizing capacity reserves the network is expected to be able to cater 130bn.

tkm. The remaining volume of 83 bn. Tkm is suggested to be gained by two sets of measures:

- Operational and local construction activities. Most important measures are the optimization of train control systems with shorter block distances by deployment of ECTS (or LBZ), centralised and IT-based slot management and allocation and the closer alignment of speeds. This group of interventions is expected to increase network capacity by 35 bn. tkm or 27%.
- Large scale construction measures. The study defines six priority corridors for rail freight through Germany, along which bottlenecks need to be removed and quality is to be enhanced. These activities could gain another 48tkm or 35% of capacity. By assuming the costs for track upgrading at 12 million €/km and for electrification at 2 million €/km the bottleneck removal programme is estimated at 11 billion euros.

Capacity and high network quality are considered the basic requisites for modal shift to happen. By providing these network characteristics, the drivers “availability”, “reliability” and “speed” are triggered. A strong focus on low cost measures and the concentration of investments along major corridors, cost efficiency in infrastructure provision is addressed, too.

ITF (2010): A vision for rail in 2050. Thompson (2010) presented a vision for the development of world railways at the International Transport Forum (ITF) in 2010. Globally four railway systems (North America, Chana, Russia, and India) carry 82% of tkm. EU-15 (2.8%) and EU-10 (1.6%) add another 4.4% of world tkm. The share of freight at rail energy use is 56% globally; no figure for Europe. Main drivers for lifting rail market shares are policy innovations and infrastructure investments.

For infrastructure no technologies are in sight for a significant enlargement of capacity on congested networks. However, Innovation: technical improvements have cut costs in rail freight by half in the past decades through the more intensive use of capacity. As concerns rail policy, main innovations since the 1970s were the separation of infrastructure from operations, franchising of services and deregulation.

NewOpera (2008). Inspired by the European Commission’s 2001 transport White Paper “Time to Decide”, the mission of the EC-funded research activity NewOpera (Castagnetti, 2008) was to explore ways how to adapt rail freight to changing business needs and market conditions by new products and services. Market analyses in several countries revealed a number of common barriers to market growth, which can be re-formulated as market drivers as follows:

- Turn rail business philosophy into a multi-product culture;
- Enhance customer orientation;
- Explore the merits of ITC technology and virtual customers service relationship;
- Make services more reliable and more consistent;
- Provide tailor-made solutions for specific customer needs.

On the infrastructure and policy side the following key elements of a successful rail future are listed:

- Market opening and support of competition to state incumbents;
- Stringent setting and enforcing of European standards;
- Empty wagons management;
- Tracking and tracing.

In a scenario process the study investigated how increasing rail freight volumes to a factor four could work on four European Corridors, containing Rotterdam – Genoa and Antwerp – Warsaw. Required actions include:

- Track parameters: minimum limits for gauge B+, axle-load of 22.5 tons, train length of 750m and standardisation of current.
- Collaborative international organisation of maintenance strategies, capacity and priority management, emergency management, toll and pricing systems and ERTMS Level 2 & 3 deployment by 2015-2020.

The study clearly states that just increasing rail freight capacity is not sufficient to successfully participate in market growth. The Service Culture means that the customer's requirements must be put at the centre of rail freight business activity. New marketing tools, intelligent applications, and the creation of a differentiated service product range giving the customers the choice between different services and prices, are the pre requisites for rail freight rejuvenation (Castagnetti, 2008).

Impacts of these strategies have been investigated along the corridor Berlin – Madrid. With road cost increases 20% and rail productivity gains of 15% towards 2020 36.7 million tkm or 16.5% of the rail market could be shifted from road to rail. With additional intermodal measures and management mode shift could be 39% of the base case rail market. CO_2-emisisons would be reduced by 2.5 Mt annually.

2.2 Railway sector strategies

Deutsche Bahn: Programme "Zukunft Bahn" (Future Rail). The modernisation and customer care programme "Zukunft Bahn" is, according to Deutsche Bahn AG, the most ambitious endeavour to improve railway performance since the German railway reform in 1993. Although DB Cargo still is the largest rail freight carrier in Europe, performance indicators and economic results turned critical in the past years: 30 minute punctuality of freight trains remain between 67% in CT and 72% in SWL, the availability of requested empty wagons is up to 20% below the desired 97% availability level, customer information in cases of faults and incidents is considered unacceptable and the productivity of rolling stock and drivers was 30% below that of competitors. In its strategy paper "Zukunft Bahn" (Deutsche Bahn, 2015) DB Cargo identifies the following drivers and fields of action to return to a profit margin of at least 50% and to an annual growth rates at least one percentage point above the European average:

- Punctuality: 95% target (30 minutes) with strict priority for core business segments;
- Availability of empty wagons: 97% of pre-ordered capacity;
- Cost reduction through administrative and operational simplification;
- More flexible customer price structures;
- Stronger, more responsible marketing units closer to core business segments.

These market drivers and the suite of measures behind them mainly focus on operational improvements and financial savings in DB Cargo's production system. Neither contains the programme "Zukunft Bahn" major transitions of rail freight technology, nor does it address a proactive customer acquisition and care programme besides already established long-term and high volume contracts.

Swiss Federal Railways: SBB Cargo Master Plan. The overall development plan of SBB Cargo was laid down in 2012 (SBB, 2012) and since then developed further according to market requirements. According to SBB's annual report (SBB 2016) and the company's sustainability future strategy statements[1] the main elements for ensuring sustainable market success are:

- Staff development: human resource management shall ensure a positive attitude of SBB staff towards the entrepreneurial development, on customer needs and on business opportunities. The core general principles apply:

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1 SBB Cargo International Strategy: http://www.sbbcargo-international.com/de/strategie-leitbild.html.

  - Concentration on core markets, namely the axis North Sea Ports to Italy;
  - Customer proximity;
  - Lean and efficient production.
- Exploitation of new technologies: automated coupling, intelligent wagons, automation, including remote controlled self-driving trains.

ERRAC 2015 update to its strategic rail research agenda (SRRA). The European Rail Research Advisory Council (ERRAC) is set in by the European Commission and consists of members from the rail industry, from policy and from academia. In its recent strategic rail research agenda (SRRA) ERRAC advocates a number of driving factors to be addressed and targets for the railway sector to be met by 2050 in order to remain a relevant player in the European freight market. The Document addresses the following fields of action:

- Intelligent mobility: Dedicated freight networks catering longer, heavier and faster trains; utilisation of freight trains similar to passenger services; improved management and traceability of trains and cargo.
- Energy and environment: quiet and vibration-free and carbon free train operation, smart grid energy management.
- Security: flexible, automated and fully connected security systems on board and on infrastructures.
- Safety: intelligent infrastructures and rolling stock for higher availability, reliability and safety.
- Competitiveness and enabling technologies: All interoperability barriers to be removed, new technologies to tackle last mile, booming markets, freight villages, mega-hubs, etc. for 50% increase of capacity from existing infrastructures.
- Strategy and economics: intelligent mixed traffic management practices, peak load pricing, automated train operation, etc. for doubling existing track capacity.
- Infrastructure: decrease maintenance costs through improved processes by at least 50%, removal of bottlenecks, re-vitalisation of older infrastructures; new track technologies including automated diagnostics systems.

Competitors' Report Rail Transport 2015/2016 by mofair and NEE (2016). In the German rail freight market about 32% of ton kilometres are carried by other companies than DB Schenker Rail (now DB Cargo). Every other year the two main organisation of these private competitors, mofair and NEE, publish a review on the state of competition and market development in the German rail freight market. The report identifies the following factors fostering or slowing rail market growth in general.

- Fair charging for infrastructure and energy. While the Railway have to carry full track access charges on all network levels, the use of local and regional roads is free for Trucks in Germany. Moreover, rail has to carry surcharges from the renewable energy act, which does not apply to diesel fuels for trucks.
- Equal treatment of local infrastructure financing and costing; as for roads, regional rail infrastructures like industry sidings, passing tracks, parking facilities or marshalling yards, should be provided and financed by the region or company profiting from it.
- Goods structures: part of the success of private operators is the focus of DB on bulk markets. These are easy to ship and come in large quantities, but they are on the decline.

Netzwerk Privatbahnen 2009: A vision for rail transport in Germany by 2030. The network of private railways (Netzwerk Privatbahnen, 2009) has formulated a strategy to enable the rail sector to cope with policy goals, namely competitive transport markets and climate protection. Main drivers for the rail market:

- Clear policy commitment for sustainable transport on rail;
- Infrastructure quality and capacity;
- Sustainable financing structures;
- Efficient organisation and regulation.

These should be pursued through:

- shifting the focus of rail investments away from high speed projects and operations (e.g. by reducing maximum HSR speeds),
- policy pressure on rail companies (namely DB AG) to use resources and act according to formulated policy goals,
- the institutional separation of infrastructure and train operation to ensure fair competition and long-term strategic investment decisions.

2.3 Policy statements

WWF, BUND, Germanwatch, NABU and VCD, 2014: Climate Friendly Transport in Germany. Five leading environmental associations, supported by Oeko-Institute and the Federal Ministry for the Environment (BMUB) have drafted a scenario for low carbon passenger transport in Germany by 2050. In the fields of trip and freight demand, propulsion systems, fuels and energy generation, mode shift and vehicle use a scenario supported by model calculations was drafted. Main drivers for freight mode shift:

- Product structures, transport distances;
- Quality (flexibility, reliability, punctuality, safety, temperature control);
- Distance to nearest siding or combined transport terminal;
- Infrastructure capacity.

Policy actions were taken from Holzhey (2010) as to double rail freight network capacity through investments, overhaul tracks and better use of existing assets. Economic measures include lowering track access charges and internalising the external costs of transport. Further, competition in the rail sector shall be fostered and the noise problem shall be solved. With these measures rail share is expected to grow by 20 percentage points to 38% in 2050, while road haulage declines by 22 points to 50% market share.

The study emphasises that the main drivers for climate neutrality of the transport sector more relies on carbon neutral fuels, vehicle technologies and regional economic concepts than on organisational measures. Reducing the energy demand of all transport sector by various measures yield in -64% GHG emissions against 1990 levels; with renewable fuels and energy the study arrives at -86%. The target of -95% thus is failed by 19.3 mill. t CO_2-eq.

UNECE 2012: TEM and TER Master Plan. With the aim to set out an investment programme in 25 European countries including Central and Eastern Europe and the Caucasus, UNECE (2011) issued an update of their 2005 North-South Trans-European Motorway (TEM) and Trans-European Rail (TER) master plan. Although 45% of the projects in the original master plan had been completed, the initiative showed that many countries lack the resources to fund the investments suggested. This i9s in particular as the plan did not foresee the world financial and economic crisis. The report concentrates on condition and on capacity bottlenecks and the closure of missing links to strengthen the competitiveness of the transport modes. Other drivers for rail competitiveness are:

- Infrastructures, staff and procedures at borders of the Schengen area;
- Intermodal links between road, rail and shipping networks;
- ITS system applications could significantly enhance capacity and quality of transport networks;
- Fair balance between operational needs and security requirements.

Successful implementation is considered to require political will, national commitment and close cooperation between other relevant parties. Clear policy objectives, strategies, implementation schedules and stringent coordination are of utmost importance here.

For pricing and financing the report postulates that for railways, the long-term goal should be that contributions of railway users cover, at least, all operation costs and, as much as possible, the infrastructure costs with the exception of the share of the costs which are summarized under the terms non-profit and social costs.

As the investment programme focuses on central and south-eastern Europe the individual projects are not relevant for this study. However, the strategic considerations are highly relevant in the context of the two European corridors considered in the LowCarb-RFC study.

UBA 2009: Strategy for Sustainable Freight Transport (Lambrecht et al., 2009). Although compiled according to the standards of an independent research study, the publication "Strategie für einen nachhaltigen Güterverkehr" (Lambrecht et al., 2009) is reported under the heading of policy papers as it was solely conducted by staff of the German Environment Agency (UBA). After a review of potentials for lowering climate, environmental and noise burdens of all means of freight transport the study concludes that mode shift constitutes a core element of sustainable transport, complementing their avoidance and mitigation. Main drivers for mode shift decisions are considered the reliability, time and costs along supply chains. Other quality indicators like flexibility, bundling capacity, frequency of safety follow with reduced importance. Respectively, policy measures recommended include the fair charging of infrastructure use, social enforcement and, most important, network investments in rail infrastructure. These measures could reduce GHG emissions in the German freight sector by 10% between 2008 and 2025. Depending on the degree of containerisation of commodities, 25% to 41% of road goods are expected to be transferrable to rail in 2025.

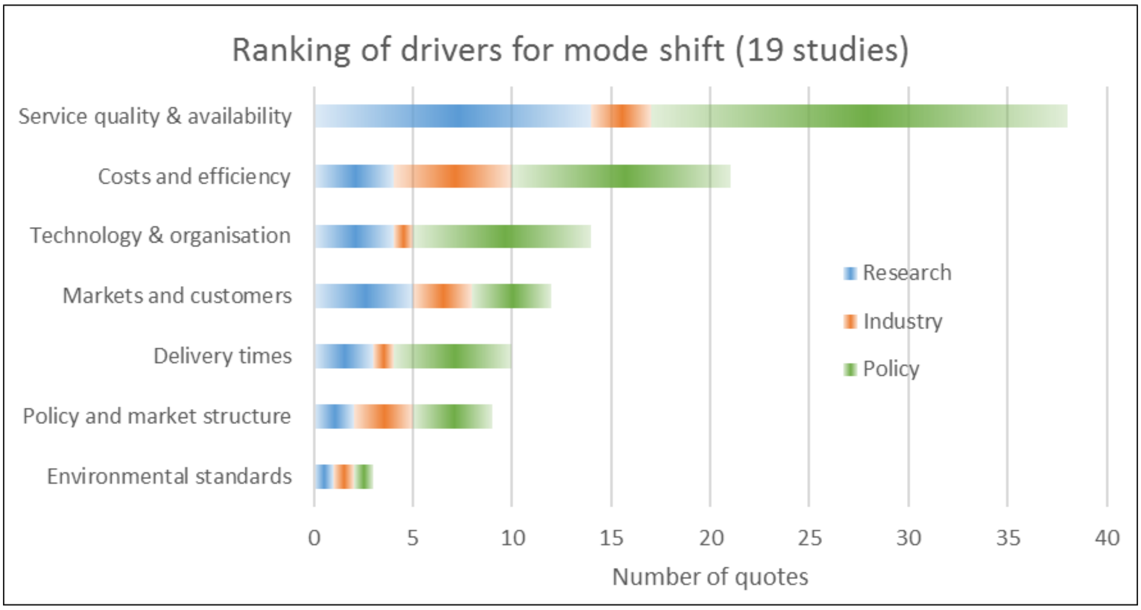
2.4 Bibliometric assessment of mode shift literature

Out of the 19 literature sources cited above we could extract 66 individual statements on drivers and barriers to mode shift to the freight railways. We have grouped these into eight categories. These can be ranked in descending order according to total quotes of the drivers:

1. Service quality & availability, including network and rolling stock availability, capacity and the density of terminals;
2. Costs & efficiency;
3. Technology & organisation within the railway undertakings;
4. Customer & market orientation, including focus product markets, information policy of the railways;
5. Delivery times, including handling times and travel speeds;
6. Policy and market structures and
7. Environmental standards.

The general ranking of drivers is in line with the findings of the Scandinavian-Mediterranean corridor: Quality and availability, followed by costs and then by a set of other factors (Figure 1). However, the results of the bibliometric assessment presented in Figure 2 suggests more weight for quality and availability than was reported by the ScanMed corridor. The direct comparison of the two exercises, however, is difficult as the bibliometric analysis did not weight the drivers mentioned by importance, the categories are different and the allocation of literature statements to categories of drivers is far from unique.

Figure 2: Bibliometric assessment of mode shift drivers by type of study



Source: Fraunhofer ISI

The seven groups of drivers can be classified into primary and secondary drivers. Primary drivers are those characteristics of the railway system, which are visible to freight forwarders and which thus impact their decisions. This is true for costs, for service quality, for delivery times, for customer orientation and partly for environmental standards. Other characteristics like technologies and organisational structures of the railway undertakings or policy and market structures are only indirectly visible to the customer through their impact in costs, speeds and quality. These secondary drivers thus remain an internal issue of the rail freight production system.

The bibliometric analysis interesting for another reason. We have grouped the 19 publications analysed into three classes according to the issuing sector: Research, Industry and Policy. We assigned the label “Research” to all industry and policy publications which appear neutral and apply to general scientific publication standards. “Industry” and “Policy” finally are sector statements, strategies and roadmaps. Figure 2 reveals that all institutional classes have quoted statements in each class of drivers, but there are significant differences in their weight.

- Research reports put particular focus on service quality, followed by costs/efficiency and other drivers. Research reports thus broadly follow the overall trend of quotes.
- Industry studies are remarkable in two areas. First, they put less weight on quality & availability and on delivery times than on cost efficiency issues. Even more remarkable is, that the railway industry seems to see only little merit in the application of new technologies & organisational structures in their sector.
- In contrast, policy studies seem to see much potential not in their own field of action, i.e. the provision of supportive market structures, but in the railway’s business, namely new technologies and service quality.
- Finally, none of the sources analysed puts much hope in environmental standards to foster the use of rail freight over trucking.

From the ranking of the drivers and the statement of relevant sources out of the selection presented above we can derive six key drivers which determine the attractiveness of rail-based services to shippers. Rail based services in this sense explicitly includes combined transport in various forms (road / rail and shipping / rail). Of these six key drivers costs for the user are at the top position of the shippers’ priority lists after we separated the category “quality & availability” into several sub-categories.

For logistics decisions relative differences of drivers between alternative transport chains are more relevant than unimodal considerations. In this paper we focus on what the rail sector and railway policy can do to re-gain or expand markets. Technologies, regulations and other measures affecting road and haulage are subject to other publications in the LowCarb-RFC project.

Table 1: Ranking of drivers for mode shift in freight transport

Rank	Driver	Description	Importance
1	**Costs**	Costs to the forwarding industry basically contain all elements of a supply chain. This is the transport costs itself, access and transhipment costs if done on own account, costs for in-house-logistics and warehousing, as well as time and delay costs. All of these cost components can be broken down in further elements, each of which has its specific drivers. The impact of costs on transport decisions, i.e. choice of transport modes, times, locations and destinations, can be expressed by price elasticities. These elasticities may vary strongly between markets, commodities, locations, and other factors.	Decisive
2	**Speed**	Fast delivery in particular for container goods. More than pure travel speed, the option of late drop-off at terminals, overnight shipment and transport during weekends (24/7) play are decisive for the timeliness perception of forwarders. Travel speeds and transhipment times at terminals get relevant when moving goods along the corridors, but with considerable access traffic from and to first and final destinations.	Relevant
3	**Reliability**	Reliability of services above a critical threshold (punctuality). In freight transport usually 30 minutes late arrival are just considered punctual. Another decisive reliability parameter is the share of cancelled trains. For describing reliability we take both issues into account.	Relevant
4	**Safety**	Protection against losses and damages of shipments. Safety in this context includes security and thus refers to all unplanned events leading to loss or damage of consignments. Delays as consequence of incidents appear under the performance indicator “reliability”.	Supportive
5	**Flexibility**	Short run changes to bookings may be essential in highly interconnected and market-driven production environments. Flexibility in this sense denotes the short-term ability to make or change bookings for rolling stock, train paths and terminal capacity with acceptable extra costs.	Supportive
6	**User tailored services**	In a post-industrial era production and logistics processes get ever less standardised. In this sense the diversification of products offered by the transport industry and its readiness to adapt existing products according to their clients’ needs is a prerequisite for market success.	Supportive

Source: Fraunhofer ISI

Although the focus of the project is on mode shift and technical improvement in the road and rail sector, first assessments by the TRP Logistics Chain Model suggest a high importance of inland navigation along the two corridors selected. In the Business-as-Usual (BAU) scenario developed by this report the future developments o the shipping sector is considered as well.

3 Scenario Method and Common Trends

3.1 Structure of the Scenario Process

Before delving into the discussion and definition of a scenario for future rail freight transport along the two selected corridors a number of dimensions and the scope of the process are set. Table 2 provides a summary of these issues.

Table 2: Dimensions and scope of the scenario process

Category	Ideal Dimensions	Practical treatment
Scenarios	Business-as-Usual (BAU), PRO-RAIL PRO ROAD	• Business-as-Usual (BAU), • Pro Rail
Years	2015, 2030, 2050	• 2015: absolute values • 2030, 2050: changes to 2015
Commodities	NST/R-10 or ASTRA: containerised, dry / liquid bulk, general cargo	• General cargo • Bulk goods (dry and wet) • Containerised goods
Transport modes	Rail only, road only CT road-rail Waterborne	• Rail: Rail only & CT main haul • Road: Road only & CT access • Combined transport transhipment
Cost types	Fixed costs Variable costs Time-dependent costs Distance-dependent costs Costs per consignment	• Fixed time-dependent costs • Fixed distance-dependent costs • Variable distance-dependent costs • Costs per unit sent
Key drivers	Costs; Travel time, reliability, information availability	• Monetary costs • Travel speed • Travel time reliability • (External costs: safety, climate change, air pollution, noise)
Geography	Ideally NUTS-2 OD pairs; minimum level: countries by corridor	• Generalised assumptions mainly based on German experiences as larges market. • Other countries discussed separately if necessary.

Source: Fraunhofer ISI

The scenario process follows the logic of main drivers for mode shift. These are grouped into two categories: (1) generalised costs for providing road, rail and intermodal services, and (2) performance indicators.

- Generalised costs contain monetary costs as well as time and reliability-related costs. We assume that cost changes in the transport sector after taxes and subsidies are passed on along the entire transport chain. For the situation 2015 we analyse current cost structures and use the default values of travel and handling times of the TRP Logistics Chain Model. For future scenarios (BAU and Pro Rail) we then focus on changes in monetary and performance costs, which implicitly include speeds and quality changes to the 2015 case.
- Monetary and performance costs are further broken down by cost categories (infrastructure, rolling stock, energy, personnel, administration) and cost type (fixed time and distance, related, variable distance related and consignment-based). Fixed and variable in this context refer to the variability of costs with train or truck load.
- Performance indicators are of different nature. They can be grouped in indicators which are not visible to the end-user directly, such as load factors, and in those who are visible. The latter category can further be split into performance indicators which impact monetary costs, such as travel time, and indicators which denote additional characteristics to the final customer, such as environmental performance, image, etc. They are discussed to underline the assumptions in the monetary and performance cost indicator.

Following this logic the Paper is organised along the main characteristics (or performance indicators) of the two scenarios (BAU and Pro Rail) in order to avoid jumping back and forth between thematic areas. To ensure transparency of the paper's structure we group the performance indicators required by the TPR logistics chain model as follows:

- Monetary and performance costs and transport efficiency
  - Fixed transport costs (per truck or train-km)
  - Variable transport costs (per truck or train-km)
  - Vehicle (truck or train) utilisation (load factors)
- Shipment speeds (including travel times and transhipment duration)
- Other quality indicators – to be translated into additional costs or times
  - Reliability, delays and congestion: to be translated into travel time add-ons and finally into variable fleet operating cost changes
  - Safety of cargo and rolling stock, information and booking processes, management, etc. to be translated into fixed or variable cost add-ons:

Beneath this two level structure of performance indicators or TPR model inputs the current situation and assumptions for the two scenarios (BAU and Pro Rail) will be spelled out for rail transport, road haulage, IWT and transhipment processes. The final scenario results will be presented in standardised parameter tables for further use in the modelling work.

First, the two cases, Business-as-Usual (BAU) and Pro Rail will be characterised through narratives. This is needed in order to keep the scenario assumptions consistent and not to lose track in the details of cost, efficiency and quality parameters. For the BAU and the Pro Rail scenario we will provide short story lines to frame the development of performance indicators. These are needed as inputs for the impact assessment with the TPR Logistics Chain Model in Working Paper 8 (van Hassel et al., 2018) and are elaborated in the subsequent sections. The scenarios shall be consistent with the development of the Pro Road scenario in LowCarb-RFC Working Paper 6 (Mader and Schade, 2018).

Starting point for the scenario narratives is the situation of the European freight transport market in 2015. This was described in detail for the rail sector in Working Paper 1 of the LowCarb-RFC project (Doll et al., 2017). Main problems of the rail sector can be summarised as follows:

- Market structure: partly national and monopolistic markets protected by less competition-friendly conditions and by specific standards, regulations and technical specifications (train control systems, electricity standards, gauge, etc.)
- Regulation: long and expensive processes for licencing of internationally applicable rolling stock, various safety standards, etc.
- Technology: Slow innovation processes, outdated coupling manual technology, different and partly restrictive train lengths, inconsistent and delayed implementation of the European Train Control System (ETCS), etc.
- Customer orientation: Of national railways mostly habit of public administrations with strong impact of labour unions, putting the management of internal processes over the improvement of customer relationships.

The scenario narratives will depart from these conditions and describe in brief how changes of the rail sector could look like from an outside view. The narratives will not answer the question how the necessary changes will be enforced. Constructing a pathway to realise the scenarios is part of Work Package 4 of the LowCarb-RFC study.

3.2 Scenario quantification method

3.2.1 Generalised cost philosophy

Costs and service quality determine forwarders' decision how to ship goods from origin to destination. Chapter 3 revealed that costs and service quality are the main factors for mode choice. Costs denote monetary expenses for hiring commercial transport services or for doing transport on own account and thus follow an entrepreneurial logic. Service quality, i.e. travel speed, reliability or safety impact the forwarder's production costs and thus are, from an entrepreneurial point of view convertible into monetary values as well. In the following paragraphs we describe how the scenarios deal with the different values.

3.2.2 Monetary costs to forwarders

Cost elements by transport mode

With the term "monetary costs" we describe the financial effort by the transport sectors to provide transport services. This includes running expenses, life cycle investment and rehabilitation costs as well as transfer payments between actors (e.g. railway undertakings to infrastructure or energy suppliers) and to public bodies in form of taxes, charges and fees. We thus follow an entrepreneurial cost model as transfer payments are relevant for the forwarder, but need to be excluded in social accounts.

Prices are then the financial contribution of forwarders to the shipper or transport and logistics undertakings. Of interest are prices (or freight rates) along entire logistics chains rather than for single transport and logistics services (carrying, transhipment, loading/unloading, storing, etc.). The chosen approach of transport chain life-cycle (TCLC) prices explicitly takes account of multi-modal combined road-rail or IWT-rail transport chains.

