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The Grand Challenge: Pathways Towards Climate Neutral Freight Corridors

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Abstract

This working paper constitutes the first public document compiled by the LowCarb-RFC study, co-funded by the Mercator Foundation and the European Climate Fund (ECF) between 09/2015 and 08/2018. This report presents a preliminary screening of the current state of discussion, recent literature and methods on the options and barriers for de-carbonising long distance freight transport by rail, inland waterways and road towards 2050. Out of this information it derives preliminary recommendations of sensitive issues and directions on critical needs for action and research directions.

We might reach deep cuts in the carbon emissions of European transport by several ways, but we do not yet know how far we can get with the two main pathways – rail or road – and what their second round impacts beyond climate gas reductions are. With mode shift to rail, studies find reduction potentials between 20% and 60% in case a broad set of technology, regulatory and market based measures are successfully implemented.

Theories and recommendations on management strategies, concepts of institutions, recipes for change management, transition pathways, etc. are often based on single case studies, which do not necessarily correspond to the rail sector. Transforming these scientific findings into helpful strategy plans is challenging and may even fail. The focus of reviewing change management processes is to remain on the rail sector, while other economic branches like telecommunications, electricity or aviation can only be of supportive nature.

Deep cuts in road haulage GHG emissions often deal with technologies and proposals for boosting the efficiency and environmental performance of road haulage, which partly are still in an experimental stage. Looking at the stagnation in the sector organization over the past decades, the challenge is to separate principally feasible from overly optimistic pathways for organization structures in the trucking business. Nevertheless, some thoughts need to be spent on disruptive non-road technologies, such as automated underground container movement systems.

With the support of these analyses, the results of the LowCarb-RFC project will add to our understanding of successful policies for mitigating carbon emissions from freight transport. Potential pathways specifically for high volume European corridors to approach a zero carbon future for long distance freight transport will hopefully support the climate debate in the transport sector. The study further involves a test lab for local impacts of low carbon freight in the German federal state of North Rhine-Westphalia (NRW) and a stakeholder platform for exchanging ideas and experiences with the industry.

1 Introduction

1.1 Purpose of this discussion paper

This first public paper by the Low Carbon Rail Freight Corridor (LowCarb-RFC) study is intended to provide an overview of the state of discussion on traditional as well as on non-conventional ways to decarbonise freight transport along major corridors in Europe. It looks at two main freight corridors crossing Germany and, in particular, the federal state of North-Rhine-Westphalia (NRW). These are the European Commission's Rail Freight Corridors no 1: Rhine-Alpine (RALP) from Rotterdam via Duisburg and Basle to Genova and the southern branch of RFC no. 8: North-Sear Baltic (NSB) from the Belgian seaports to Poland and the Baltic states. Conventional rail improvement and policy packages are considered, emerging industry and technology trends as well as completely new transport solutions. The paper results from several project internal discussion workshops and literature reviews in specific areas of interest. From the work presented here we will identify open questions and further research directions to be pursued by the study. Where possible first hints on policy implications are given.

1.2 European transport policy and climate change

Transport is a key sector for a successful climate mitigation policy. This is first because it emits up to 30% of global greenhouse gases. Second, its emission rate is strongly linked to consumption levels. This is because a large proportion of passenger and freight vehicles use fossil fuels. This dependency is even stronger for the commonly heavy and long-distance freight sector than for passenger mobility.

A lot of options are discussed for mitigating freights' and logistics' GHG emissions, which may – with some degree of simplification – be categorised into three major clusters: shift, improve and avoid.

- Option 1: Shift as much as possible of demand from road to rail and shipping, including inland waterway transport (IWT) and short sear shipping (SSS). This approach is e.g. followed by the 2011 EC transport White Paper and the freight strategy of the German Environment Agency (UBA 2009).
- Option 2: De-carbonise road transport. This may be possible by hydrogen, biofuel or synthetic fuels or by the electrification of motorways. New technologies such as full or semi-autonomous driving, enhanced fuel efficiency, etc. will support this pathway, but in any case, new systems with new risks and shortcomings will have to find their way into the trucking market.

- Avoiding transport activities by more efficient production and distribution strategies and by more conscious consumption patterns has not materialised so far. This option may, however, become relevant within the digital transition of the economy.

Before discussing these options for road and rail freight transport along the two corridors selected we take a brief look at European policy to support rail in the past decade.

1.3 State of play – major sources of GHG emissions

Table 1 shows the limited options to mitigate transport-related GHG emissions in the near- and even in the long term.

Table 1: GHG emission share and reduction potentials by sector

Sector	Total GHG emissions share 2012	GHG reduction potential to 2030	GHG reduction potential to 2050
Power	31,0%	-54 to -68%	-93 to -99%
Industry	18,8%	-34 to -40%	-83 to -87%
Transport	19,7%	+20 to -9%	-54 to -60%
Residential / Services	13,3%	-37 to -53%	-88 to -91%
Agriculture	12,0%	-36 to -37%	42 to -49%
Other	5,3%		

Source: UIC / CER (2015)

Rail accounted for only 1.5% of GHG emissions in transport, including power for electric traction in 2012, which is considerably less than rail's market share. In contrast: Road accounted for 70.9% of GHG emissions.

Table 2: External costs from climate change by transport mode in Europe 2008

Segment		**External costs from GHG emissions (mill. €/a)**		**GHG unit costs (€/100 pkm / tkm)**	
Market	**Mode**	**Direct emissions**	**Upstream emissions**	**Unit**	**Unit costs**
Freight	**HGV / LDV**	33632	10567	tkm	19.6
	Rail	413	1947	tkm	5.1
	IWT	516	194	tkm	4.9
Passenger	**Car / Coach**	90792	29770	pkm	21.7
	Rail	630	3354	pkm	9.6
	Air	22166	3356	pkm	54.0

Source: Data from van Essen et al. (2011)

According to the latest issue of the study series External Costs of Transport commissioned by the International Railway Union (UIC) reporting figures for Europe, 2008 (van Essen et al., 2011) indicates that 24% of GHG emissions across all modes as well as within road transport are due to freight movements by heavy goods vehicles (HGVs) and light duty vehicles (LDVs) (compare Table 2).

The comparison between road and other modes of freight transport gets more expressed when looking at the average climate change costs per ton kilometre (tkm). Even when including all upstream costs associated with the extraction and transport of crude oil, the refinery and distribution of fuels, and the generation of traction electricity, with the current European power mix the railways still cause only a fourth of climate change impacts than road haulage. In passenger transport this ratio is roughly 2:1. This comparison and the fact that the electrification of road vehicles appears to be much easier in passenger than in freight transport indicates the need for prioritising freight over passenger in terms of European climate mitigation strategies.

Table 3: Key Performance Indicators for the selected corridors

Performance indicator	**Rhine-Alpine**	**North Sea - Baltic**
Route	(Rotterdam/Amsterdam -) Duisburg – Düsseldorf – Köln	Berlin - Hannover – Bielefeld - Köln (– Antwerp)
Freight transport demand 2012	371,984 kt (only international)	7,820,281 kt (total) 363,754 kt (international)
Freight transport demand Germany	234,301 kt (import and export)	3,652,427 kt 209,832 kt (import and export)
Freight demand growth (exp. 2030)	7% p.a. 40% total (2030)	Road 42%, rail 36%, IWT 22%, total: 34.5%. Germany: 25,5%
Freight demand by commodities	21% manufactured articles, 14% building material, 13% chemicals, 12% petroleum and ores	27% manufactured articles, 14% minerals & building materials, 12% petroleum, 11% chemicals
Freight demand share by modes	11.4% rail, 34.3% road, 54.3% IWT	11% rail, 69% road, 20% IWT+SSS

