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Modeling Different European Freight Scenarios and Impacts for North Rhine Westphalia

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Abstract

This paper presents the assessment of two extreme scenarios for cost cuts in rail freight and for the electrification of road haulage for two European freight corridors by 2050. The scenarios Pro Rail for competitive freight railways and Pro Road for greenhouse gas neutral road transports aim at quantifying the potential contributions of these two respective directions of transport and climate policy to climate protection and sustainability.

Pro Rail drafts a future, in which rail transport costs decline by 66 % through regulatory frameworks, entrepreneurial measures and the consequent application of digitalisation and automation. At the same time, road haulage costs increase by 25 % through taxes, charges and regulation. In contrast, Pro Road describes a future in which road transport operates carbon neutral through overhead wires, batteries and fuel cells.

The market share of the railway triples in the Pro Rail scenario against the reference case in the year 2050. This is partly at the expense of trucks, but also at the expense of shipping. Along the Rhine-Alpine-Corridor, 2050, GHG emissions decline from 60 Mt to 35 Mt CO2-eq in the Pro Rail scenario and to 22 Mt in the Pro Road scenario. Through the combination of both measures, a further reduction to 16 Mt would be feasible. As both of these extreme scenarios are unlikely to be realised, climate policy needs to exploit the full emission reduction potentials in all modes.

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Keywords: Scenario analysis, modal choice, decarbonizing

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1. Introduction

This paper deals with long-distance freight transport along major European corridors. These long distance corridors are one of the most steadily growing sources of greenhouse gas emissions in Europe. It is also the most difficult to address by renewable energies and other standard climate mitigation measures in transport. Starting from the classical suite of strategies such as “avoid”, “shift” and “improve”, the LowCarb-RFC methodology concentrates on the modal shift to rail and on mitigation measures in all freight modes along the two major transport corridors through Germany: the Rhine-Alpine (RALP) corridor from the Benelux countries to Northern Italy, and the North Sea-Baltic (NSB) corridor from Benelux via Poland to the Baltic States. Besides major European strategies, the project considers the implications for transport policy at the intersection of these two corridors in the German federal state of North Rhine-Westphalia (NRW). The project focuses on rail as a readily available alternative to transport large quantities of goods along busy routes using electric power in a potentially carbon-neutral way.

In this paper the development of freight demand scenarios along the Rhine-Alpine and the North Sea-Baltic core network corridors for the years 2030 and 2050 are developed and assessed. The scenarios depart from the common assumption that the power sector will be 95 % decarbonised by 2050 and that all technological and organisational options in the transport sectors are activated in order to either shift goods to rail or to avoid greenhouse gas (GHG) emissions in road haulage as much as possible. To this extent, the LowCarb-RFC scenarios reflect extreme cases for improving rail’s competitiveness and for decarbonising road transport.

This paper is structured as follows. In section 2 the potential for mode shift to rail is assessed. In section 3 the business as usual scenario is developed, while in section 4 the alternative scenarios are given. In section 5 the developed method is given. The results are presented in section 6. Finally the conclusions are given in section7. ere introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

2. The potential for a modal shift to rail

2.1 Drivers of modal shift

In Doll and Köhler 2018, a review of the main drivers of a modal shift in freight transport along two of the major European rail freight corridors: RFC1: Rotterdam-Genoa and the western part of RTC8: Antwerp-Warsaw was done. Key publications for the review include the German railway’s strategy “Zukunft Bahn” (Deutsche Bahn 2015), the EC core network studies on the Rhine-Alpine (EC 2014), North Sea-Baltic (Wojciechowski, 2016) and Scandinavian-Mediterranean corridors (Trautmann, 2016), the CERRE policy papers (Crozet et al. 2014), the EC-funded studies BESTFACT (Permala and Eckhardt 2015) and PLATINA II (Lambrechts and Dasburg-Tromp 2014), the CE Delft and TRT study on modal shift drivers (De Boer et al. 2011) and the studies Rail Network 2030 (Holzhey 2010) and Financing Sustainable Rail Transport (Sutter et al. 2016) conducted for the German Federal Environment Agency (UBA). Institutional reports from ERRAC, ITF, the Network of European Railways (NEE), CER and other institutions have also been reviewed. A detailed compilation of the studies is available in LowCarb-RFC Working Paper 5 (Doll and Köhler 2018).

From 19 literature sources, we extracted 66 individual statements on the drivers for and barriers to a modal shift to rail. We grouped these statements into eight categories that can be ranked in descending order according to the mentioned frequency of the drivers as depicted in **Error! Reference source not found.**. The statements were also assigned to one of three stakeholder groups: (1) research community, (2) railways and rail manufacturing industries and (3) policy and civil society organisations.