The modelling of the potential future development of rail based transportation departs from current cost structures. Basic cost elements in land based transport are

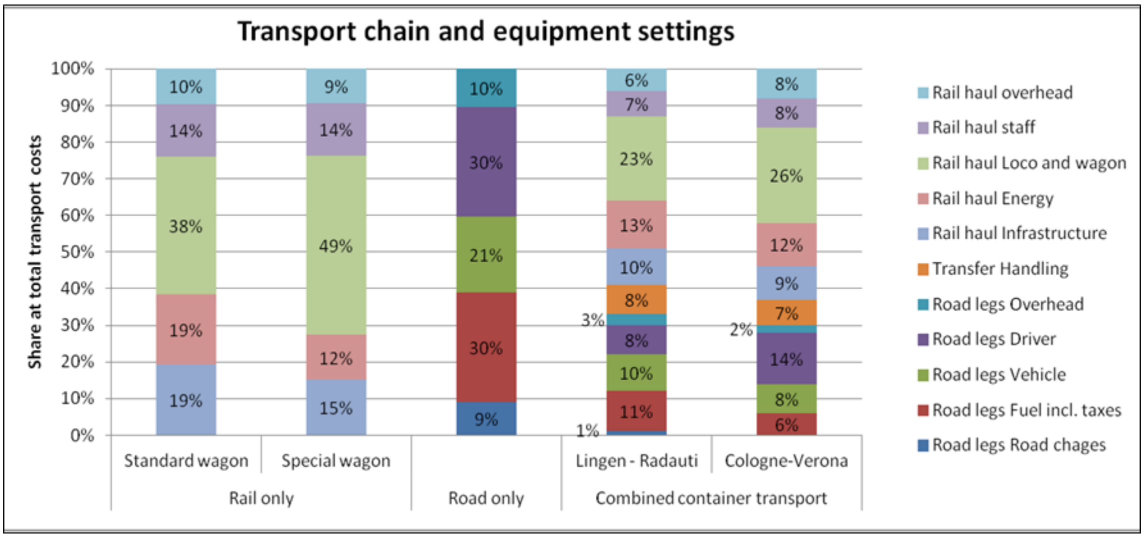
- Infrastructure charges, reflecting the cost of infrastructure provision, maintenance and operation after state subsidies;
- Rolling stock related costs, including depreciation, maintenance and insurance of locomotives, wagons, trucks and other equipment;
- Energy costs for diesel, electricity and other power sources including taxes;

- Personnel costs for drivers and servicing staff;
- Overheads: including administration, book keeping and communication.

We consider cost structures for rail only, road only, inland navigation (barge services) and combined road-rail transport with containers. Rail costs vary significantly by a number of factors like the type of wagon and locomotive. Special wagons, e.g. for transporting cars, may easily account for 25% higher capital and servicing costs compared to standard cars. Additional costs are imposed by ECM certification for maintenance cycles or noise abatement measures. Diesel locos are more flexible but cost approximately 50% more than electric locos. Additional cost drivers are the equipment with ETCS (€400 000 per unit) and the compliance with latest emission standards.

We compiled current cost structures in freight transport form HWH (2015), Bänsch (2014) and Alpine Convention (2016). Out of the cost structures presented in Figure 3 we find that rail services are dominated by rolling stock (loco and wagon), energy and infrastructure costs. In contrast, road haulage is dominated by staff (driver) and fuel costs. For the two combined transport relations looked at in HWH (2015) still the most relevant single cost block is railway rolling stock costs (26%) followed by rail energy and road driver costs. Transhipment costs connecting the road legs to the rail haul account for 7% of combined transport costs.

Figure 3: Average share of cost categories in rail, road and combined road-rail transport in Europe, 2015



Source: Fraunhofer ISI with data from HWH (2015)

Entrepreneurial costs and market prices

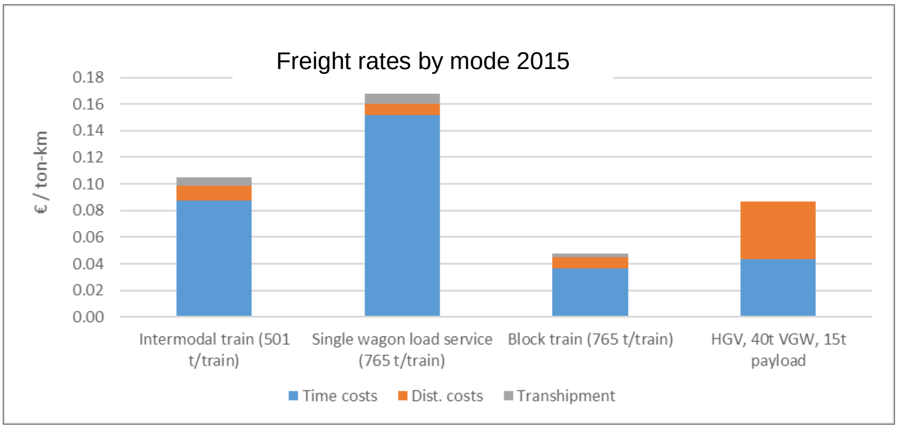
The Flemish freight model (Flemish Traffic Centre, 2017) reports cost structures of rail services by cost type and rail service. Table 3 presents the numbers per train-hour, train-kilometre and loading / unloading process. Figure 4 adds trucking costs from BGL (2017) and transforms the figures to €/ton-kilometre for a 600 km haul with speeds of 51 km/h for container and block trains, 12 km/h for single wagon load services and 60 km/h for HGVs. The data suggests that block trains are absolutely competitive to trucking, while container trains a just about equal and single wagon load cannot compete in terms of costs.

Table 3: Cost structure of rail freight services by the Flemish transport model

Service	Time costs (€/train-hour)	Distance costs (€/train-km)	Transphipment costs (€/train)
Intermodal (501 t/train)	2192	5.49	1950
Single wagon load (765 t/train)	1394	6.57	3491
Block train (765 t/train)	1394	6.57	1098

Source: Flemish Traffic Centre (2017)

Figure 4: Comparison of freight rates by mode and service categories, example for a 600 km relation



Source: Fraunhofer ISI with data from Flemish Traffic Centre (2017) and BGL (2017)

Rail freight tariffs are the price which forwarders have to pay to rail companies to get their order shipped between the locations of delivering the consignment to and receiving it from the rail freight operator. From the railway undertaking's (RU's) point of view tariffs are the price paid by their customer, which may or may not be cost based. As in other industries prices are reflecting market conditions and the negotiating power of suppliers and customers. Huge customers with regular shipments thus will get better conditions than smaller ones with irregular demand. To survive in the long run, tariffs on average need to be cost based. Assuming that, in the following we neglect the existence of bargaining effects.

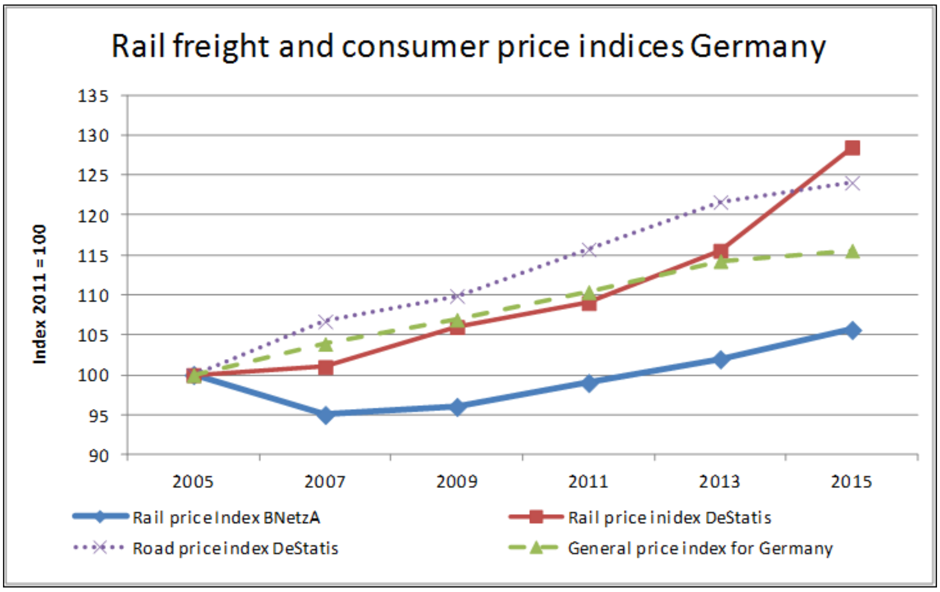
Other impacts on freight rates are various forms of non-market revenues. These may come from the state in form of subsidies or from other branches of a fully or partly integrated railway company. We take these into account as a means of policy to impact costs and prices of transport modes. In the following the components of rail and combined transport costs are analysed as basis for future projections.

Dynamics of monetary costs

ConTraffic (2014) shows that levels and structure of life cycle cost of freight wagon operation strongly depend on kilometres performed and on the share of empty runs. With 25% empty runs costs per loaded wagon-kilometre range between 0.80 €/km at 25000 km/a, and 0.50 €/km at 150000 km/a. In case of completely avoiding empty headings costs would be around 20% to 20% lower, ranging between 0.60 and 0.40 €/km. For comparison: HGV operating costs range between 0.65 and 0.90 €/km.

Driven by the market pressure of private competitors pushing into the market, the better utilisation of train capacity and supportive entrepreneurial and marketing measures the development of prices for rail freight services on busy corridors are well below average costs. Data of the German federal statistical office (DeStatis) on regular freight rates show an increase by 28% from 2005 to 2015. In contrast, the market observation of BNetzA (2017), taking into account changes of product structures, rebates for large clients, etc., reports a very modest price increase of 6% over the past decade with stronger fluctuations in intermediate years. According to Bundesnetzagentur (2016) average standard freight rates of the railways across all companies were 3.44 Ct./tkm in 2015 against 2.66 Ct./tkm in 2011. This corresponds to an annual price increase of 7.4%, which is well above the general inflation rate in Germany. Booming demand between 2005 and 2007 even resulted in a drop of prices actually paid by 5% due to economies of scale (Figure 5). This development demonstrates the fixed costs issue of rail operations: due to the price elasticity of demand freight rates may enter downward or upward spirals of cost and demand.

Figure 5: Freight user and general consumer price indices, Germany, 2005-2015



Source: Fraunhofer ISI with data from www.DeStatis.de

For comparison: the general consumer price index was at +16% in 2015 relative to 2005. In real terms, actual rail freight rates according to BNetzA thus have declined by roughly 9% in this period. For road freight rates only DeStaits data is available. Average growth rates since 2005 are similar to DeStatis rail freight figures, but rail freight rates appear to rise faster than road haulage rates between 2013 and 2015. Comparing the road figures to the BNetzA rail freight rates, however, draws a more positive picture for rail's competitiveness.

3.2.3 The costs of service quality and infrastructure provision

According to the philosophy of generalised costs, changes in performance through improved load rates, speeds and reliability are already incorporated in the estimates of monetary costs. In the subsequent sections we discuss quality and service level changes expected for 2030 and 2050. But these assumptions are not implemented explicitly into the impact assessment framework of the Low-Carb-RFC study on top of the cost changes elaborated in this section.

In order to account for potential rebound effects or cost implications of investment measures, the assessment of the Pro Rail and Pro Road scenarios in subsequent Working Papers 7 and 8 define additional Mod Rail and Mod Road cases where cost improvements of the full scenarios drafted here are cut by half.

3.3 Common Trends to 2050

Some developments around freight transport on the two corridors selected are considered unique across all scenarios. These are described briefly in the following sections.

3.3.1 Freight transport demand projections

For national demand projections we refer to the PRIMES energy models of the European Commission, which is currently updated within the research project REFLEX (Möst, 2017). Table 4 present total demand development in most corridor countries 2015, 2030 and 2050 according to the PRIMES model (E3MLab / AUTH (2014). As PRIMES is strictly considering EU member states, data for Switzerland is not provided. Developments between countries are quite unique: Germany, the Netherlands and Italy show similar total growth rates of freight movements of 34% to 37% from 2015 to 2030, while Belgium and Poland show approximately twice as high growth rates. Generally rail is assumed to grow above the general market trend, which is particularly expressed for Belgium and Poland.

Table 4: Relative change of transport demand by mode and corridor country 2015 - 2030 and 2050 according to PRIMES

Transport modes	**Germany**		**Belgium**		**Netherlands**		**Italy**		**Poland**	
	2015-2030	**2015-2050**	**2015-2030**	**2015-2050**	**2015-2030**	**2015-2050**	**2015-2030**	**2015-2050**	**2015-2030**	**2015-2050**
Road	25%	35%	38%	67%	23%	36%	20%	37%	40%	72%
Rail	21%	43%	65%	130%	29%	53%	24%	43%	51%	81%
IWT	16%	28%	25%	65%	17%	30%	15%	34%	58%	110%
TOTAL	**24%**	**36%**	**39%**	**74%**	**20%**	**34%**	**19%**	**37%**	**42%**	**74%**

Source: Fraunhofer ISI with data from PRIMES

Demand projections for the two corridors selected in this study relate to the PRIMES assumptions in the following way:

- Rhine-Alpine: The 2014 EC corridor study (HaCon et al., 2014) projects 1.7% annual demand growth 2012 to 2030 or a total growth of ton-kilometres 40%. With 24% demand growth 2015-2030 for Germany and the Netherlands the Primes values are about 75% of EU projections. For Belgium, however, Primes and the corridor studies come close. The update of the growth expectations along the RALP corridor in its second work plan (Wojciechowski, 2016) is described by Table 5.

Table 5: Revised growth rates for the Rhine-Alpine Corridor

Mode	Relative growth 2010-2030 without TEN-T interventions	Relative growth 2010-2030 with-out TEN-T interventions
Road	40%	35%
Rail	41%	55%
IWT	39%	41%

Source: Wojciechowski (2016)

- North-Sea Baltic: the 2014 NSB corridor study (Proximare, 2014) provides mode-specific and total rates for 2012-2030. These are: Road 42%, rail 36%, IWT 22%, total: 34, 5%. The projections were not updated in the second NSB work plan (Trautmann, 2016). Corrected for the different time spans covered by the projections, German and Dutch corridor forecasts come close to Primes. For Poland Primes exceeds the NSB forecasts by far.

In total we can way that there is no fundamental difference between Primes and the corridor studies, We thus combine the corridor results for the period 2015 – 2030 with the Primes results further to 2050.

Overall demand remains unchanged between the Baseline Scenario and the Pro Rail scenario. This is, however, a simplification as changing transport conditions will alter transport demand to some extent.

External demand drivers like GDP, income levels, employment, world economic structures, etc. are implicitly reflected in the demand levels and thus are not discussed specifically. However, we take a closer look at the impact of the changes to come with an increasing digitalisation of industrial processes.

3.3.2 Digitalisation in the production sector

The concept of Digital Industries is believed to entirely reshape the means of industrial production. It is likely to have an impact on several areas in conjunction with manufacturing. Arising trends include amongst others the real gross value added generated by companies through new product lines, the overall effectiveness and degree of automation of production sites, the professional profile of production workers and the cooperation between employees and robots as well as the design of supply chains. Furthermore, the possibility of relocating production facilities from low wage countries back to Europe gets more likely in cases where human labour is replaced by highly automated machinery.

In order to approach potential emerging trends in the field of automating and digitalizing production, and the impacts on freight demand, a series of interviews with representatives from the automotive industry and the mechanical engineering industry were conducted during 2017. They confirmed the likeliness of relocations taking place to some degree because of the potential savings through digital industry technologies and processes. This would mean less maritime transport to Europe, and thus reduced port hinterland traffic. On the other hand, continental goods flows could increase.

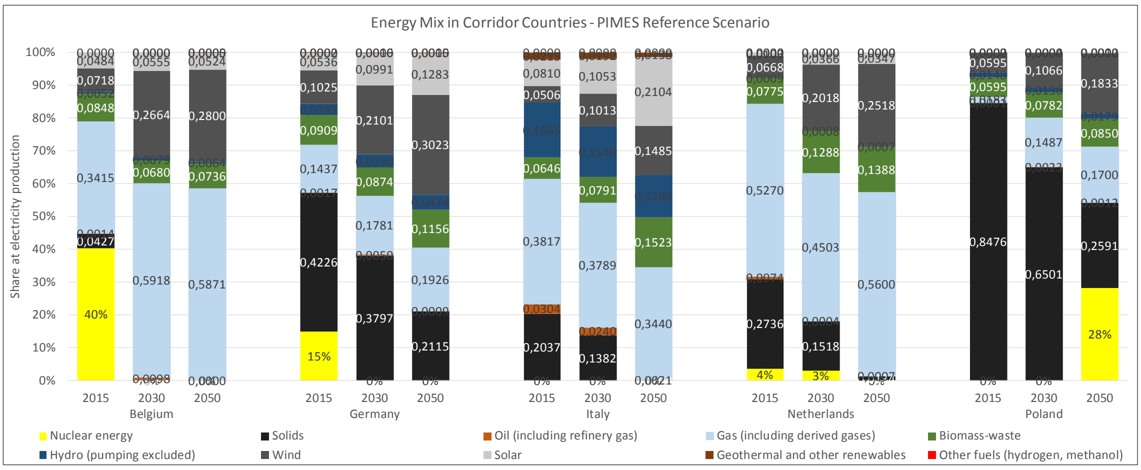
From questionnaire-based scenario evaluations the impact of those technologies on the commodity flows within the European Union, the Rhine-Alpine Corridor and the North-Sea Baltic Corridor were determined. It was found that the digital industry technologies are in fact likely to have an influence on the freight volumes of the processing industry. However, the scenario analysis revealed that the actual impact on the commodity flows within the investigated traffic zones is rather small with only between 0.51 and 0.56 percent additional growth of the total freight volume.

We can conclude that digital Industry trends do have a significant impact on the production itself and its environment. The influence on the commodity flows within the European Union, the Rhine-Alpine Corridor and the North-Sea Baltic Corridor is, however, not substantial and not likely to cause major consequences for overall traffic. Accordingly, we leave the demand projections from the EC corridor studies and from the Primes model unchanged for this study.

3.3.3 Electricity generation

The LowCarb-RFC scenarios concentrate on what happens specifically in the transport sector. Thus, despite its importance for transport’s sustainability performance, we leave policies on the energy market, namely on electricity production, constant for all scenarios. We select the most ambitious GHG reduction pathways in power generation as we want to explore which impact mode shift policies and road electrification have on top of transitions in the energy sector. Currently the share of renewable and nuclear energy in the corridor countries range between 62% in Belgium, 40% in Germany, 35% in Italy, 18% in the Netherlands and 7% in Poland.

Figure 6: Energy Mix for electricity production in corridor countries except Switzerland 2015 to 2050



Source: Fraunhofer ISI with data from PRIMES and IEA

Following Deutsch Bahn's integrated business and sustainability report 2016 the company uses 42% renewable energies already in 2015. According to the European Commission's Low Carbon Roadmap of 2011 all economic sectors in the EU are to reduce GHG emissions by 2050 compared to 1990 levels by around 80% (IEA, 2014). While the power sector shall contribute 95% reduction, transport is allowed a reduction of only 60%. This is excluding electric traction energy and is thus to be achieved by energy efficiency and clean combustion fuels. The figures in Table 6 indicate the large potential benefits of the transport sector from electrification strategies.

Table 6: GHG reduction potentials by sector

GHG reductions compared to 1990	2005	2030	2050
All sectors (territorial principle)	-7%	-40 to -44%	-79% to -82%
Power generation (excl. imports)	-7%	-54% top -68%	-93% to -99%
Transport (incl. aviation, excl. maritime)	+30%	+20% to -9%	-54% to -67%

Source: IEA (2014)

The Climate Protection Scenario for a 95% reduction of GHG emissions across all sectors by 2050 (Klimaschutzszenario KS95) issued by the German Environment Agency (Öko-Institut and Fraunhofer ISI, 2015) arrive at similar cuts. Although 95% of total GHG emissions are reduced, oil will still remain the major contributor in 2050. For the power sector we apply the KS95 to electrified rail and road transport. Other decarbonisation and efficiency strategies are discussed in the Pro Rail and Pro Road scenarios specifically.

3.3.4 Railway electrification

Across Europe the electrification of rail networks has risen from around 30% in 1975 to 60% of lines in 2008. Since then the development came to a halt, which may be due to the economic crisis and the respective decline in rail markets. The major European freight corridors are 100% electrified along the entire Rhine-Alpine corridor (RALP) and the Benelux-part of the North-Sea-Baltic (NSB) corridor section to Poland considered in this study. The eastern part of the NSB route is electrified by 97% in Germany and 91% in Poland. (Wojciechowski 2016 and Trautmann 2016). Already by 2030 can assume the TEN-T requirements of 100% electrification on all corridor lines and on their main access routes are fully met.

For climate and environmental performance, however, the share of tons carried by electric trains is relevant. Electric locos are cheaper in operation than diesel traction, but under some circumstances using diesel locos under overhead wires is preferable over changing locomotives between electrified and non-electrified network parts. We thus assume electrified train kilometres being lower than the share of electrified track. But through further line electrification and battery-hybrid engines they are assumed to increase to 100% in RALP by 2030 and on NSB by 2050.

Table 7: Assumed shares of electrified train-km by corridor 2015 to 2050

Corridor	2015	2030	2050
RALP, all countries	90%	100%	100%
NSB, Benelux countries	90%	100%	100%
NSB, Germany	90%	95%	100%
NSB, Poland	80%	90%	100%

Source: Fraunhofer ISI

With the last two sections the greenhouse gas emissions for electrified rail are set and remain constant for all 2030 and 2050 scenarios. What remains subject to the individual scenarios in the field of energy consumption is the energy efficiency in all modes, the use of clean and climate-neutral combustion fuels for diesel locos, trucks and barges, and the degree of electrification of road transport.

4 Scenario Narratives

4.1 The Business-as-Usual case

The following sub-sections draft the broad lines and ideas of a freight transport scenario for European corridors, which more or less follows current policy and business plans and thus retains current transport systems until the mid-21st century. In the BAU scenario we do not consider major technological or organisational innovations disrupting long-distance freight transport – although some potentially disruptive trends already be identified: automation, platform based demand and supply management and the electrification of road transport.

The BAU scenario describes a state where European and national freight transport policy more or less remains as it was in 2015. Planned infrastructure projects like the Iron Rhine will be completed and all modes will remain just sufficient capacity to hold their modal share of 2015 through small to medium sized capacity investments. Efficiency improvements develop more continuously and somewhat faster in rail transport through moderate reform processes in the railway undertakings than in road haulage. Thus, already in the BAU scenario towards 2050 rail freight can make up some of the competitive disadvantages experienced in the past.

4.1.1 Transport policy environment

In the BAU scenario policy settings will more or less remain as they are observed in 2015. Of course we will see some policy actions enforced by the EC bearing fruits. The railway markets within the member states will be formally liberalised, reducing the role of the state owned rail freight operators to a non-dominant market participant. The two biggest issues slowing down international rail traffic, incompatible technical and organisational standards as well as more or less uncoordinated planning procedures between member states will however remain. Some level of Euro-scepticism among European countries keep incompatible funding, pricing and planning rules in place and will thus slow the process of market opening and technical standardisation.

In road and inland waterway transport we do not expect major political changes towards 2050. Road charges along the corridors and truck size and weight limits will be relaxed only moderately (see below). Cabotage will be completely free but social dumping will be combatted more efficiently in all corridor countries.

4.1.2 Pricing & regulation regimes

Rail access charges are more or less equal along the corridor countries today. However, with its master plan rail freight the German government has announced a 50% cut in freight access charges from 2019 on. In the BAU scenario we will not consider these as we start from the policy situation and plans of 2015. However, we will see some effect on rail user charges from increasing volumes over mainly fixed network costs.

A cautious relaxation of regulatory frameworks across corridor countries and in European law will remove some additional cost pressure from rail and intermodal transport. Elements addressed already in the BAU case include more standardised rolling stock licencing, international customs procedures, train drivers' permissions and vehicle specifications or relaxed social rules for a more flexible use of drivers and other personnel. However, changes will be slow and more or less uncoordinated in single corridor countries.

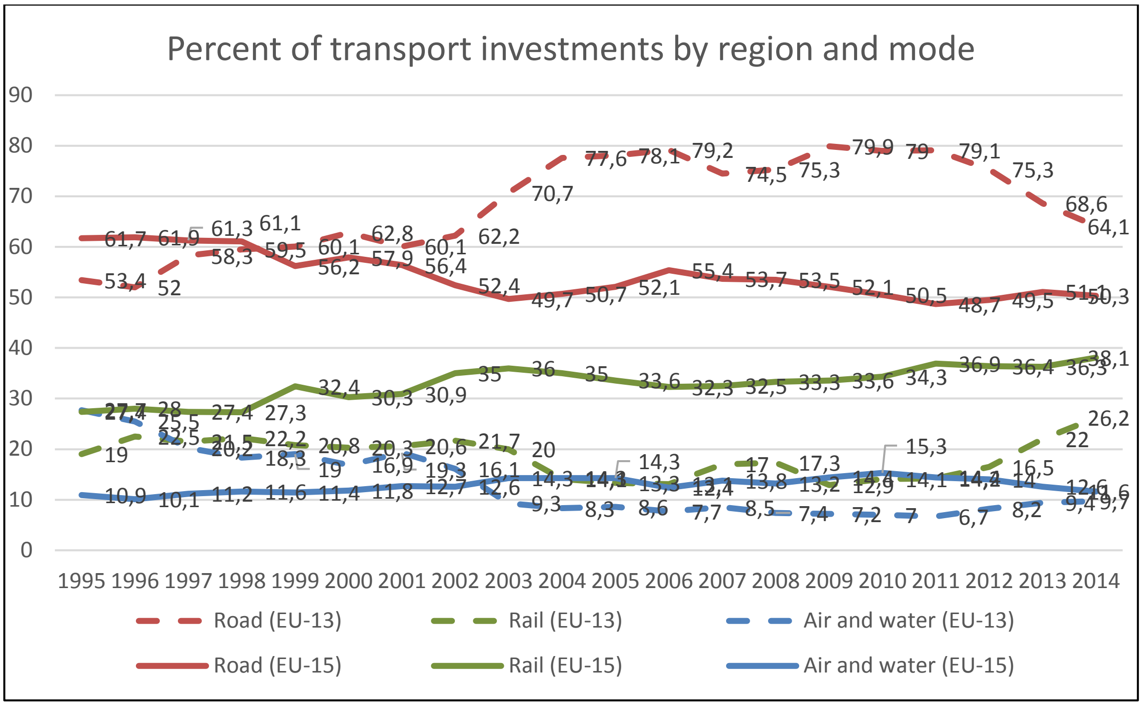
Road user charges are expected to remain as they are today. We do not consider tariff increases by adding additional cost categories, but we consider that through more intensive network rehabilitation measures a decline of tariffs through more traffic is limited. In the BAU case we also do not see major changes to labour or social legislation.

4.1.3 Infrastructure investments

According to data of the European Environment Agency (EEA) total transport infrastructure investments in 33 EEA member countries have declined from 0.98% of GDP in 1995 to 0.79% of GDP in 2013. Government spending exceeded 1% of GDP only during the years of the major EU enlargement 2002 – 2005 and the post world financial and economic crisis period with the economic stimulus programmes 2008 / 2009.

