Fraunhofer

FROM LOCAL TO EUROPEAN LOW EMISSION FREIGHT CONCEPTS

SUMMARY REPORT 3
LowCarb-RFC—EUROPEAN RAIL FREIGHT CORRIDORS GOING CARBON NEUTRAL

DOLL, KÖHLER, SIEVERS, GRIMM, HORVAT
(FRAUNHOFER ISI)
EIBAND, GÖRTZ, REMMERT, KLUKAS (FRAUNHOFER IML)
MAIBACH AND PETRY (INFRAS)
SCHADE AND MADER (M-FIVE GMBH)
VAN HASSEL AND VANELSLANDER (TPR,
UNIVERSITY OF ANTWERP)
KENNY (TRANSPORT & ENVIRONMENT)
NIKLAS SIEBER

Funded by
STIFTUNG MERCATOR FOUNDATION
European Climate Foundation

FUNDED BY

STIFTUNG MERCATOR FOUNDATION

European Climate Foundation

CONSORTIUM

Fraunhofer

Fraunhofer Institute for Systems and Innovation Research ISI (Project Coordinator)

Fraunhofer Institute for Material Flows and Logistics IML

MFIVE

INFRAS THINKING FOR TOMORROW

TRANSPORT & ENVIRONMENT

TPR
Department of Transport and Regional Economics
University of Antwerp

FROM LOCAL TO EUROPEAN LOW EMISSION FREIGHT CONCEPTS

SUMMARY REPORT 3

LowCarb-RFC—EUROPEAN RAIL FREIGHT CORRIDORS GOING CARBON NEUTRAL

Claus Doll, Jonathan Köhler, Luisa Sievers, Anna Grimm, Djerdj Horvat (Fraunhofer ISI)
Agnes Eiband, Dorothe Görtz, Maximiliane Remmert, Achim Klukas (Fraunhofer IML)
Markus Maibach, Christoph Petry (INFRAS)
Wolfgang Schade, Simon Mader (M-Five GmbH)
Edwin van Hassel, Thierry Vanelslander (TPR, University of Antwerp)
Samuel Kenny (Transport & Environment)
Niklas Sieber

Karlsruhe, March 2019

EDITORIAL INFORMATION

FROM LOCAL TO EUROPEAN LOW EMISSION FREIGHT CONCEPTS

SUMMARY REPORT 3

LowCarb-RFC—EUROPEAN RAIL FREIGHT CORRIDORS GOING CARBON NEUTRAL

Claus Doll, Jonathan Köhler, Luisa Sievers, Anna Grimm, Djerdj Horvat (Fraunhofer ISI)
Agnes Eiband, Dorothe Görtz, Maximiliane Remmert, Achim Klukas (Fraunhofer IML)
Markus Maibach, Christoph Petry (INFRAS)
Wolfgang Schade, Simon Mader (M-Five GmbH)
Edwin van Hassel, Thierry Vanelslander (TPR, University of Antwerp)
Samuel Kenny (Transport & Environment)
Niklas Sieber

Karlsruhe, March 2019

Funded by
Stiftung Mercator Foundation and European Climate Foundation

Edited by
Fraunhofer ISI

Contact:
Claus Doll
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48, 76139 Karlsruhe, Germany
Tel.: +49 721 6809-354
Email: claus.doll@isi.fraunhofer.de
www.isi.fraunhofer.de

CONTENT

ABSTRACT

This third and final summary report of the study LowCarb-RFC turns the attention on low carbon emission scenarios from the European perspective to the German region of North Rhine-Westphalia (NRW). For NRW we developed and assessed specific rail modal shift and road electrification scenarios towards 2050. To achieve profound cuts in GHG emissions we find that planning periods need significant shortening, and system transition has to start immediately. In particular, new technologies to boost rail capacity are needed as shifting all rail freight to electric trucks would require inconceivable road network expansions.

Total investment costs between 2015 and 2050 range between 15 billion euros for a lower bound rail investment case to 19 billion euros for motorway electrification and expansion. None of these costs create major disruptions to the NRW economy or labour market and thus do not constitute an excuse for not acting.

The NRW case study finds lower GHG reduction potentials, –16 per cent, than the European corridors studies (–28 to –43 per cent) for the railway expansion and modal shift scenarios. For road electrification all cases find a potential of some –60 per cent. Interestingly, also for GHG mitigation costs NRW values are lower in the Pro Rail case (140 euros per ton CO_2-eq.) than in the corridor studies (around 600 euros per ton CO_2-eq.). Environmental and safety external costs suggest that GHG mitigation shall be prioritised. For profound and fast decarbonisation, all options are needed, including CO_2-efficient shipping.