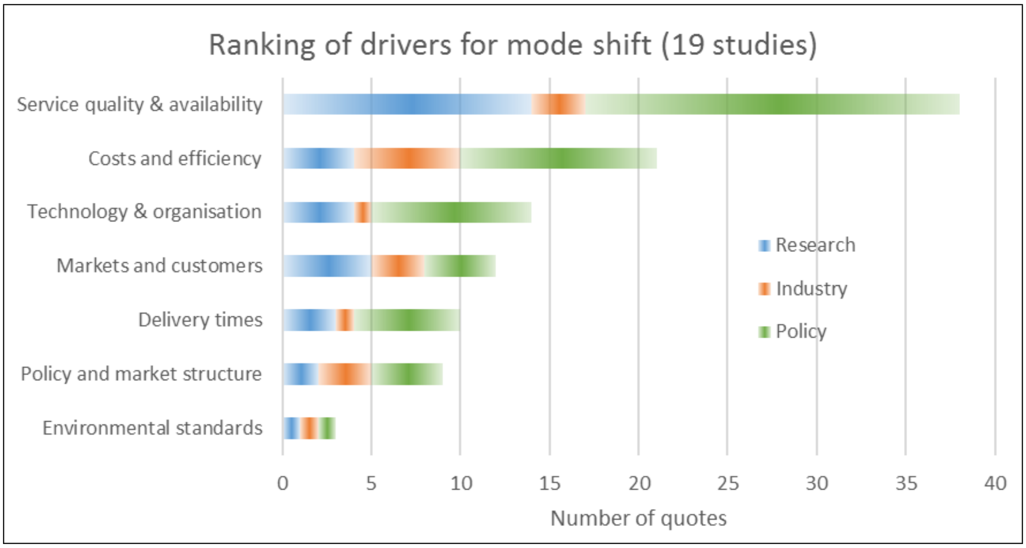

Fig. 1. (a) first picture; (b) second picture
Source: Fraunhofer ISI

The seven groups of drivers can be divided into primary and secondary drivers. Primary drivers are directly visible to customers and include quality, price and delivery times. Secondary drivers, such as technology and market structures, determine primary drivers and are internal to the rail production system. They are highly relevant because new technologies and organisational structures together with supportive policy packages are indispensable for improving the railways' competitiveness.

2.2 The competitiveness of transport modes today

We construct scenarios on the potential competitiveness of transport modes based on the concept of generalised costs because quality and prices are the two decisive elements determining whether shippers send consignments by road, rail or inland waterway transport (IWT). This concept translates the main quality features of shipping alternatives along the entire transport chain, i.e. from door to door, into market prices. These are then added to the actual freight rates in order to obtain a single virtual cost value.

For the monetary part of the generalised costs, we assume that changes in the transport operators' cost burden translate directly into freight rates to their customers. This assumption does not comply fully with observations in the freight sector over the past decades. While decreases in taxes or infrastructure charges in the railways have not translated directly into freight rates, motorway charge increases have mostly been passed along to hauliers' clients. For the 2030 and 2050 scenarios, we ignore such market forces and assume transparent pricing structures. Second, for the non-monetary part of generalised costs, we concentrate on delivery and delay times. We do so implicitly because the interrelationship between network saturation, travel speeds and delays is complex, for railways in particular, and depends on several operational standards and infrastructure configurations.

In this study, we reviewed detailed cost items of road, rail, barge and intermodal transport with generalised, bulk and containerised cargo. 2015 cost structures were analysed for the cost categories infrastructure, vehicles, energy, labour and administration. This cost structure forms the basis for later forecasts towards 2030 and 2050 in various scenarios. We consider five cost categories: infrastructure, rolling stock, energy, staff, and overhead costs. While rail is dominated by locomotive- and wagon-related costs, road hauliers' expenses focus on drivers and fuel. In combined transport, transhipment costs add 10 % to the cost structure, which needs to be offset by efficiency gains elsewhere in the transport chain to make the service attractive. Parts of these costs are fixed per shipment, others are variable by distance or variable by time. In single wagonload rail transport, the fixed costs make up about 36 % of the total costs for a 500 km shipment. For road haulage, no fixed costs were considered for loading and unloading. For absolute freight rates, we consulted data from the Flemish freight model (Flemish Traffic Centre 2017).

Together with road haulage costs from the cost information system of the German Federal Association for Road Haulage, Logistics and Disposal (BGL, 2017). The data suggest that block trains are completely competitive with trucking, while container trains are about equal and single wagonloads cannot compete in terms of costs. The large differences in rail costs per ton-kilometre are caused by different load factors, i.e. the number of tons per train. The overall load factor in rail transport results from the tons per loaded wagon, the share of empty wagons in the network, and the length of trains in wagons per locomotive. The same factors are relevant for truck and barge transport with the exception of train length.

The weight of goods per wagon, truck or vessel depends on the current consignment and the type of cargo: there are weight-sensitive bulk goods and space-sensitive consumer goods. The share of empty wagons is close to 50 %, while the share of empty trailers in road haulage ranges around 20 % in Western Europe. The length of trains is restricted to between 650 m and 740 m in Europe. Container and bulk trains are usually this long, while single wagonload trains are often much shorter.

3. The business-as-usual scenario

The BAU scenario adheres to current policy and business plans and retains the transport systems as they are at present until the mid-21st century. In the BAU scenario, we do not consider major technological or organisational innovations disrupting long-distance freight transport – even though some potentially disruptive trends can already be identified: automation, platform-based demand and supply management and the electrification of road transport.

The BAU scenario describes a state in which European and national freight transport policy remain more or less the same as they were in 2015. Planned infrastructure projects like the Iron Rhine will be completed and all modes retain sufficient capacity to keep their 2015 modal share through small to medium capacity investments. Efficiency improvements are more continuous and somewhat faster in rail transport than in road haulage due to moderate reform processes in railway undertakings. Rail freight can therefore already improve some of the competitive disadvantages experienced in the past in the BAU scenario towards 2050.

The 2030 and 2050 forecasts are based on transport sector statements, an in-depth literature review and simulation model applications. The relevant transport and energy forecast models are the European tools PRIMES (E3MLab / AUTH, 2014) and ASTRA (Doll et al., 2016). These sources are used to predict the generalised costs of rail, road and waterborne transport, as well as their load rates. Load rates (or load factors) in freight transport play a decisive role for final transport prices as high load factors help to distribute fixed costs across more ton-kilometres and make better use of otherwise unutilised capacity. Load factors ultimately express quality issues, since we can assume higher quality results in higher demand for a particular service.