In Western Europe (EU 15 countries) there is a continuous trend towards reduction of budgets for road infrastructure and investments in rail. The share of rail expenditures rose from 27% of transport infrastructure investments in 1995 to 38% in 2014 (see Figure 7). In the decade 2002 to 2012 the new EU member states (EU13) saw a clear peak in road investments going up to 80% of investment budgets. Luckily this trend has reversed, bringing road investment shares down to 64% in 2014.

Figure 7: Mode share at transport investments 1995 to 2014



Source: reproduced according to EEA (2017)

For the Business-as-Usual scenario we assume total transport investments to remain around 0.8% of GDP. In the corridor countries we expect 2014 conditions to remain with 50% of investment money going to road, 38% to rail and the remaining 12% to shipping and aviation. For the two corridors this means that all key performance indicators, e.g. full electrification, 100% of sections allowing for 740 metre or longer trains, full ETCS level 2 equipment, etc. until 2050. The speed of complying with these, however, will be slower for the NSB corridor than along RALP. Capacity will be extended such that, together with ECTS deployment, projected rail demand will be met and quality indicators like reliability, availability and safety will remain at 2015 levels.

4.1.4 Rolling stock

The railways will see some degree of modernisation of loco and wagon fleets. In particular diesel locomotives will be replaced by electric or fuel cell electric hybrid locomotives towards 2050. The number of multi system locomotives will exceed demand for international traction and all wagons will be low noise. Major parts of the wagon fleet will be equipped with power and connected to the internet to allow tracking and special treatment of the cargo (cooling, monitoring, etc.).

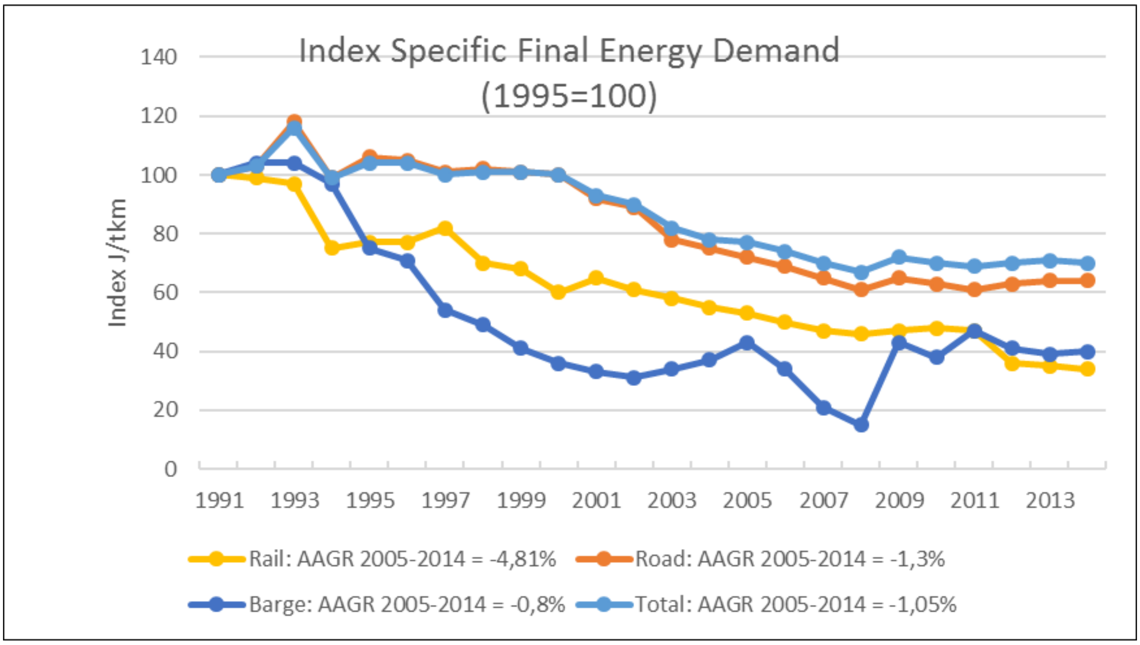
Trucks will be highly automated, but still require human drivers. Consequently, accidents are reduced and road capacity is used more efficiently. New motors and fuels reduce fuel costs and CO2 emissions by 50% on average.

4.1.5 Energy efficiency

According to EU Transport in Figures (EC, 2017b) within the EU28 the railways account for 2% of final energy consumption in 2015. Between 1995 and 2013 the energy consumption of the passenger and freight railways in the EU28 countries has dropped from approximately 270 to 225 Peta-Joule (UIC/IEA 2016). In the same period total freight demand increased by 4.7% and passenger demand rose by 21.8%.

Data from Germany suggests that since the early 1990s all land transport modes have improved their energy efficiency. While in 2014 road haulage seems to have reached a plateau at 64% of 1991 values efficiency, rail and barge transport have dropped to 34% and 40% respectively and are still on a slightly declining pathway (Figure 8).

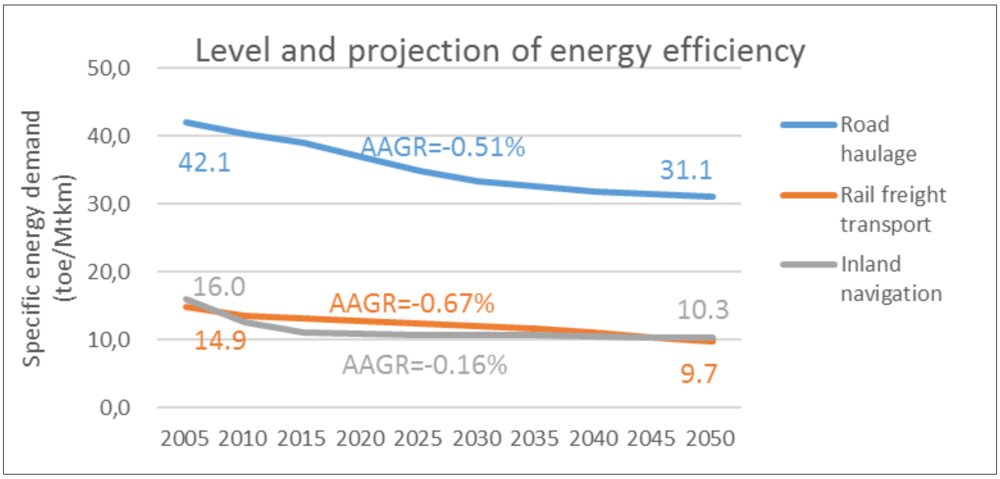
Figure 8: Energy efficiency index for land freight transport in Germany 1991 to 2014



Source: Fraunhofer ISI with data from BMVI (2017)

Across the corridor countries the PRIMES model estimates the average primary energy consumption (in tons of oil equivalent toe per ton kilometre transported) in road transport at 250% vs. the specific energy consumption in rail and inland waterway transport. In addition, the PRIMES reference scenario shows that rail energy demand declines faster than road or inland shipping with an average annual growth rate of -0.67% (Figure 9).

Figure 9: Specific energy consumption by mode 2005 - 2050



Source: E3MLab and AUTH (2014)

In all LowCarb-RFC scenarios we consider these improvement rates for the total effect from engine efficiency, aerodynamics and driver assistance systems. In the individual scenarios Pro Road and Pro Rail we add impacts from changing load rates and automation.

4.2 The Pro Rail narrative

Pro Rail constitutes an extreme vision for European freight transport markets along the major corridors. External pressure through markets and policy, railways will exploit all forms of measures to improve efficiency and to gain market shares. This includes consequent digitalization, automation, cooperative business models and proactive customer relations. As markets grow and the role of ICT becomes even stronger, new players will continue to enter the railway business. These might be global technology or retail companies, or investors from finance or production sectors. Railway infrastructures may or may not be transferred from national to European responsibility, but in any case we will see a trans-national train control facility similar to Eurocontrol with its national subsidiaries in airspace management.

The scenario process follows the logic of "generalised costs", according to which improvements in service quality, reliability or travel speeds are interpreted as economic costs experienced by the customers of freight railways, hauliers or inland navigation undertakings. We chose this external perspective as the approach of the LowCarb-RFC study is to check how much mode shift policies can contribute to climate mitigation in long-distance freight transport.

4.2.1 Policy environment

Rail: Euro-scepticism will most likely continue to exist, but pressure from the production industry for more competitive and reliable transport alternatives will force national governments to cooperate. European countries will give up protectionism and finally support full market opening and – more important – a Europe-wide coordination of rail infrastructure access, train path booking and network management. Moreover, planning of infrastructure investment and maintenance activities across national borders is improved.

Road: Trials with a general relaxation of truck weight and size limits on a European level, i.e. in cross-border traffic, have been stopped to avoid the decline of with rail and shipping. The same holds for the electrification of motorways with overhead wires for HGVs. Accordingly, the cost and loading efficiency gains in road haulage to be expected by 2050 are limited.

4.2.2 Market Structure

Under the Pro Rail regime we assume massive support programmes for niche markets, new players and alternative technologies in the rail sector. Test fields will allow progressive transhipment, loading/unloading, waggon coupling or train formation technologies to demonstrate their efficiency potentials and scalability. By 2050, some alternative approaches in several rail technology areas will survive, bringing down rail operation costs considerably.

Digitalisation, automation and customer orientation will be integral parts of national and European investment plans stocked with dedicated funds for their implementation and enforcement. These changes mean that the focus of transport investment planning turns from a predict-and-provide nature towards a design oriented approach.

Open market regimes will allow new players in the fields of rail equipment provision or rail transport services to grow. The role of national incumbents will further decline in market power. On the other hand, European alliances of freight railways will develop and form different structures, which are able to react to changing market demands more flexibly.

4.2.3 Pricing & Regulation

By 2050 we assume all transport infrastructures to be treated through a single pricing structure. Prices are based on social costs, i.e. the preference of citizens for a particular state of the environment they live in. This has implications for both modes:

Rail: Track access charges are set to marginal costs for operation and maintenance on all relevant freight networks. This means a reduction against 2015 of 75% and against BAU of 50%.

Road: For road transport we assume a levy of full marginal social costs. Besides infrastructure wear and tear these include safety, noise, environmental / climate and congestion elements. Given the limited extension of the road network under the Pro Rail regime, congestion costs are expected to rise considerably from 2015 levels.

4.2.4 Infrastructure investments

To cater for the additional demand for rail expected in the Pro Rail scenario we assume annual investment in rail projects and network rehabilitation (passenger and freight) going up by 50% between now and 2050. This implies that total transport expenditures go up from 0.8% to 0.95% of GDP of road, IWT investments remain unchanged. The rail share of investments rises from 38% to 48% while road declines from 50% to 42%. In this case rail dominates the investment activities of EU and member states in transport networks.

Most rail investments go into extra capacity, the development and full roll-out ETCS level 3 and the network preparation for longer and heavier trains with a common loading gauge along all corridors and relevant access routes.

Besides the direct financing aspects we assume that in the Pro Rail scenario investment activities are well coordinated between individual countries and European institutions. Moreover we assume that by more stringent planning procedures and more efficient stakeholder and citizen involvement processes from the start of planning activities on, the time span from project description to implementation declines from around 25 years to between 10 and 15 years.

4.2.5 Rolling stock technology

All freight trains can operate completely autonomously. Locos and wagons are connected to the internet for full control of functionality, cargo conditions, remote positioning, etc. Wagons are equipped with automated coupling and transhipment terminals can handle the transfer of containers from truck to train and vice versa 24/7 without large crews. Maintenance and servicing of locos and wagons (as well as infrastructures) reduces down times and costs.

4.2.6 Energy efficiency

Diesel as a locomotive fuel is phased out by 2050. Large parts of the network, including access lines to the major corridors with medium relevance, are electrified. All non-electrified routes or sections are served by hybrid locomotives operating with pantograph plus battery or fuel cell propulsion.

By 2050 the rail power mix is 100% renewables, mainly wind and solar. Solar power, excess wind energy during off-peak phases plus waste energy from industrial processes are utilised for generating hydrogen for fuel cell engines. Power storages on board of locos and in the grid further support a smooth integration of renewable railway energies into the national power mix of the corridor countries. Additional imports of renewable fuels finally help stabilising power supply. In consequence, rail operates with a 93% to 99% greenhouse gas (GHG) reduction from current levels (Table 6).

Road haulage operates under BAU assumptions. This is an improvement on truck efficiency and there are some large scale tests of alternative propulsion technologies like electrified highways, but still trucks mainly run on hydrocarbon fuels by 2050. These may, however, partly be generated synthetically. But as assumed for the BAU scenario we do not assume a major decline in energy or carbon intensity with these test field technologies.

5 Generalised Costs by Scenario

In this section we draft scenarios of generalised cost changes for rail, road and inland waterway transport for the years 2030 and 2050 in the Business-as-Usual (BAU) and Pro Rail scenarios, the additional Pro Road scenario will be elaborated in the respective Working Paper 6 of the LowCarb-RFC study. The concept of generalised costs implies that changes in travel speeds or reliabilities are converted into perceived costs by the forwarder. Nevertheless we elaborate on these non-monetary factors in the subsequent chapter.

The logic of presenting the generalised costs in this chapter is as follows:

- Cost Categories: these move along the main cost elements presented in Figure 3.
- Transport modes: here we focus on rail and road. For completeness we briefly touch inland waterway transport (IWT) issues.
- Scenarios and years. To maintain readability of the text we discuss relevant changes in BAU 2030/2050 and Pro Rail 2030/2050 each in a common section.
- Cost structures. Following the logic of the TPR chain model for transport impact assessment (compare Working Paper 7) we distinguish between
  - Fixed costs per shipment, e.g. for loading and unloading;
  - Variable time related costs, e.g. asset depreciation or administration;
  - Variable distance related costs, e.g. infrastructure fees, energy, etc.

5.1 Infrastructure costs

Infrastructure costs denote the charges which transport companies need to pay for the use of rail tracks, roads and transhipment terminals.

We subsume infrastructure costs under the category “distance-related variable costs” as they do commonly not vary with the number of wagons in a train or the actual loading of trucks. In both cases there are exceptions with the weight component of some rail access charges or the load-dependent Swiss heavy vehicle fee. Terminals also will charge per TEU and thus are closer to variable costs at least in the rail sector.

5.1.1 Rail transport

Present 2015. Rail infrastructure costs account for 15% to 20% of rail shipment costs in (western) Europe today. For Germany 76% of these are infrastructure access charges, where the remaining 24% are related to terminals, stations and other services provided by the infrastructure manager (compare Table 8 with red values indicate extrapolated values).

Table 8: Cost structures in German rail freight transport 2011 to 2015

Cost / price indicator	2011	2013	2015	2017
Track access charges (€/train-km)	2,73	2,88	3,03	3,17
Share track access at infrastructure fees	76%	76%	76%	76%
Share infrastructure charges at tariffs	19%	18%	17%	17%
Resulting total costs (€/train-km)	18,9	21,1	23,5	24,5
Index of resulting total costs	100,0	111,4	124,0	129,8

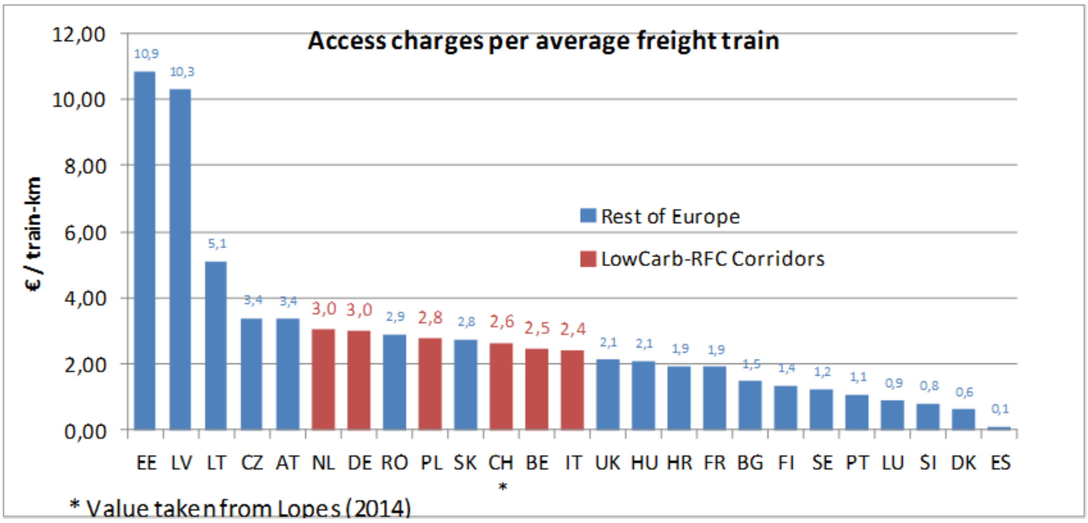
Source: Data from Bundesnetzagentur 2016 and previous editions

Track access charges for freight traffic vary widely across Europe. Based on infrastructure undertaking's network statements, Lope (2014) has assembled access charges across several train characteristics (length, weight, number of axles, speed, time of day, class of infrastructures, etc.). The paper concludes that the different charge structures between European countries make planning of train paths challenging and thus constitutes a major barrier to more international rail freight traffic.

Along the LowCarb-RFC corridors track access charge levels are quite similar, ranging between 2.43 €/train-km in Italy and 3.03 €/train-km in the Netherlands. Figure 10 presents average charge levels with the corridor countries highlighted based on data from the European Commission's Rail Market Study (EC, 2016). Charging structures are, however, different as some countries consider train-km only, while others take train and gross ton kilometres (tkm) into account. This is:

- Per train-km only: the Netherlands (NL), Belgium (BE), Italy (IT) and Poland (PL);
- Per train and ton-kilometre: Germany (DE) and Switzerland (CH).

Figure 10: National track access charges for average freight trains



Source: Fraunhofer ISI with data from EC (2016) and Lopes (2014)

BAU 2030/20506: In 2015 we start from an average pricing level of 3.00 €/train-km for conventional and CT trains in the corridor countries. For the Scenarios towards 2050 we assume the following changes:

- Policy interventions: Although in 2017 the German government has announced the deduction of rail freight access charges by 50% in their rail freight master plan (…) we assume remain with policy plans which were on the table in 2015 only in the BAU scenario. This we keep public subsidy policies unchanged all through the BAU scenario.
- Economies of scale. Towards to 2050 we expect rail access charges to decline anyway due to density effects through additional demand. This is expected to be -10% in 2030 and -20% in 2050.

Pro Rail 2030/2050: We consider two impact factors on rail freight track access charges towards 2050: political interventions in form of subsidies and investment aids, and scale effects through more traffic on a network which is characterised by approximately 80% of fixed costs.

- Policy interventions. By 2030 we assume the German plan of reducing access charges for rail freight by 50% to have been implemented and to have been taken over by all other countries along the corridors considered in this study. By 2050 we go a step further and assume a further subsidisation of rail infrastructure costs towards marginal social cost prices as in the Scandinavian countries along the RALP and NSB rail freight corridors. This would be charges of 50% in 2030 and 35% by 2050 compared to 2015 through subsidies alone.
- Economies of scale. Fast development and consequent implementation of ECTS Level 3, overhaul tracks, level-free crossings at core rail network nodes

and the automation of processes will allow to cater 40% more traffic (Schäfer et al., 2011) along main freight lines. Predictive maintenance is expected to add another 10% of cost reduction. Applying both potential up on the 50% cost reduction of the BAU scenario in 2050 would result on 68% lower infrastructure costs compared to 2015 levels. Given the large investments needed we remain with the 40% reduction of costs in 2030. We can thus reduce charges by further 10% in 2030 and 30% in 2050.

In total we receive cost levels of 45% in 2030 and 25% in 2050 relative to present (2015) track access charges.

5.1.2 Road haulage

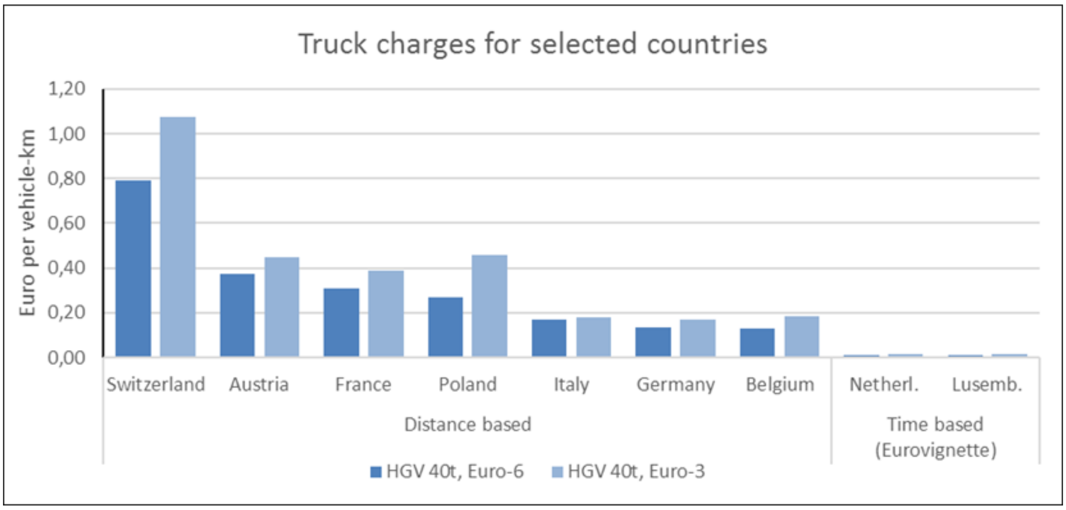
Present 2015: HGV charges for road use only account for 9% of trucking costs, and thus are less than track access charges for rail freight transport. Current road charging systems for trucks in Europe are quite different in terms of objectives, charging technologies and in terms of tariff structures (compare ISI and UPM, 2017):

- Technologies range from simple toll booth installations to sophisticated satellite based charging systems.
- Tariff structures start from area wide, time-based tariffs (vignette) via simple distance related charges to highly differentiated tariff regimes.

Switzerland, which has not been included in the exhibit, operates the most sophisticated road charging system in Europe since 2001. In the Swiss heavy vehicle fee, trucks are charged according to their distance travelled, actual weight and their environmental standards, with tariffs greatly exceeding HGV tariffs in the EU Member States. The revenue of the Swiss road charge is to a large extent, used to co-fund the Alpine railway base tunnels through the Lötschberg and the Gotthard (compare T&E, 2016).

Figure 11 provides an impression of the levels and differentiation of HGV motorway tariffs in the corridor countries and in neighbouring areas. Distance based charges are magnitudes higher than the vignette tariffs related to the 120,000 annual kilometres driven by trucks. Where possible the distance based systems have been differentiate by exhaust emission standards Euro-5 versus Euro-3.

Figure 11: Tariff structures for HGVs on motorways in selected countries



Source: T&E (2016)

- **BAU 2030 / 2050**: Lorry charges on motorways distinguish between general truck use and the use of trucks for combined transport. In 2050, however, the differences are minor as they are applied by a few countries only, namely Switzerland. For Simplification we assume a 10% reduction in road user charges across Europe, leading to an average charge of 0.20 €/HGV-km for general cargo and 0.18 €/HGV-km for combined transport.

  Scale effects of growing traffic volumes drive charges down. This will be compensated by the fight against rapidly deteriorating road networks in many European countries and by additional externality charges towards 2050. Accordingly we expect average charge levels to remain at the level of 2015 by 2030 and 2050. This holds for all types of cargo trucked.

- *Pro Rail*: According to the examples of Switzerland concerning cross financing and of Austria concerning the installation of a closed funding system for road transport we assume road charges to rise considerably. This also because in the Pro Rail scenario road traffic levels stagnate or even decline, while the network has to be maintained more or less in its current form. For 2050 for general cargo we assume tariff levels between the Austrian and the Swiss case, which is 0.60 €/HGV-km to be reached gradually over 2030.

  For trucking in combined transport we assume the same deduction of charges to be applied as for rail access charges, i.e. 50%. This results in road user charges for trucking in CT of 0.30 €/HGV-km in 2050.

Specific issue trucking for combined transport: Some countries (e.g. Switzerland) allow a rebate on road user charges for trucks used in combined transport. These reductions partly compensate for the handling costs at intermodal terminals. According to Figure 3 cargo handling costs at terminals range in the order of 8% of combined transport costs. This, however, strongly depends on the route length and the number of transhipments. Across the RALP corridor looked at in this study we assume a 10% deduction of HGV road toll costs for access to and from CT terminals. This does not hold for the NSB corridor.

5.1.3 Intermodal transhipment

Bieler and Sutter (2016) report investment costs for conventional CT terminals of 35.5 million euros. Of these, investment costs for a typical transhipment crane range around 5 mill. euros. With an expected investment horizon of 20 years, a 3,5% interest rate and an average annual turnover of 50 000 consignments we receive capital costs of 49.96€ per unit. These are, however, not fully price relevant as in different countries terminals are subsidised by either investment aids (Germany), operational support (Austria) or rail / CT mode share quotas (Switzerland). If we consider the 80% investment grant in Germany the residual average user contribution to terminal investment costs is 10€/consignment.

Handling costs of consignments in transhipment facilities consist of craning, movement, storage and other services, as well as the extra costs of trucking compared to a road-only shipment. Variable operating costs for personnel, maintenance, shunting, energy and equipment) of 31.65 € per transhipment (Bieler and Sutter, 2016). Together with average infrastructure costs this amounts to 42.65 €/unit or to approximately 40.00 €/TEU. The corridor analyses in hwh (2015) confirm this value by suggesting handling costs between 30 € and 50 € per transhipment. In seaport facilities, where transhipment is closely connected to wider logistics services, transhipment costs can even range around 185 €/TEU/.

Handling services at transhipment terminals are commonly charged by the volume of loading units processed and thus need to be considered as variable costs in the logic of the TPR freight chain model.

- **BAU 2030 / 2050**: Container terminals are already now highly subsidised. This may either be by public investment aids as in Germany, by subsidising the entire rail leg of freight movements including transhipment as in Austria or by active mode share policies like in Switzerland. We assume these policies to be carried on in the business-as-usual case, i.e. no change against the present situation in 2015.
- **Pro Rail 2030 / 2050**: in the rail scenario we assume the provision, maintenance and operation of transhipment facilities to be subsidised 100% by public money. This is to support the sustainable rail leg of freight movements and in the same time to keep freight systems as flexible as possible.

Issues by commodity: Intermodal transport distinguishes between three types of products, which had the following shares in European cross-border combine transport in 2016 at the number of consignments: containers and swap bodies 74%, craneable semi-trailers 20%, rolling motorway 6% (UIRR, 2017). Heavier containers or non-container loading units like swap bodies are more costly than pure container transhipment. We assume handling prices of 50€/TEU for general cargo in swap bodies and 60 €/TEU for bulk goods.