ZUSAMMENFASSUNG

Dieser dritte und letzte Kurzbericht der Studie LowCarb-RFC verlagert die Sichtweise von den europäischen Korridoren auf die Region Nordrhein-Westfahlen (NRW). Für NRW wurden spezifische Nachfrageszenarien bis 2050 entwickelt und bewertet. Für das Erreichen umfangreicher THG-Reduktionen müssen Planungszeiten deutlich verkürzt und die Systemtransformation sofort eingeleitet werden. Insbesondere müssen durch neue Technologien Kapazitäten bei der Bahn geschaffen werden, da die Verlagerung aller Bahngütertransporte auf elektrifizierte Lkw exorbitant umfangreiche Ausbauten des Straßennetzes erforderte.

Die gesamten Investitionskosten zwischen 2015 und 2050 bewegen sich zwischen 15 Milliarden Euro für die untere Grenze des Schienenausbaus und 19 Milliarden Euro für Elektrifizierung und Ausbau der Autobahnen. Keine dieser Kosten erzeugt größere Verwerfungen der Volkswirtschaft oder des Arbeitsmarktes und bietet damit keine Entschuldigung nicht zu handeln.

Die Fallstudie NRW findet geringere THG-Einsparpotenziale (–16 Prozent) gegenüber den Korridorstudien (–28 bis –43 Prozent) für die Bahnerweiterungs- und Verlagerungsszenarien. Die Elektrifizierung des Straßenverkehrs erreicht in allen Fällen eine Reduktion von 60 Prozent. Interessanterweise sind auch die GHG-Vermeidungskosten im Pro Rail-Szenario für NRW niedriger (140 Euro pro Tonne CO_2-eq.) als in den Korridorstudien (um 600 Euro je Tonne CO_2-eq.). Externe Kosten für Umwelt und Sicherheit legen nahe, Klimaeffekte zu priorisieren. Für eine tiefe und schnelle Dekarbonisierung des Güterverkehrs werden hierzu alle verfügbaren Optionen, inklusive einer CO_2-armen Schifffahrt, gebraucht.