The assumptions in this scenario can be split into general assumptions for 2030 and 2050, which hold true for all scenarios, and assumptions, which are specific to the BAU case. The general assumptions can be summarised as follows:

- Demand projections by mode and country are derived from the PRIMES reference scenario (Möst 2017), but are adapted to the EC studies for the Rhine-Alpine (Wojciechowski, 2016) and the North Sea-Baltic (Trautmann, 2016) corridors. These already show the largest growth for rail (+43 %), followed by road haulage (+35 %) and IWT (+28 %).
- The digital industry concept is assumed to entirely reshape the means of industrial production. New trends include real gross value added generated by companies through new product lines, the cooperation between employees and robots, the design of supply chains or the relocation of production facilities from low-wage countries back to Europe.

- Energy market policies related to electricity production remain constant for all scenarios. According to the European Commission's Low Carbon Roadmap of 2011, all the economic sectors in the EU are to reduce their GHG emissions by around 80 % by 2050 compared to 1990 levels (UIC and IEA 2016). For the electricity sector, we use the 95 % mitigation scenarios supported by the German Federal Environment Agency (Öko-Institut and Fraunhofer ISI 2015).

The specific scenario assumptions for the BAU case and the resulting cost reduction rates by 2050 relative to 2015 are briefly described in

Table 1. Specific assumptions and cost reduction potentials in the BAU scenario

Cost Category	Railways	Road haulage
Load factors	Corridor extension to 740m trains; European wagon management and cargo trading platforms.	Without longer trucks, only slight improvement possible in loaded hauls and use of truckload space.
	+45 %	**+10 %**
Infrastructure	Policy plans: halving rail track access charges	No major change to current pricing practices on European motorways
	-20 %	**+/-0 %**
Rolling stock	Soft removal of regulatory barriers but additional administrative hurdles; better management of wagon fleet	Stop trials with longer and heavier vehicles; some field tests with electrified motorways; more expensive trucks (+20 %), constant maintenance costs
	-25 %	**+9 %**
Energy costs	Full electrification (-10 % primary energy demand) and improved energy efficiency through driver assistance (-5 %).	Modest improvement in logistics planning, better aerodynamics (-21 %), driver-assistance systems.
	-12 %	**-26 %**
Labour costs	More or less stable for drivers; decrease for local workers due to automation of terminals and track works.	Competition for truck drivers by higher wages and stronger enforcement of social legislation (driving and rest times, etc.) drives personnel costs up.
	-20 %	**+/-0 %**
Administrative costs	Productivity increases mainly in administrative structures (+25%); some extra management costs.	Advanced use of IT technologies and networking (-20%); formation of larger haulage companies
	-25 %	**-20 %**
Total generalised costs	Dominant drivers: rolling stock and energy costs.	Dominant drivers: driver and fuel costs
	-25 %	**-19 %**

. More details and the reductions for the intermediate year 2030 andfor the three categories of goods - unitised, bulk and containerised cargo - are described in Doll and Köhler (2018).

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	-25 %	**-19 %**

Source: Fraunhofer ISI

We see considerable cost efficiency gains towards 2050 along the corridors in the BAU scenario already, which are bigger for rail (-18 %) than for road (-13 %) or for IWT (-8 %). This assumption is based on current observations of the successes in re-structuring the sector. There are still enormous efficiency potentials on the railway market, some of which will be tapped by measures that have already been implemented today. These include public subsidies, opening markets, digitalisation, asset and labour management or the concentration on core markets.

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

4. Alternative scenarios development

As long as energy prices remain low for whatever propulsion trucks use, the development of demand is not likely to change significantly in the next years and decades. Logistics will continue to introduce new tools to meet the demand of the transportation market for high frequency delivery, a sector in which rail cannot play a major role. The structure of goods is also expected to continue to develop away from traditional rail formats. If any unexpected changes occur, road haulage can respond more quickly to new opportunities than rail can. Safer, quieter and less polluting trucks driving in platoons instead of trying to overtake each other at very low speed differences help to increase public acceptance of them in the coming years. Improved traffic information, platooning, driver-assistance systems, mobile networks as well as connected, remotely-driven and autonomous lorries will drive down the operating costs and increase the energy efficiency of road haulage. Thus, without substantial policy intervention to improve the rail system and promote the use of rail freight, it is much more likely that the Pro Road vision will become reality than the Pro Rail vision.

Table 2 summarises the main assumptions and the average cost evolutions from 2015 to 2050 for rail and road transport in the Pro Road scenario. Interestingly, the use of new technologies like digitalisation and automation let drop costs in both cases, Pro Road and Pro Rail, against 2015. Main drivers of the stronger drop of road costs are more efficient use of road infrastructure due to demand shifts to road, the low costs of electric propulsion and the replacement of human drivers by automation.

Table 2: Assumptions and cost reduction potentials in the Pro Rail and Road scenarios

Cost Category	Railways	Road haulage
Load factors	As BAU: 740m trains; European wagon management and cargo trading platforms.	Longer and heavier trucks, European cargo trading platforms, horizontal cooperation & mergers
	+45 %	+15 %
Infrastructure	As BAU: Policy plans: halving rail track access charges	No more environmental charges; more traffic sharing fixed infrastructure costs; heavier trucks decreasing costs per ton.
	-25 %	-40 %
Rolling stock	As BAU: soft removal / extension of regulatory barriers; management of wagon fleet	New digital equipment, aerodynamic elements and electric drive trains by 2030; payoff of these costs towards 2050.
	-20 %	+5 %
Energy costs	As BAU: Full electrification and improved energy efficiency through driver assistance (-5 %).	Growing prices plus multiple effect of efficiency gains, regulations, alternative energy sources, driver assistance systems and automation.
	-12 %	-26 %
Labour costs	More or less stable for drivers; decrease for local workers due to automation of terminals and track works.	Longer vehicles, automation and remote control of trucks
	-20 %	-70 %
Administrative costs	Productivity increases mainly in administrative structures (+25%); some extra management costs.	Rapid development of digital administration tools and lower insurance rates due to safer vehicles
	-25 %	-40 %
Total generalised costs	Dominant drivers: rolling stock and energy costs.	Main drivers: more efficient infrastructure use, energy efficiency and the replacement of human lahour.
	-25 %	-35 %

Source: Fraunhofer ISI

5. Modeling approach

The modelling approach is divided into 2 part. In the first part the main method is explained, while in the second subsection the data needs for the model are given.