5.1.4 Summary of infrastructure cost assumptions

The figures for present (2015) costs in absolute values and BAU and Pro Rail (2030 and 2050) cost developments in relative terms for the group of infrastructure related costs are summarised in Table 9. Infrastructure costs are completely fixed to changing load rates except for the Swiss heavy vehicle fee and some rail access charging regimes. For simplification reasons we ignore the weight component of infrastructure costs. There is also no direct link to travel times or speeds.

Load factors: through higher vehicle load space utilisation or though less empty runs, a better utilisation of train capacities within given maximum train lengths or through longer trains. A further reduction of specific infrastructure charges of 25% to 50% per ton kilometre could be possible.

Table 9: Infrastructure costs by scenario and commodity 2015 to 2050

Mode and commodity	Present	**BAU** relative to 2015		**Pro Rail** rel. to 2015	
	2015	2030	2050	2030	2050
Rail only and CT rail leg – var.-dist. costs, 2015 in € / train-km					
General Cargo	3,0	90%	80%	40%	25%
Bulk goods	4.0	90%	80%	40%	25%
CT	3,0	90%	80%	40%	25%
Road only & CT road leg – var.-dist. costs, 2015 in €/HGV-km					
General Cargo	0,20	100%	100%	150%	300%
Bulk	0,20	100%	100%	150%	300%
CT (RALP)	0,18	100%	100%	125%	150%
Combined transport transhipment – fixed costs, 2015 in €/TEU					
General Cargo	50	100%	100%	0%	0%
Bulk goods	60	100%	100%	0%	0%
Containerised goods	40	100%	100%	0%	0%

Source: Fraunhofer ISI

5.2 Rolling stock costs

Rolling stock consists of locomotives and wagons in rail transport and of trucks and trailers in road haulage. They are driven by investment and maintenance costs for the vehicle, which can be considered more or less fixed with annual vehicle kilometres. In rail transport, however, a variable component of rolling stock costs is added by the costs for owning or leasing wagons. Thus, at least for rail, rolling stock variable costs are split into a distance and a time-variable component.

5.2.1 Rail traction and wagons

Present 2015: According to Figure 3 the costs for locomotive and wagons accounts for 38% of rail freight costs against 19% infrastructure costs when operating with standard wagons. This corresponds to average rolling stock costs of 6.00 €/train-km. These two cost elements show different characteristics concerning cost variability and possibly cost development.

- Loco costs are more or less fixed with train length and weight up to certain limits. Traction unit (loco) costs amount to 64% of rolling stock costs when operating with standard wagons, This is around 4.00 €/train-km for general cargo and container trains. For heavy bulk trains we assume an increase of

25% (5.00 €/train-km). The difference of loco costs by commodity types of course depends on the fleet operation policy of the railway undertaking.

- 50% of (fixed) loco costs are considered related to annual driving distance, i.e. 2.00 € for general carto and CT, and 2.50 €/km for bulk.
- The remaining 50% of fixed rolling stock costs are considered variable with time rather than with distance. With an average speed of 51 km/h along the Rhine-Alpine corridor (Table 23 and EC 2014) we receive 102 €/hour for general cargo and container trains, and 128 €/hour for bulk trains. A look into single commodities and their specific requirements for wagon material would allow for a more differentiated view.
- Wagons vary with train length and thus the number of wagons per train, wagon type and with the loading weight. Wagon costs are thus variable. Costs for wagon use are around 32% of rolling stock costs (2.00 €/train-km) for standard equipment, while they may be up to three times as high (6.00 €/train-km) if special wagons are used. We assume standard wagons for general cargo and container trains against a share of 50% special wagons (4.00 €/train-km) for bulk goods. We do not distinguish between wagon technologies, i.e. we do not consider the more expensive low noise retrofitting of wagons.

BAU 2030/2050: Market opening: the productivity of rail freight traffic largely depends on the ability to organise train paths and to run smoothly over long distances. Current regulations and arrangements for cooperation between rail companies constitute a serious obstacle. In the case of moderate market opening and soft regulatory reforms in Europe we assume repeating half of the productivity gain of locos in the coming 35 years (+30%). For freight wagons the impact of regulatory reforms will be smaller. We assume +25% productivity by 2050. We assume that these productivity increases entail some administrative hurdles and that capital costs of rolling stock will be much lower than operating expenses. Consequently, due to moderate market opening and regulatory reforms costs per tkm in BAU reduce by 25% for locos and 15% for freight wagons for general cargo.

Pro Rail 2030/2050: In a more extreme scenario we assume the full establishment of a European Railway Area with widely de-regulated and / or unified technical and operational standards. The long and expensive licencing process of rolling stock will be significantly reduced and train paths can be booked and managed instantly across Europe at a single customer interface. This will impact the operations part of locomotive and wagon life cycle costs significantly. We assume cost impacts of -60% for locos and wagons.

Issues by commodity: Commodity-specific operating capital costs of locos and wagons have been described above. For future development pathways of loco fixed costs we assume that higher train utilisation rates imply more traction power and thus slightly less steeply falling traction costs on both BAU and Pro Rail. This argument does not hold for wagon costs as they are variable anyway.

5.2.2 HGV capital and running costs

Present: Detailed data on the cost structure in road haulage by market segment for Germany is available by the BGL Cost Information System (BGL, 2017). For truck-trailer combinations in (national) long-distance transport the following cost structure is recommended as basis for tariff calculation by haulage companies. Table 10 identifies the most relevant cost positions of truck operations (German conditions, 2015) being driver wages and subsistence (33.8%), diesel and additions (22.7%), administration and management (10.0%) and road tolls (8.9%). These four cost categories account for over 75% of truck operating costs in long-distance services. With 89% of total 130000 annual kilometres this amounts to 1.47 €/km.

BGL (2017) splits vehicle purchase costs 50:50 to time dependent and fixed (invariable) cost categories and breaks them down to years assuming a service life of a truck of 5 years and of a trailer of 8 years. Total capital costs make up 11.1% of trucking costs. Other vehicle related costs are maintenance and repair (8.4%) and vehicle-related taxes and charges (4.2%). All together vehicle related costs constitute a share of 23.7% of total capital and operating costs in national German long distance traffic.

Of these, 45% can be related to the annual driving distance of trucks. Subtracting fuel and road charges, which are considered elsewhere in this report, only 8% of annual truck operating costs are distance-based vehicle costs, resulting in 0.12 €/km.

Table 10: Costs for 40t truck-trailer, national traffic, Germany 2015

Group	**Details**	**€ / year**	**Share**	**€ / km or h**
Distance-Related costs (€ / km)				
Capital	Distance-dependent depreciation	7937,50	4,6%	0,07
Fuel	Diesel	38355,20	22,4%	0,33
	Additions (urea / AddBlue)	531,96	0,3%	0,00
Servicing	Oil	409,92	0,2%	0,00
	Maintenance and repair	9216,00	5,4%	0,08
	Cleaning	1104,00	0,6%	0,01
	Tyres	3042,00	1,8%	0,03
Charges	Distance-based road tolls	15187,50	8,9%	0,13
	Other mission costs	600,00	0,4%	0,01
Directly time-related costs (€ / h)				
Personnel	Driver wage	54177,57	31,6%	22,39
	Driver subsistence	5472,00	3,2%	2,26
Indirectly time-related costs (€ / h)				
Capital	Time-dep. depreciation	7937,50	4,6%	3,28
	Financing costs	1416,70	0,8%	0,59
Charges	Certification fees	414,25	0,2%	0,17
	Time-related road tolls	0,00	0,0%	0,00
	Vehicle tax	929,00	0,5%	0,38
	Insurance	5860,00	3,4%	2,42
Other	Spare trailers, etc.	495,20	0,3%	0,20
	Other fixed costs	1200,00	0,7%	0,50
Management	Administrative personnel	9450,00	5,5%	3,90
	Material costs	7660,00	4,5%	3,17
TOTAL		171396,30	100,0%	
Average	Distance-related cots	76384,08	44,6%	0,65
	Thereof: rolling stock	13771,92	8,0%	0,12
	Time-related costs	95012,22	55,4%	39,26
	Thereof: rolling stock	8898,45	5,2%	3,68

Source: Data from BGL (2017)

Over half (55%) of lorry costs in long distance travel are fixed with travel distance, i.e. are broken down per hour of vehicle use. These are half of capital costs, wages, taxes & charges and management costs. Excluding wages, time-dependent infrastructure charges and management costs only 5.2% of total costs are time-related vehicle costs. For an average truck and trailer combination with an annual number of 2420 productive hours this is 3.68 €/vehicle-hour.

BAU 2030/2050: For the four cost groups related to vehicle ownership and operations cost we assume the following developments until 2050:

- Capital costs for trucks will rise slightly due to automation and driver support technologies. We assume a 20% increase by 2050.
- Maintenance and repair as well as vehicle-related taxes and charges (besides infrastructure charges) will remain unchanged.

Weighting these assumptions with the relevance of the respective cost categories we 9.4% higher vehicle costs in 2050 compared to 2015. We select the following factors for general cargo by truck: 2030 +4%, 2050 +9%.

Pro Rail 2030/2050: In the rail scenario we might see a more proactive steering of transport policy towards sustainability. Besides road charging the following instruments are to be applied:

- Capital costs increase by 50%. This is due to a stricter requirement of environmental and safety features of vehicles, the diversification of power trains and fuels, and a strong market consolidation of truck producing OEMs.
- Maintenance and repair costs will increase by +30% by 2050 due to the diversification of power trains and the ever more complex engine technology.
- Taxes and charges: we assume a higher differentiation of vehicle taxes by environmental standards, fuel consumption and safety features. Together with a general increase in tax levels this means a doubling of taxes and charges already from 2030 on.

Weighting by cost category means +35% costs in 2030 and +52% costs in 2050.

Issues by commodity: Bulk goods in long distance haulage need special vehicles, e.g. tanker or silo Lorries. Markets for these types of vehicles are smaller than for standard truck-trailer combinations. Thus we can assume 50% higher capital costs. Assuming maintenance and taxes the same we calculate 23% higher costs or 0.43€/truck-km in 2015.

Vehicles used solely in combined transport are exempted from vehicle circulation tax in Germany. This reduces overall vehicle costs by 18%, resulting in 0.29€/truck-km. We assume this to be the case for all other corridor countries.

5.2.3 Inland navigation barges and vessels

In barge transport with only little automation in the BAU case and no significant changes in shipping regulation we do not assume visible changes in the costs of maintaining and operating vessels. However, fixed loading and unloading costs may go up due to scarcities at transhipment terminals.

In the Pro Rail scenario, in contrast are assumed to decline by 30% by 2050 due to automated terminals and investments in more terminal capacity. Variable vessel operating costs may also decline drastically due to the application of barge trains and predictive maintenance of the ships.

5.2.4 Summary of rolling stock costs

Table 11 overleaf summarises 2015 cost levels and 2030 / 2050 cost developments for rolling stock related costs by commodity and scenario for road and rail transport. Specific issues for cargo handling in combined transport do not apply. However, there are issues concerning time and distance-sensitive costs. Time sensitive costs are related to fixed capital depreciation and thus do not vary with load factors.

5.3 Energy and fuel costs

5.3.1 Rail traction energy

Present: With 12% to 19% of rail transport costs energy are about as high as network access charges, which is 3.00 €/train-km on average. Three elements contribute to the development of energy costs over time: energy efficiency, energy mix and energy prices by source. Energy costs vary with the weight of trucks and trains, but also depend on their empty weight. Insofar energy costs range in between fixed and variable costs. For simplicity reasons we consider them as variable in this study.

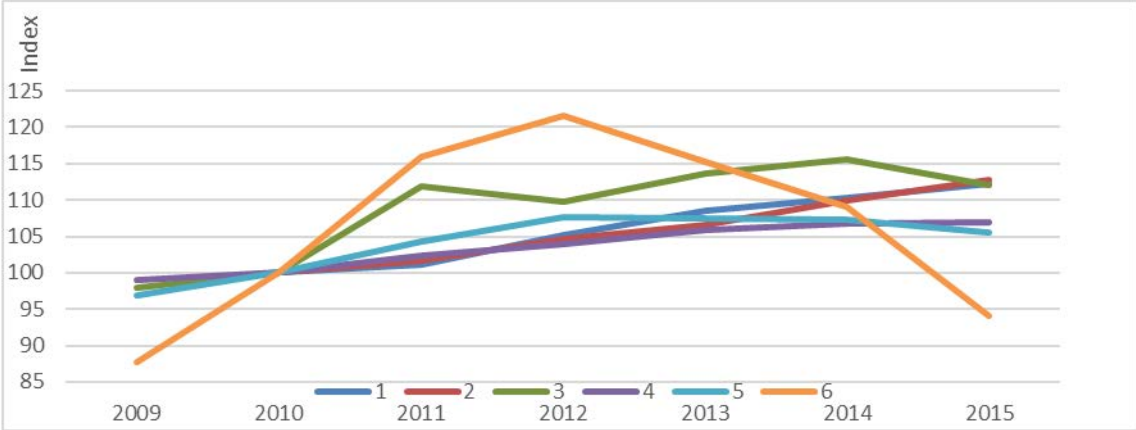
Energy prices for the German freight transport sector can be retrieved from the annual statistics of the association of transport undertakings VDV (2017). According to the figures, traction energy (3) as well as overall rail producer costs (2) developed above the general inflation rate (4). Diesel prices (6) show a steep rise and decline around a peak in 2012.

Table 11: Rolling stock costs by scenario and commodity 2015 to 2050

Mode and commodity	Present	**BAU** relative to 2015		**Pro Rail** rel. to 2015	
	2015	2030	2050	2030	2050
Rail fixed	€ / t	Loading and unloading of block trains and single wagon load			
General Cargo	9,38	104%	109%	80%	67%
Bulk goods	9,38	104%	109%	80%	67%
Containerised	9,38	104%	109%	80%	67%
Rail var dist	€/train-km	Block train and SWL services, CT rail haul			
General Cargo	2	90%	75%	70%	40%
Bulk goods	2,5	92%	78%	73%	46%
Containerised	2	91%	76%	72%	43%
Rail var time	€/train-h	Block train and SWL services, CT rail haul			
General Cargo	102,00	90%	75%	70%	40%
Bulk goods	128,00	92%	78%	73%	46%
Containerised	102,00	91%	76%	72%	43%
Road fixed	€ / t	Truck loading / unloading, add. services			
General Cargo		104%	109%	115%	125%
Bulk goods		104%	109%	115%	125%
Containerised		104%	109%	115%	125%
Road var dist	€/HGV-km	Road haulage and CT access / final haul			
General Cargo	0,35	104%	109%	135%	152%
Bulk goods	0,43	104%	109%	135%	152%
Containerised	0,43	104%	109%	135%	152%
Road var time	€/HGV-h	Road haulage and CT access / final haul			
General Cargo	3,68	104%	109%	135%	152%
Bulk goods	3,68	104%	109%	135%	152%
Containerised	3,68	104%	109%	135%	152%
IWT fixed	€/t	IWT cargo handling costs at ports			
General Cargo	9,38	104%	109%	80%	67%
Bulk goods	9,38	104%	109%	80%	67%
Containerised	9,38	104%	109%	80%	67%
IWT var dist	€/ship-km	IWT only services and CT main haul by ship			
General Cargo	8,70	100%	100%	100%	40%
Bulk goods	8,70	100%	100%	100%	40%
Containerised	8,70	100%	100%	100%	40%
CT Access fixed	€/TEU	Transhipment road to rail/IWT in CT chains			
Containerised	0	0%	0%	0%	0%
CT access var km	€/HGV-km	Truck operation in first and last mile in CT chains			
Containerised	0,29	104%	109%	135%	152%

Source: Fraunhofer ISI

Figure 12: Transport related price indices for Germany, 2009 – 2015



Source: reproduced according to VDV (2017). legend: (1) labour cost index in land transport; (2) producer price index in rail transport; (3) Producer price index traction electricity; (4) overall consumer price index; (5) consumer price index transportation; (6) producer price index diesel fuel.

For EU28 countries UIC/IEA (2016) reports the following facts on rail energy consumption in EU28 countries: The electrified railway network has doubled in length between 1975 and 2013, totalling 221 000 km of tracks in 2013. The share of electrified tracks in the total railway network reached 61% in 2013. Railway specific energy consumption dropped by 19.6% for passenger services and by 22.3% for freight services between 1990 and 2013. Railway specific CO2 emissions fell by 41% for passenger services and 46% for freight services between 1990 and 2013. At the same time the share of renewable electricity has considerably increased.

BAU 2030/205: Energy mix: along the two corridors investigated by the LowCarb-RFC project we assume full electrification and sole use of non-diesel locomotives on the main corridor lines as well as on major access routes. Non-diesel locos are electric locos on the main run and various forms of hybrid locos with renewable power sources on access lines. Currently about 30% of rail traffic are with diesel until 2050 these will completely phase out and will be replaced by fully electric or some type of hybrid locos.

Electric locos are 2/3 of the life cycle costs of diesel engines, which is mainly due to cheaper energy supply and more efficient energy use. Replacing the remaining 30% of diesel power by electricity would reduce energy use – and thus energy costs – by 10%. The production of alternative fuels for hybrid locos, namely hydrogen or bio methane, could eat up some of these savings. We expect cost savings through traction electrification thus around 7% as a conservative estimate by 2050.

Energy efficiency can also be enhanced with efficient driving through automation and driver support systems, through lightweight construction and optimised routing and track maintenance. The effects of these measures depend on a number of factors and may be small. We thus assume a wider corridor of 5% of energy savings by 2050.

Energy prices are difficult to predict. On the one hand more renewable energies mean more challenging electricity network control activities driving costs upwards. On the other hand less dependency on fossil fuel imports for rail make costs and thus prices of energy provision more predictable in the long run. As we are on a trajectory of phasing out of diesel only electricity prices, and to some extent the production costs of carbon neutral combustion fuels, matter. Looking at the major endeavour of implementing the energy transition all over Europe in the best case we assume stable energy prices. In the worst case we assume electricity costs to rise by 10% each decade, i.e. +35% towards 2050.

Pro Rail 2030/205: Against the rather conservative assumptions in the BAU scenario, for the Pro Rail case we assume innovations for more energy efficiency in rail transport to bear fruits. The basic assumptions are:

- Higher energy efficiency of engines of 15% by 2050. This can be achieved through extensive use of recuperation energy within the network or in on-board storages (super caps, etc.), highly efficient electric motors, advanced engine control systems, etc.
- Additional savings of 20% through predictive and automated driving, aerodynamics of whole train sets, etc.

With constant energy prices as was assumed for the BAU case we thus receive energy cost savings of 35% in 2050 against 2015. The respective technologies will enter the market rather rapidly as they promise cost reductions without touching the fundamentals of rail travel. We thus assume 20% less energy costs to be realised by 2030.

Issues by commodity: Heavier trains consume more energy, in particular when breaking energy is wasted. Train weights usually vary between 1700t and 5000t (PLANCO and bfg 2008). Very heavy ore trains might even reach weights of 1000t and more. In long distance rail freight. We assume the energy consumption of bulk traffic being about 2/3 above the energy consumption of general cargo (mixed) or container trains, i.e. 5.00 €/train-km.

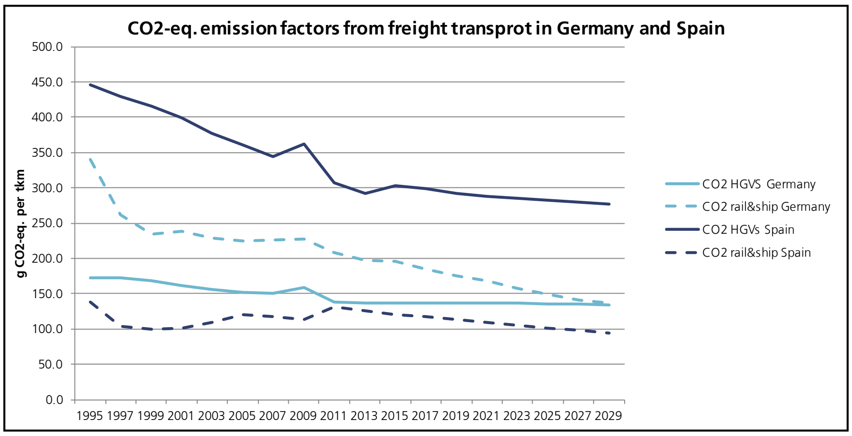
5.3.2 Fuel costs in trucking

Present: Current fuel and related costs for truck operation are taken from the Cost Information System of the German Association for Road Haulage, Logistics and Disposal (BGL, 2017). For a 40t truck-trailer combination in long distance travel with Euro-VI emission standard annual energy costs of 40 993 €/a compute from the following assumptions:

- Annual performance: 130 000 km. This value has slightly increased form around 120 000 km/a since the early 2000s.
- Diesel consumption: 0.31 l/km. Since 1965 fuel consumption of trucks were cut about half. In the 15 years 1996 - 2011 technical improvements have lead to 6% higher fuel efficiency; higher load rates per vehicle (+14%) and a shift to heavier trucks (+7) have further improved average fleet emissions per ton of payload (Dünnebeil / Lambrecht, 2011). T&E (2015) constitutes a stagnation of truck fuel efficiency in the past decade due to concentration on engine power rather than on fuel economy (compare Figure 13).
- Diesel price, net without taxes: 1.004 €/l. The index in Figure 12 demonstrates impressively how fluctuating diesel prices have been during the past decade. Given that they play a larger role for trucking than energy costs do for rail their rise and fall by 40% between 2005 and 2015 impacted cross modal competitiveness to a large part.
- Urea / Carbamate (e.g. AddBlue) addition: 531.96 €/a. This additional substance has been introduced with the Euro-V emission standard. With the Selective Catalytic Reaction (SCR) urea reduced the content of nitrogen oxides (NOx) in diesel vehicles' exhaust fume. According to the World Bank's Urea Price Monitor average prices have fallen slightly fallen by 20%, but with extreme fluctuations by 100% around 2008. There is a competition of using urea as fertiliser or for transportation.

For the two future scenarios these impact factors and their variability need to be considered. Broken down to CO_2 equivalents as a more generic indicator for energy consumption Figure 13 shows the slope of emission factors from 1995 and their projection to 2030 by the ASTRA system dynamics model for Germany and Spain (ISI / UPM, 2017). The figures compare long distance road haulage to mass transport, i.e. rail, inland navigation and coastal shipping. Due to the summary of mass transport modes and the high share of shipping in Spain against a marginalised rail sector, the respective emission factors of the country are low. For trucking we see a 25% decline in CO_2 intensity 1995 to 2015, but a projected stabilisation of these values until 2030. German rail freight showed a way steeper decline of nearly 50%, which is due to a mix of more renewable energy plus higher transport efficiency.

Figure 13: Rail and road GHG emission factors 1995 to 2030, Germany and Spain



Source: ISI / UPM (2017) ; Fraunhofer ISI ASTRA model results

BAU 2030/2050: For most of the impact factors we see slight changes by 2030 and even by 2050:

- Truck driving performance: We assume a slight increase of the annual performance due to market consolidation and better logistics planning. However, these remain modest as in long distance trucking in central Europe markets and logistics management are considered mature. We assume +5000 km annually each by 2030 and 2050.
- Fuel consumption of HGVs will decline due to improvements of engines and aerodynamic measures at trucks. In the BAU scenario progress is assumed according to the PRIMES reference scenario. Expressed in energy consumption per tkm relative to 2015 this is -15% in 2030 and -21% by 2050. For rail we assume another improvement of 8% by 2030 and 26% by 2050 due to driver assistance systems (Figure 9).
- Diesel price: For the future of transportation diesel prices we see three conflicting trends: Further cost increases in exploiting ever more difficult sources, increased consumption by emerging economies like India or Africa, and on the contrary reduced demand by established economies like Europe, China and North America through electrification and synthetic combustion fuels. In the BAU scenario we assume prices go up by 50% until 2030, but then fall back to 2015 levels as the third impact factor takes effect.

  Urea needed for Euro-V trucks: prices are assumed to follow diesel prices. On the other hand we see engine-internal solutions and fuel technologies for eliminating NOx contents of exhaust fumes come into play. Additive substances like Urea will thus phase out in the medium term already.

Fuel consumption is driving the truck energy costs to a large extent as all other parameters are varied only slightly. Final fuel costs develop from 0.315 €/vkm in 2015 to 0.416 €/vkm by 2030 and 0.233 €/vkm by 2050.

Pro Rail 2030/205: For the railway scenario we take the same assumptions on truck efficiency as in the Business-As-Usual case.

Differences by commodities: According to Dünnebeil / Lambrecht (2011) a difference in 5t of payload varies fuel consumption by 6l/100 km. They report the following payloads and fuel consumption rates by commodity:

- Volume goods (consumer goods): 7t and 27 l/100 km
- Average across all goods: 13t, 30 l/100 km. We assume this for the category “General Cargo” (GC), but respect the tendency for more consumer goods and thus lower payloads will be transported (see section “Productivity”)
- Bulk goods: 17,5t, 33 l/100 km. We use these additional 3 l/100 km for dry and liquid bulk goods (BG).
- Combined transport in many countries allow additional 4 tons of payload, i.e. a permissible truck weight of 44t. This would result in 2.4 l/100 km extra fuel use. We add this to the bulk good’s fuel consumption value.

The values do not differ by commodity, although different load rates in reality will impact fuel consumption to some extent. Table 12 summarises the assumptions by impact factor and scenario.

Table 12: Assumptions and results for truck energy costs by scenario

Indicator	Unit	Present 2015	BAU 2030	BAU 2050	Pro Rail 2030	Pro Rail 2050
Performance	km/a	130000	135000	140000	135000	140000
Fuel consumption	l/km	0,310	0,276	0,233	0,276	0,233
Fuel price (net)	€/l	1,004	1,506	1,004	1,506	1,004
Add. substances (AddBlue)	€/a	531,96	0	0	0	0
Overall average costs	€/vkm	0,315	0,416	0,233	0,416	0,233

5.3.3 Inland navigation energy costs

For energy costs of inland ships we assume the same decline in costs as for general vessel operating costs. With a shift from conventional diesel fuel to LNG a cost reduction of 30% by 2050 is conceivable.

5.3.4 Summary of energy and fuel costs

Table 9 summarises the cost level and development assumptions for rail energy and truck fuel costs 2015, 2030 and 2050. Specific assumptions on intermodal transhipments do not apply as they are contained in the respective infrastructure costs. Energy and fuel costs are fully distance-related, so there is no component for the mission time of trains or trucks.