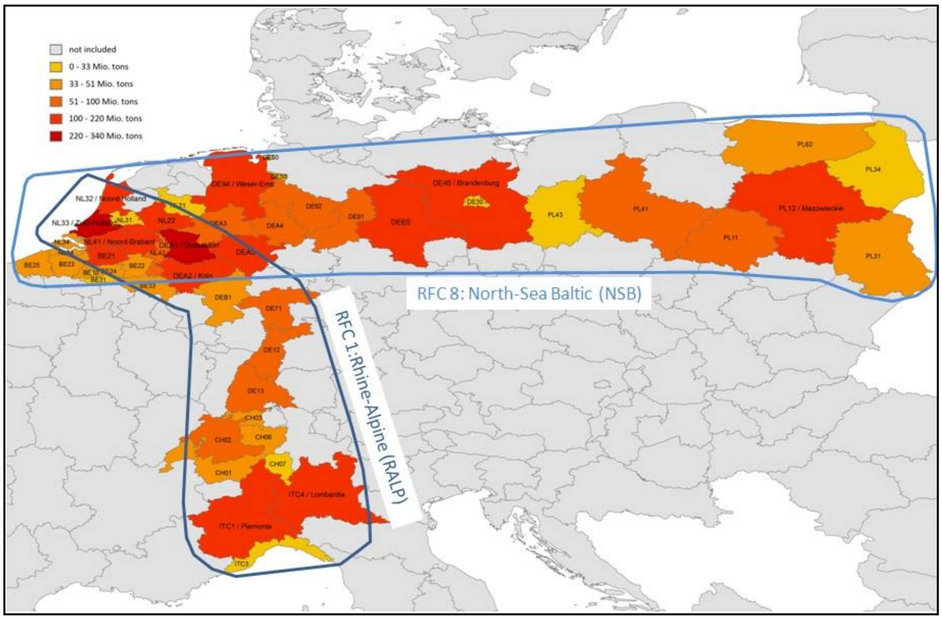
Source: EC (2014b), PROXIMAR (2014)

About half of freight movements are long distance transport. Most of it concentrates on the highly industrialised, densely populated and economically strong regions from the southern UK over the Benelux countries, northern France, Germany, the Alpine States and Northern Italy. This so-called “blue banana” broadly follows the river Rhine and connects the Benelux (Belgium and the Netherlands) seaports to the industrial areas of

Italy. In the corridor concept of the European Commission this corresponds to Rail Freight Corridor (RFC) 1: Rhine-Alpine (RALP). In 2010 it carried 1.75 million tons of goods including intra-zonal flows according to the EU's ETIS-PLUS database. This corresponds to 10.4% of the European freight market, which is 16.8 million tons in 2010. The official corridor report (EC 2014b) finds about 21% of corridor traffic being international, at which rail and IWT take the lion's share with 65.7% (compare Table 3).

Likewise important for European economic development and cohesion is the connection from the North Sea gateway ports to the New Member States, namely Poland and the Baltic countries (Lithuania, Latvia and Estonia). With 2.28 million tons lifted in 2010 the southern branch of Rail Freight Corridor 8 from the Benelux seaports via NRW to Poland carries 13.6% of European inter-regional freight volumes and appears thus even more important than the Rhine-Alpine route. This comparison is to be considered with care as the ETIS-PLUS data seems to ignore most of the SSS flows from the Benelux to northern Italian seaports. Total volumes including all branches and the extension to Estonia are even at 7.8 million kt (PROXIMAR 2014 and Table 3).

Figure 1: NUTS-2 regions along the European rail freight corridors 1 (Rhine-Alpine) and 8 (North-Sea-Baltic) by transport volumes



Source: own illustration

Together the two corridors cater a fourth of inter-regional freight transport in Europe. Moreover, both routes are characterised by a mix of transport modes and commodity types. They thus provide interesting and relevant candidates for investigating potentials and barriers to successful European low carbon freight transport strategies.

2 De-Carbonising Freight through Mode Shift

This section will briefly consider current developments and basic options for a major cut in long distance freight's GHG footprint via shifting traffic towards more climate-friendly modes. Climate-friendly modes include the railways, inland waterway transport (IWT) and some still to define alternative and unconventional forms of moving goods. Hereby we take the implicit assumptions that rail and the unconventional modes are 100% carbon neutral either through electricity from renewable sources or by compensating emissions elsewhere, e.g. through carbon trading mechanisms. Some of these options, in particular the application of trading mechanisms, are applicable to other modes too (compare Section 4). IWT is assumed to follow fuel efficiency gains as developed in road transport using cleaner fuels and advanced filter technologies.

2.1 European railway and freight policy

The scenario building process of this study concentrates on the climate mitigation potential of putting more freight on rail. Comparative studies on the external costs of transport were conducted and their results fed into Green and White Papers of the EC on fair and efficient transport prices in 1995 and 1998. In parallel, the EC promoted the concept of Freight Freeways from 1997 on and launched the intermodal investment programme Marco Polo in 2003. Stopping the decline of rail freight due to the liberalisation of European freight markets in the 1990s was one of the major objectives of this policy initiative. To monitor the current state of mode shift policy in Europe, based on Doll, Schade and Rothengatter (2015) a closer look is taken towards European and national policies impacting on the sector.

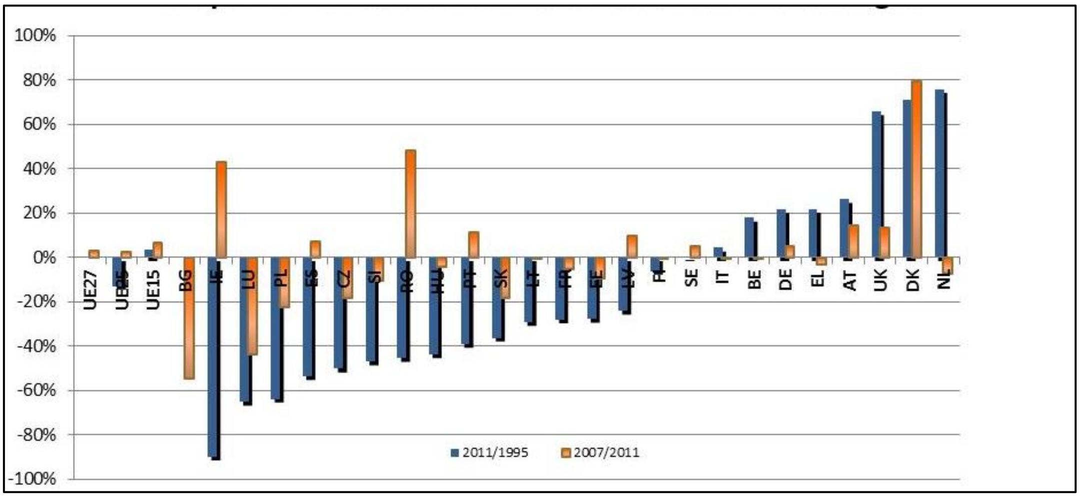
European railway reform policy began with Directive 1990/440/EG already in 1990, and was followed by three railway packages 2001 to 2004 and a fourth package currently under negotiation. Objective of the EC's railway policy is to overcome the technical and organizational fragmentation, and create a common free and competitive rail transport service sector, increasing the attractiveness of railways. Successes were made by separating infrastructure management from train operations, by establishing the European Railway Agency (ERA), by defining and implementing the European Rail Transport Management System (ERTMS) on major lines, by easing the licensing technologies for international operations and finally by investing in Trans-European transport corridors.

These efforts have culminated in the transport White Paper of the European Commission (2011), assigning a major role for GHG mitigation to passenger and freight rail. By 2050 these shall become the dominant modes of transport in appropriate distance bands. The EC White Paper formulates goals for the Greenhouse Gas reduction in transport (among others) until 2050. A reduction in carbon emissions of 60% compared to the base year 2008 shall be reached. It also develops a roadmap for reaching this goal. Concerning freight, relevant policy measures are the following:

- 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed.
- A fully functional and EU-wide multimodal TEN-T 'core network' by 2030, with a high quality and capacity network by 2050 and a corresponding set of information services.