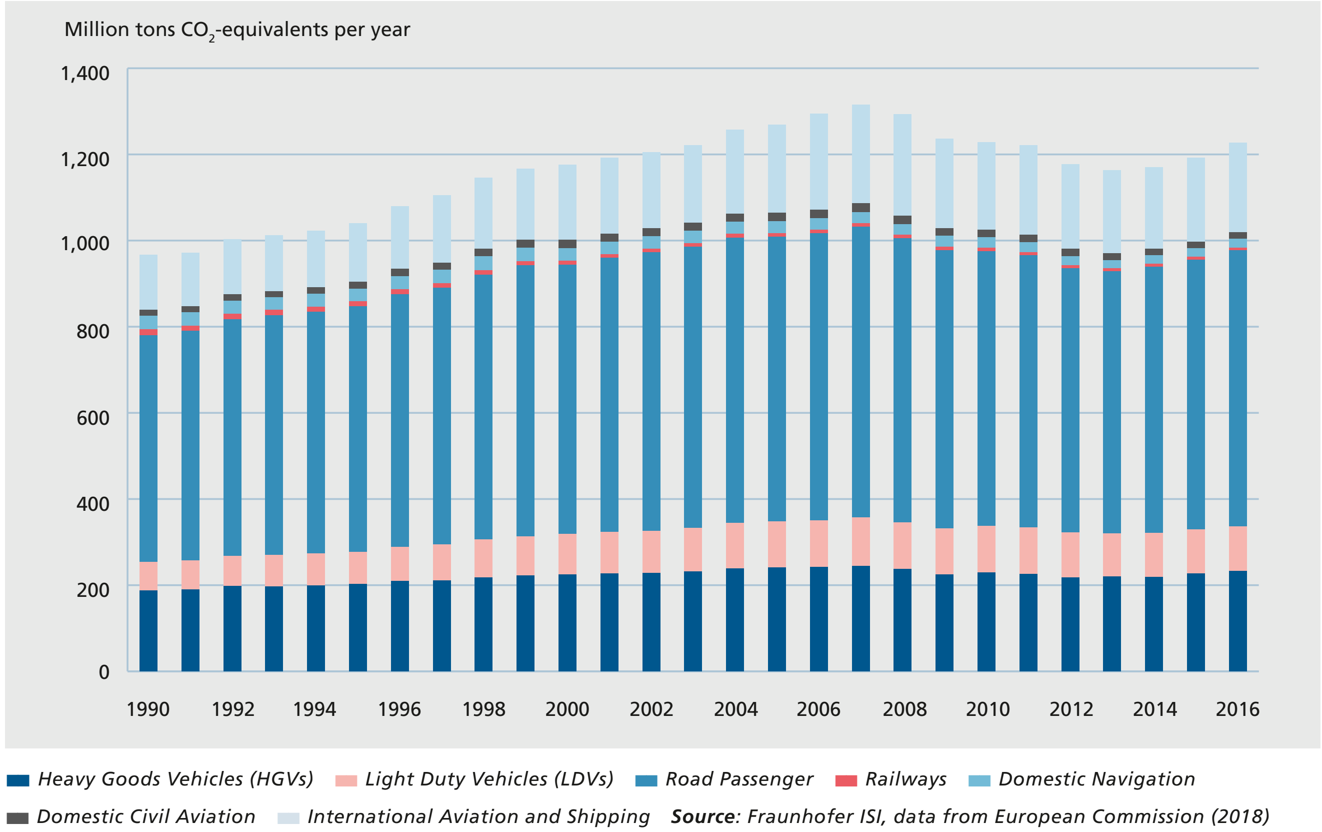
1 INTRODUCTION

1.1 BACKGROUND

In the 28 EU Member States, heavy goods vehicles (HGVs) accounted for a remarkably constant 19 per cent share of domestic transport's greenhouse gas (GHG) emissions from 1990 to 2016. Light duty vehicles (LDVs) added another 7 per cent (1990) to 9 per cent (2016), so that long distance and regional freight transport together contributed 27 to 29 per cent to the EU28's GHG emissions. Road passenger transport took the lion's share of this with 52 per cent of emissions in 2016, while the remaining 20 per cent were almost completely due to international shipping and aviation. The GHG contributions of the railways and inland navigation across the EU are negligible. Figure 1 shows the annual emissions in transport by mode and sector from 1990 to 2016.

The figure shows that freight transport emissions are relevant for climate mitigation strategies, even though passenger cars are still the dominant emitter. However, this may change with the market uptake of electric and other new energy vehicles (NEVs). Trucks have a limited ability to convert to new energies. The volume to energy capacity of batteries is far below that of hydrocarbon fuels, and infrastructures for hydrogen are insufficiently developed. Synthetic fuels and biofuels for combustion engines are of course possible, but their energy efficiency is relatively low. To achieve a satisfactory level of energy efficiency and a high driving range, trucks must run directly on electric power.

FIGURE 1: Annual GHG emissions in the EU28 by transport mode and sector



Source: Fraunhofer ISI, data from European Commission (2018)

Figure 1 also reveals that GHG emissions in transport are not declining as they should. In fact, emissions even started to rise again in 2015 and 2016, the most recent years with data availability. None of the basic strategies for cleaner transport: "decoupling transport demand from economic growth", "modal shift to rail" and "reducing vehicle emissions" has shown much effect over the past 20 years. With the exception of the global financial and economic crises 2008 to 2012, demand has been growing, improved vehicle fuel efficiencies have been eaten up by increased motor power (and partly by emission limits), and rail network improvements have been offset by cost reductions in trucking.

Of the many options discussed for low-carbon freight transport, the LowCarb-RFC study looks at two of the most significant measures. First, the traditional goal of shifting massive amounts of freight from road to rail. New technologies like freight platforms, automation and advanced train control systems might inject new energy into this "old" idea. Second, the study looks at the comparatively new topic of electrifying motorways. Currently, trials across Europe are collecting experiences with this concept and could spark implementation plans towards the early 2020s.

The study does not look at options for decoupling freight demand from economic growth. Some impulses in this direction can be derived from our review of change management and business model literature in this report. In-depth research on the topic, however, remains outside the scope of this study.

1.2 CONTEXT: THE LOWCARB-RFC STUDY

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

The LowCarb-RFC study concentrates on long-distance freight transport along major European corridors because this is one of the most steadily growing sources of greenhouse gas emissions in Europe. It is also the most difficult to address using renewable energies and other standard climate mitigation measures. 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 mitigation measures in all freight modes along the two major transport corridors crossing Germany: the Rhine Alpine corridor (RALP) from the Benelux countries to Northern Italy, and the North-Sea-Baltic corridor (NSB) from Benelux via Poland to the Baltic States. Besides major European strategies, the project concentrates on the implications for transport policy at the intersection of these two corridors, 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, and thus potentially in a carbon-neutral way. Within this setting, the project pursues three streams of investigation:

- *Stream 1: Railway Reforms*. This section of the LowCarb-RFC project explores rail freight as a major pillar of climate mitigation policy. It considers the current slow pace of climate mitigation in the freight transport sector and asks how regulatory frameworks, company change management processes or new business models could accelerate it.
- *Stream 2: European Scenarios and Impacts*. Cost and quality scenarios are established for rail, road and waterway transport along the two corridors, and their impacts on the modal split, investment needs and sustainability are modelled. This stream forms the analytical core of the study and provides the basis for the subsequent analysis of intervention pathways.
- *Stream 3: Case Study NRW*. This step analyses the transport scenarios and intervention pathways at the level of the local conditions in NRW and looks at the implications for investments or disinvestments in infrastructures, jobs, economic prosperity and the environment.