Table 13: Energy costs by scenario and commodity 2015, 2030 and 2050

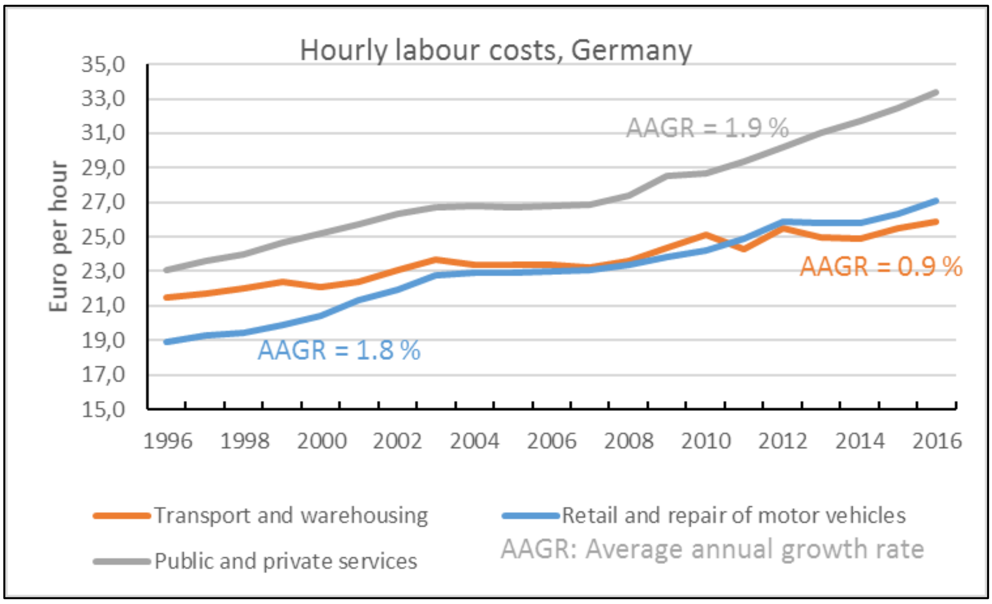
Mode and commodity	Present	BAU relative to 2015		Pro Rail rel. to 2015	
	2015	**2030**	**2050**	**2030**	**2050**
Rail only and CT rail leg – var. dist. Costs - 2015 in € / train-km					
General Cargo	3.00	95%	88%	80%	65%
Bulk goods	5.00	95%	88%	80%	65%
CT	4.00	95%	88%	80%	65%
Road only & CT road leg –var. dist. Costs - 2015 in €/HGV-km					
General Cargo	0.315	132%	74%	132%	74%
Bulk goods	0.336	132%	74%	132%	74%
Containerised / CT	0.360	132%	74%	132%	74%
IWT main haul – distance costs - 2015 in €/ship-km					
General Cargo	8,70	90%	70%	90%	70%
Bulk goods	8,70	90%	70%	90%	70%
Containerised / CT	8,70	90%	70%	90%	70%

Source: Fraunhofer ISI

5.4 Personnel costs

Labour costs are more relevant for road haulage (30%) than for rail freight transport (14%, compare Figure 3). Across all land transport modes labour costs have been steady increasing slightly above the general consumer price index since 2010 (Figure 12). For land transport labour costs we can estimate a real growth of 0.7% p.a. in real terms, but the figure does not allow a split by mode. For Germany labour cost indicators are available for transport and warehousing in general, sales and repair of vehicles and public and private services (Figure 14). These allow some conclusions for road and rail services.

Figure 14: Labour cost indices Germany 1996 to 2016 for selected branches



Source: Fraunhofer ISI with data from DeStatis online database

Although acknowledging the different wage standards in Europe we assume these costs to be representative for the major parts of the two corridors looked at in the LowCarb-RFC study. Personnel costs are fully time dependent; fixed or variable costs related to train or HGV travel distance thus do not apply.

5.4.1 Rail driver and staff costs

Present 2015: Staff costs in rail freight include wages and social contributions for the loco driver and station personnel at marshalling yards and freight terminals. They range in the order of magnitude of 2.20 €/train-km. With an average train speed of 51 km/h (Table 23 and EC 2014) we receive time-based costs of 112.20 €/train-hour in 2015.

Due to the strong position of labour unions in rail transport we can assume a stronger increase of wages than in trucking over the past years. This is confirmed by the development of public and private services in Figure 14, which we assume to meet personnel structures in the still publically dominated rail sector. With some caution we can estimate a real labour cost growth in rail of about 1% p.a.

BAU 2030/2050: Labour costs is the result of two trends: hourly labour costs per employee and labour productivity.

- Labour rates. We project the past trend of labour costs into the future until 2050. This implies that the bargaining power of labour unions just remains about as is as a result of shortage of skilled staff at the one side and the potential threat of automation on the other side. 1% per year implies 16% higher wage rates in 2030 and 42% higher rates in 2050.

- Labour productivity will further increase. According to VDV statistics (VDV 2017).
- Labour productivity per tkm in rail freight has increased by 39% between 2005 and 2015. This is 3.3% improvement per year. We assume this rate to be somewhat lower towards 2050 as the low hanging fruits of productivity increase seemed to be skimmed off with traditional technologies and only moderate automation take-up in the BAU scenario.

In total labour costs in the BAU scenario will drop by 1.0% p.a. We thus receive cost reductions of 16% and 42% in 2030 and 2050.

Pro Rail 2030/2050: Due to massive investment in automation technologies and international industry standards we see a drastic increase in labour productivity growth rates in the rail sector. Parts of these will be eaten up by additional customer services provided and a strengthened bargaining position of labour unions. But still we see an average annual productivity increase of labour costs of 1.5%. This leads us to 25% less labour costs in 2030 and 68% less by 2050.

5.4.2 Lorry driver costs

Personnel costs are mainly driver wages and some minor additions for subsistence. For German national long distance transport these are estimated by BGL (2017) and listed in Table 10.

Present 2015: According to BGL recommendations driver costs including subsistence amount to 24.65 €/truck-km. Road haulage is characterised by a less regulated and way more international labour market than rail. Here wages in the past hardly exceeded the general inflation rate. The transport and warehousing curve in Figure 14 confirms this assumption.

BAU 2030/2050: In the BAU case we consider that by 2050 still most trucks on public roads operate with drivers. But autonomous vehicles have brought about some efficiency gains on some pilot roads along the corridors reducing labour input in total by 20% in 2050 against 2015. However, drivers also need to be more skilled and the massive shortage of skilled personnel will drive wage costs up. We estimate 10% and 20% labour cost reductions by 2030 and 2050.

Pro Rail 2030/2050: Here we see a strict control of automation technologies in trucking reducing potential efficiency gains to 15%. Labour rates will in the same time sharply rise as social standards, wage dumping and certifications will be controlled effectively by European and national bodies. This and the lag of skilled personnel across Europe brings about more stringent requirements for initial and regular driver training. All of these activities together will cause labour costs in road haulage to rise by 5% in 2030 and 10% in 2050 rather than to decline.

5.4.3 Inland navigation labour costs

In inland waterway transport we assume only little changes to current staff costs. Automation potentials are there, but will most likely remain limited except for tran-shipment services. After 2030 we thus assume a 30% drop in labour costs against 2015 and 2030 in both, the BAU and the Pro Rail scenario.

5.4.4 Summary of personnel costs

In both modes, road and rail, we do not see specific issues for bulk or container goods. Also there is no relevance of CT transhipment services as related labour costs had been covered under the heading “infrastructure costs” above. Table 14 summarises the assumptions in the common form.

Table 14: Labour costs by scenario and commodity 2015 to 2050

Mode and commodity	**Present**	**BAU relative to 2015**		**Pro Rail rel. to 2015**	
	2015	**2030**	**2050**	**2030**	**2050**
Rail only and CT rail leg – time costs, 2015 in € / train-h					
General Cargo	112.20	84%	58%	75%	32%
Bulk goods	112.20	84%	58%	75%	32%
Containerised	112.20	84%	58%	75%	32%
Road only & CT road leg – time costs, 2015 in €/HGV-hour					
General Cargo	24.65	90%	80%	105%	110%
Bulk goods	24.65	90%	80%	105%	110%
Containerised	24.65	90%	80%	105%	110%
IWT main haul – time costs, 2015 in €/vessel-hour					
General Cargo	4,34	100%	70%	100%	70%
Bulk goods	4,34	100%	70%	100%	70%
Containerised	4,34	100%	70%	100%	70%

Source: Fraunhofer ISI

5.5 Administrative costs

With 10% administration, management or overheads have the same share for rail and road services. Despite it is the smallest under the cost categories considered here it is worth looking at under the merits promised by digital industry and the connection of transport services. As independent of train and truck fleet driving performance administrative costs are usually allocated to mission times rather than to driving distance.

5.5.1 Overheads in rail transport

Present 2015: Figure 3 suggests an amount of 2.00 €/train-km for management and administration. Statistics on their past development are not available. With 51 km/h average train speed from Table 23 we receive 102 €/train-hour.

BAU 2030/2050: Increased labour productivity in the railways primarily takes place in administrative structures. Here we assume a reduction of administrative costs by 25% between now and 2050.

Pro Rail 2030/2050: Efficiency gains in the P'RO RAIL scenario will be way more expressed than in BAU. Similar to the assumptions for labour costs we see a cut of administrative costs of 70% possible towards 2050. This can be realised by replacing still common paper-based communication and planning forms by highly connected IT solutions, by efficient cooperation among European railways and industry bodies and finally by big data applications, deep learning and predictive maintenance to better use available resources.

Issues by commodities: Combined transport chains are commonly organised by a single forwarder. Administrative costs are thus not to be added up for the rail and the road leg. For the rail leg Figure 3 suggest administrative costs in the order of magnitude of rail transport staff costs, i.e. 112.20 €/train-hour.

5.5.2 Management in trucking

Present 2015: Figure 3 and Table 10 suggest administrative costs of 0.15 €/truck-km or 7.07 €/truck-hour for a standard 40t vehicle in national long-distance travel.

BAU 2030/2050: Administrative costs will decline by some 20% due to the advanced use if IT technologies and networking among companies. Also the trend towards larger trucking companies, which started with the market liberalisation in Germany in 1993, will further carry this development.

Pro Rail 2030/2050: We do not expect any change in the development of administrative costs for truck companies against the BAU scenario.

Issues by commodities: For trucks used in combined transport Figure 3 suggests overheads being 14% to 38% of vehicle operating costs on the road leg in combined transport, while they account for 33% in truck only transport. Comparing overhead costs to personnel costs even suggests lower overhead rates in combined transport related to unimodal truck transport. We thus apply 20% lower administrative costs in container transport to account for some synergies in organising the transport chain with rail.

5.5.3 Administration costs in inland shipping

In IWT we assume the same overhead rate of 10% as was found for rail transport. This results on a value of 0.87 €/vessel-km in 2015. For the two scenarios we assume no changes in this cost block.

5.5.4 Summary of administrative costs

Administrative costs are summarised for all three modes in the usual manner.

Table 15: Administrative costs by scenario and commodity 2015 to 2050

Mode and commodity	Present	**BAU** relative to 2015		**Pro Rail** rel. to 2015	
	2015	2030	2050	2030	2050
Rail only and CT rail leg – time-related costs, 2015 in € / train-h					
General Cargo	102.00	90%	75%	75%	30%
Bulk goods	102.00	90%	75%	75%	30%
Container in CT	112.20	90%	75%	75%	30%
Road only & CT road leg – time-related costs, 2015 in €/HGV-h					
General Cargo	7.07	95%	80%	95%	80%
Bulk goods	7.07	95%	80%	95%	80%
Container in CT	5.66	95%	80%	95%	80%
IWT main haul – distance costs, 2015 in €/ship-km					
General Cargo	0,87	100%	100%	100%	100%
Bulk goods	0,87	100%	100%	100%	100%
Container in CT	0,87	0%	0%	0%	0%

Source: Fraunhofer ISI

5.6 Total cost overview

With the data above we can summarise fixed time-related, fixed distance-related and variable costs by mode, type of service, scenario and year. The comparison by cost categories is drawn in Table 16.

To compare transport modes with the data in Table 16 some assumptions on travel speeds and loading capacity utilisation have to be taken. These values will be discussed in more detail in the subsequent chapter 7. For a comparison between road and rail use the following simplified values and assumptions:

- Travel speeds of trains on the Rhine-Alpine corridor have been observed as 51 km/h (EC, 2014). We use this value without differentiating between commodities.
- Travel speeds for truck in German long-distance transport result from assumptions in BGL (2017): 2420 productive hours per vehicle and 89% out of 130 000 kilometres driven per year. These figures result in an average speed of 48 km/h, i.e. less than rail speeds. Assuming trucks on the main European corridors to be utilised more efficiently we assume an average speed of 60 km/h.
- Load rates of trains are assumed 500 to for all commodities in 2015. By 2050 this value will increase to 727 t/train in the BAU scenario and will triple to 1547 t/train in the Pro Rail scenario.
- Load rates for trucks result from 27 to loading capacity of a 40 t truck-trailer combination and a use of load space due to empty headings and unused space in loaded trucks of around 50% (ISI / UPM, 2017). Here we also assume that these average values do not match with the very competitive conditions along the corridors. We assume a load rate of 20 tons per HGV for general cargo and bulk, and of 24 tons per truck in container transport. In the BAU and the Pro Rail scenario the load factors will increase to 22 t/HGV in 2050.

The resulting costs per ton kilometre are presented in Figure 15 by mode and scenario. The values relate to a 300 km haul. In the combined transport case (CT) a 200 km main haul by rail with a 100 km access and final haul by truck was assumed. In this case truck loading rates were lifted by 10% to reflect special conditions for CT terminal access.

Table 16: Summary: cost development by scenario, commodity and mode

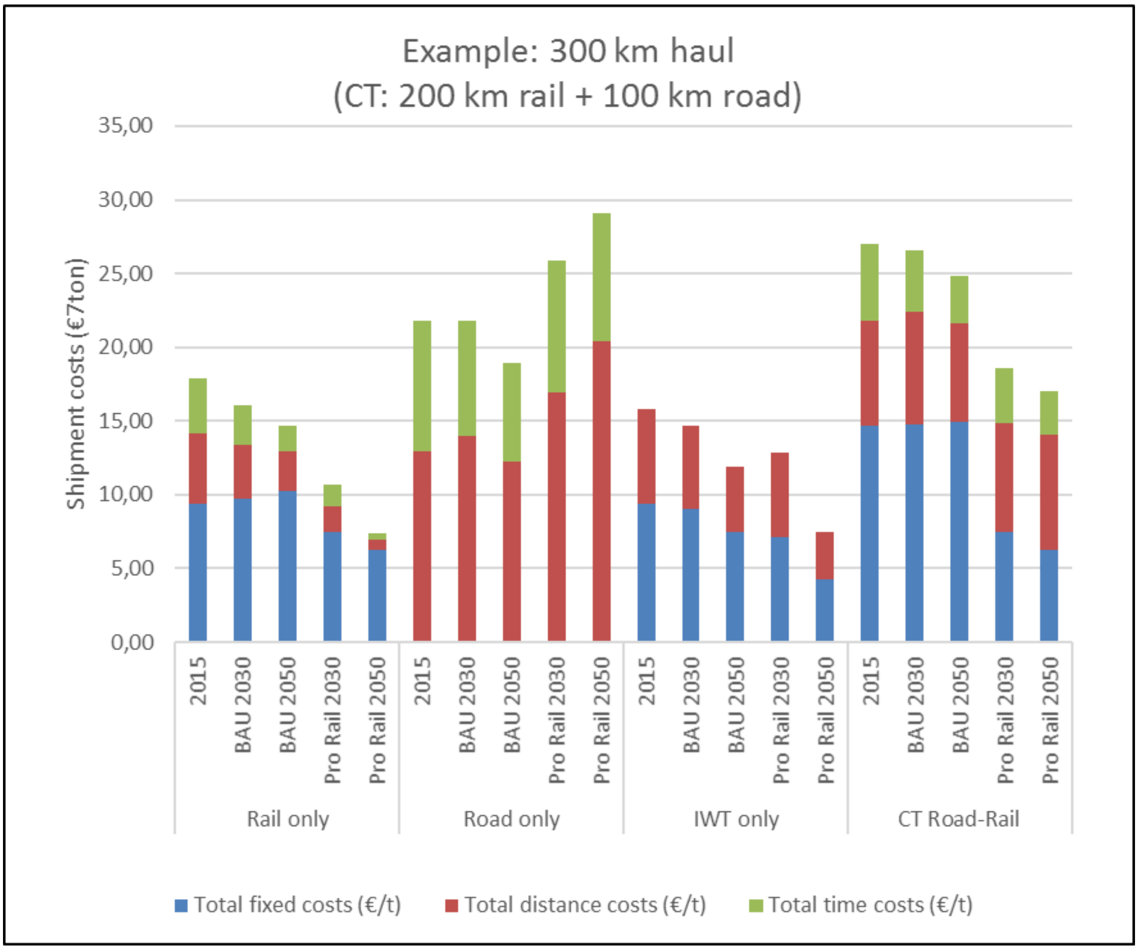
Mode and commodity	Present	**BAU** relative to 2015		**Pro Rail** rel. to 2015	
	2015	2030	2050	2030	2050
Rail fixed	€/t				
General Cargo	9,38	104%	109%	80%	67%
Bulk goods	9,38	104%	109%	80%	67%
Containerised	9,38	104%	109%	80%	67%
Rail variable km	€/train-km				
General Cargo	8,00	92%	82%	63%	44%
Bulk goods	11,50	93%	83%	65%	47%
Containerised	9,00	92%	83%	65%	47%
Rail variable hour	€/train-h				
General Cargo	316,20	88%	69%	73%	34%
Bulk goods	342,20	89%	71%	74%	37%
Containerised	326,40	88%	69%	74%	35%
Road fixed	Not applicable: In vehicle operation				
General Cargo	N/A	100%	100%	100%	100%
Bulk goods	N/A	100%	100%	100%	100%
Containerised	N/A	100%	100%	100%	100%
Road variable km	€/vehicle-km				
General Cargo	0,87	113%	104%	137%	173%
Bulk goods	0,97	113%	106%	137%	172%
Containerised	0,99	113%	100%	137%	**167%**
Road variable hour	€/vehicle-h				
General Cargo	35,40	92%	83%	106%	108%
Bulk goods	35,40	92%	83%	106%	108%
Containerised	35,40	92%	83%	106%	108%
IWT fixed	€/t				
General Cargo	9,38	104%	109%	80%	67%
Bulk goods	9,38	104%	109%	80%	67%
Containerised	9,38	104%	109%	80%	67%
IWT variable	€/ship-km				
General Cargo	22,60	92%	79%	92%	56%
Bulk goods	22,60	92%	79%	92%	56%
Containerised	22,60	92%	79%	92%	56%
CT fixed	€/TEU				
Containerised	40	100%	100%	0%	0%
CT access var km	€/HGV-km				
Containerised	1,65	104%	89%	116%	116%

Source: Fraunhofer ISI

Under the chosen conditions, rail and IWT freight rates are just below those of road haulage and well below CT costs. The picture remains more or less equal in the BAU scenario 2030 and 2050, but changes completely in the Pro Rail scenario. Here, rail and IWT are only 25% of the freight rates in road haulage. Combined transport is still twice the costs of rail and IWT, but is available at about half the freight rates of trucking. So for flexibility reasons, CT now is a viable and even economically interesting alternative.

These values are just examples and will vary with OD relationships along the two corridors. Transport distances and the availability and structure of combined transport connections are decisive for the competitiveness of the modes. These characteristics are elaborated in detail with the TRP logistics chain model in Working Paper 7 of the LowCarb-RFC study.

Figure 15: Summary: cost development in main haul services by scenario, mode and commodity 2030 and 2050



Source: Fraunhofer ISI

6 System Performance

We can express the productivity of transport systems in terms of how well the capacity of the means of transport are utilised, and in terms of for how long these assets are occupied with providing the service. Load factors have direct implications for parts of monetary costs, while travel times impact other parts of direct monetary costs and at the same time determining another cost category: time costs.

6.1 Load factors

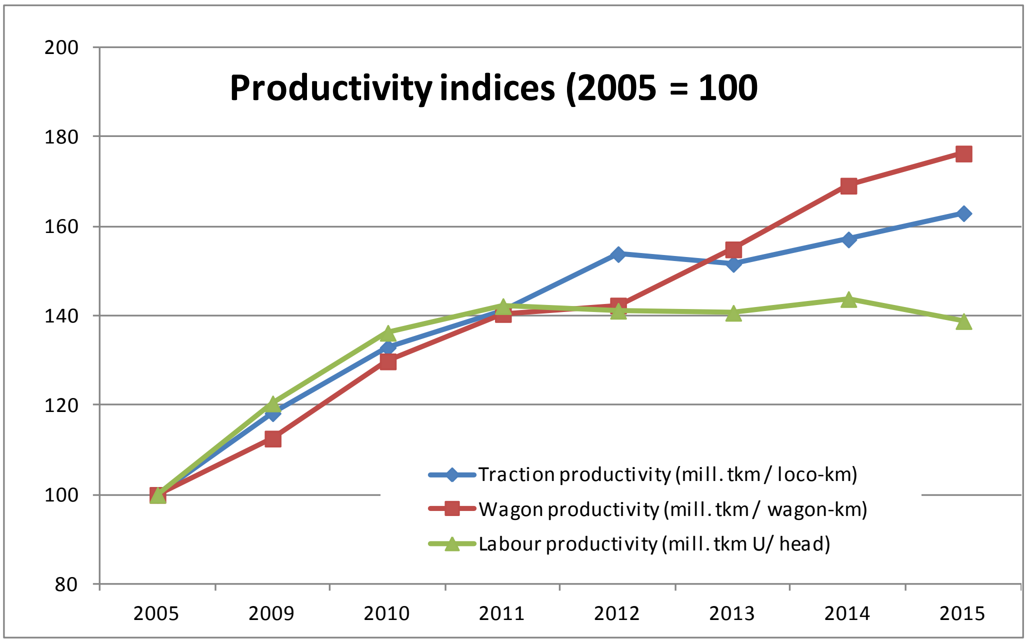
In Chapter 5 we have classified the costs for providing transport services into fixed and variable parts. Fixed costs are those which do not change in absolute terms when the utilisation of trains or trucks change. But this will be the case for per-unit average costs, and so the utilisation rate matters for the price the final customer (forwarder) has to pay for the service.

This does not hold true for variable cost elements as they rise or shrink with higher or lower utilisation rates and thus do not impact the final price. In real terms costs are seldom completely invariant or absolutely proportional with train or truck load rates. Sometimes even strong non-linearity, e.g. when an additional loco or truck trailer is needed beyond a certain utilisation rate, need to be dealt with. These issues are subject to the TPR logistics chain model implementation.

6.1.1 Freight train tonnage

Data on transport performance and the rolling stock in public German rail freight services provided by VDV (2017 and earlier editions) suggests that both, locos and wagons, are still in a trajectory of growing productivity. For locos the productivity has increased from 25.1 mill. tkm/loco-km in 2005 to 41.0 mill. tkm/loco-km (+63%) in 2015. For wagons the figures are 0.85 and 1.49 mill. tkm/wagon-km (+76%) over the same decade. For comparison: labour productivity improved from 1.24 to 1.73 mill. tkm/head (+39%) from 2005 to 2015. The annual indices for 2005 and 2009-2015 in Figure 16 shows that the productivity of wagons constantly rose in the past decade, while locomotive productivity flattened and labour productivity even declined after 2012.

Figure 16: Productivity indices for traction, wagons and labour in German public rail freight transport 2005-2015



Source: Fraunhofer ISI with data from VDV (2017) and earlier editions

For some years with consistent data structures the VDV statistics allow comparative indicators for non-public railways, i.e. rail business for company-internal shipments only. Here productivities are lower and productivity increases for materials and labour are less expressed.

Train capacity: From VDV statistics we can estimate an average tonnage of freight trains in Germany of 486 t/train (values up to 2010 only). As this includes feeder traffic, along the major European corridors utilisation rates will be way closer to technical and legal limits. Train carrying capacity is influenced by train length, loading per wagon and the number of empty wagons.

For train loads along the major European rail freight corridors we look at typical examples of more or less fully loaded trains. From scientific work accompanying the Federal German Investment Plan (BWVP) 2015 in BVU et al. (2012) we get the following examples:

- Single wagon load with industry goods (fertilisers), Seelze-Mannheim (436 km): 679 m length, 737 t cargo (1595 t gross weight), 36 wagons. We assume this an average general cargo service along the corridors. Under current length restrictions of 740m another 5 wagons or 14% more capacity from train length would be possible.

- Block train, coal, (long version), Hamburg-Beddingen (259 km): 700 m length, 2207 t of cargo (3310 t gross weight), 42 wagons and 2 locos. We assume this as the standard train configuration for bulk goods along the RALP and the NSB corridors. Due to the anyway high train weight we do not see much potential for further increasing train loads with longer trains.

Empty wagons

According to DeStatis (2016) in 2014 average container loads including empty units were 8.48 t across all shipments and 9.54 t/TEU in international traffic. The share of empty containers was 21% and 16% respectively. Details are given in Table 17.

Table 17: Rail container loads by transport market, Germany, 2014

Parameter	Natio-nal	Inter-national	… sent	… receipt	… transit	Total
Empty containers (1000 TEU)	816	349	114	235	133	1297
Loaded containers (1000 TEU)	2436	1894	978	916	646	4975
Cargo (1000 t)	23711	21393	11461	9932	8110	53214
Average container load incl. empty units (t/TEU)	7,29	9,54	10,50	8,63	10,41	8,48
Average container load, loaded containers only (t/TEU)	9,73	11,30	11,72	10,84	12,55	10,70
Share of empty containers	25%	16%	10%	20%	17%	21%

Source: compilation with data from DeStatis (2016)

Present 2015: According to ConTraffic (2014) we estimate a share of 25% empty wagons in single wagon load, i.e. for general cargo. For bulk transport with block trains the share of empty wagons carried would be more close to the share of empty containers shipped, i.e. in international traffic, i.e. 15% according to Table 17.

BAU 2030/2050: For general cargo and container shipment we assume some minor improvements in the handling of empty wagons and containers, resulting in a 10% higher efficiency in 2050 compared to 2015. Actual improvements in the management of rolling stock may be higher, but the shift in cargo towards lighter goods eats up some of these advances. In bulk transport we see no changes to current rates of empty wagons.

Pro Rail 2030/2050: It will hardly be possible to completely avoid the transport of empty wagons or containers on the network. But we assume the share of 25% in general cargo and 16% in container shipment to be reduced by 30% by 2050.

Measures to do so include open data platforms among all wagon keepers, tracking and tracing of all units in real time and the standardisation of equipment. Modular systems of freight wagons with a unique platform and flexible and exchangeable modules for varying commodities. Counter-effective trends are, as in the BAU case, changes in goods structures. For bulk transport we assume half of this effect, i.e. an improvement by 15%.

Utilisation of loaded units

With two axles and an axle load of up to 22.5 t the gross weight of a wail wagon can be 50 t. For a number of lighter consumer goods, however, volume limits are more restrictive than ton limits. From BVU et al. (2012) we see bulk trains already utilising their maximum weight of 50t. More cargo could only be achieved by more axles per wagon as with ore trains, or by increasing the standard axle loading.