Despite this, the prime political goal, as expressed in the White Papers of 2001 and 2011, to substantially increase the passenger and freight transport share of the railway market, has not yet been achieved. The modal shares of railways in the passenger transport market have not changed much and have actually decreased in the freight transport market over the past 25 years. According to the 4th rail market monitoring study (RMMS) of the European Commission the decline is most significant in Southern and Eastern Europe with 50% and more reduction in market shares. But there are success stories: Denmark, the Netherlands and the UK report increases in market shares above 60% from 1995 to 2007 and / or from 2007 to 2011. While some countries nor or less made up for the loss in market shares in the first period with gains in the second, a constant positive development path over the entire time span can be constituted for Austria, the UK and most dynamically for Denmark (Figure 2).

Figure 2: Rail market share development by country 1995-2012



Source: EC (2014)

The difficulties arising over this long process of restructuring the railways are caused by a number of factors: the technological and organizational fragmentation of EU railway organizations; the long life and high fixed costs of railway technology; the long time needed for migration of new technology and regulations; the national railway policies protecting their state companies; the resistance of trade unions against competitive structures; and low market pressure because of high national protection and subsidy.

2.2 Potential future pathways

A core role for overcoming these problems is devoted to the Member States. In particular for freight transport, long distance corridors with flexible access and prices that enable rail to compete with road for infrastructure use are essential. Departing from this observation, the 2050 roadmap of the LivingRAIL project devotes a major role in achieving substantial mode shift targets to national railway policy and to the railway themselves. However, we can currently observe a movement into the opposite direction. Member states and their national freight carriers are developing scenarios of getting out of single wagon load transport. This market segment, which still contributes to about 50% of freight markets, is to a large extent well suitable for truck transport and once gone will hardly come back to rail no matter how good service offers are.

To improve railways' competitiveness, the sector is promoting a set of measures which had been discussed through the past decades already. The Shift to Rail Joint Undertaking, equally funded by the European Commission and the railway industry, focuses on a set of rather simple sector quality targets: halving life cycle costs, doubling capacity and increasing reliability and punctuality by 50%. Means to achieve these measures include lightweight construction, longer trains, higher speeds, on-board and interconnected control systems and real time passenger and freight customer information platforms. Given the slow pace of innovation uptake in most European railways and the reluctance of forwarders to use rail due to the sector's complexity and inflexibility, one may assume that other measures than enhancing technical performance may be needed to substantially boost rail freight market shares in Europe.

Pathways for a successful re-organisation of freight railways may include:

- Incorporate the core concepts and production philosophy of the digital industry to boost efficiency and customer satisfaction;
- proactive marketing, new and possibly unusual business models to actively enter new markets and to get closer to customers;

- open cooperation with the road and shipping sector to make best use of available capacity;
- consideration of new forms of transportation to more effectively serve specific markets or regions, and finally
- changing management processes within the railways and in transport policy to speed up innovation and to make the sector more flexible and adaptive,

In case the railways fail to adapt to contemporary market structures, road haulage will most likely take over further market segments from rail. And that is not necessarily hindering the de-carbonisation of freight transport. Steps towards low carbon road freight transport are already made by road trials with overhead wire HGVs, new truck fuels including hybrid concepts, longer vehicles with better aerodynamics, and driver assistance systems for eco-driving and even fully automated trucks (compare Section 4). The decisive question for designing European and national freight policies then is, how far both alternatives can get into deep cuts in GHG emissions, how feasible or likely these scenarios are and which costs and side effects they involve.

2.3 Recent studies on mode shift to rail

2.3.1 European research

After publication of the EC (2011) Transport White Paper a number of roadmapping and strategy studies have been issued by the European Commission to seek for ways how to move the transport sector into the White Paper’s direction. The main results can be summarised as follows:

- **LivingRAIL**
  Achievement of the 2011 White Paper mode shift targets of 50% freight on rail and inland waterways by 2050 requires massive investments in capacities and a complete change of the railways‘ and policy business cultures towards complete customer orientation. Speed and cost changes alone will only achieve around 7 percentage points of mode shift gains. But achieving the White Paper targets will cut GHG emissions by 45% and air pollutants by 80%. Funding of the expected €1345 bn. of investment, maintenance and operation costs is feasible if the available instruments of cross-funding from road and air charging are utilised moderately but consequently.
- **TRANSFORuM** (Rupprecht Consult, EC-FP7, http://www.transforum-project.eu/):
  In its long-term outlook for long-distance freight, the project points to rising energy costs, outsourcing trends, automation, e-commerce, the sharing economy, aging, etc. In total, it is concluded that less freight transport will be needed due to the foreseeable economic and demographic future of Europe. But infrastructure investments and bottleneck relieve, in particular in the upper Rhine valley, are still needed al-

though public acceptance might be problematic. Efficiency and service quality finally are of utmost relevance for solving this conflict.

- **Marathon** (EC-FP7, 2011-214, http://www.marathon-project.eu/):
  The project follows up on previous technical development and demonstration projects like TIGER and TIGER PLUS. It developed and tested a 1500 m freight train on the SNCF network to demonstrate feasibility of highly efficient freight transport solutions. Faster and longer trains were also conceptionally designed in order to demonstrate the potential spectrum of moving the very traditional rail freight sector towards the market needs of the 21st century. Final goal was to explore the potential of bundling and operating cost reduction in rail freight to increase competitiveness against road. These goals were achieved by the project.

2.3.2 National studies

The Study “**Financing a Sustainable Freight Transport Infrastructure**” Sutter et al. (2016) commissioned by the German Environment Agency (UBA) drafts scenarios of infrastructure with the following strategies reflecting the strategy of the currently issued German federal transport investment plan:

- Financing system: Extension and further differentiation of the HGV and rail access charges, cross-funding from road and increased public sector contribution to rail and intermodal infrastructures, installation of rail funds;
- Infrastructure supply: 60% to 70% more rail capacity with extension of main corridors; doubling of terminal capacity, concentration on maintenance instead of new constructions in roads;
- Regulation for lower fuel consumption and better market access: further decrease of CO_2 emission limits for new road vehicles; energy efficiency limits, priority for freight trains on specific corridors, extension of environmental zones and logistics centers in cities.

With these measures, tkm in rail are 25% higher (and road is 9% lower) in the target scenario compared to the business-as-usual case. Rail share thus is 23% compared to 18% without the above measures. Gross value added and employment in Germany do only change slightly across all modes, but show a clear shift between modes and economic sectors. While the business-as-usual scenario forecasts a further increase in CO_2 emissions, the target scenario arrives a reduction by 18%.

The study “**Climate Neutral Germany 2050**” (UBA 2014) commissioned by the Federal Environment Agency UBA drafts a technology oriented scenario of a GHG-neutral transport sector in Germany by 2050. Main measures to be taken towards that stage, according to the study, are (i) the increase of European fuel taxes, (ii) an extension of the HGV motorway toll to all roads and all lorry types with add-ons for noise and air pollution external costs, and (iii) the removal of capacity bottlenecks in the German rail network. The exact impact of these measures on mode share is not provided, but together with a large-scale electrification of road transport GHG emissions of transport are nearly entirely eliminated. See also similar results in KCW (2012) and Zimmer et al. (2013).

2.3.3 Further publications

Particularly for freight, **Kordnejad (2014)** looks at intermodal light trains in order to combine the advantages or rail (high capacity on the main haul) with that of road haulage (flexibility in regional distribution). The loading space utilization of the train, the transhipment cost and fuel prices are considered the most problematic parameters. The concept of cost-efficient small-scale terminals might overcome some of these disadvantages. Tappich and Horwath (2015) add the lack of terminal capacity to the potential risks for increased mode share for rail.

Nelldal and Andersson (2012) compare business-as-usual scenarios for GHG emissions in the EU with worldwide best practices in rail share. Main measures for achieving high rail shifts are high speed investments and an extension of medium speed networks.