This third and final summary report of the LowCarb-RFC project focusses on Stream 3, i.e. adapting the two major European corridor scenarios towards 2050 to the local conditions in the German federal state of North Rhine-Westphalia. After an assessment of the transport, economic and sustainability impacts, the report turns to the LowCarb-RFC Summary Reports 1 and 2. It assesses the NRW findings in the light of the European corridor results and the previous findings on institutional reforms and business models for national rail services.

1.3 PURPOSE AND STRUCTURE

Previous publications from the LowCarb-RFC project looked at improved rail freight performance as a way of mitigating greenhouse gas (GHG) emissions (Summary Report 1 of the LowCarb-RFC study, Petry et al., 2018) and the impacts of large-scale changes in the modal shift and in road haulage technologies along two major European freight corridors. The rail freight corridors RFC-1 from Rotterdam to Genova and the southern arm of RFC-8 from Antwerp to the Polish-Lithuanian border (Summary Report 2 of the LowCarb-RFC study, Doll et al., 2018) were examined. The main findings are that it takes time for large and traditional companies like the European rail carriers to adapt to new market conditions and business models and these changes cannot completely eliminate freight transport's GHG emissions. No matter what happens on the rail, it is necessary to decarbonise road haulage as well. However, this pathway also contains pitfalls. It might prove impossible to provide the necessary infrastructure to transport the majority of freight on electrified highways, economic and social problems may occur, and external effects other than GHG emissions may affect the assessment of rail versus road-based solutions.

In this final summary report of the LowCarb-RFC study, we break the general and large-scale findings down to the regional level of the German federal state of North Rhine-Westphalia (NRW), which is where the two corridors meet. RFC-1 cuts through NRW from north to south, while the southern branch of RFC-8 touches the Ruhr area with the port of Duisburg. This case study is also closer to day-to-day policy planning as it cuts off the extreme freight demand development forecasted for some of the scenarios along the two major corridors. A ceiling of +/–75 per cent of demand changes is considered in the scenarios in the year 2050 compared to the Business-as-Usual (BAU) case when investigating the potential infrastructure, economic, social and sustainability impacts.

The report is organised as follows: Section 2 discusses transport scenarios for the two European freight corridors on NRW territory. Details on individual corridor sections are taken from the project assessment of the German Federal Investment Plan (BVWP) 2030. Section 3 derives the infrastructure demand and related investment costs associated with the NRW scenarios for improved rail and carbon-free road transport. Section 4 delves into the larger economic impacts of the required investments by scenario, and Section 5 presents their environmental and safety implications. These four sections summarise and interpret the results of Working Paper 9 (Eiband et al., 2018) of the LowCarb-RFC project.

Finally, the report turns back to the analyses in the LowCarb-RFC Summary Reports 1 and 2. Following a brief review, Section 6 interprets their findings in the light of the insights from the NRW case study. Section 7 gives a short overview on the transformation of institutions and technology regimes. Section 8 derives policy recommendations from the work performed in the LowCarb-RFC project.

2 LOCAL SCENARIOS FOR NORTH RHINE-WESTPHALIA

Stream 3 transfers the results of streams 1 and 2 to the local conditions in NRW in order to outline the regional effects of structural changes in road and rail transport. NRW was selected as the reference region because it is crossed by two trans-European transport network (TEN-T) corridors (Rhine-Alpine corridor and North-Sea-Baltic corridor) and is an interesting region due to its location and population density. This summary report assesses the necessary investments and disinvestments as well as the environmental and social impacts of changing transport volumes and infrastructure investment activities in alternative scenarios towards 2050.

2.1 INTRODUCTION TO THE NRW CASE

North Rhine-Westphalia (NRW) is an important logistics area for Germany as well as Europe due to its strategic location in the heart of Europe. North Rhine-Westphalia connects Germany directly to the Netherlands, Belgium and France and plays an important role in the European internal market as well as for international and national trade and transport flows. NRW has the largest population, 17.9 million inhabitants, of all 16 German federal states and the highest population density, 524 inhabitants per km², of the 13 German regions (Statistisches Bundesamt, 2016).