5.1 Method

The developed method should allow the assessment of different scenarios in which conventional rail improvement and policy packages are considered, including emerging industry and technology trends as well as completely new transport solutions. The project develops two scenarios: a Pro Road and a Pro Rail scenario. As both scenarios go to extremes with regard to cost cuts and quality improvements, a Modest Road (Mod Road) and Modest Rail (Mod Rail) scenario are added.

These different scenarios affect cost elements of either road or rail transport. In addition, the parameters in a future scenario include changes in infrastructure (shorter distances when a new railway line is used), different speeds and reliability levels. All have an effect on the generalised costs and therefore the choice of transport mode. This influences the total ton-kilometres (tkm) and vehicle-kilometres driven in NRW. The main objectives of this paper are to:

- Develop a method to assess different scenarios (BAU, Mod Rail, Pro Rail, Mod Road and Pro Road) for the years 2030 and 2050.
- For the different scenarios and both freight corridors, determine the change in modal shift, transport volume and capacity needs and the effects on the infrastructure in NRW.
- Determine the total greenhouse gas emissions per year for each scenario.

The method used in this working paper is designed to assess the impacts of different future scenarios on the modal choice and GHG emissions for two main freight corridors through NRW.

The two corridors (RALP and NSB) in this project are mapped in Figure 2. The zones north or west of NRW in the corridors are shown in blue. In both corridors they represent the Benelux area. The zones south or east of NRW are highlighted in grey, while NRW zones are marked in red.

For each corridor, we distinguish seven different cargo flows (the directions in brackets concern the NSB corridor):

- Transit from North (West) to South (East) (from blue to grey)
- Transit from South (East) to North (West) (from grey to blue)
- From NRW to South (East) (from red to grey)
- From NRW to North (West) (from red to blue)
- From South (East) to NRW (from grey to red)
- From North (West) to NRW (from grey to blue)
- Internal NRW flows

The main indicators determined for each of these different cargo flows are:

- Ton-kilometres (tkm) (road, rail, IWT)
- Twenty-foot equivalent unit-km (TEU-km) (road, rail, IWT)
- (Loaded) vehicle kilometres (road, rail, IWT)
- Modal split (TEU or ton)

In order to calculate the modal split*, we determine the generalised costs for each mode of transport. The main purpose of having four different cargo flows is that each of these cargo flows features different cost structures. IWT cargo flows for dry and liquid bulk are usually unimodal (without pre and post haulage), while there is much more inter- or multimodal transport† for containers and general cargo. This can be seen in Table 33.

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* The share of a certain transport mode on a transport link (origin destination pair)

† Intermodal transport refers to container transport, while multi-modal transport is usually associated with general cargo.

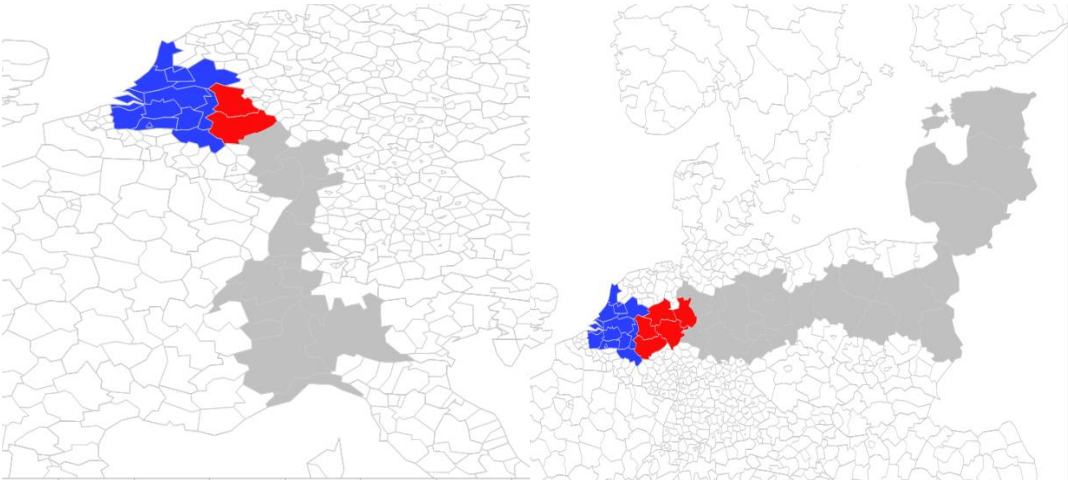

Figure 2: Considered corridors (RALP left, NSB right)

Table 3: Different forms of transport for the considered commodity types.

	Unimodal			Inter-/multi-modal	
	Road	Rail	IWT	Rail	IWT
Containers	X			X	X
Dry bulk	X	X	X		
Liquid bulk	X	X	X		
General cargo	X			X	X

With respect to intermodal and multi-modal transport, we distinguish two alternatives:

- Maritime flows (a seaport as origin or destination)
- Continental flows

For the maritime flows, the origin (or destination) of the cargo flow is a seaport. This means that there is only post- (or pre-) haulage and a handling cost.