Den Boer et al. (2011) provide an overview of studies on the GHG potential through mode shifts to rail. Among others they looked at the measures assumed by the studies, their likely costs and their potential for increasing rail use and for mitigating CO_2 emissions. The review found a maximum market share of rail at 36% of tkm, requiring an improved service quality. Infrastructure constitutes a major bottleneck as this can cater only another 20% in terms of train kilometres. While improved supply in rail services would reduce GHG emissions by 10%-12%, the internalization of external costs throughout the EU would contribute only 2% in GHG reduction. An overview of studies considered in the report is given by Table 4. The Table briefly categorises the studies by types of measures and area, and by their impact on rail freight volumes.

Other options for heavy rail are longer trains. These can outweigh the risk from longer trucks in international haulage. Depending on configurations of both, scenarios for Sweden show up to +5.4% in ton-kilometres for rail and reductions up to -350 kt of CO_2-emissons in road haulage and shipping.

Table 4: Studies, measures and rail market impacts investigated

Study	Measures studied	Scope	Rail growth
Vasallo and Fagan (2005)	Full market opening, interoperability, international focus and productivity-enhancing infrastructure	EU	100%
Zimmer and Schmied (2008)	(a) Theoretical potential based on trip length and the assumption that the share of rail can rise significantly on longer distances (b) Potential from a practical perspective (BGL)	EU	a 90% b 7%
FERRMED (2008)	131-211 billion Euro investment in infrastructure provision and quality of supply (FERRMED standards); improvement of the core EU network covering 54% of population and 66% of GDP.	EU	8-15%
NEA (2004)	TEN network construction	EU	12%
Bühler and Jochem (2008)	a Road pricing based on MAUT b Improvement of quality of supply by speed increase of 24% of combined trip	Germany	a 14% b 60%
PRC (2007)	Road pricing based on MAUT	Netherlands	3-4%
van Essen et al. (2008)	Full internalisation of external and infrastructure costs	EU	10%
Significance (2009)	Full internalisation of external and infrastructure costs	EU	10-32%
Schade et al. (2008)	Doubling and tripling of oil price	EU	6%

Source: Den Boer et al., (2011), Table 14

Further investigations on the role of mode shift and intermodal freight networks on the greening of logistics and on reducing carbon emissions from freight transport are presented in Bouchery and Fraanso (2014), Rich, Kveiberg and Hansen (2011), Sanchez et al. (2015) and Stelling (2014).

2.4 Drivers and barriers

2.4.1 Infrastructure investments

The most limiting factor for mode shift to rail seems to be infrastructure capacity. In particular along the core network corridors, more than 20% of additional traffic requires massive investments which consume considerable construction time and budgets. Barriers to rail network investments include:

- *Funding systems*. Only with substantially more public money, user participation and cross-funding from road sufficient capacity for doubling or even tripling rail freight volumes is conceivable.
- *Planning procedures*. In Germany exploration and planning procedures take 15 to 25 years before the actual construction works even start. With policy intruding planning or construction processes, projects might be very lengthy and tend to overshoot cost projections by far. Clear rules could help here to make planning and construction processes more efficient than they are today.
- *Noise exposure*. Freight trains are a substantial source of disturbing and partly even harmful noise levels around and in dwellings. Citizens get increasingly sensitive to such issues and get more aware of their rights to participate in decision-making processes. Without solving the railways' noise problems new investments in the European core economic zone will get very difficult, expensive and lengthy at best.
- *Land values.* Economic activity usually takes place in regions with high population density. Here, transport infrastructure construction competes with industrial sites, settlement development or recreational facilities. In the European core area land thus gets scarce and rises in value driving the costs in investment project up.

Further factors are missing cooperation in long-term policy planning, competition between stakeholder groups, unclear decision frameworks or technical standards, complex operating rules and weak direct user relationships.

Drivers and barriers to more use of rail in freight transport are often two aspects of the same criterion, e.g. high or low prices, dense or sparse frequencies, etc. In freight transport factors like costs, shipment times, reliability or flexibility are commonly considered more relevant than in passenger travel. However, also freight forwarders and shippers are driven by routines, capacities and personal judgements. Therefore transparency, clearness of information, supportiveness and good customer relations may play a role in modal choice.

Den Boer et al. (2011) have formulated a list of drivers / barriers to choosing rail freight. They consider the perspectives of the various decision makers, which is the actual transport user (logistics service provider), the shipper (producer) and society (represented by transport policy). Although the balance of factors differs among markets, the hard factors, i.e. costs, time and reliability, are found to be the dominant drivers from the users' perspective. The lack of supply side quality in comparison to actual transport demand is found to be due to three basic characteristics:

- The *balance of market power.* Compared to large rail carriers even the major forwarders are often in a weak position, but large networks are needed for providing effective wagonload services.

Table 5: Drivers and barriers for using rail freight

Perspective	**Drivers / constraints**
User	**Costs** (transport, inventory, handling)
	Time (transport/speed, lead, just in time probability)
	Quality (reliability, flexibility, information/traceability, transparency/simplicity, security)
	Cargo (Physical characteristics, transport requirement)
Supplier	**Services and network** (frequency, destinations, service orientation, price)
	Infrastructure (terminals, interoperability, supplier, capacity)
Society	**Accessibility/mobility** (congestion, safety)
	Environment (air quality, GHG emission, noise emission)
	Social cost (internal and external cost)

Source: Den Boer et al. (2011)

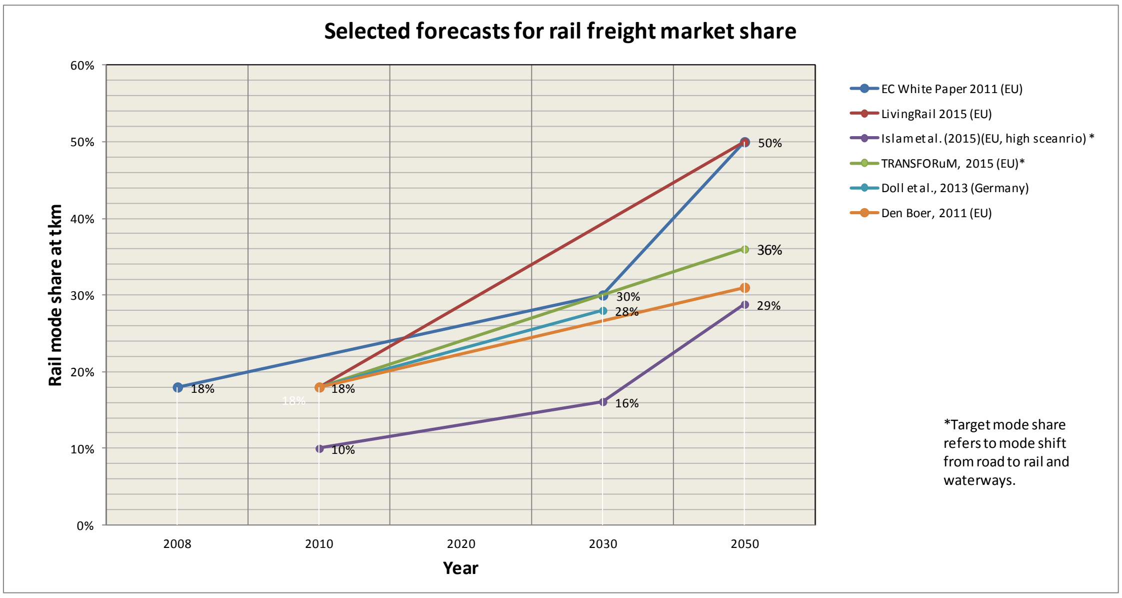
- *Limited geographical coverage of rail freight service offers*. This deficiency is inherent to the modern rail sector. Door-to-door services organised by rail carriers, could be a way to remain in the market in more remote areas.
- *Complexity of service* offers of the railways, often being much less clear for shippers than road haulage tariffs. Sector interviews reveal that in general the perception of what defines a good service offer widely differs between market participants. While the railways often see technical parameters in the foreground, forwarders expect simplicity and flexibility of services without having to deal with the railways' complex production system running in the background.