The European region "DEA" defining North Rhine-Westphalia has a larger population than some of the individual countries along the two major transport corridors investigated in the LowCarb-RFC study, such as the Netherlands (17 million), Belgium (11.4 million) and Switzerland (8.4 million) (Eurostat, 2019). Moreover, with the port of Duisburg, NRW hosts the largest inland port in Europe and is home to a vital logistics industry. It therefore constitutes an interesting and very relevant case study area when looking at the impacts that may arise from drastic policy interventions intended to curb the greenhouse gas emissions from transport.

The rapid growth of the global economy (European Commission, 2017) and the increase of freight transport as well as commuter flows (Deutscher Gewerkschaftsbund, 2016) have placed an increasing burden on the transport network in NRW. From 1990 to 2014, traffic on the motorways in NRW increased by 22.8 per cent. (MBWSV, 2016). Apart from regional traffic, especially transit transport and seaport hinterland traffic originating from the ZARA ports (Zeebrügge, Antwerp, Rotterdam and Amsterdam) (SCI Verkehr, Fraunhofer IML, 2015) present a challenge to North Rhine-Westphalia's transport network. This development has already led to visible overuse on some routes, indicated by delays to rail transport (Plöchinger and Jaschensky, 2013) and frequent congestion on the roads (Liebsch, 2017). Within the last six years, traffic jams in NRW have grown about 280 per cent in terms of kilometres, from 161,000 km in 2012 to 455,000 km in 2017 (ADAC e.V., 2012, 2017). This corresponds to 31 per cent of the value for Germany as a whole in 2017. The predicted growth of economic and transport activities within the region and the continuous rise in global trade volume both contribute to the steep increase in the traffic loads on the transport infrastructure in NRW.

2.2 CURRENT FREIGHT TRANSPORT CONDITIONS IN NRW

When assessing the need for future infrastructure investments, the first step is to establish an inventory of current networks and their bottlenecks or capacity reserves. Throughout this assessment, we concentrate on road and rail infrastructures along the two major European transport corridors Rhine-Alpine and North Sea-Baltic in NRW. We assume that inland navigation has sufficient infrastructure capacity reserves to cater for even larger demand shifts in the future.

Traffic conditions may vary strongly over time and between individual sections of road and railway networks, reflecting differences in demand levels and infrastructure capacity. The data availability for capacity assessment models differ widely between road and rail infrastructure so we discuss the method for assessing capacity utilization rates separately for these two modes.

Road network

Regarding the road network, the European corridors passing through NRW territory consist solely of motorways. Therefore, the German road capacity model for multi-lane motorway sections (FGSV, 2008) can be applied to estimate quality indicators by section. The model expresses loads in passenger car units (PCU) per 24 hours. It distinguishes between light traffic, i.e. passenger cars, motorcycles, vans and trucks up to 3.5 tons gross vehicle weight, and heavy traffic, i.e. trucks and truck-trailer-combinations above 3.5 tons, and coaches. Heavy traffic is assigned two PCUs compared to one PCU for light traffic (Intraplan Consult, 2012). The weighted sum of light and heavy traffic volumes provided by traffic count data equals the total 24-hour traffic volumes per section. The data used for the mean daily traffic intensity were generated using the 2015 road traffic census published by the Federal Highway Research Institute (BASt) (BASt, 2017).

For an exemplary motorway section between “Leverkusen” and “Leverkusen West” on the A1, light traffic has a share of 87.2 per cent out of 105,766 vehicles. This is equivalent to 92,228 PCU of light traffic and consequently 27,076 PCU of heavy traffic, which sums up to 119,304 PCU per 24 hours on this section. Figure 2 illustrates the results of the calculations for each section of the two European transport corridors on NRW territory and shows the difference in the mean daily traffic intensity. The busiest sections appear to be in the greater Cologne area, as well as near Oberhausen and Duisburg.

The traffic loads per motorway section alone, however, do not indicate actual traffic conditions without information on road capacity as well. Therefore, the total daily loads per road section were allocated to the actual number of motorway lanes for each section. Total traffic volumes are measured in average annual daily traffic (AADT), i.e. in vehicles per 24 hours in the year 2015. The allocation assumed an equal distribution of AADT across all lanes of a road section. This assumption appears justified under congested traffic conditions as drivers will make maximum use of the available road space. The six resulting traffic quality grades range from A / B, which indicates very good or good traffic quality with a mean daily load of 0 to 11,530 vehicles per lane, to F–, which is the worst situation with a mean daily load of more than 26,135 vehicles per lane (Intraplan Consult GmbH, 2012). Traffic quality was assumed to be critical from grade E (“inadequate”, 18,920 to 20,990 vehicles per day and lane), and the sections allocated this grade and lower were identified as bottlenecks.