In order to determine the modal split for each mode of transport (or transport option), the generalised transport costs are calculated. Besides the cost functions, the distances are also needed as an input to:

- Calculate the generalised costs
- Calculate the ton-kilometres and vehicle-kilometres involved.

The cost functions for road, rail and IWT are taken from van Hassel et al. (2016) and adapted to incorporate cost changes due to possible future developments. These cost functions are described in detail in the full working paper (Van Hassel et al, 2018).

5.2 Data

As stated above, the model needs different types of data: cargo data, distance data and cost data of the different transport options. With respect to the cargo flow data, we distinguish different main cargo groups:

- Containers (unitised)
- Bulk cargo

    - Dry bulk
    - Liquid bulk
- General cargo

The data are taken from the ASTRA model. Different sources are used for distance data. We calculate road distances using Google maps. Distances are calculated from the centres of the NUTS-2 regions. The road distance data are determined for the following cases:

- Both OD matrices (30x30 and 40x40)
- From each rail terminal to the centre of a NUTS-2 region (needed for the pre- and/or post-haulage calculation)
- Road distance for each OD pair on NRW territory.

For rail transport, distances are determined between different rail terminals (containers and bulk) for the following cases:

- Both OD matrices (30x30 and 40X40)
- Rail distance for each OD pair on NRW territory.

We use OpenStreetMap data for the rail distances (OpenStreetMap, 2015).

For IWT transport, distances are determined between different IWT terminals (containers and bulk, using Blue Road Map‡ (2017) for the following cases:

- Botch OD matrices where IWT transport is possible (22x22 and 31X31)
- IWT distance for each OD pair on NRW territory.

Different sources are used for the cost data. These data are collected for road, rail and inland waterway transport and taken from other research projects and data collected in the LowCarb project working group. See van Hassel et al (2018) for a full overview of the data used.

6. Results

The results of the scenario analysis are given in two parts. In the first one the impact of the different scenarios are given based on the internal cost, while in the second section the cost are given for the external cost.

6.1 Internal cost

The developed model is calibrated with transport flows generated by the ASTRA-EC System Dynamics model. It is then possible to calculate the modal split and the TEU kilometres, ton-kilometres and vehicle-kilometres in North Rhine-Westphalia by applying the calculated spreading factor (μ). It is also possible to change the input parameters related to the cost structure and determine the impact of these changes on the parameters mentioned above. We can further consider the effect of changing freight flows (forecasts for 2020 and 2030). The changes to the input parameters are taken from the different scenarios:

- Pro Rail scenario
- Pro Road scenario

Comparing the BAU scenario to the Pro Rail and Pro Road scenarios reveals the following differences:

- There are significant differences in terms of modal split. These differences depend on the inputs from the various scenarios. A Pro Rail scenario leads to a high market share of rail transport, mostly at the expense

‡ http://www.blueroadmap.nl/

of IWT and road transport to a smaller extent. The Pro Road scenario has the opposite effect as it increases road market shares on the expense of IWT and rail to a smaller degree.

- In the bulk good segment, rail market growth in the Pro Rail scenario is fed equally by road and IWT transport. Nevertheless, the strongest impact of the Pro Rail scenario is on the modal share of IWT.
- Road transport retains a high market share in absolute terms, especially in NRW. This is mainly due to the short distances involved for the majority of transport volumes (within NRW) so that road transport is very dominant.
- In both scenarios, there is a very large increase in the TEU-kilometres, ton-kilometres and vehicle-kilometres for NRW and for each corridor as a whole. This is due to the increase in demand for freight transport (1.7 % growth). The number of vehicle-kilometres is smallest in the Pro Rail scenario, but the capacity of the railway infrastructure needs to be taken into account as well. This scenario is only possible if the rail infrastructure can accommodate such a strong increase in train vehicle-kilometres.
- With respect to CO2 emissions, the absolute volume increases in all the scenarios. The smallest increases are observed for the Pro Rail scenario for both freight corridors (+ 35 % in 2015 for the RALP corridor and + 53 % for the NSB corridor).

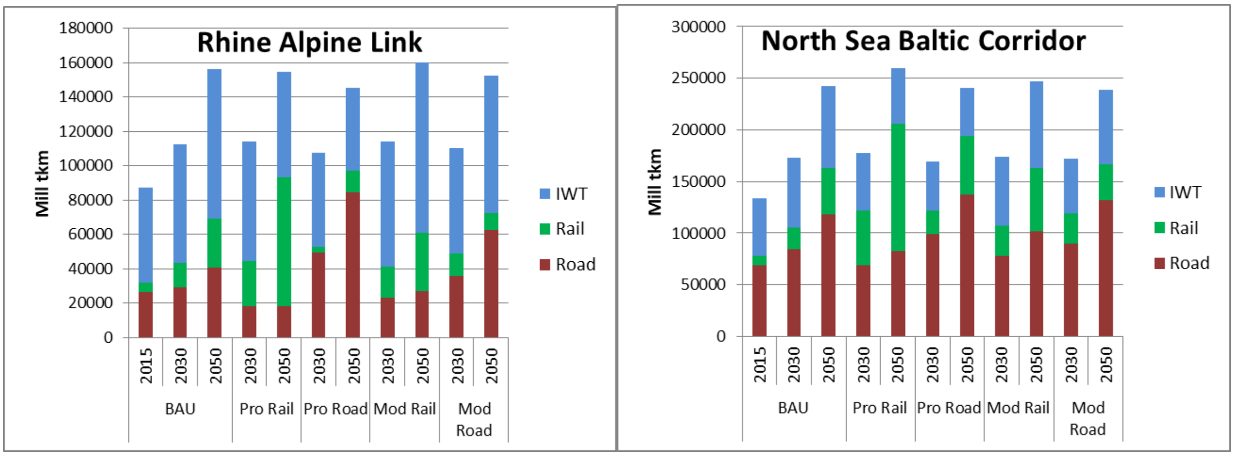

Figure 3: Transport volumes on the corridors 2015 to 2050

Over the course of the LowCarb-RFC project, the results are interpreted as follows:

- The modal shift identified by the transport model constitutes a theoretical maximum of market reactions. In reality, we observe that modal shares are rigid and change only slowly over time. Limited network capacity and the inoperability of certain cargo types on rail are the most constraining factors. The model does not consider capacity constraints. However, the full-scale scenarios Pro Rail and Pro Road and their more moderate variants represent options for preparing the transport systems. Feeding back these results into the scenario assessments makes it possible to define respective investment strategies for these cases.
- Scenarios need time to unfold. Because investments were not considered in the model, the respective long planning and construction periods were also omitted. This implies that, even if we provide sufficient infrastructure, realising the theoretical shift potentials could lag behind our figures by 20 years or more.
- Cost reduction scenarios need to be supported by policy and entrepreneurial strategies. The assumed cost reductions can only be realised if they are partly covered by the public sector and if the railways develop sufficient and partly radical innovations. Change management and institutional reforms are thus integral elements of the Pro Rail scenario, in particular. These issues are covered in detail by other reports of the LowCarb-RFC project.
- Concepts for inland waterway transport are crucial. The assessment of fixed rate GHG emission scenarios clearly shows that, even though unrealistically high market shares of the railways are computed, the reduction in GHG emissions due to modal shifts alone remains rather modest. Besides the fact that the

fixed rate GHG emission concept deliberately excludes decarbonisation strategies of the railways and the power sector, the demand shift from IWT to rail is mainly responsible for this result. A low-carbon strategy that aims at curbing transport sector emissions needs to maintain a balance between all the climate-friendly modes.

- Real GHG mitigation potentials of modal shift scenarios need to consider other crucial factors. These include the decarbonisation of the power sector, the electrification of today's diesel-powered trains or the use of low-carbon combustion fuels, efficiency gains and developments in road and IWT transport. These issues will be assessed in a separate scenario evaluation process in the LowCarb-RFC study.

6.2 External cost

External costs are primarily determined by the expected strong increase in transport volumes. Total costs increase in the BAU scenario by more than half. In contrast, the Pro Road scenario manages to reduce external costs in 2050 by 42 % (RALP) and by 34 % (NSB) compared to 2015. This is a remarkable result, because not only road volumes increase during this period, but the costs for CO2 emissions as well. This reduction is achieved through extensive decarbonisation of road freight. The Pro Rail scenario shows a smaller reduction in road freight emissions, resulting in external costs in 2050 that are similar to the 2015 level. Local air pollution becomes increasingly important.

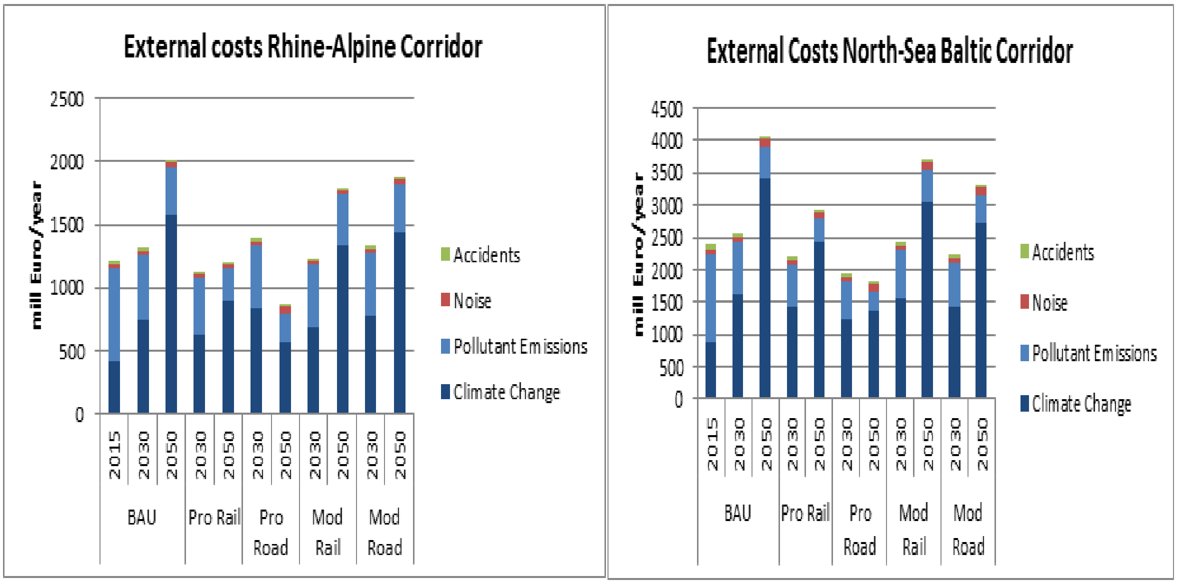

Figure 4: External costs by effects

Climate change costs represent the largest share of external costs, followed by air pollution. Noise and accidents do not play an important role here, since noise affects only limited numbers of residents near motorways, the accident rates on motorways are relatively low and additional technical improvements, in particular automated and autonomous driving, will reduce the number of casualties on motorways even further by 2050.