Present 2015: In general cargo the examples rather show an average load of 14 to 30 tons per wagon with 20 t on the main haul. Even with volume restrictions limiting carriage we see a case for ICT-driven load space optimisation.

BAU 2030/2050: No change to 2015 in terms of the general use of volume to weight capacity of wagons in bulk transport. Despite the change in goods structure towards lighter general cargo we expect increased use of logistics management tools to slightly lift load space utilisation by 20% in 2050 in general cargo and container transport.

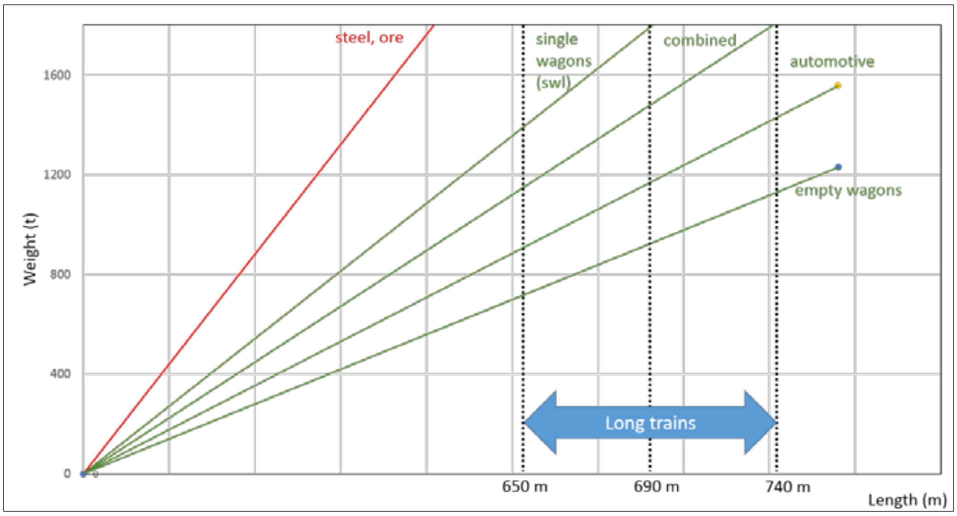
Pro Rail 2030/2050: Loading wagons is the task of forwarding industries. Better IT services and communication can possibly help improving the utilisation of vehicles, but we do not see this having a major impact. We assume +10% improvement in the Pro Rail scenario.

Train length utilisation

Statistics of the German Transport Operators' Association (VDV) suggest an average utilisation 500 t/train across the entire network. By comparing the weight of empty to full trains in Figure 17 we can estimate that this net load corresponds to a total train length of 550 to 600m and an average gross train weight of around 1600t.

According to EC (2014) only 19% of trains on the Rhine-Alpine corridor use their maximum length, while only 4% to 14% use their available weight through Switzerland. Similar information on the North-Sea-Baltic corridor is not provided by the respective EC corridor study (Proximare, 2014).

Figure 17: Weight and volume limits of freight trains



Source: reproduced according to EC (2014) / Pulfer et al. (2014)

Train weights are restricted along the corridor sections from Rotterdam to Genoa according to national regulations. Main driver for restricting train weight is track gradient. Therefore limits may strongly differ within a single country and depend on the type of traction (single our double). Maximum weights with single (double) traction range from 2700t in the Netherlands to 700t (1400t) up mountain in Switzerland. Most of Germany allows for 22500t while most of Italy restricts train weights to 1600t regardless of traction type (Pulfer et al., 2014).

Train lengths on the corridor reach form unrestricted 740m in parts of the Netherlands and Switzerland to less than 690m in North Rhine-Westphalia and Italy (Pulfer et al., 2014).

BAU 2030/2050: Due to the investments needed we assume only a partial relaxation of the length and weight restrictions on the network. But towards 2050 there will be a larger number of trains utilising their maximum limits. We take a cautious estimate by assuming a 10% to 20% increase train utilisation towards 2050 to 750 m across all corridors.

Pro RAIL 2030/2050: We assume the entire corridor main lines equipped for 1500m trains by 2050. Weight limits are adapted accordingly, such that productivity increases of trains in terms of numbers of wagons of 100% are realised.

Overall train productivity increase

The table below summarises the efficiency potentials of train capacity use for the 2050 scenarios. In the BAU case even the very modest assumptions on improvements accumulate up to 45% efficiency gains in the case of general cargo in 2050 against 2015. With only 10% higher efficiency bulk transport is assumed to work more or less as today in the coming 35 years.

In the Pro Rail case we assume a massive re-structuring and cooperation of the railways, the use of automation, big data and artificial intelligence, as well as infrastructure extensions to cater 1500 m trains in order to maximise the utility of their assets. In contrary we must assume some changes on goods structures towards lighter goods and maybe towards more distributed origins and destinations of shipments. In consequence we assume a tripling of load factors in general cargo and in container shipments, and even a doubling of train loading efficiency with bulk traffic.

Table 18: Overall productivity improvements in rail capacity use

Mode and commodity	Present	**BAU** (to 2015)		Pro Rail (to 2015)	
	2015	2030	2050	2030	2050
Efficiency improvement due to less empty wagon movement					
General Cargo	25%	1,05	1,10	1,20	1,40
Bulk goods	20%	1,00	1,00	1,05	1,10
Container in CT	16%	1,05	1,10	1,20	1,40
Efficiency improvement due to higher utilisation of loaded wagons					
General Cargo	50 t/wg,	1,05	1,10	1,15	1,30
Bulk goods	20 t/wg.	1,00	1,00	1,07	1,15
Container in CT	11,3 t/TEU	1,05	1,10	1,15	1,30
Efficiency improvement due to longer trains					
General Cargo	650 m	1,10	1,20	1,30	1,70
Bulk goods	700 m	1,05	1,10	1,25	1,60
Container in CT	700 m	1,05	1,10	1,25	1,60
Efficiency improvement due to higher utilisation of loaded wagons					
General Cargo	740 t/train	1,21	1,45	1,79	3,09
Bulk goods	2200 t/train	1,05	1,10	1,40	2,02
Container in CT	800 t/train	1,16	1,33	1,73	2,91

Source: Fraunhofer ISI. Symbols: wg. = waggon

6.1.2 Road haulage utilisation rates

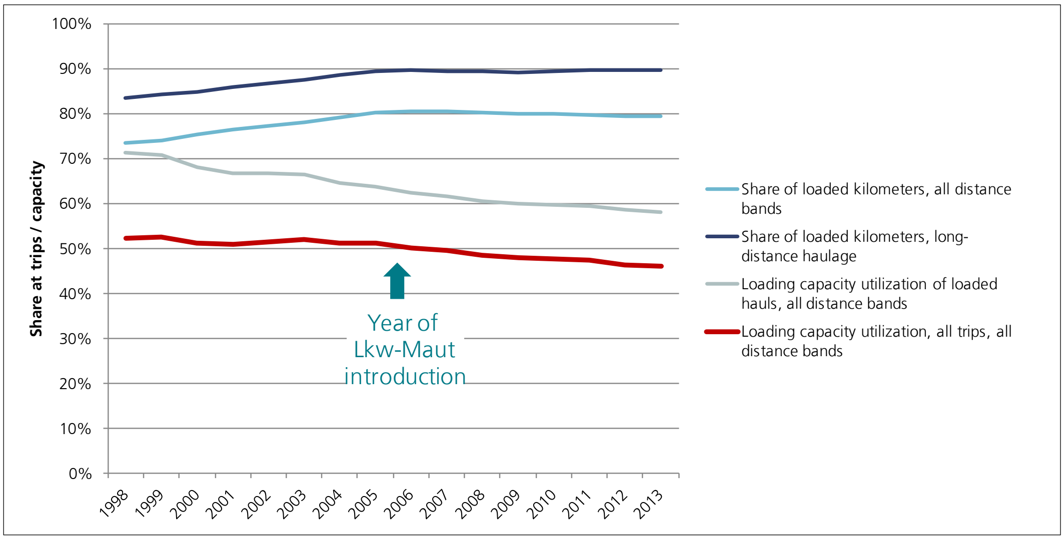
The load of trucks can be measured in tons or in volume entities, e.g. m^3 or palette spaces. As trucks are restricted in weight and volume, both might be a limiting factor. I.e. trucks can be fully stuffed with consumer electronics but do not meet the permissible weight limit, or they may be loaded upon their weight limit with steel products and still have empty space available. For reasons of simplicity, we use tons per vehicle (tkm) or vehicle per kilometre (vkm) to describe load factors. But bearing the above in mind, this might be misleading. As markets all over Europe change from heavy mass products to lighter consumer goods, ton-based load rates decline over time with all other parameters remaining unchanged.

Present 2015. On demand of the European Commission in 1993, the market for road freight transport in Germany was liberalised. Since then, the number of haulage companies has drastically increased. Together with the fall of the Iron Curtain and the appearance of eastern European low wage trucking companies on the market, price pressure, in particular in international transport, increased. Consequently, efficiency improved, which can be seen in time series on the share of loaded hauls (see Figure 18). The rates show a constant increase of the share of loaded trucks, (i.e. a decline in empty headings) until 2006 and then stay constant in long distance haulage. Due to overcapacities, the share of loaded headings then slightly decreased in local and regional haulage, with the onset of the world economic crisis.

Another issue related to the efficient use of vehicles is the load factor of loaded vehicles. As in the years before, average utility of loaded vehicles fell further even in the first months of 2005 to 58.8% (BAG, 2005). The structural effect of the freight market towards more high value / low weight goods and the more rigid availability of delivery time windows and warehousing policies in the production industries are responsible for this trend and cannot be compensated by the hauliers' attempts for higher cost efficiency. Figure 18 shows the ratio between maximum load weight and actual weight[2] of the transported goods, constantly declined in the past decades in Germany. As a net effect, the overall utilization of available truck loads slightly declined between 1998 and 2013. A real impact of the introduction of policy interventions such as the German HGV motorway toll on this overall loading efficiency of trucks cannot be constituted in aggregate statistics.

2 Remark: Load space utilization is increasingly more limited by volume of cargo rather than by weight. Thus the presented utilization measure constitutes only a proxi to actual utilization rates.

Figure 18: Share of loaded headings and capacity utilization for Germany



Source: Fraunhofer ISI with data from BGL e.V. and KBA

A detailed look on the logistics sector by the extensive market consultations of the German Office for Freight Transport reviewing the impacts of the then newly implemented HGV toll (BAG, 2005 and 2006) as well as additional sector consultations by ISI / UPM (2017) leads to the following statements:

- Even under the double burden of high fuel and toll costs, no economically sensible options for a further reduction of empty headings exist.
- In long distance trucking load rates of loaded trucks are expected to exceed 90%; 2005 utilisation rates are estimated at 82%.

Measures taken by companies to increase efficiency include the optimization of delivery times, the acquisition of additional return freight via freight exchange platforms and co-operations among undertakings. In recent years, companies increasingly use software solutions to optimize logistics processes and test different forms of permanent or temporary outsourcing, in particular of border crossing hauls (BAG, 2016).

BAU 2030/2050. The development of truck load rates is driven by demand structures, company structures and the costs of trucking.

- A doubling of market growth by 2050 against to 2015 is a strong case for more bundling and thus for higher truck utilisation rates. This trend will, however, be slowed down by the movement towards lighter products (as we stick to the measure of tons per truck) and more pressure towards same day delivery in particular in general cargo markets.

- The trend towards crowding out smaller transport businesses and the accumulation of market power by a fewer number of large trucking companies or company networks will continue. This also helps reducing empty headings and filling load spaces.
- Costs per truck movement in the BAU scenario will fluctuate around 2015 values driven by rising infrastructure and wage costs, and unstable energy costs (Table 13).

Load rates on the main corridors are comparably high: 20t of 27t capacity for general cargo and bulk against 22t out of 30t capacity for container traffic. We assume these to rise by 10% towards 2050 due to the appearance of larger trucks on some relations and due to further company mergers.

6.1.3 Combined transport

In combined rail-road transport capacity use can be referred to the load per standard container unit (TEU) and to the number of containers per vehicle. The load per container includes the utilisation of container space and weight as well as the share of empty containers shipped. The number of containers per vehicle means train length for the rail leg and truck size & weight limits for road.

Table 19 shows that in long-distance transport container loads have been increasing by 20% in the decade 2003 to 2013 and are systematically higher than load rates on shorter distances.

Table 19: Container load rates Germany 2003 – 2011 and 2014

Year	Total CT consignments			CT consignments >300 km		
	1000 TEU	1000 t	t/TEU	1000 TEU	1000 t	t/TEU
2003	11197	77856	6,95	1534	10635	6,93
2004	11123	68557	6,16	1550	10760	6,94
2005	12631	79976	6,33	1560	10828	6,94
2006	14049	89441	6,37	1566	11710	7,48
2007	13087	84291	6,44	1407	10511	7,47
2008	12740	85762	6,73	1168	9089	7,78
2009	10613	71633	6,75	1084	8638	7,97
2010	12556	86827	6,92	1241	9847	7,93
2011	13877	97148	7,00	1305	10805	8,28
2003-2011	111873	741491	6,63	12415	92823	7,48

Source: Heinrichs et al. (2014)

6.1.4 Summary of vehicle utilisation rates

Present 2015. The summary of assumptions on the development of road factors per train and truck in Table 20 reveals that the theoretical potential for productivity rains in the rail sector is way higher than on road haulage. This asset needs to be utilised for making good use of the sector's strength.

Table 20: Train and truck utilisation rates by scenario and commodity 2015 to 2050

Mode and commodity	Present	**BAU** (to 2015)		Pro Rail (to 2015)	
	2015	2030	2050	2030	2050
Rail only and CT rail leg – utilisation rates 2015 in t / train					
General Cargo	740	121%	145%	179%	309%
Bulk goods	2200	105%	110%	140%	202%
Container (uni-modal/CT)	800	116%	133%	173%	291%
Road only & CT road leg – utilisation rates 2015 in t / HGV					
General Cargo	20	105%	110%	105%	110%
Bulk goods	20	105%	110%	105%	110%
Container (unimodal)	20	105%	110%	105%	110%
Container (CT access)	22	105%	110%	105%	110%

Source: Fraunhofer ISI

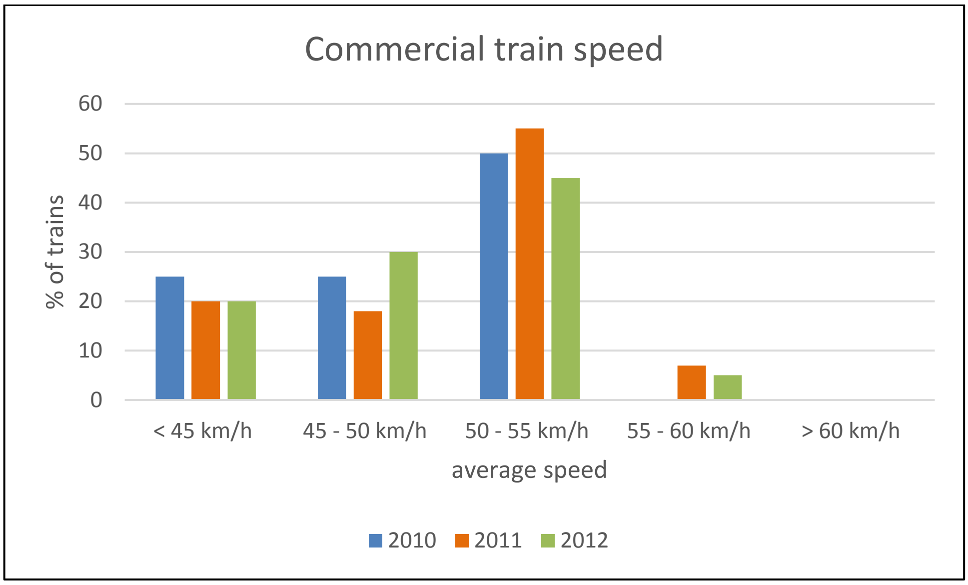
6.2 Delivery time and speeds

Shorter transport times imply better capital utilisation and thus lower average costs per ton of cargo. Half of vehicle capital costs, wage costs and administrative expenses are commonly allocated to transport services using the duration of vehicle occupancy. In order to match the transport time indicators better with common units we use speed (in kilometres per hour km/h) instead of travel times (e.g. hours per kilometre), although the latter would be more consistent with the scenario indicators in other sections of this document.

6.2.1 Rail transport

Travel time in rail transport include the times used by a train set between two rail nodes, plus the shunting and transhipment times at the origin, destination and in between the journey. In the Rhine-Alpine corridor study (EC, 2014) speed samples of typical freight trains were taken. Average speeds including shunting time were distributed as depicted in Figure 19. Averaging these records with the respective probabilities results in an average freight train speed of 51 km/h.

Figure 19: Distribution of freight train travel times on the Rhine-Alpine corridor 2010-2012



Source: Re-edited with data from EC (2014)

For bulk and general cargo services in Germany BVU et al. (2012) provide the following data:

- Wagon load (general cargo) from Zielnitz to Karlsruhe with re-arrangement in Magdeburg, Seelze and Mannheim, 693 km. The direct travel time of the three sections without shunting: 12.4 hours against the full travel time including re-arrangement at the intermediate stops of 60 hours. This results in an average theoretical speed on the network of 56 km/h, while the real travel speed experienced by the user and train operator is only 11.6 km/h.
- Block train (bulk, coal) from Hamburg to Beddingen, 259 km. Here BVU et al. (2012) compare a single journey to a round trip including train preparation and driver exchange. Direct haul in one direction takes 5.3 hours, corresponding to 48.9 km/h. This is the travel speed experienced by the customer. The round trip takes 27 hours, resulting in an operating speed of 19.5 km/h. This is the speed to be considered for computing time-related fixed costs.

These observations lead to two insights:

- Train speeds for the customer are not necessarily identical with train speeds for internal cost calculation at the train operating company. Differences are particularly obvious for one-directional cargo flows with special wagons, i.e. Bulk, which then have to go back empty.

- Travel speeds are particularly low for customers and operators in case trains have to be re-arranged. This is commonly true for general cargo in single wagon load trains.

Table 21 summarises the different perspectives and types of services and their impact on average train speeds in long distance rail freight transport. For container transport we gave a speed range as data for the preparation of train sets was not available.

Table 21: Average train speeds by type of service and affected body

Affected body	General cargo (single wagon load)	Bulk goods (block trains)	Containerised goods (block trains)
User-experienced travel speeds (km/h)	11.6	48.9	51.0
Operator-experienced travel speeds (km/h)	11.6	19.5	30 - 40

Source: Fraunhofer ISI

BAU 2030/2050. In the coming decades the conflict between passenger and freight traffic on rail will sharpen as in both sectors volumes intend to grow. For average speeds on the network we assume that capacity investments and the increasing implementation of ETCS level 3 will just maintain to keep current speeds of around 50 km/h. For container and wagon load transport we assume efficiency improvements in marshalling yards and terminals. On the contrary, however, the consolidation of terminals and shunting facilities towards fewer large entities is expected to continue, such that detour traffic eats up some of the time gains through IT-based train arrangement and management.

Pro Rail 2030/2050. The Raise-IT project initiated by EGTC Rhine-Alpine elaborates on optimising capacity along the Rhine-Alpine corridor by integrating urban nodes. The study followed up on the CODE24 project, which looked at respective network improvement and policy measures. The main message of the study is to reduce maximum train speeds to optimize the rail production system for all types of traffic[3]. Assuming some of these operational concepts to be realised we can assume constant average speeds of freight trains on the network between 70 and 80 km/h, which corresponds ton +50% of average speeds by 2050.

For wagon load traffic the Pro Rail scenario assumes fully IT-based and automated marshalling processes. The wait time of wagons on marshalling yards thus

3 Compare http://egtc-rhine-alpine.eu/portfolio-item/raise-it/.

can be reduced by a factor three towards 2050. This would about double experienced travel speeds without the increase in on-track speeds. In total we expect an increase of average speeds in wagon load transport of 250% in 2050 relative to 2015. This would then still be just below 30 km/h.

6.2.2 Road transport

Present 2015. Commercial speeds of HGV on congestion-free motorways are 80 km/h. According to EC directive 561/2006/EC every 4.5 hours of driving time 45 minutes rest are obligatory. Adding some reduced speed due to congestion (5% of motorway kilometres with 10 km/h speed) and 30 minutes of access time on secondary roads at 50 km/h we receive an average speed of 65 km/h.

BAU 2030/2050. Rising demand along the major European corridors will just be compensated by minor infrastructure extensions and by traffic management and driver assistance systems. Average speeds thus will remain constant.

Pro Rail 2030/2050. We assume a concentration of investment funds on rail infrastructure. Stricter enforcement of social rules, including rest times, will further cause travel speeds for trucks to decline. However, the drop will be minor as automation, driver assistance systems and finally the shift of some truck volumes to rail will catch up some implications of congestion and stricter regulation.

6.2.3 Transhipment in combined transport

Specific times for the transhipment of cargo in intermodal terminals is composed of the wait times of trucks or trains for being serviced, the processing of the transhipment (craning) itself and finally the wait time of the train or truck for departure. Detailed information on processing times of intermodal cargo at terminals is not available. We thus assume it to be 8% of rail travel times according to the relation of transfer handling costs in intermodal chains in Figure 3. With a 500 km haul and an average speed of 52 km/h in CT services this results in 45 minutes per transhipment. For reasons of simplicity and consistency we let the transfer times develop reverse to rail travel speeds.

6.2.4 Summary: shipment times

According to the elaborations and assumptions above, Table 22 presents the BAU and Pro Rail scenario assumptions for average unimodal service speeds without delays.

Table 22: Average speeds excl. delay, BAU and Pro Rail 2015 to 2050

Mode and commodity	Present	**BAU** (to 2015)		Pro Rail (to 2015)	
	2015	2030	2050	2030	2050
Scheduled rail transport speed (km / h)					
General Cargo	11.6	105%	120%	120%	150%
Bulk goods	48.9	100%	100%	150%	250%
Container in CT	51.0	120%	120%	120%	150%
Scheduled road transport speed (km / h))					
General Cargo	65	100%	100%	98%	95%
Bulk goods	65	100%	100%	98%	95%
Container in CT	65	100%	100%	98%	95%
Scheduled service time at terminals (hours per TEU)					
General Cargo	0.75	95%	83%	83%	67%
Bulk goods	0.75	100%	100%	67%	40%
Container in CT	0.75	83%	83%	83%	67%

Source: Fraunhofer ISI

6.3 Reliability

As revealed by a survey conducted by Booz&Company for PwC Strategy& (2017) focusing on the satisfaction of European logisticians with rail services, the rail freight gets increasingly competitive. 75% of the interviewed logistics managers were highly satisfied with the offered quality of their rail freight services. The survey also identified punctuality in terms of delivery in time to be the main driving factor for the decision of logistic companies for a specific rail freight offer which accounted for 58%. In comparison, only 55% of the interviewed managers considered the price to be the crucial factor for the decision process. This challenges findings by the ScanMed corridor study (ETC et al., 2014, Figure 1). Also the transport time with 44% and the rail network coverage which accounted for 42% in the survey plays a key role in the decision making process. With respect to reliability, 37% of the logistics managers indicated further considering the flexibility regarding capacities for the decision of a specific rail freight company.

Furthermore, the survey also payed attention to the perceived reasons of customers for reduced quality of rail freight services. With 38% ranking at the top, insufficient punctuality was seen as the main reason together with a lack of quality with respect to the handling of orders (35%) and a reduced availability of freight wagons (28%). To sum up, 52% of the logistics companies which participated in the survey expects further bottlenecks, especially on the main corridors from south to west and east to west which can only be addressed and prevented by an expansion of rail networks and an optimized capacity - and ordering system.

6.3.1 Rail freight punctuality

Punctuality is one of the key criteria for service reliability in transport and is as thus frequently reported by sector publications. Having a look at the results with respect to arrival punctuality of the six corridors along the Rhine-Alpine Core Network provided below, it can be seen that arrival punctuality is even lower for transnational corridors compared to national routes which are operated by Deutsche Bahn or SBB for example but higher compared to Polish trains. In none of the corridor routes, the arrival punctuality met the target of 80%. Having a look at the corridor from Freiburg to Novara, the arrival punctuality increased over time, finally on average accounting for 53% of the trains which arrived in time where punctuality is defined as an arrival at destination within a 30 minutes time span. Similarly, also trains running on the corridor between Rotterdam and Melzo reached their destination on average in 61% of the cases in time. As far as the corridor between Zeebrugge and Gallarate is concerned, it still accounts for 69% of the trains arriving within a time span of 30 minutes relative to the announced arrival time. With respect to the North Sea - Baltic Core Network Corridor, no quality aspects are included in the study (EC, 2014a).

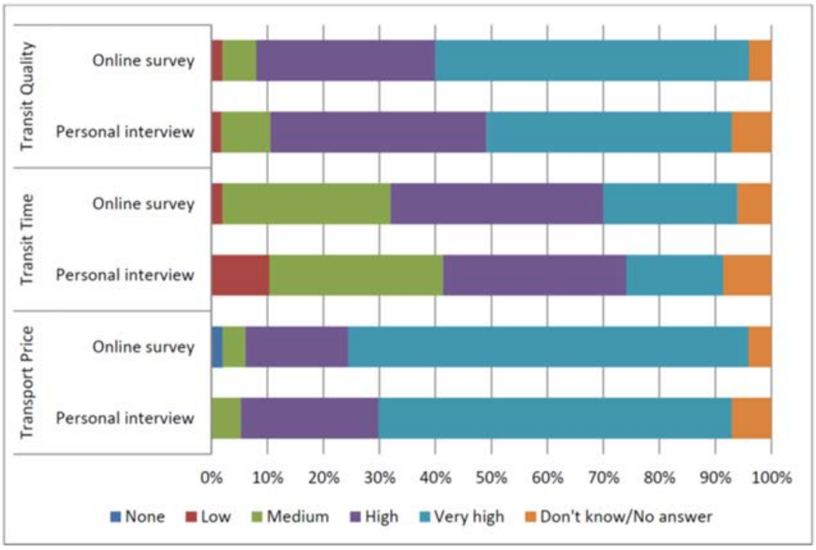
In contrast to previous results, as shown in Figure 20, the Transport Market Study for the Scandinavian Mediterranean RFC does not provide detailed numbers on reliability, instead the authors conducted interviews with stakeholder groups, thereby offering insight into customers' satisfaction. With respect to transport quality, factors like reliability, punctuality, safety & security as well as travel information have been included. With respect to asked transport quality in form of an online survey, a bit more than half of the customers (around 55%) ranked transport quality extremely high when weighting the factors influencing their decision with respect to the offering rail company service. Similarly, almost 40% of the stakeholders in a personal interview indicated that transport quality is a very high influencing factor for their decision. With only around 30% of the interviewed stakeholders who ranked transport time very high when evaluating their rail service, it becomes clear, that for customers, reliability in terms of punctuality matters more than the exact travel time (ETC, 2014).