A deeper analysis of these barriers and drivers requires a concrete regional and market setting.

2.5 Summary of potential modal shift and GHG reduction potentials

Figure 3 summarises the estimates of possible modal shift. Although these in themselves are quite impressive numbers, requiring more than a doubling of rail demand, they are still quite remote from the White Paper target of 50% rail market share.

Figure 3: Comparison of rail freight mode share visions and scenarios



Source: Fraunhofer ISI

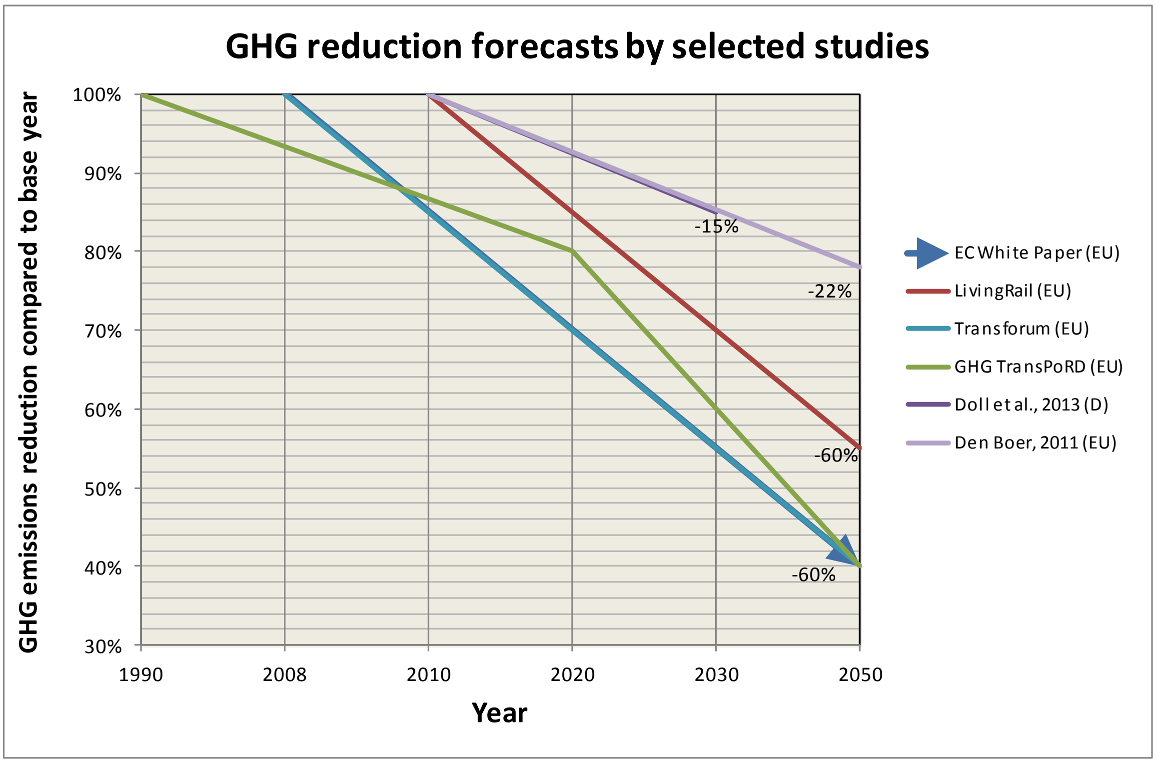
2.6 GHG reduction potentials

Figure 4 summarises the greenhouse gas reduction potential expected by various studies from mode shift in European freight transport. While some analytical studies (e.g. GHG TransPoRD, Schade et al., 2012) with explicit consideration of technological options in vehicle and fuel provision arrive at GHG reduction values close to the forecasts of the EC White Paper, other studies remain more cautious. Nevertheless, also the -40% expectation by the LivingRAIL project, which “only” takes mode shift to rail into account, is also impressive.

The latest scenarios for Germany in the framework of the “Energiewende” include cuts of around 80% of GHG emissions from transport. These scenarios include a multitude of measures from de-carbonizing road transport by hydrogen and electric propulsion, synthetic fuels for aviation and massive mode shift to rail on long-distance relations. It must, however, be said that the climate impact of mode shift scenarios only leads to significant results in case the rail sector is carbon-free with full electrification and powered by renewable sources.

A number of studies find a 50% to 100% increase of rail market share possible. Infrastructure investments and a de-regulation of the use of infrastructures and of market access are commonly considered to have the broadest incentive effect for more rail. In simple terms this can be expressed as “making the rail system simpler for the railway undertakings and the users”.

Figure 4: GHG scenarios for Europe



Source: Fraunhofer ISI

The most prominent barriers are the lack of customer orientation of the railways, national rules for infrastructure operation, contractual requirements and the licensing of rolling stock. Although the implementation of these well-known recipes along major European freight routes would bring additional money to the mostly state-owned rail companies and would cut greenhouse gases by 20% to 60% without any further technical or regulatory measures, resistance on several levels is high. Thus we can conclude that it is not new technology which the railway sector primarily needs to drastically improve its market position, but the implementation of market-oriented thinking and action in the existing company and policy institutions. Options to proceed this way are explored in the following Section 3.

3 Managing Change and Reforming Railways

To design concrete steps towards reforming the European rail freight sector we take a deeper look into the essentials of the theory of institutions to understand how large and mature industrial organisations arise, what their goals are and their customers and policy systems. After doing so we sketch out the idea of organizational change management as one of several ways to deal with conventional problems of infrastructure providers, such as structural inertia and path dependence. Thereafter, we take a brief look into contemporary literature on the railway sector and investigate what it contributes to the theoretical discussions. Finally we look across other sectors, namely aviation, telecommunications and electricity markets, which had gone through liberalisation and reform processes recently.

3.1 Theory of Institutions

Recent studies on the drivers and barriers to mode shift in transport arrived at the conclusion, that neither radical technical nor organizational changes alone are required to improve the railways' market position, but changes within the deeper structures of their institutional bodies (Doll, Jaroszweski and Biosca, 2014). This is because railways have evolved – as integrated enterprises covering infrastructure, safety and services at the same time – from the early days of first steam trains in the 18th century as state owned enterprises, and have only gradually adapted to new technologies and market requirements. And still they are state-owned undertakings despite the efforts of the European Commission to introduce competition and to remove barriers between their mainly national territories (Drew and Ludewig, 2011).

Profound changes of organizations are the subjects dealt with by the economic discipline of institutional theory. Keywords of its activity space include: rational myths, isomorphism, and legitimacy. Central to the theory is to investigate the processes by which structures become established as authoritative guidelines for corporative or social behaviour. Structures thereby include schemes, rules, norms, and routines. The creation, diffusion, adoption and adaptation of such changes over space and time are described by four respective pillars of institutional theory.

The way how institutions react to market powers or other forms of internal and external pressures depends on the internal structure of the institution as well as on the type of environment they are located in, i.e. the same institution could react quite differently to demands and challenges when displaced from one country to another. Likewise, the set of instruments and measures used to reform institutions not only needs to be tailored to the institutional setting, but also to its prevailing economic, social and cultural environment.

Literature on the subject distinguishes between old (or historical) institutionalism versus the new theory of institutions. The historical institutionalism more or less describes a rational evolution of the relationship between users and actors over time. This mainly case study based approach helps clarifying the relationship between individuals and institutions. In contrast, the new institutionalism created around the 1990s denies this strict rational links and brings evidence from social science in form of cognitive and cultural explanations to the behaviour of supra-institutional units into the discussion. The new institutionalism can be described by the following elements:

- **Property Rights**: E.g. can the problem of external effects be avoided by internalisation?
- **Principal-Agent-Theory**: Information asymmetry, risk aversion, opportunism, leading to adverse selection, moral hazard and hold-up.
- **Transaction cost theory**: transaction specific investments, uncertainty, frequency (classical contracts, long-term contracts, execution in organizations with impacts on markets, networks, hierarchies, make-or buy, internationalization strategies, acquisition relationships).
- **Neo-Institutionalism**: do organizations respond to pressures from their institutional environment?