For the exemplary section from “Leverkusen” to “Leverkusen West”, six lanes have an AADT of 119,304 vehicles per 24 hours, which translates into 19,884 vehicles per lane per 24 hours. Accordingly, the section between “Leverkusen” and “Leverkusen West” is graded E (“inadequate”). This calculation was made for each section on the two TEN-T corridors for road transport and is illustrated in Figure 3.

The blue line in Figure 3 shows the total length of the overloaded sections along the two corridors in kilometres. In summary, in 2015, 40 of a total 104 sections in NRW on the two corridors were allocated traffic quality grade “E” or worse, which means they have reached a critical traffic saturation level. These 40 sections make up 176 km of a total 534 km. Only eight sections, with a total length of 44 km, could be assigned traffic quality grade “A / B”, implying that free flowing traffic is possible along the TEN-T corridors.

One of the three sections assigned grade “F–” is located on the A1, starting at the intersection “Wuppertal-Nord” until “Wuppertal-Langerfeld”. The other two sections are connected to each other and form part of the A3. Traffic quality remains critical starting at the “Leverkusen” intersection through “Leverkusen Zentrum” until “Köln-Mülheim”.

Rail network

The University of Münster determined the mean daily load of the railways in the year 2011. Projected to 2015, the mean daily loads fluctuate between 0 and 770 trains; 65 of 118 sections were under strain and carried more than 200 trains per day. On average, this implies 227 trains per day. The University of Münster took detailed data for each railway section (IVM, 2011).

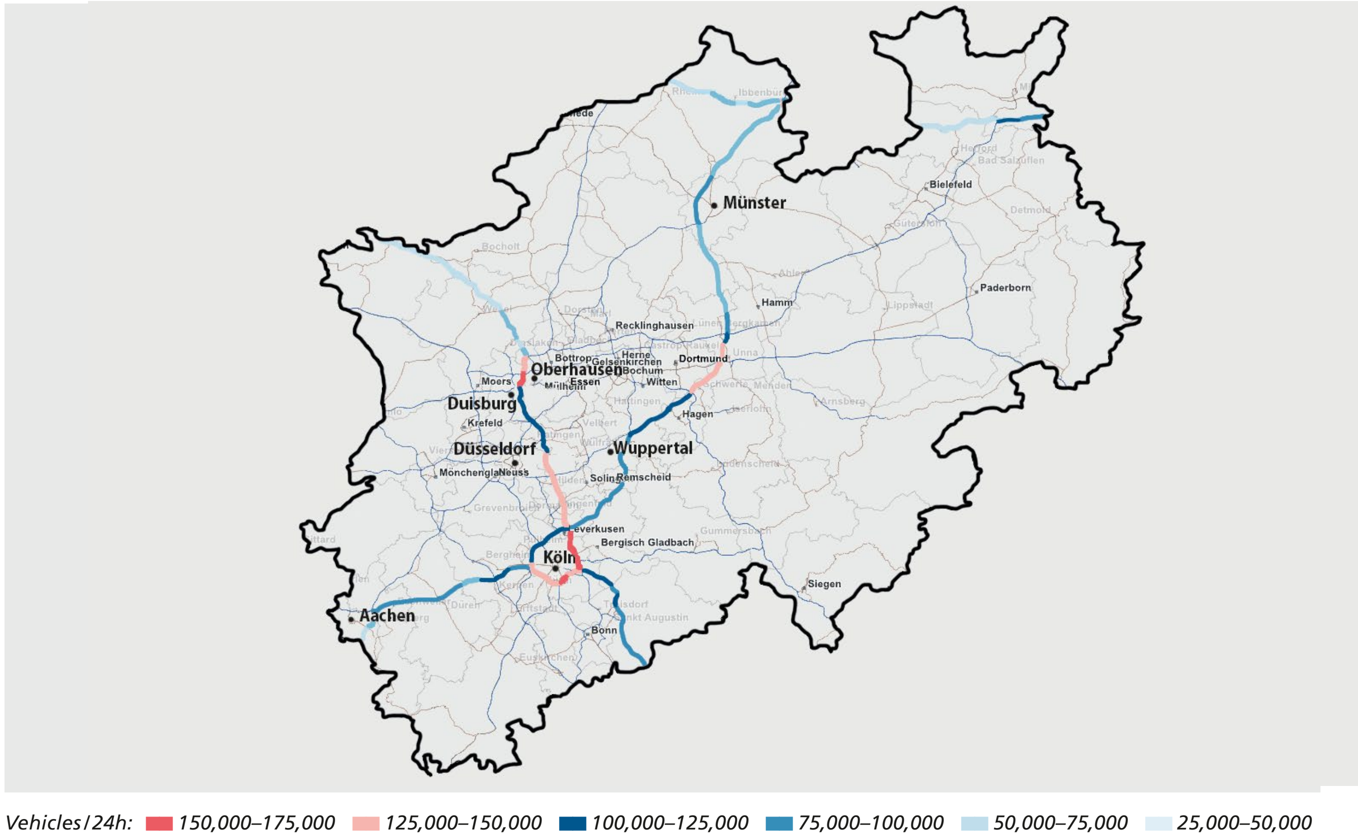
To determine the occupancy rate for every section in per cent, the quotient was calculated from the given load and the capacity in trains per section.