Table 23: Arrival punctuality along the RALP Corridor with max. 30 minutes arrival delay

Origin - Destination	2010	2011	2012	2013	Average
Freiburg - Novara	54%	48%	51%	58%	53%
Antwerp-Novara (1) (diff. routes)			46% 77%	62%	93%
Rotterdam - Melzo		60%	61%		61%
Rotterdam - Novara				54%	54%
Cologne - Gallarate	56%	68%	65%		63%
Zeebrugge - Gallarate				68%	68%
AVERAGE					65%

Source: EC (2014)

Figure 20: Assessment of quality indicators for freight transport mode choice



Source: ETC (2014, p. 17)

A review of **statements on punctuality by the national railway operators** in the corridor countries plus France reveals the following picture:

- Germany and Netherlands: especially Deutsche Bahn Group is directing its attention towards customer satisfaction. With its Railway of the Future quality program which started in 2016 as part of the strategy DB2020+, the company succeeded in putting its focus on punctuality. After years of deteriorating results with respect to punctuality, both DB Cargo and DB Arriva experienced an improvement compared to 2015 as far as punctuality is concerned. DB Cargo increased its punctuality up to 75.6% in 2016 compared to 73.9% in 2015 and

DB Arriva even reached in time in 91% of the cases in 2016 compared to 90.6% in 2015.

- Switzerland: In contrast to Deutsche Bahn Group, punctuality, which in case of SBB Cargo is defined as an arrival time up to three minutes after the announced time, with respect to freight traffic even worsened by 1.1 percentage points between 2015 and 2016 from 74.9% up to 73.8%. However, the company aims at improving its punctuality also in the area of freight traffic since in case of passengers punctuality with a value of 88.8%, SBB is said to be the most punctual railway (SBB 2016).
- France: Having a look at the situation of freight reliability in France, the French National Railway Corporation (SNCF) does not provide any numbers with respect to their punctuality of rail freight. Generally speaking, the company group as a whole aims at improving its punctuality. Similarly, also Trenitalia for Italy and as well as SNBC, the national railway company of Belgium, do not offer detailed information with respect to punctuality of rail freight (SNCF 2016).
- Poland: Although PKP Cargo as the department of rail freight of the national polish rail company PKP Group does not contain any numbers with respect to punctuality in their business report (PKP Cargo Capital Group, 2016), the company also defines reliability, including among others punctuality, as key performance indicators, which should be improved. Nevertheless, in case of Poland, the Office of Rail Transport (UTK, 2017) provides detailed information with respect to punctuality of freight trains even on a quarterly basis, further distinguishing between domestic and international traffic as seen in the tables below.

As shown in Table 1, not even half of the freight trains reached their destination on time, neither with respect to domestic traffic and even deteriorating over the year and finally on average reaching a value of 41.2%, nor in case of international traffic for which the result also worsened over the year with on average only 27.3% of the trains arrived at their destination on time. In sum, the overall level of punctuality reaches on average a value of 41.2%. A similar picture can also be drawn with average delay figures indicating that overall freight trains have a mean delay of 453 minutes. As far as domestic traffic is concerned, freight trains arrive on average with a delay of 464 minutes whereas in case of international traffic freight, trains arrive on average with a delay of 409 minutes. In addition, on average, a relatively high number of 4507 freight trains have been cancelled which indicates that punctuality should be improved.

Table 24: Quarterly level of punctuality and average delay of freight trains in Poland, 2016

Traffic category	**Q1: Jan-Mar**	**Q2: Apr-Jun**	**Q3: Jul-Sep**	**Q4: Oct-Dec**
	Overall level of punctuality (reference not defined)			
Overall	41.79%	43.21%	41.50%	38.28%
domestic traffic	43.86%	46.26%	43.96%	40.54%
international traffic	23.33%	28.88%	29.39%	27.39%
	Average delay of freight trains **(reference not defined)**			
Overall	412 min	427 min	465 min	509 min
domestic traffic	424 min	433 min	478 min	523 min
international traffic	365 min	405 min	414 min	451 min

Source: Available at https://utk.gov.pl/en/markettatistics-and-ann/quarterly-statist/freight-market/13425,Punctuality-of-freight-trains-in-2016.html

The **international railway statistics 2015** of the International Union for Railways (UIC 2017) provides delay records for a sample of countries by infrastructure managers (IM) and railway undertakings (RU). Infrastructure manager data refers to 5 minute delays against time tables, while RU data refers to 60 minute delays. IM data in addition provides the share of cancelled trains. Table 25 compares the three indicators, where on-time arrivals where converted into delayed trains to keep the three data items consistent. For none of the corridor countries one hour delays by railway undertakings are available.

Usually one would expect the share of trains delayed by one hour or more to be magnitudes lower than trains late by 5 minutes or more. This hypothesis is not supported by UIC statistical data, which raises questions on data definition and origin. 5-minute days range between 10% (BLS, Switzerland) to 40% 41% (FS, Italy). The share of cancelled trains reaches from above 30% in Spain, Hungary and Romania to a stated value of zero for Lithuania.

Looking more detailed into single countries reveals the following picture. As shown in Table 25, there are huge differences both, across countries and companies, with respect to their reliability of freight trains in 2015. Lithuanian Railways, the national railway company of Lithuania, ranked at the top with nearly 100%, strictly speaking 99%, of their trains arriving with less than 1 hour delay. Similarly, also the French national railway company SNCF mobilité, and VR, the national railway company of Finland, performed quite well with around 97% of their freight trains arriving with less than 1 hour delay. Having a look at Bulgaria and Spain, there are small differences with respect to the corresponding railway company concerning the punctuality of freight trains. Starting with Bulgaria, while the national railway company BDZ Cargo accounted for almost 95 of the trains arriving in time which is defined as a delay of less than 1 hour, the Bulgarian Railway Company (BRC), the first privately held rail freight company in the country, only accounted for 89% of their freight trains which arrived with less than 1 hour delay in 2015. A similar picture was also drawn for Spain where 92% of freight trains of the national railway company RENFE arrived with less than 1 hour delay compared to around 83% with respect to the Catalan railway company FGC. Taking into account Austria, still around 76% of the freight trains of the national Austrian railway company (ÖBB) arrived with less than 1 hour delay in 2015. In contrast, as far as Slovenian Railways (SZ), the national railway company of Slovenia, is concerned, with 55 percent, only half percent of their freight trains arrived with less than 1 hour delay. Similarly, also around 54% of the freight trains operated by CFR Marfa, the national railway company of Romania, arrived with less than 1 hour delay in 2015.

Present 2015. We can conclude an average punctuality share along the Rhine-Alpine corridor of 65% in the years 2010-2013 against a 30 minute punctuality threshold. UIC statistics suggest a mean punctuality share of 75% (Austrian value) against a 60 minute threshold. With a simple binomial model where trains are either punctual (delay = 0) or delayed (delay = threshold) we receive average late times of all freight trains between 10.5 minutes (RALP corridor) and 15.0 minutes (UIC statistics). For its higher relevance we choose the 15 minutes average delay.

In addition we value the cancellation of services with a late time of 12 hours. The UIC statistics do not provide values for the LowCarb-RFC corridor countries nor for any other large central European region. So we take a cautious approach with 5% of services cancelled across all service types. This sums up to 36 minutes of additional delay across all trains and implicitly considers availability shortages of wagons. Total delay and non-availability time thus is roughly 50 per train.

We convert this into relative travel time increases as follows: An international transport typically covers a distance of 600 km with an average speed of around 50 km/h for block trains and 11.6 km/h for single wagon load services (Table 22). These are travel times from terminal to terminal in unimodal rail transport of 12 and 52 hours respectively. This would mean 6.9% additional travel time for bulk and container trains, and 1.6% travel time increase for single wagon load services or general cargo. Finally, we assume an additional average extra travel time of 2% for all services.

Table 25: Freight train delay records by country and operator 2015

Country, railway undertaking and year	Share of trains late by less than 1 hour (RU data)	Share of trains late by less than 5 minutes (IM data)	Share of can-celled services (IM data)
Corridor Countries			
DE - DBAG 2015		72.9%	
CH - BLS 2015		90.5%	
CH - SBBCFFFFS 2015		80.6%	
IT - FS 2015		59.2%	
Other countries			
AT – ÖBB	75.7%		
BG - NRIC 2015		92.9%	4.3%
BG – BDZ Cargo 2015	94.6%		
BG – BRC 2015	89.4%		
CZ - SZDC 2015		42.1%	
ES - ADIF 2015		86.5%	15.6%
ES - FGC 2015	83.2%	61.20%	21.0%
ES - RENFE 2015	92.0%		
FI - VR 2015	97.2%		
FR - SNCF MOBILITES 2015	97.2%		
HR - HZINFRA 2015			32.1%
HU - GYSEV/RÖEE 2013			1.0%
HU - MAV 2015		63.8%	25.6%
LT - LG 2015	99.0%	98.0%	0.0%
NO - JBV 2015		77.60%	
LV - LDZ 2015		85.30%	
PT - IPSA 2015		80.8%	14.6%
RO - CFR 2015	54.0%	72.7%	32.7%
SE - TRAFIKVERKET 2015		77.9%	
SI - SZ 2015	54.7%	31.4%	27.8%
SK - ZSR 2015		75.1%	27.8%

Source: UIC (2017)

BAU 2030/2050. In this case, considering a balance between rail network expan-sions together with operative improvements on the one hand, and growing traffic on the other, leads to the assumption of on average unchanged delays in 2030 and 2050 compared to 2015.

Pro RAIL 2030/2050: We assume a huge expansion of IT-platforms for asset - and capacity management of infrastructure and rolling material together with more capacity-enhancing infrastructure investments. Consequently, less delays are expected which finally translates into a reduction of the delays by half.

6.3.2 Road transport

Present 2015. The Handbook on emission factors for road transport HBEFA (2017) version 3.3 provides kilometres driven by vehicle category, road type, country and for four different driving conditions:. For motorways in Germany, Austria, Switzerland, Sweden, Norway and France we get the following speeds and shares at vehicle kilometres:

- free flow to dense, 80 km/h, 95.4% at vkm;
- saturated, 30 – 70 km/h (average 50 km/h), 3.0% at vkm;
- stop&go, 5 – 30 km/h (average 18 km/h), 1.6% at vkm.

The weighted average speed is 97.6 km/h, which means 2.4% more time needed for driving. If we assume the two international corridors to be more congested than the rest of the countries we can assume a travel time add-on due to congestion of 5%. As these are only due to access demand (recurring congestion) we further double this value for taking into account accidents, bad weather, technical problems at vehicles and other incidents.

BAU 2030/2050: The German federal infrastructure investment plan (BWVP) estimates an increase of road traffic in Germany by 2030 of +67% compared to 2015. In a more cautious approach we assume these additional volumes by 2050. Driving conditions will only partly be eased by additionally provided road capacity, traffic management and driver assistance systems. Congestion levels will thus considerably go up by +100% on the main axes of the European road network.

Pro Rail 2030/2050. In the Pro Rail case even less efforts will be taken to tackle road congestion. We thus assume an increase of congestion and incidence related delays to +200% relative to 2015.

6.3.3 Transhipment in combined transport

Flexibility and reliability in combined rail-road transport is driven by the reliability of road and rail services, but also by capacity availability in transhipment nodes.

For the Rhine-Alpine corridor the respective market study (EC, 2014) has assessed the capacities 2005 and the required capacities 2025 on German territory. For all but two terminals (Koblenz and Karlsruhe) the study finds required capacity expansions between 40% and 200%. For terminals outside Germany similar pressures on capacity can be expected.

Contrary to this demand, the forecast of terminal handling times in Table 22 proposed a reduction on handling times by 17% towards 2030 and by 33% towards 2050. This can be achieved by over-complying with the suggested investments plus a consequent automation of terminal handling and capacity allocation processes. These technologies can also help improving on the terminals' reliability. But here we are more cautious as improving both, average process time and delays, at the same time might be difficult.

Table 26: Actual and estimated terminal capacity 2008 and 2025, German part of RFC1

Rail-Road Terminals	**Capacity 2008 (in 1000 TEU)**	**Capacity needs 2025 (in 1000 TEU)**	**Capacity expansion needs (in 1000 TEU)**
Duisburg	460	1260	+800 (+174%)
Neuss / Düsseldorf	270	561	+291 (+108%)
Cologne	494	969	+475 (+96%)
Koblenz	50	25	-25 (-50%)
Frankfurt	199	266	+67 (+34%)
Mannheim / Ludwigshafen	500	1220	+720 (+144%)
Karlsruhe	247	215	-32 (-13%)
Basle	150	315	+165 (+110%)
TOTAL	2370	4831	+2461 (+51%)

Source: EC (2014); Remark: we use TEU instead of the ILU for processing capacity figures as stated in the EC (2014) assuming that these correspond.

6.3.4 Summary of reliability assumptions

With the broad assumptions on late times in rail and road transport taken above we see a slightly smaller impact on rail travel times than in the road sector; the delay impacts 2015 are however remarkably nearby. Driven by the scenario narratives we see a strong decline in rail delays against a boost in road congestion towards 2050. Table 27 summarises the findings.

6.4 Other quality and performance indicators

Safety and security

Transport safety has two implications for the shippers: the disturbance of the transport chain and thus delays due to accidents on the one hand and damages to the cargo on the other hand. Late times due to accidents are less relevant for rail and are already internalised in congestion average HGV delays.

Security of supply chains in contrast constitutes a different topic. This is, however, less in control of transport policies and thus not relevant for the scenario process in the LowCarb-RFC study.

Flexibility & customer orientation

The acquisition of information before and during the transport of goods constitutes considerable costs for the forwarder. Through agents, trading platforms and automation these efforts can be eased, in particular for intermodal and rail transport. The respective effects have already been captured by the cost category "administration" of the various transport modes. We thus resign an additional cost or benefit category.

Table 27: Transport service reliability 2015 to 2050

Mode and commodity	Present	**BAU** (to 2015)		Pro Rail (to 2015)	
	2015	2030	2050	2030	2050
Extra rail transport time rail due to delays (% of planned shipment time)					
General Cargo	6.9%	100%	100%	75%	50%
Bulk goods	1.6%	100%	100%	75%	50%
Container in CT	6.9%	100%	100%	75%	50%
Extra road transport time road due to delays (% of planned shipment time)					
General Cargo	10%	150%	200%	200%	300%
Bulk goods	10%	150%	200%	200%	300%
Container in CT	10%	150%	200%	200%	300%
Extra service time at terminals due to delays (% of planned service time)					
General Cargo	6.9%	100%	100%	90%	80%
Bulk goods	6.9%	100%	100%	90%	80%
Container in CT	6.9%	100%	100%	90%	80%

Source: Fraunhofer ISI

6.5 The valuation of performance indicators

The performance of transport services is part of the forwards' entrepreneurial cost structure. Already in the forecast of monetary costs we have implicitly include the impacts of capacity expansion, travel speed and reliability improvements. The performance scenarios in this section thus serve more as a justification of the partly deep cuts in rail production costs according to the philosophy of generalised user costs.

To respect the fact that respective infrastructure investments might be delayed and might cause additional costs to the system, additional "moderate rail" (Mod Rail) and "moderate road" (Mod Road" scenarios are defined for the assessment of transport sustainability impacts in later working papers 7 and 8 of the LowCarb-RFC project. They are defined by cutting all generalised cost improvements in all categories by 50%.

7 Options for implementation

A significant modal shift from road to rail in freight transport will require a considerable expansion in the capacity of the rail freight network along the corridors and in particular in Germany. An expansion in rail freight can be assessed as the (interacting) combination of the following aspects:

- track infrastructure (extra tracks or new railway lines to overcome bottlenecks),
- train control systems (such as ERTMS),
- longer trains (currently 600m on the corridors considered, 740m is planned and 1500m has been studied),
- higher load factors for trains and reduction in the movements of empty wagons.

7.1 Track infrastructure

Holzhey (2010) studies the infrastructure implications of an 84% increase in freight traffic from 2008 to achieve 213 bn tkm per year by 2025. This is part of the UBA 2009 strategy for sustainable freight transport (Lambrecht et al., 2009). The rail freight network in Germany is characterised by bottlenecks i.e. capacity limitations in sections of the main freight axes, such that the projected increases in capacity imply new infrastructure. Improvements in operational methods and minor improvements to train control (New systems such as ECTMS are discussed separately), together with optimised pricing arrangements such as time-based pricing are estimated to be able to contribute around 40 bn tkm to capacity. Minor infrastructure measures such as sidings and loops to enable trains to overtake together with electrification of secondary lines to enable through working with a single electric locomotive can contribute a further 32 bn tkm to capacity.

Allowing for these improvements, capacity implications of a doubling of the number of goods trains is examined. This identifies several sections where there is considerable under-capacity, which would prevent the achievement of the projected increase. These are summarised in Table 28.

For the two corridors considered in the study, the Rhine-Alp corridor is severely restricted. The sections Emmerich-Oberhausen, Bonn — Bingen/Mainz, Rhein-Main — Rhein-Neckar, Mannheim — Karlsruhe, Freiburg — Basel all form part of this corridor, such that this corridor will suffer from insufficient capacity for most of the route in Germany. Since this study was undertaken, work has started on upgrading Emmerich-Oberhausen (a 3rd track) and on doubling the sections from Karlsruhe to Basle to provide 4 tracks instead of two.

Table 28: Route sections with an estimated capacity deficit of 50 trains per day or more

Route section	Capacity deficit (trains per day)
Rosenheim-Salzburg	50
Emmerich-Oberhausen	50
Göttingen-Bebra	60
Hannover-Göttingen	120
Hamburg — Lüneburg — Uelzen — Celle	130
Bonn — Bingen/Mainz (both sides of the Rhine)	140-210
Koblenz - Trier	70
Freiburg — Basel	150
Mannheim — Karlsruhe	170
Würzburg — Nürnberg	170
Rhein-Main — Rhein-Neckar (three routes combined)	200
Total	1310 to 1380

Source: EC (2014)

The next step in the analysis is to consider intensified use of alternative routes to route trains away from the bottlenecks. These are:

Table 29: Infrastructure bottlenecks in the German rail network

Bottleneck	Avoiding route
Hamburg-Hannover	Hamburg — Wittenberge— Magdeburg — Halle —Jena — Nürnberg and Reichenbach— Hof — Regensburg
Cologne-Bonn-Mainz/Wiesbaden	Ruhr-Sieg
Fulda-Frankfurt-Mannheim / Karlsruhe-Basel	Heilbronn-Stuttgart-Gäubahn to Switzerland
Koblenz-Trier, Cologne-Bonn-Mainz / Wiesbaden	Cologne-Trier
Hamburg-Hannover	Buchholz or Winsen — Soltau — Celle
Rhein-Main — Rhein-Neckar	Bingen-Karlsruhe
Gemünden-Nürnberg	Gemünden-Bamberg-Fürth
Würzberg-Nürnberg	Würzburg-Ansbach
Stuttgart - Augsburg	Aalen — Nördlingen— Donauwörth

Source: Compilation from BVU et al., 2012 and Holzhey (2010)

Relatively inexpensive upgrading of these lines including electrification will reduce the requirement for major infrastructure investments.

The two corridors in the present study are explicitly considered in the UBA calculations. The expansion of demand in the NSB corridor can be accommodated by on the Hamm-Paderborn-Kassel-Halle route.

However, the RALP corridor is found to require capacity expansion along the corridor itself. This is now in progress. The projected cost of upgrading the 73 km Emmerich-Oberhausen route from two to three tracks is € 2285 million. The route upgrade was officially commenced in January 2017[4].

The expansion of the Karlsruhe-Basle corridor to 4 tracks has begun. The projected cost for the expansion over the 160 km route is € 7973 million (€ 49.83 million/km). The planned date for completion of the whole route is 2031.

There remains the bottleneck of the central Rhine between Cologne and Wiesbaden/Mainz, continuing from Bingen/Wiesbaden to Mannheim.

Between Cologne and Mainz/Wiesbaden there is no realistic possibility for expansion of the existing tracks, because of the narrow Rhine valley. Holzhey (2010) proposes that goods traffic to France be diverted to the Cologne - Bitburg - Trier (Eifelstrecke) route. Although the route has heavy gradients (up to 2%) electrification would enable the route to take up the projected traffic to France. The 'right bank' Cologne-Wiesbaden would have to be complemented by routing additional traffic via Siegen and Frankfurt. The proposed expansions for the RALP are summarised in Table 30.

In summary, Holzhey (2010) provides evidence that a significant modal shift to rail from road will require a large increase in the number of freight trains, of the order of at least a doubling in the total number of freight trains on the DB network. A network analysis shows that significant increases in capacity can be accommodated by rerouting and electrifying routes that are not currently used for long distance traffic. The North Sea Ports-Berlin-Warsaw corridor can accommodate the projected extra traffic by extensive use of the Hamm-Paderborn-Kassel-Halle route.

However, some corridors will require capacity expansion. The RALP corridor in particular requires major investment in expansion. While the Emmerich-Oberhausen and Karlsruhe-Basle sections are now being upgraded, further expansion will be required to address the bottlenecks between Cologne, Mainz-Wiesbaden and Mannheim-Karlsruhe. The section Offenburg-Basle is planned to be equipped

4 DB Netze (2017) https://www.emmerich-oberhausen.de/pressemeldung/bindeglied-fuer-europa-baubeginn-der-ausbaustrecke-emmerich-oberhausen.html.

with an upgraded train control system to at least the equivalent performance of the EU ECTS/ ETRMS level 2 (Bund, 2017).

Table 30: Proposed network expansion in the RALP area by UBA

Route	Track expansion	Electrification	Status
Emmerich-Oberhausen	3rd track		In progress
Bingerbrück-Hochspeyer		69km	No plans
Neustadt-Winden-Wörth	2nd track Winden-Wörth 12km	Neustadt-Wörth 43km	No plans
Rastatt	4 tracks 4km		In progress
Offenburg-Basle	3 / 4 tracks ~60km		In progress
Venlo-Rheydt	2nd Track 16km		Planned
Cologne(Troisdorf)-Oberkassel	3 / 4 tracks 13km		No plans
Heidelberg (Wieblingen)-Heidelberg Hbf	3 / 4 tracks 3km		No plans

Source: Holzhey (2010) p. 118 Corridor D: ARA Ports/Rhine-Ruhr-Switzerland

The draft German Federal Investment Plan (BVWP) 2030 (BMVI, 2016) includes expansion of capacity between Frankfurt and Karlsruhe via Mannheim by building two new tracks for this route. The estimated cost is €3800 million. Work has not started on this project.

Overall, the current long term plan as detailed in BWVP (2016) does not completely address the requirements for the Rhine-Alpine corridor identified by Holzhey (2010). There is also no consideration of the rerouting of freight trains over the Cologne-Trier route, which would require electrification to maximise the potential of this route to relieve the Cologne-Mainz/Wiesbaden sections. Furthermore, there is no consideration of the rerouting of freight trains over the Bingen-Ludwigshafen-Wörth-Karlsruhe route. There has been some minor upgrading of the Mainz-Ludwigshafen-Mannheim section, but there are no plans for the Ludwigshafen-Wörth-Karlsruhe section (Bund, 2017). There is no planned start date for the expansion between Frankfurt (Zeppelinheim) and Mannheim (Bund, 2017). Thus the current long term plan for German railways detailed in BWVP (2016) is not sufficient to provide for the doubling of freight traffic in comparison to 2008 levels.

The investment plan for doubling German rail network capacity drafted in Holzhey (2010) considers three levels of interventions: a set of immediate measures with focus of port hinterland traffic and closing gaps in the network, a growth programme providing additional capacity to core nodes in the network and a set of new infrastructures. Costs range between 305 million euros for the immediate programme to over 20 billion euros for additional infrastructures. Relating these to the additional traffic volume, which could then be catered by the network suggests that the costs per tkm of new infrastructure investment are 100 times higher than the measures of the immediate programme.

All programmes together cause investment of 407 €/tkm in 2010 prices or 450 €/1000 tkm in 2015 prices. Depreciating this value over 30 years with a 3% interest rate leads to annual costs of 23 €/1000 tkm. Adding additional network maintenance costs of 30% leads to 0.03 €/tkm.

Table 31: Estimated costs for rail infrastructure investments for doubling track capacity in Germany

Programme / measures	**Costs (mill. Euros 2010)**	**Additional traffic volume (mill. tkm)**	**Add. traffic volume per 100 mill. euros (mill. tkm)**	**Costs per billion tkm (mill. euros)**
Immediate programme port hinterland	205	20,000	6,557	15
Growth programme	2100	20,000	952	105
Additional infrastructures [1]	>20,000	15,000	75	1,333
TOTAL all programmes	22,405	50,000	245	407

[1] Wendlingen-Ulm, Karlsruhe-Basle (RALP corridor), Y-track Hamburg-Bremen-Hannover, Rhine-Main-Neckar

Source: Holzhey (2010)

Putting these figures into relation: With a social interest rate of 2% and a 50 year depreciation period we receive an annuity of 440 million euros for the total of all programmes in Table 31. Related to annually 50 billion tkm shifted to rail this is 0.80 €-Ct./tkm. Current track access charges are around 3.00 €/train-km (Table 8). With 740 t/train for general cargo (Table 18) this is 0.40 €-Ct./tkm. This means that the doubling capacities in the German rail network without other measures (longer trains, more efficient control systems, etc.) would imply a doubling of track access charges for new traffic of a 50% increase for total rail freight.

To make such programmes feasible we either need political consensus for these expenditures or further efficiency enhancement technologies to ship more payload over these expensive infrastructures.

7.2 Train control systems

The next aspect to be considered is the application of new generation train control systems. The EU has developed the ERTMS system. ERTMS level 2 system uses satellite communications for continuous position monitoring of the train and the provision of continuous signalling information to the driver. This removes the requirement for trackside signals and enables more precise train operations with reduced headways between trains. SBB has reported capacity increases of up to 25% for tracks carrying mixed freight and passenger traffic.[5] The EU has developed a deployment plan for ERTMS level 2 and on the Rhine-Alpine corridor The Netherlands, Belgium and Switzerland are implementing ERTMS level 2 on their entire network (EC 2017a). While Germany has not implemented ERTMS, it does have a system with equivalent capabilities installed on the high speed lines. ERTMS costs more than conventional signalling, but if lineside signals can be reduced or replaced, operational costs are reduced:

Table 32: Costs of implementation of ETCS (level 1 and level 2)

Category	Level 1 €/km double track	Level 2 €/km double track	Installation of equipment on trains
Studies, technical documentation, design etc.	20 000	100 000	110 000
Infrastructure construction	90 000	400 000	340 000
Total system costs	110 000	500 000	450 000
Observed costs	35 000 to 140 000	140 000 to 940 000	120 000 TO 800 000
Annual operating and maintenance	15 000	130 000	110 000

Source: Urbanek (2016)

ERTMS level 3, which implements moving block signalling, is in development and will bring further cost savings and capacity increases. It checks train integrity by satellite and removes the requirement for track circuits or axle counters. Current plans envisage Europe-wide deployment of ERTMS level 3 and the associated capacity gains for freight trains and mixed used tracks as well as dedicated high-speed routes by 2030. This implies that a scenario in which moving block signal-

5 http://www.ertms.net/wp-content/uploads/2014/09/ERTMS_Factsheet_10_Increasing_infrastructure_capacity.pdf.

ling is implemented on all rail freight corridors by 2050 is realistic, especially because the change from ERTMS level 2 to level 3 does not require trackside infrastructure. Lines completed with ERTMS level 2 (or equivalent in Germany) by 2030 can therefore be assumed to be upgraded to moving block signalling by 2050.