When talking about institutional reforms we need to clearly define what shall be reformed into which direction. In the theoretical framework there is no unique definition what makes an institution. Institutions consist of units defined by markets, organizations, explicit (legal) rules and implicit (cultural and social) norms and value systems. In our case, we may consider several bodies and groups of actors as such.

- the railway companies, consisting of infrastructure undertakings and rail carriers;
- the railway industry, consisting of OEMs and several levels (tiers) of suppliers;
- regulatory bodies, consisting of national and transnational agencies;
- transport policy, consisting of supra-national, national and local entities;
- transport users, consisting of forwarding and logistics companies and their national or international associations;
- other stakeholders with interests related to rail freight transport, i.e. citizens organizations, NGOs, etc.

The objectives of institutional reforms are defined by the objective of this study. This is to encourage the railway sector, rail industry and users to take any conceivable and sensible measure to substantially lift the number of goods transported by rail through the provision of innovative technologies, high quality services and sufficient capacity. Most important appears to be a competitive and transparent framework which enables the transition from a defensive and risk-averse toward an open, cooperative, forward looking and maybe risk-friendly business and policy culture.

3.2 Transformation pathways in network industries and organizational change management

The theoretical framework for consciously altering the behaviour and the perspective of employees, work forces or entire companies is subsumed under the key word “change management”.

Starting with investigations on improving the performance of workers in U.S. energy companies in the 1930s, in the 1950s a three-phase model was proposed by Kurt Lewin and was operationalised by John P. Kutter. Their first and fundamental observation was that the motivation of employees is more impacted by the attention given to them rather than by the working conditions per se. The three major phases of change management derived from that are:

- Unfreezing phase: making companies and their employees sensitive for existing or upcoming threats and make them aware of the necessity for a change.
- Moving phase: development and testing of solutions which partly solve the problem.
- Freezing phase: stabilise the solutions found and develop new routines to prevent the company from returning to old habits.

Change management leads to an iterative learning process in which not only the situation of the entity before and after the change process, but also the change process itself need to be observed, assessed and adjusted continuously. Essential for a successful management of reform processes is the presence of “change agents / teams” in the upper hierarchy of company management structure, who communicate visions and goals, steer processes and demonstrate the value of short term changes.

Over time, the practice of change management has developed to a more continuous and implicit task. Change managers are usually replaced by external consultants and their competences are expected from all management levels. Moreover, change processes constitute a permanent state of many companies and have become much faster compared to the 1950s, such that the three phases can hardly be separated from each other. These phases must then be applied to the rail freight sector for the design of sectoral reform.

3.3 Institutional reforms in the rail freight market

With currently four railway packages in place or under way, the European Commission is making strenuous attempts to turn national rail carriers into competitive and active providers of customer-oriented passenger and freight services. With the Shift-to-Rail (S2R) joint undertaking, the EC further pushes the development of more innovative railway technologies. A major pillar is the corridor-based approach with a focus on transnational institutions improving competition, interoperability and new rail products using the strengths of railways on long distances (such as Alpine Transit Transport). Some Member States support these activities, but one must note that many do not support this policy and carry on protecting their national incumbents. In many cases, the railways thus act in a less innovation-friendly environment with little incentives to extend market shares.

Going through a number of key publications on reforming railways, we can identify the following fields of activities which need to be tackled in order to stimulate a positive business culture and market perspective within the railways and to improve their attractiveness and competitiveness.

- Policy alignment: Clear government visions of transport sector priorities and a stringent alignment of separate incentives for infrastructure managers (IM) and railway undertakings (RU) along these principles (McNulti, 2011). Ensuring investments to serve customers and a greater level of long-term planning and the transition from traditional “predict & provide” to more pro-active “design & manage” policy cultures appears to be essential (PPIAF, 2011).
- Regulatory models: Within public decision frameworks as well as in public-private relations, a clear separation of responsibilities and a greater degree of freedom and autonomy of subsidiary units (local entities, contracted companies) helps unfolding innovation processes and fitting business best to prevailing local conditions (McNulti, 2011). Joint ventures and pilot cases can support establishing the necessary knowledge and experiences.
- Institutional design of network operations (track access management, priority rules for freight and passenger transport, independent network agency, specific freight corridors, one-stop-shop services, track access charges and incentives towards rail freight). These design elements need to be selected and adjusted carefully and based on real market evidence rather than on theoretical considerations only. According to the Inno-V (2012) study, the vertical competition of sectors (e.g. among freight operators) only helps making rail more efficient in case scarcity of capacity is not an issue, while competition within transport sectors does not improve the competitive situation of rail transport.
- Funding arrangements for freight transport and innovative logistics solutions: As freight transport is about making money, the careful design of funding arrangements

is essential in terms of steering business activities and market behaviour of companies and institutions. It is also essential to open the view towards multimodal thinking, changing the sectoral perspectives. Funding mechanisms, e.g. the German "Performance and Funding Agreement" (LuFV) between Deutsche Bahn AG and the federal government, are closely related to and thus need to be aligned to the design of company structures of the (former) state owned railways, including ownership, operations and the role of the public sector.

- Appropriate framework conditions for the diffusion of innovative logistics concepts and role of the public sector: The uptake of technology innovations and the development of innovative processes and business models cannot be pre-determined in all cases by governing institutions. It seems thus important to design, establish and maintain open, flexible and innovation-friendly structures in large organizations. Issues to be considered include securing the framework conditions, planning and approval procedures and risk transfer mechanisms (e.g. in the form of citizens bonds). This also implies new roles of the relationship between the public sector with its different roles (regulatory body, owner, supervisor) and the professional rail sector.
- Communication: International experience with reforms has proven that a comprehensive communication strategy is essential. This is to design and coordinate a sophisticated outreach and information dissemination programme to consult the public, employees, shippers, and other stakeholders about their concerns, to explain the need for reforms and the resulting benefits, and to keep stakeholders informed of progress (PPIAF, 2011).
- Inter-company relationships: Business co-operation models of railway logistics and road haulage undertakings in domestic, transnational and combined transport segments are proposed for making the transport sector more robust against external threats (strike, weather extremes, large accidents, etc.) and to optimise logistics chains by combining the best elements out of several transport modes or company structures. Examples include the organization of combined transport and road-rail co-operation, which may be organised in open versus closed systems.

These fields of activity towards kick-starting and maintaining institutional reform processes partly overlap and are most likely incomplete.

3.4 Lessons from multiple sectors

Institutional reforms in several infrastructure sectors have shown interesting experience which can be used as starting points for new approaches to develop innovative railway solutions. For this purpose it is important to screen the relevant literature to extract possible lessons and recommendations.

Table 6 summarises the literature. The key findings so far can be summarised as follows.

- Infrastructure: Most relevant are the recommendations for financing transport infrastructure on several levels, especially related to infrastructure in combined transport (OECD, EU, Germany, other countries); compare the comprehensive overview provided in Roland Berger (2013).
- Railway reform: There are several studies which have evaluated and compared the railway reform process in the late 1990s in several countries. A good overview is presented in CER 2011. A major issue is the impact analysis with regard to the separation of railway services and railway infrastructure (e.g. the use of privatization of rail infrastructure). There is consensus that rail freight transport needs a direct and standardised access for third parties in order to prepare the level playing field for competition in the traction markets. In order to promote combined transport, the incentives for all in one logistics suppliers are essential.
- Liberalization in the aviation market: The most interesting issue is the development of market access, market segmentation and alliancing, showing as well that international (e.g. global) standards (and markets) are vital to maximise incentives for new market entrants. Aviation and coastal shipping are perfect examples to demonstrate the relevance of transnational interoperability.
- Liberalization in the telecom market: Some studies are available which summarise experience on the development of the regulatory framework and the financing of basic services and the new role of the public sector as regulatory body focussing on creating a level playing field for international competition.
- Public private partnerships: There is a large number of studies available which develop and assess possible frameworks for ownership, service provision, financing, risk sharing and business development. Possible solutions in the financing of intermodal infrastructure and specific rail freight infrastructure are identified (e.g. RFF 2012, UNECE 2012).
- Freight transport: There are several studies on institutional settings and policies to promote combined transport, especially in transalpine rail transport (Switzerland) and city logistics (e.g. Bestfact 2016). In addition, new and innovative cargo systems are evaluated. An interesting example is the new Swiss project ‘Cargo sous-terrain’ with new institutional approaches to private financing and sharing delivery models (Dullaert et al., 1999).