Applied to the section “Aachen Central” to “Aachen West”, for example, the occupancy rate was 145 per cent based on an actual load of 285 trains in 2015 and a calculated capacity of 196 trains. This section is highly overloaded and requires capacity enhancements. We define every section with an occupancy rate of more than 110 per cent as overloaded in line with the methodology used in the BVWP (BMVI, 2015), and requiring intervention measures.

In total, there are 93 sections with idle capacity meaning traffic in these sections can flow without restrictions. On 20 sections, between 85 per cent and 110 per cent capacity is used; this indicates an economical occupancy rate and a traffic flow without bigger impacts (IVM, 2011). The remaining five sections have been classified as overloaded so that delays are a daily problem.

The line deficiencies of these critical sections result from the difference between actual loads and theoretical capacity. For

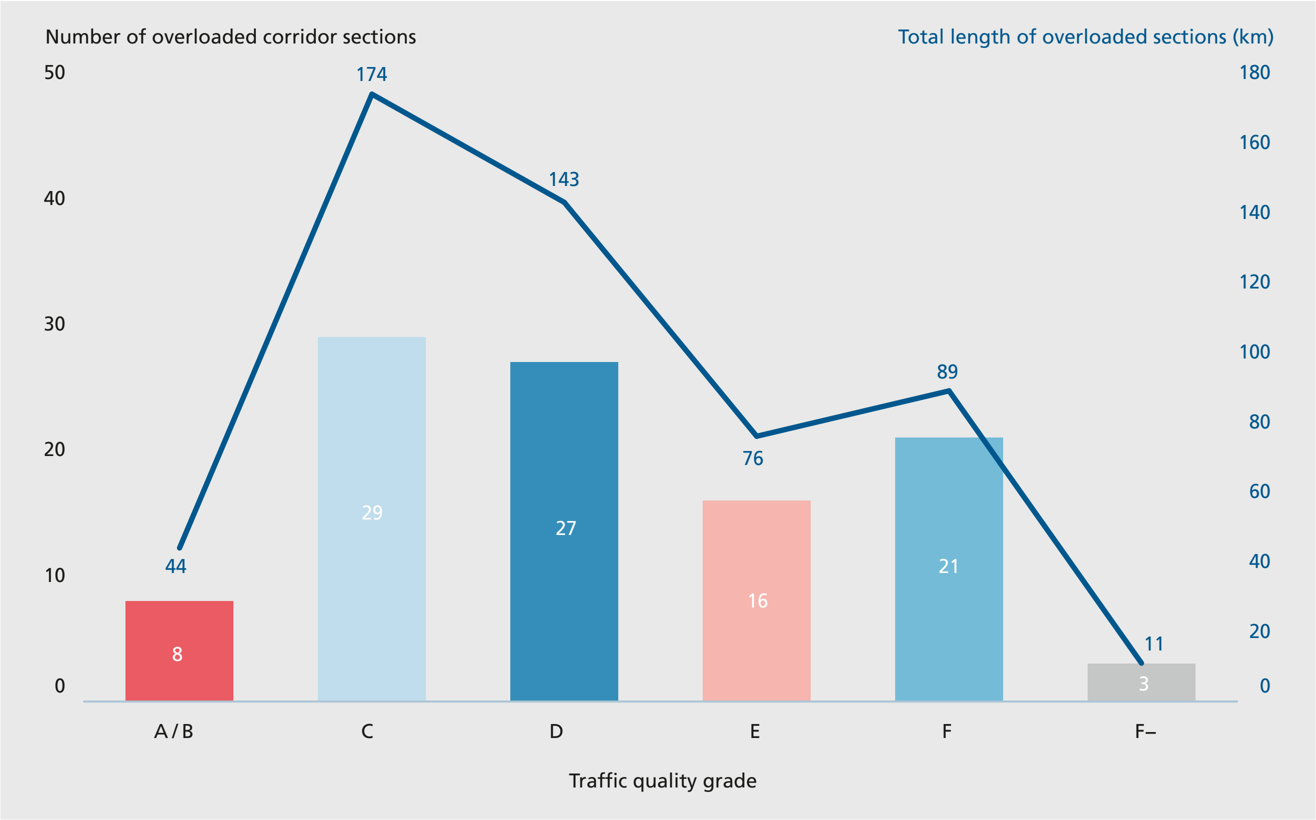
FIGURE 2: **Mean daily traffic volume on the road infrastructure on the TEN-T corridors in NRW in 2015**