Comparing the costs in the 2050 scenarios, Figure 4 reveals that all the scenarios reduce the external costs compared to BAU. However, the cost reductions are highest in the Pro Road scenario with a decrease of around 60 %, followed by Pro Rail with 40 % in the RALP corridor and 27 % for the NSB corridor. The lower results in the NSB corridor are due to the larger share of non-electric trucks here. Both moderate scenarios produce only modest improvements between 9 % and 20 %. External cost reductions in the Pro Road scenario amount to 1.1 billion euros per year on the RALP corridor and to 2.1 billion euros per year in the NSB corridor.

7. Conclusions

We can summarise the conclusions from this work as follows:

- Rapid decarbonisation of road transport through electrification is indispensable to achieve the climate targets in transport.
- Strong railways are needed to achieve even deeper cuts in GHG emissions and compensate those segments of road haulage that cannot be electrified. The sector needs to standardise and simplify technologies and operations.
- Inland waterway and coastal shipping need to play an integral role in decarbonisation strategies as they still have available capacities and a small carbon footprint.
- Sustainability considerations will probably focus on greenhouse gas emissions as their economic costs increase and because other externalities can and will be mitigated technically.
- If all measures were implemented, we can achieve up to 70 % reduction in GHG emissions of freight transport along major European corridors. Combining road and rail measures achieves the highest mitigation results.
- The annual investment costs required are huge, ranging between 10 billion euros per year for decarbonising road transport to 100 billion euros for a massive modal shift to rail.
- CO_2 mitigation costs then range from 2500 euros per ton for decarbonising road to 20000 euros per ton for massive shifts to rail. The costs of decarbonising the energy sector are excluded here.

These results clearly indicate what a huge undertaking it is to decarbonise the European long-distance freight sector. Cheaper and quicker options are badly needed, funding issues must be solved and decision pathways need to be drastically accelerated to achieve our 2030 and 2050 targets.

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References

Automobilwoche (2012): Kein Bock auf autonomes Fahren: Mazda mit neuer Marketingstrategie. Automobilwoche.de http://www.automobilwoche.de/article/ 20170103/nachrichten/170109987/kein-bock-auf-autonomes-fahren-mazda-mit-neuer-marketingstrategie (21.01.2017).

Bernhart, W. and Roland Berger (2016): Automated Trucks. Retrieved from: https://www.rolandberger.com/de/Publications/pub_automated_trucks_the_next_big_disrupter_in_the_automotive_industry.html (05.12.2017).

BGL (2017): Kosteninformationssystem KIS (Cost Information System). Regularly updated leaflet collection, 42nd update, November 2015. Bundesverband Güterkraftverkehr, Logistik und Entsorgung (BGL e.V.) / BDF Infoservice. Frankfurt am Main.

Continental AG (2016): Continental Mobilitätsstudie 2016: Der vernetzte Truck. Retrieved from: https://www.continental-corporation.com/resource/blob/12706/ a8 87d44ab91a956354a4081e0bd9c35e/mobistud-2016-pdf-data.pdf (22.11.2017).

Crozet, Y., J. Haucap, B. Pagel, A. Musso, C. Piccioni, E. van de Voorde and T. Vaneslander (2014): Development of rail freight in Europe: What regulation can and cannot do. CERRE Policy Paper. Universities of Lyon, Düsseldorf, Rome and Antwerp for the Centre on Regulation in Europe (CERRE).

De Boer, E., H. van Essen, F. Brouwer, E. Pastori, A. Moizo (2011): Potentials of Modal Shift to Rail Transport - Study on the projected effects on GHG emissions and transport volumes. CE Delft and TRT (Milan) on behalf of the Community of European Railway and Infrastructure Companies (CER). Delft.

Deutsche Bahn (2015): Zukunft Bahn -- gemeinsam für mehr Qualität, mehr Kunden, mehr Erfolg. Deutsche Bahn AG. Berlin.

Doll, C. and J. Köhler (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.

Doll, C.; L. Mejia-Dorantes and J. Vassallo (2016): Economic impact of introducing road charging for Heavy Goods Vehicles. Report prepared by Fraunhofer-Institute for Systems and Innovation Research ISI (Karlsruhe) and Universidad Politécnica de Madrid UPM. Study commissioned by Transport & Environment, Brussels.

DVV Media Group GmbH (2018): BAG-Prognose: Wachstum des Güterverkehrs flaut bis 2021 stark ab. DVZ. Retrieved from: https://www.dvz.de/rubriken/markt-unternehmen/single-view/nachricht/wachstum-des-gueterverkehrs-flaut-bis-2021-stark-ab.html (10.04.2018).

E3MLab and AUTH (2014): Primes Model 2013/2014 Detailed Model Description. E3MLab/ICCS at National Technical University of Athens.

EC (1997): Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. Brussels.

EC (2014): Rhine-Alpine Core Network Corridor Study. Final Report. Brussels.

EC (2016): Fifth report on monitoring development of the rail market. Report from the Commission to the European Parliament and the Council. COM (2016) 780 final. Brussels.

E-mobil BW GmbH (2015): Automatisiert. Vernetzt. Elektrisch. Retrieved from: http://www.e-mobilbw.de/files/e-mobil/content/DE/Service/Publikationen/e-papers/EPaper_Fahrzeugvernetzung/files/assets/common/downloads/publication.pdf (09.12.2015).

Fiorello, D., F. Fermi, D. Bielanska (2010): The ASTRA model for strategic assessment of transport policies, System Dynamics Review vol 26, No 3 (July–September 2010): 283–290.

Flemish Traffic Centre (2017): An Overview of the strategic freight model Flanders (ppt by Pieter Van Houwe).