Annex 2 provides a detailed overview of studies by sector with brief descriptions of assumptions and findings.

Table 6: Examples of studies on railway reforms (extract from Annex)

Railway reforms international	
EU Commission, 2013	Report on the implementation of the provisions of Directive 2007/58/EC on the opening of the market of international rail passenger transport (fourth Railway Package)
PPIAF (2011)	Railway Reform: Toolkit for Improving Rail Sector Performance
J. Campos (2001)	Lessons from railway reforms in Brazil and Mexico
Nash et al. (JETP, Sept 2012)	Measurement of Transaction Costs – Evidence from European Railways
Nash et al. (JTEP, May 2013), 2012	Comparing three models for Introduction of Competition into Railways
Community of European Railway and Infrastructure, 2011	Reforming Europe's Railways – Learning from Experience
Monsalve C. (2012) / World Bank	Railway Reform in South East Europe and Turkey On the Right Track?
Laperrouza, Finger, 2009	Coherence between institutions and technologies in infrastructures Exploring socio-technical governance regimes in liberalizing network industries
Laperrouza, Finger, 2009	Discussion paper series on the Coherence between institutions and technologies in infrastructure. Regulating Europe's single railway market: Integrating performance and governance:
Holvad, Raje, Preston (2003)	Railways in Transition: A review of reforms in Europe, Japan, New Zealand South America.
Obermauer, 2001	Railway reform in Japan and the EU: Evaluation of Institutional Changes
Railway reforms in Germany	
BMVBS, 2012	Bedeutung und Entwicklung des intermodalen Verkehrs mit der Bahn in Deutschland und die Bedeutung staatlicher Förderung
Bieling, 2008	Liberalisierung und Privatisierung in Deutschland: Versuch einer Zwischenbilanz
Glodzinski, 2006 (Seminar)	Infrastruktur und Staatsversagen: Erklärungsfähigkeit der neuen politischen Ökonomie am Beispiel des Eisenbahnwesens
Railway reforms in the UK	
Inno-V (2012) and Nash (2014):	European rail companies: impact of separation on railway cost efficiency
Department for Transport (2012)	Reforming our Railways – Putting the Customer First
McMulti (2011)	Realising the Potential of GB Rail
Railway reforms in Sweden	
Transport Analysis (2014)	Railway in Sweden and Japan – a comparative study
G. Alexandersson (2013)	Next stop for Swedish rail reforms? New Government Committee reviewing the organisation of the sector
KTH / Nelldal 2001	The Swedish railway sector since the 1988 railway reform

Note: the entries in this table are to be understood as references and are not repeated in the reference section to this paper. Source: INFRAS and Fraunhofer ISI

4 Pathways for De-Carbonising Road Freight

Several competitive advantages of railways today will be mitigated by trucks in the future. In the following the briefly discuss some of the options to de-carbonise road freight. We do so without going much into detail, but to provide an overview of potential development pathways.

4.1 De-carbonisation options for trucking

4.1.1 Zero emission vehicles and infrastructures

Trucks also dispose of technological options to become electrified. These options differ between the truck categories. Long distance transport could be delivered by trucks operating under a catenary, i.e. by trolley trucks or trolley-hybrid trucks. This approach would however require the electrification of about 25-40% of the 13.000 km motorway network in Germany, and eventually its neighbour countries. At least on high demand relations (port-hinterland connections, Hamburg-Ruhr-Area transport), the system could recover the required investment cost. To cover non-electrified sections, such trolley trucks could be set-up as hybrids that either use a battery, a fuel cell or a diesel engine. Another option of electrification would be the production of synthetic fuels from electricity (power-to-liquid, PtL) and the use of fuel cells. This seems less realistic than trolley trucks.

For trucks between 3.5 and 12 t of gross vehicle weight (GVW) that provide regional delivery services, potential solutions for decarbonisation are either hydrogen fuel cells or combustion engines running on biogas or synthetic gas (power-to-gas, PtG).

Light duty trucks (up to 3.5 t of gross vehicle weight) and trucks up to 7.5 t GVW used in last mile delivery are already being replaced by pure battery electric vehicles. This option in particular depends on the generally underestimated reduction of battery costs and the level of ambition that will be assigned to achieve air pollution targets in urban areas.

Consequently for any use of trucks there exists at least one low-carbon option that could become reality until 2050 using reasonable assumptions.

4.1.2 High energy efficiency solutions

Electrification of trucks via batteries and catenaries is the first option to drastically improve their energy efficiency. Fuel cells and power-to-x are also considered as electric power-trains, but are less efficient due to upstream losses. Additionally electric trucks will be able to recuperate energy while braking or driving downhill.

Introducing electronic coupling of trucks driving one after the other on motorways with narrow distances (platooning) will reduce air resistance drastically and thus increase energy efficiency by about 5 to 15 percent according to the position of the truck.

Additionally, truck regulations on weights and dimensions are already being adapted to enable longer trucks such as the EuroCombi to be freed from restrictions in Germany in 2017, improving the aerodynamics of trucks without compromising maximum loads.

4.1.3 Safety issues

The safety of trucks can be improved drastically by three measures: (1) introduction of driver assistance systems similar as in cars, e.g. emergency brake systems. (2) by platooning, and (3) by autonomous trucks. As of today, it remains unknown how close the safety level of trucks could come to that of railways by deploying (2) and (3).

4.2 Drivers of a Pro Road vision

The first driver of a Pro Road vision is technological development being more dynamic for road than for rail mode, due e.g. to the shorter “life” of road vehicles. Apart from the improvement of road freight technologies, the second driver of a Pro Road vision would be the failure of European railway reforms, such that barriers and obstacles for cross-border rail traffic continue to apply. The same then holds for the technological and organizational fragmentation of the European railway system. A further and potentially very important driver of a Pro Road vision is automation. Within the coming years, automation will already enable platooning, reducing the energy and labour costs of trucks. Full automation could reduce the labour share of trucking costs by 25-30%.

4.3 Overview of GHG reduction measures in road haulage

GHG reduction measures in road haulage can basically be grouped into three types:

- R&D funding for new technologies in trucking and promotion of their diffusion.
- Regulatory measures.
- Market-based measures.

It can be argued that public R&D funding for prototypes and first field tests should be provided, possibly together with funds provided by the industry. This concerns (1) alternative drive train technology, and (2) ICT for research on platooning and on driver assistance systems. Regulatory measures in particular focus on (1) energy efficiency standards or CO_2 efficiency standards of new trucks, and (2) standards on weights and dimensions. Substantial aerodynamic improvements could be achieved e.g. by side skirts and boat tails that would change the geometry of the truck, but require longer trucks to maintain capacity.

Market-based can be fuel taxes, road user charges or vehicle circulation taxes. Effectiveness of such measures could be improved by differentiating between vehicles causing lower or higher environmental impacts, as is the case with the German heavy goods charge on motorways, for which the charging levels are higher for trucks complying only with older EURO emission classes (e.g. EURO III or IV), while EURO VI trucks are exempt from extra environmental charges.

Furthermore logistics operations can be improved to reduce GHG emissions. Often each measure only makes up for small-scale savings of GHG and apply very specific to a certain situation such that substantial reductions will only be achieved by adapting individually many single logistics chains.