7.3 Longer trains

Making freight trains longer constitutes the single most effective measure for increasing the sector's productivity (CER, 2016). The EC envisages a standard train minimum train length of 740 m along the rail freight corridors. Currently train lengths in Europe vary between

- 600 m and less in Italy, the Iberian Peninsula and most of Scandinavia,
- 740 to 750 m in most of central Europe and
- 835 m in Denmark and 1000 m in Estonia.

Experiences worldwide, research projects and European pilot applications show that there is no theoretical limit to the length of freight trains and that re-designing infrastructures to cater longer train sets is possible. CER (2016) report train lengths of 4000 m and more in Canada, Australia, South Africa and the U.S. Most of these solutions are not suitable to the mixed traffic networks in Europe, and thus new ideas have to be developed.

Pilot projects in Europe include the 1000 m train project in Denmark (Danish Ecological Council, 2015). This shall offer an attractive transit line from Germany to Sweden by going into Malmo and thus shall help shifting goods from road to rail. The 836 m trial from the Danish border at Puttgarden to Lübeck and Hamburg by DB Netz AG is valuable for gaining experiences, but does not fully support the Danish and Swedish efforts. The German Freight Transport and Logistics Master Plan (BMVI ...) suggests further tests up to 1500 m. Other corridor countries like Switzerland or Poland have no intention to increase train lengths beyond 750 m so far.

The EU-funded research project MARATHON (Castagnetti and Toubol, 2014) in cooperation with SNCF could demonstrate that under European network conditions 1500 m freight trains can be operated. But the study also points out that the higher risk of failure with 1500 m trains currently suggests they are operated outside busy main lines. There are investment needs along several elements of the infrastructure (control systems, overhaul tracks, shunting yards), but these are feasible and not very time consuming.

For the 2050 Pro Rail Scenario we define a standard freight train length of 15000 along the entire corridors including main and alternative lines of 1500 m. Trains will be equipped with two synchronised locomotives to ensure dynamic acceleration and brake behaviour. This goal is for 2050. By 2030 we envisage a train length of 1000 m in average along the corridors. CER (2016) reports results from DB, where on a busy mixed route an increase in freight train length from 740m to 1000m is estimated to provide a net increase in capacity of 19.5% for a 35% increase in train length, allowing for the extra demands on track capacity of longer trains as well as the reduction of the number of trains. Extending this estimate for a further 50% increase in train length to 1500m can be assumed to generate at least a further 38% capacity expansion or a more than 50% expansion in capacity compared to the present train length of 740m. Note that 1500m trains are assumed to require two locomotives and extra braking controls, such that the economics of scale in rolling stock would be limited.

Investments in following infrastructure elements are needed:

- Strengthening bridges to safely cater passing trains if needed (experiences from Germany and France suggest this not to be a major problem);
- Extension of siding sand passing loops;
- Extension of marshalling yards where needed (obsolete with self-driving locos and automated coupling, which allows splitting into two shorter trains);
- Adjust train safety and control systems (obsolete with ETCS, which is designed for a maximum of 4095 m);
- Radio kits for remote controlling locomotives;
- Upgrade wagon frames to withstand pulling and compression forces.
- Automated coupling.

8 Conclusions

8.1 Review of findings

In this discussion paper we have reviewed the key drivers for mode shift in freight transport along two of the major European rail freight corridors: RFC1: Rotterdam-Genoa and the Western Part of RTC8: Antwerp-Warsaw. Through a literature review of railway undertakings, public institutions and the research community we have identified the following drivers:

1. Costs: Costs to the forwarding industry basically contain all elements of a supply chain. Monetary transport costs are the single most important driver of most mode choice decisions. Other supply chain characteristics follow with considerably less weight.
2. Speed: fast delivery in particular for container goods.
3. Reliability of services above a critical threshold (punctuality).
4. Safety against losses and damage of shipments.
5. Flexibility: short run changes to bookings may be essential in highly interconnected and market-driven production environments.
6. User-tailored services, in a post-industrial era production and logistics processes are becoming less standardised.

In this study we have reviewed detailed costs of road, rail and intermodal transport and for each of them have made assumptions on their potential development towards 2030 and 2050 for the Business-as-Usual (BAU) and Pro Rail scenarios. Have also looked at the potential efficiency increases and on reliability issues in the transport sectors. Finally we converted all this information into general cost development indicators.

In the BAU scenario we see a clear decline of rail transport costs towards 2050. This assumption is based on current observations of successes in re-structuring the sector. The still available enormous efficiency gains of the railway market will partly be utilised by measures which have already been implemented today. This is enabled by market opening and privatisation in the rail business.

In the BAU scenario road transport will also profit due to company mergers and the long-term independency from fossil fuels. While road freight rates are expected to decline by 17% towards 2050, the relative cost advantage of rail is still 26%.

The Pro Rail scenario is characterised by massive investments in rail capacity in the form of new infrastructure, but more importantly in high capacity and flexible train control and communications systems such as ETCS / ERTMS level 3. With advanced asset and demand management platforms train, wagon and container space are filled close to system saturation. These measures mean that rail costs per ton kilometre are expected to declining by 76% towards 2050 for general cargo.

Truck operations in the Pro Rail scenario are partly restricted and are subject to stricter social rules and much higher road charges. In total truck operating costs are expected to climb up by 27% in 2050 relative to 2015. Therefore, the relative cost advantage of rail improves further to 81%.

Table 33: Illustrative cost development for a 300 km haul with general cargo by scenario 2030 and 2050 relative to 2015

Mode	BAU 2030	BAU 2050	Pro Rail 2030	Pro Rail 2050
Rail unimodal	-10%	-18%	-40%	-59%
Truck unimodal	0%	-13%	+19%	+33%
IWT unimodal	-7%	-25%	-19%	-53%
CT Rail-Road	-2%	-8%	-31%	-37%

Source: Fraunhofer ISI

Looking at single cost categories we find that in the rail sector the deepest reductions, more than -70% against 2015 cost rates, have been assumed in infrastructure due to massive state subsidies and for labour and overhead costs due to automation and the application of highly sophisticated management tools. In contrast the road sector is expected to see the most drastic cost increases in infrastructure charges and vehicle operating costs due to strong regulations in favour of the rail sector in the Pro Rail scenario (Table 34).

The results for cargo transport presented in Table 33 consider the impact of reduced travel time, reliability or any other quality indicator indirectly. Travel time and congestion see considerable improvements in the rail sector due to advanced train control systems. These effects are, however, already included in the shipping cost figures above. In road haulage we expect some kind of stagnation in the BAU scenario, but a clear rise in the Pro Rail case as here clearly less money is invested in extending the road network.

Table 34: Cost developments 2050 by category, mode and scenarios relative to 2015

Cost category	**Rail**		**Road**		**IWT**	
	BAU	**Pro Rail**	**BAU**	**Pro Rail**	**BAU**	**Pro Rail**
Infrastructure	-20%	-75%	0%	200%	0%	0%
Vehicle	-25%	-60%	9%	52%	0%	-60%
Energy	-12%	-35%	0%	15%	-30%	-30%
Personnel	-42%	-68%	-20%	10%	-30%	-30%
Administration	-25%	-70%	-20%	-20%	0%	0%
TOTAL	-18%	-59%	-13%	33%	-8%	-37%

Source: Fraunhofer ISI

With a social interest rate of 2% and a 50 year depreciation period we estimate an annuity of 440 million euros for all programmes. Related to 50 billion tkm moved annually this is 0.8 €-Ct./tkm. Current track access charges are around 0.40 €-Ct-/tkm. This means that the doubling capacities in the German rail network without other measures implies a 50% increase of average infrastructure charges per ton of cargo.

As such huge investments are not self-financing, either political will or additional measures further lifting the tons shifted to rail are required. Declining operating costs of the railways and savings in environmental effects may partly counterbalance rising infrastructure costs. The Swiss Alpine base tunnels have shown that political will plus accounting for all potential benefits can make such projects feasible.

8.2 Discussion

In this paper we have derived two scenarios of freight transport generalised costs, which are able to profoundly restructure the level playing field between road, rail and inland waterway transport along major European corridors. The assumptions are far reaching and ignore limiting and rebound effects through capacity scarcity and increasing operational complexity with more dense traffic on the rail network. Although we have shown that additional capacity may be provided with limited additional average infrastructure costs per ton kilometre, current experiences with land availability, planning and construction times and public acceptability will most likely not allow the full capacity investment programme needed to be in place by 2030 or even by 2050.

Massive infrastructure investments, high frequency train schedules and 1500 m trains are pretty distant from the majority of contemporary railway enhancement programmes. With the newly opened Swiss Alpine base tunnels and the Betuweroute from Rotterdam to Germany two impressive pieces of rail freight infrastructure have been built, SNCF has successfully tested 1500 m trains in the MARATHON project and ETCS level 2 train control systems are implemented. But on the other hand Germany lags behind connecting the Swiss and Dutch infrastructures with powerful access links, EC corridor standards envisage 740 m trains, ETCS level 2 works with different dialects across Europe and ECTS level 3 is not even defined yet.

The Pro Rail scenario also requires far reaching company internal and technological modernisation programmes. Full digitalisation and linking of all operational processes, the automation of train driving, train formation and cargo handling are only some examples of how the rail sector needs to adapt to new opportunities and market demands. In fact this means a complete renewal of the sector within the coming 30 years. We thus go beyond incremental changes with well known technologies and forms of operation and looked into a fundamental system transformation within the Pro Rail scenario.

If we remain on a pathway of incremental changes and investment programmes some re-gains of market shares are still possible, but they will remain moderate. Studies on feasible rail investment programmes arrive at a maximum figure of 22% to 24% market share in the coming decades. This still means a 50% increase in current rail volumes and thus an enormous challenge for the networks. But even if all of that increase is withdrawn from trucks, for road haulage this only means a decline by about 8%. This is far below the projected growth of around 60% from 2015 to 2050. Accordingly, these moderate scenarios will not help road traffic to decline and thus to effectively approach GHG reduction targets.

Whether large investment programmes and cost level changes lead to a market success for the transport modes affected depends on some further factors: the openness, flexibility and market orientation of the companies and the clearness of transport policy. Both issues have been elaborated in Summary Report 1 of the LowCarb-RFC project (Petry et al., 2018) for the railway sector. The report finds that a strong external driver through clear policy goals and action needs to go hand in hand with internal reform processes, the adoption of new technologies and business models and the development and growth of innovative market niches. For both policy and transport undertakings, these reform processes do not necessarily mean a complete removal of current structures, but a thorough review of technologies, procedures, legislations and management structures. Without doing so the envisaged deep cuts on the cost structures in the Pro Rail scenario, and even the rather optimistic assumptions for the Business-as-Usual scenario will not be realised.

To take account of these limitations, the transport demand impact assessment in Working Paper 7 and the environmental impact assessment in Working Paper 8 consider two additional scenarios. These are the Mode Rail and Mode Road cases, which simply assume only 50% of the generalised cost reduction potentials to be realised in the freight markets. The logistics chain model used for the transport impact assessment then shall investigate whether these intermediate cases are sufficient to reach a tipping point of forwarders' mode choice.

8.3 Outlook

The deep cuts on rail production costs and strong increases in road costs are expected to have a profound impact on mode share. To get an idea of the order of magnitude of mode shift effects we can do the following "back of the envelope" calculation: Cross price elasticity values for rail with respect to relative change of road prices by 10 commodity types are given in (Schürch, 2009). Values range from 0.15 for solid fuels and ores to 1.05 for food and fodder and 1.35 for minerals. With a central value of 0.60 we would receive 62% additional traffic on the rail network in 2050.

This rough estimate is considerably lower than market potential studies and policy objectives: Holzhey (2010) estimates a doubling of rail freight capacity and the 2011 White Paper of the European Commission sees additional 200% to 300% of traffic on European freight railway networks. Due to the non-linear nature of decision structures in particular in the case of major capacity changes, a more detailed and sophisticated impact assessment is needed to capture likely mode shift and resulting GHG mitigation effects.

Of course, the railways are not the only active players in the freight market. Assumptions for a progressive road haulage scenario (Pro Road) are presented in a separate Working Paper 6 of the LowCarb-RFC study. The impact assessment will be carried out by the TPR logistics chain model in the LowCarb-RFC project and will be published in the subsequent Working Paper 7 on transport impacts and in Working Paper 8 on sustainability impacts for the European corridors RALP and NSB. All corridor-related results will be condensed in Summary Report 2. More local impacts including detailed investment scenarios, employment and economic effects for the federal state of North Rhine-Westphalia are finally subject to Working Paper 9 and Summary Report 3.

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9 LowCarb-RFC Project Publications

The below list of 9 working papers and 3 summary report is in parts preliminary as some of the material is in preparation by the time of releasing this report. A current list of publications is at:

- Fraunhofer ISI: LowCarb-RFC project website: https://www.isi.fraunhofer.de/en/competence-center/nachhaltigkeit-infrastruktursysteme/projekte/lowcarb_rfc.html
- Stiftung Mercator, Climate-Friendly Freight Transport in Europe: https://www.stiftung-mercator.de/en/project/climate-friendly-freight-transport-in-europe/
- Transport & Environment, Low Carbon Freight: http://lowcarbonfreight.eu/

Summary Reports

Petry, C., Maibach, M., Gandenberger, C., Horvat, D., Doll, C. and Kenny, S. (2018): Myth or Possibility – Institutional Reforms and Change Management for Mode Shift in Freight Transport. Summary Report 1 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Infras, Fraunhofer ISI, T&E.

Doll, C., J. Köhler, A. Eiband, E. van Hassel, S. Mader (2018): The Contribution of Mode Shift and New Technologies to Climate Mitigation in Freight Transport. Summary Report 2 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI, Fraunhofer IML, TPR/UNiv. of Antwerp, M-Five.

Doll, C. et al. (2018): Policy and business - how rail can contribute to meet transport climate targets in the freight sector. Summary Report 3 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI, Fraunhofer IML, TPR/UNiv. of Antwerp, M-Five.

Working Papers

Doll, C., Köhler, J., Maibach, M., Schade, W. and Mader, S. (2017): The Grand Challenge: Pathways Towards Climate Neutral Freight Corridors. Working Paper 1 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI and IML, INFRAS, TPR and M-Five. Karlsruhe.

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Meyer, N., Horvat, D., Hitzler, M. and Doll, C. (2018): Business Models for Freight and Logistics Services. Working Paper 4 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI. Karlsruhe.

Doll, C. and Köhler, J. (2018): Reference and Pro Rail Scenarios for European Corridors to 2050. Working Paper 5 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI. Karlsruhe.

Mader, S. and Schade, W. (2018): Pro Road Scenario for European Freight Corridors to 2050. Working Paper 6 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. M-Five GmbH. Karlsruhe.

Van Hassel, E., Vanelslander, T and Doll, C. (2018): The Assessment of Different Future Freight Transport Scenarios for Europe and the North Rhine Westphalia region. Working Paper 7 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. TRR, University of Antwerp and Fraunhofer ISI. Antwerp.

Doll, C., Sieber, S., Köhler, J., Sievers, S., van Hassel, E. and Vanelslander, T. (2018): Sustainability Impact Methods and Application to Freight Corridors. Working Paper 8 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI TPR/University of Antwerp, Karlsruhe.

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10 Annex 1: Mode Shift Studies Reviewed

Institutions / reference	Study acronym / name	Brief description	Identified Drivers for rail freight success	Recommended measures	Impacts
Research					
de Boer et al. (CE Delft, TRT), 2011; client: CER	Potential for Mode Shift to Rail Transport	Study on the projected effects on GHG emissions and transport volumes. Review of drivers and market potentials for European rail freight	Costs (transport, inventory, handling), Transport - / lead time, scalability of arrival time, Quality: reliability, flexibility, information, transparency, security; Cargo handling characteristics	Networks: market opening, interoperability, international focus, efficiency; Road and fuel pricing	(++) Scientific study Contains market growth estimates
Holzhey (KCW), 2010; client: UBA	Schienennetz 2025/2030	Conceptual rail freight network in Germany for +125% tkm in 2025/2030 against 2009	Reliability and availability through sufficient capacity; Cost efficient infrastructure provision; Focus on main corridors	ETCS or similar for closer train distances; Local improvements (sidings, level-free crossings, etc.); Additional tracks and electrification along major corridors	Capacity effect: - local measures +27%; - large investments: +35% Estimated costs: €11 bn
Castagnetti, 2008; client: EC	NewOpera – the Rail Freight Dedicated Lines Concept	Study following the 2001 EC Transport White Paper; by new products and services	Multi-product culture; Customer orientation, including tailor-made solutions; Explore / use ITC technologies incl. tracking & tracing; reliable and consistent services; market opening and competition; international standards	Standarisation of current, axle load 22,5 t or more; train length 750 m or more; common management of capacity, priorities, emergency, pricing, etc.; European empty wagon management	Network investment Madrid-Berlin (costs road +20%, rail -15%): - rail share + 16.5% Intermodal scenario: - rail share +39.7%; - CO2-2,5 Mt

Institutions / reference	Study acronym / name	Brief description	Identified Drivers for rail freight success	Recommended measures	Impacts
Skinner, Hill et al. (AEA Technology, CE Delft, TNO), 2012; client EC	EC Transport GHG Routes to 2050	Technology and policy scenarios for meeting a 60% reduction transport CO2 emissions incl. international maritime shipping and aviation	Among other drivers for reducing CO2 emissions: Availability user acceptance prices quality and speed Consider rebound effects	Policies for CO2-rection: energy system, vehicle efficiency, transport system efficiency. For freight: distribution concepts, sustainable investment, traffic / sped management; economic instruments	Cumulated emissions 2010-2050: energy system -29%, vehicle & transport system efficiency -9%, economic. instruments. -21%; Freight intermodality alone 2050: -5%
Allan et al. (AECOM Ltd.), 2016; client: UK-DfT	Future Potential for Modal Shift in the UK Rail Freight Market	Review of potentials for growth in the UK rail freight sector after an unexpected decline in traditional rail freight markets	Focus on growth markets; infrastructure capacity, costs, flexibility, awareness & attitudes, skills & training	Markets: Intermodal, construction, channel tunnel, express parcels, automotive; Investment, new systems, promotion, engagement, facilitation/funding, regulation, research, HRM	GHG savings through mode shift: up to 19% of current HGV emissions
Industry					
Deutsche Bahn AG (2015)	Zukunft Bahn (Future Rail)	Strategy paper of DB AG for economic success in all its business areas	Punctuality (95%/30 min.); Availability of empty wagons; Cost reduction (-30%); Capacity increase	Priority for core business segments and A-customers; Alignment of closer customer care with real capacities	(++) Rail sector strategy
SBB Cargo (2012)	Master concept for rail freight	Broad concept for fostering rail freight market share in Switzerland	Active engagement of SBB in freight markets in close cooperation with customers; Awareness for latest technologies for efficiency and customer satisfaction	Human resource management and training; Concentration on core markets;	(++) Rail sector strategy

Institutions / reference	Study acronym / name	Brief description	Identified Drivers for rail freight success	Recommended measures	Impacts
				Pilot projects automated coupling, self driving trains, etc.	
ERRAC (2015)	Rail Route 2050: the sustainable backbone of the Single European Transport Area	Strategic Rail Research Agenda (SRRA) of the European Rail Research Advisory Council (ERRAC), update	Single European vehicle and infrastructure authorisation; Europe-wide interoperability; fair intermodal competition Meet customer expectations; environmental performance; enhance competitiveness	Strengthen ERA; enhance and deploy ERTMS; fully internalise externalities; Meet technology challenge, improved ICT systems; Cost effective technologies incl. retrofitting solutions; staff motivation and training	Mode share rail freight 2000-2050: 11,5%-22,2%
mofair / NEE (2016)	Wettbewerber-Report Eisenbahn 2015/2016	Bi-annual competitors report on the state of competition in the German railway market	Fair charging for infrastructure and energy; Equal treatment of local infrastructure financing and costing	Lower track access and energy cost burdens; Public investments in local rail networks (industry sidings, park and passing tracks, marshalling yards); more stable financing cycle	No forecasts made
Netzwerk Privatbahnen, 2009	Ein Leitbild für die Eisenbahn im Jahr 2030 in Deutschland	Policy communication on a vision for rail transport and needs for action in Germany by 2030	Policy commitment; Infrastructure quality & capacity; Sustainable financing; Efficient organisation	Less attention to HSR projects and max. speeds; Policy enforcing sustainable behaviour of incumbents; Separation of IM and RU	No quantification
Policy					

Institutions / reference	**Study acronym / name**	**Brief description**	**Identified Drivers for rail freight success**	**Recommended measures**	**Impacts**
UNECE, 2011	TEM and TER revised Master Plan	Investment programme for North-South Trans-European Motorway (TEM) and Trans-European Rail (TER)	Border crossing procedures; Intermodal links; ITS System application; Balancing operations and security needs	Formulate clear policy objectives; Restrict rail pricing to variable and social costs	
Crozet, Y., J. Haucap, A. Musso, E. van de Voorde, et al. 2014, for CERRE	Development of rail freight in Europe: What regulation can and cannot do	Policy paper by key European rail experts for the Centre on Regulation in Europe (CERRE).	Economic growth; Generalised costs (monetary + temporal costs; VOT, reliability) Access to networks and terminals by all RU Customer-tailored products	Rail de-regulation; Fair charging and taxation; Address key markets; High quality train paths; Non-discrimination and co-operation	No quantitative Scenarios; Statistical correlation between rail market growth and de-regulation indices is weak.
Erhardt et al. (2014); WWF, BUND, Germanwatch, NABU & VCD supported by Öko-Institut	Klimafreundlicher Verkehr in Deutschland (Climate Friendly Transport in Germany)	Five leading environmental associations, supported by the Federal Ministry for the Environment have drafted a scenario for low carbon passenger transport in Germany by 2050.	Product structures, transport distances; Quality (flexibility, reliability, punctuality, safety, temperature control); Distance to nearest siding or combined transport terminal; Infrastructure capacity	Double rail capacity through new investments, overhaul tracks, better use of existing capacity (ETCS, etc.); lower access charges and internalise external costs; foster competition; Lower noise impact	In the market segments automotive, chemicals and stones & ores rail doubles its market share; Total rail share grows from 18% to 38%; Road share declines from 72% to 50%
Lambrechts & Dasburg-Tromp (2014); PBV / PANTEIA,EC	PLATINA2 – Platform for the implementation of NAIADES II	The coordination action explores ways to strengthen inland waterway transport (IWT) in the EU. D1.3 reviews selected studies and practice cases on mode shift to IWT and rail.	(1) Transport costs door-to-door – most important; (2) reliability; (3) transit time; (4) flexibility and (5) safety	Marketing and demonstration cases for shippers is essential for attracting attention towards rail and IWT solutions.	No quantitative results provided (networking activity)

Institutions / reference	**Study acronym / name**	**Brief description**	**Identified Drivers for rail freight success**	**Recommended measures**	**Impacts**
Permala & Eckhardt (2015); VTT, PTV, UoW, VGTU, ESC, NEW, Trans. EC FP7	BESTFACT – Best Practice Factory for Freight Transport	The project reviews 158 practice cases in three clusters: urban areas, green logistics/co-modality and paperless processes. By making better use of good practices EU sustainable freight transport goals shall be supported.	General drivers: costs (fuel prices, taxes), unreliability of road; location of processing sites; containerisation, supply chain control. Specific for CT: network / intermodal capacity, high speed services, gauge for 45' containers; long start-up times	New markets: food / pallets for retail, parcels, flowers. Recommendations for green logistics and co-modality: - Intermodal services and connections, - new technologies - Decarbonising - Collaboration	
Castagnetti & Toubol (2014). New Opera et al. for EC-FP7	MARATHON	Following on the New Opera, TIGER and TIGER-PLUS projects the study implemented a demonstration case for a 1500 m train in France.	Capacity generation; the frequency set the traffic bundling for economies of scale; an operating cost reduction; readily available services; De-carbonisation of services	Capital rotation and following a offer driven business approach (door-to-door); logistics solutions and marketing to fill up spaces; moderate upgrades of overtaking lanes, terminals and train control systems	MARATHON-train: track cap. +67%, costs/t -30%, Scenario Paris –Marseille: operative margin +6%, freight rates -3.3%, new demand +1.6%, accidents -20%, GHG -2% to -6%
Lambrecht et al. (UBA), 2009	Strategie für einen nachhaltigen Güterverkehr		Most relevant: reliability, times and costs; Quality (flexibility, bundling capacity, network coverage, frequency, safety, user friendliness, etc. Production sector organisation (globalisation, diversification, just in time, commodities); Cooperation / city logistics; enforcement of social rules	Network investments (needed for quality and capacity); HGV tolls incl. external costs; Simplification of border crossing services; Support of CT	Total THG emissions in freight transport 2008 – 2020 back to 2005 levels = -9.6% Mode shift potentials containers >300 km (50 200-300 km; +15% containerisation in 2025: - 2005: 8%-16%, - 2025: 25%-41% of road volumes

Institutions / reference	**Study acronym / name**	**Brief description**	**Identified Drivers for rail freight success**	**Recommended measures**	**Impacts**
The Future Railway - The Industry's Rail Technical Strategy 2012 Supporting Railway Business	Technology Strategy Leader Group (TSLG), 2012	Departing from the Rail Value for Money Study, the report rolls out a strategy for actions for the rail industry	Cost cuts and improvement of user experience. Drivers: electric traction, no lineside signalling, no service interruptions	Real-time intelligent TMS; Management strategy for condition-based intervention; High-capability strategic freight network; Automated trains, modular rolling stock design; Co-ordinated planning, operations & management	Results not quantified; similar cost saving as "Rail Value for Money" study, but with a broader mix of interventions. Low Carbon energy efficient railway
Realising the Potential of GB Rail - Report of the Rail Value for Money Study	Department for Transport (DfT), 2011	Starting from the observation of high costs and inefficiencies in the UK rail sector the review explores ways to significantly cut costs while improving users' and tax payers' value for money.	Supply chain costs; Service reliability	Clear incentives to users and the rail sector; Efficient supply chain, asset and HR management; Inclusive implementation plan	Cost savings 3.5 bn. GBP 2012-2019 through incremental changes

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