Furtado, F. (2018): Decarbonising Road Freight. Results of expert opinion survey. Decarbonising Road Freight Transport Workshop. Retrieved from: https://www.itf-oecd.org/decarbonising-road-freight-results-expert-opinion-survey (28.06.2018).

Holzhey, M. (2010): Schienennetz 2025/2030 - Ausbaukonzeption für einen leistungsfähigen Schienengüterverkehr in Deutschland. KCW GmbH, Berlin, commissioned by the Federal Environment Agency (UBA), UBA-Texte 42/2010. Berlin.

ITF and OECD (2017): Managing the Transition to Driverless Road Freight Transport. Retrieved from: https://www.itf-oecd.org/managing-transition-driverless-road-freight-transport (06.12.2017).

Lambrechts, P. and N. Dasburg-Tromp (2014): PLATINA2 – Platform for the implementation of NAIADES II. D1.3: Comparison of Existing Modal Shift Studies. Study funded by EC FP7. PBV and PANTEIA.

Lopes, S.C.R.B. (2014): Infrastructure Charges for Freight Trains in Europe. DECivil, Instituto Superior Técnico, University of Lisbon. Técnico Lisboa. Lisbon.

Mader, S. and W. Schade (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.

McKinsey (2016): Delivering Change - Die Transformation des Nutzfahrzeugsektors bis 2025. Retrieved from: https://www.mckinsey.de/files/de_delivering_change.pdf (06.12.2017).

Möst, D. (2017): REFLEX – Analysis of the European energy system under the aspects of flexibility and technological progress. Project Brochure. Project funded by the EC's H2020 programme. Co-Ordinator: University of Dresden. Website: http://reflex-project.eu/.

OECD and IEA (2017): The Future of Trucks - Implications for energy and the environment. Retrieved from: https://www.iea.org/publications/freepublications/ publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf (28.09.2017).

Öko-Institut and Fraunhofer ISI (2015): Klimaschutzszenario 2050, 2nd final report. Study commissioned by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). Berlin, Karlsruhe.

Panteia (2013): Contribution to impact assessment of measures for reducing emissions of inland navigation. Zoetermeer.

Permala A. and J. Eckhardt (2015): BESTFACT – Best Practice Factory for Freight Transport. Deliverable D3.2: Recommendation and policy tools. Project co-funded by EC-FP7. VTT. Espoo.

Petry, C., M. Maibach, C. Gandenberger, N. Meyer, D. Horvat, J. Köhler, C. Doll and S. Kenny (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. Fraunhofer ISI, Fraunhofer IML, M-Five, INFRAS, T&E, TPR/UNiv. of Antwerp. Zürich, Karlsruhe.

pwc, 2016. The era of digitized trucking. Transforming the logistics value chain.PriceWaterhouseCoopers.

Randelhoff, M. (2017): Automatisierung des Straßengüterfernverkehrs. Zukunft Mobilität. Retrieved from: https://www.zukunft-mobilitaet.net/113531/analyse/ automatisierung-strassengueterverkehr-selbstfahrende-lkw-autonom-automati sierte-nfz-nutzfahrzeuge/ (2017).

Schade, W. (2005). Strategic Sustainability Analysis: Concept and application for the assessment of European Transport Policy. Nomos-Verlag, Baden-Baden, Germany

Slowik, P. and B. Sharpe (2018): Automation in the long haul: Challenges and opportunities of autonomous heavy-duty trucking in the United States. Working Paper 2018-06. International Council of Clean Transportation (ICCT).

Sutter, D., M. Maibach, D. Bertschmann, L. Ickert, M. Peter, C. Doll and A. Kühn (2016): Finanzierung einer nachhaltigen Güterverkehrsinfrastruktur: Anforderungen und Rahmenbedingungen für eine zukunftsorientierte Entwicklung des Güterverkehrs - eine systematische Analyse auf der Grundlage eines Ländervergleichs - Teilvorhaben ohne Luftverkehr (UBA-FB 002354), supported by UBA, Dessau-Roßlau.

T&E (2016): Are Trucks Taking Their Toll? - External Costs of trucks and the review of the Eurovignette Directive. Transport & Environment. Brussels.

Trautmann, C. (2016): North-Sea Baltic – Second Work Plan of the European Coordinator. Report to the European Commission. Brussels.

UBA (2012b): Daten zum Verkehr, Berlin.

UIC and IEA (2016): Railway Handbook 2016 – Energy Consumption and CO2 Emissions, Focus on Sustainability Targets. International Energy Agency IEA, International Union of Railways UIC. Paris.

Van Essen, HP.; A. Schroten; M. Otten; D. Sutter; C. Schreyer; R. Zandonella; M. Maibach; C. Doll (2011): External costs of Transport in Europe 2008 – Update Study. Report to the International Union of Railways UIC. CE Delft, Infras, Fraunhofer ISI. Delft.

Van Hassel, E., H. Meersman, E. Van de Voorde and T. Vanelslander (2016): North-South container port competition in Europe: the effect of changing environmental policy, Research in transportation business & management-issn 2210-5395,p. 1-15

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.

Wakabayashi, D. (2018): Uber's Self-Driving Trucks Hit the Highway, but Not Local Roads. The New York Times. Retrieved from: https://www.nytimes.com/ 2018/03/06/technology/uber-self-driving-trucks.html (06.03.2018).

Wietschel, M., W. Schade and S. Mader (2017): Machbarkeitsstudie zur Ermittlung der Potentiale des Hybrid-Oberleitungs-Lkw. Karlsruhe. Studie im Rahmen der Wissenschaftlichen Beratung des BMVI zur Mobilitäts- und Kraftstoffstrategie.

Wojciechowski, P. (2016): Rhine-Alpine, Second Work Plan of the European Coordinator. European Commission. Brussels.