5 Conclusions: Research Priorities

5.1 Climate mitigation potentials

We might reach deep cuts in the carbon emissions of European transport by several ways. But we do not know yet how far we can get with the two main pathways – rail or road – and what their second round impacts beyond climate gas reductions are. With mode shift to rail studies find reduction potentials between 20% and 60% in case a broad set of technology, regulatory and market based measures are successfully implemented.

The picture on GHG reduction potentials in road haulage is more scattered. A large number of measures exist to improve fuel efficiency, for electrification and to cut the life cycle carbon content of fuels. Putting both streams of measures together a reduction of freight transport related carbon emissions might range between 40% and 80%. So it seems worthwhile exploring both pathways in detail.

5.2 Barriers to low carbon pathways

The currently fast development in HGV research and the installation of multiple test fields for automation and electrification suggests that barriers against solutions improving the sector's competitiveness are low within the trucking sector as well as in transport policy. The picture changes, however, considerably when it comes to measures for GHG reduction. The current EC directive on truck weights and dimensions (directive 2015/719 of the European Commission) remains cautious in which options they allow for improving the aerodynamics of HGVs, and fuel economy standards for trucks are not yet in sight. Thus, despite the various options for cutting road freight emissions are on the table, we might face the situation that road transport attacks rail and shipping markets with automated and longer vehicles, but does not contribute itself to GHG mitigation.

In the rail markets, the barriers to any kind of change are more visible than in the road sector. Long established networks of rail carriers, technology providers, infrastructure managers, policy and labour unions have created a complex and rigid institutional setting within which one element cannot easily be changed without affecting others. With various forms of state protection, many of the state-owned European railway companies have become so resistant to change that even the prospect of growing market shares and thus more income is unable to trigger a rapid adaptation of contemporary, market-oriented management styles across the institutions.

In both cases, road and rail, active climate mitigation policy thus needs an approach based on management of institutional reforms, rather than the increasing the support of R&D. While in the road sector this mainly concerns policy, the need for radical institutional renewal concerns all levels of the railway system.

Rail (and IWT) are in most cases inter-modal per se. So the improvement of intermodal interfaces is of utmost importance for these means of mass transport.

Apart from access to and from road and rail terminals increased coordination of trucking, rail and shipping would help to realise further efficiency gains in the sector. This seems to be of particular interest for the hauliers and rail operators in times of scarce track capacity as well as of truck drivers. New business models and the breaking-up of current institutional structures might help in this respect.

5.3 Digitisation and automation

These technologies may have a profound impact on rail as well as road transport and on their interfaces. One night think of fully automated freight shuttles in combination with highly automated freight terminals. Although driver costs are not a major issue with longer trains, terminal access services for smaller quantities might profit and the automation of terminals with robotic loading and unloading facilities might improve flexibility and punctuality, and allow round the clock servicing.

Under the keyword “digital economy” we may see several radical shifts in the way we produce and distribute goods. Replacing the shipment of semi and final products by 3D printing, instant on demand manufacturing, delivery by drones or robots, and the use of robots in the service sector may change the structure and volume of transport demand. From our current perspective it is not known whether these developments will favour emissions reduction or not.

5.4 Final remarks

The objective of this paper is to explore which technological developments and institutional characteristics of core European freight markets are to be looked at closely when designing a carbon neutral system towards the mid of this century. This endeavour is obviously not simple as multiple policy, investment and research programmes over the past decades have not changed the way we move goods around in Europe profoundly. From our quick ride across the two major options for addressing freight’s energy consumption and environmental impact, namely shifting goods to rail and shipping and to improve the climate and energy efficiency of trucking.

By following this approach a quick ride across current conditions, technology options, institutional issues, drivers and barriers in mass transport markets and in road haulage lead to a number of research priorities.

1. Rail freight markets can be dynamic and can play a major role in national freight markets as some good examples of European countries reveal. Detailed case analyses need to look closely behind these good practices.
2. Rail, however, is largely strangled by partly outmoded and complex legal and operational settings, by national protectionism and low innovation rates of market oriented technologies and management practices. Looking at ways and procedures to lift the potential of freight railways to become proactive mobility providers appears to be of utmost importance for freight transport's GHG emissions. Research in this area not only addresses structures and traditions in the railway sector, but also within policy and regulatory institutions.
3. The road sector seems to have a bundle of low carbon technologies at hand. Although the sector is not subject to a regulatory framework similar to the railways and despite the cost advantage higher energy efficiency would promise, there was only moderate advantage in the past and a structured discussion of implementation pathways and priorities is still missing. An important research priority thus is to establish low carbon roadmaps for road haulage.
4. It is most likely that road transport takes up new technologies way quicker than the railways, but mainly with the objective to improve its competitiveness. To ensure that this development neither spoils GHG reduction targets nor that it attacks cleaner modes cooperative solutions and strategies need to be looked at. The railways are in most cases providing the main haul of intermodal chains. Improving the interface between rail and roads would thus certainly help.
5. New ways of moving goods may be conceivable for the longer term future. The railway companies with their broad experience in organising mass transport would be a natural candidate to adopt these technologies. In order not to let these solutions be implemented by investors with potentially limited sustainability interest, strategic thinking and the willingness to take risks are essential.

To conclude we can find that institutional reforms are most urgent for a deep cut in greenhouse gas emissions on busy European freight corridors, and which direction these changes most likely need to take. While a range of technological options are available, the railways in particular face a rigid institutional setting which restricts innovation. This project integrates these issues to indicate potential pathways towards carbon neutral freight corridors by 2050.

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Abbreviations

BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (Berlin)
CE	Committed to the Environment (Delft)
CER	Community of European Railways and Infrastructure Companies (Brussels)
CO_2	Carbon dioxide
EC	European Commission
ECF	European Climate Fund
EEA	European Environment Agency (Copenhagen)
ERA	European Railway Agency
ERTMS	European rail traffic management system
EU	European Union
Fraunhofer IML	Fraunhofer-Institut für Materialfluss und Logistik (Dortmund)
Fraunhofer ISI	Fraunhofer-Institut für System- und Innovationsforschung (Karlsruhe)
GDP	Gross Domestic Product
GHG	Greenhouse gas
HGV	Heavy goods vehicle
ICT	Information and Communication Technologies
IM	Infrastructure managers
INFRAS	INFRAS AG (Zürich)
ITF	International Transport Forum
IWT	Inland Waterway Transport
kt	kilo-tonne (1000 t)
LDV	Light Duty Vehicle
LuFV	Leistungs- und Finanzierungs-Vereinbarung (Performance and Funding Agreement) between DB AG and the German federal government
M-Five	M-Five GmbH Mobility, Futures, Innovation, Economics (Karlsruhe)
NEA	Netherlands Economics Associates (part of Panteia)
NGO	Non-governmental organization
NRW	North-Rhine-Westphalia (German federal state)
NSB	North-Sea Baltic (CNC no. 8)
NUTS	Nomenclature des Unités Territoriales Statistiques
OECD	Organisation for Economic Co-Operation and Development
OEM	Original equipment manufacturer
pkm	Passenger kilometre
PPIAF	PPIAF – Public Private Infrastructure Advisory Facility
PtG	Power-to-gas

PtL	Power-to-liquid
R&D	Research and Development
RALP	Rhine-Alpine (CNC no. 1)
RFC	Rail Freight Corridor
RFF	Réseau ferré de France
RMMS	Rail Market Monitoring Study (EC)
RU	Railway Undertaking
S2R	Shift-to-Rail (EC Joined Undertaking)
SNCF	Société Nationale des Chemins de fer Français (French national railways)
SSS	Short Sea Shipping
TEN-T	Trans-European networks for transport
tkm	Ton kilometre
TPR	Department of Transport and Regional Economics (University of Antwerp)
UBA	Umweltbundesamt (Federal Environment Agency)
UIC	International Union of Railways (Paris)
ZEW	Zentrum für Europäische Wirtschaftsforschung (Mannheim)