Vehicles/24h: 🟥 *150,000–175,000* 🟥 *125,000–150,000* 🟦 *100,000–125,000* 🟦 *75,000–100,000* 🟦 *50,000–75,000* 🟦 *25,000–50,000*

Source: *Own representation based on Openstreetmap (2018), BASt (2017)*

FIGURE 3: Distribution of traffic quality grades in 2015



Source: *Own representation based on BASt (2017) and Intraplan Consult GmbH (2012)* the given example “Aachen Central” to “Aachen West”, the line deficiency was calculated as 285 – 196 = 89 (trains per day). “Cologne Central” to “Cologne West” is the most critical section on the TEN-T corridors in NRW with a line deficiency of 174 trains per day. This is followed by “Cologne Messe Deutz” to “Cologne Central” (119 trains per day), “Aachen Central” to “Aachen West” (89 trains per day), “Westhofen” to “Schwerte” (50 trains per day) and “Bonn Central” to “Bonn Mehlem” (41 trains per day). In total, there were 19 km of overloaded rail tracks along the TEN-T corridors in NRW in 2015.

2.3 DEFINING LOCAL SCENARIOS FOR NRW

Five scenarios examine the development of road and rail traffic and the implications for investments or disinvestments in certain infrastructures, jobs, economic prosperity and the environment. These scenarios differ in terms of the share of transport modes in the modal split. While the "business-as-usual" (BAU) scenario describes traffic development as published in the Federal Transport Infrastructure Plan 2030 (BVWP) (BMVI, 2015) and is used in most studies examining developments in the transportation sector, the other scenarios look at alternative developments. The scenarios for NRW differ from the scenarios for the European freight corridors due to their focus on infrastructure. The corridor scenarios started from cost considerations and their impact on freight transport volumes, while the NRW case immediately departs from given demand changes. The NRW case study focuses on investment requirements as well as on the entailed social and environmental impacts on the TEN-T corridors in NRW.

Business-as-usual (BAU): The transport volume development on the TEN-T corridors in NRW until 2030 was determined using data from the BVWP. Unlike the trans-European corridor cases (see Working Paper 5 of the LowCarb-RFC study, Doll and Köhler, 2018), the inland waterway transport (IWT) in NRW accounts for a much higher percentage of the total traffic volume. This is due to the huge importance of the Rhine and the inland waterway canal system. In addition, almost all waterways in the state are part of the TEN-T corridors, whereas only a fraction of the road and rail infrastructure is located along these corridors. In total, this scenario expects 42.3 billion ton kilometre to be transported by road and 8.5 billion ton kilometre by rail in 2030. This implies an increase of 27 per cent on the roads and 23 per cent on the rails compared to 2015. The transport volume on the inland waterways increases by 15.3 per cent to 41.2 billon ton kilometres. Extending this scenario to 2050 leads to traffic volumes of 58.2 billion ton kilometre on the roads and 11.3 billion ton kilometre on the rails. In contrast to the previous working papers, the BAU scenario is treated here as an equivalent scenario. The BAU scenario depicts the development that results if the responsible players take no further measures to promote a mode of transport. The BAU scenario is based on the BVWP data and can therefore be classified as most likely.

Moderate Road (Mod Road): This scenario describes a development that favours road transport. It assumes that the rail transport volume will fall by 25 per cent in 2030 compared to the BAU scenario in this year. Assuming that the growth rate on waterways remains constant at 15 per cent as in the BAU scenario, this means there is a corresponding shift to road transport. This leads to a 5 per cent growth in total road transport volume until 2030. Projecting these growth rates until 2050 leads to a “Mod Road 2050” scenario with road transport accounting for 53 per cent and rail for 5 per cent. Compared to the BAU scenario in 2050, this represents a 10 per cent increase for road and a 44 per cent decrease for rail.

Moderate Rail (Mod Rail): The Moderate Rail 2030 scenario describes the opposite development. In this case, the rail transport volume increases by 25 per cent, so that the share of road transport decreases by 5 per cent. The development described for 2030 is projected up to 2050 in the “Mod Rail 2050” scenario. Road transport then accounts for 44 per cent of the transport volume compared to 15 per cent on rail. The two moderate scenarios describe a more or less realistic development of transport volumes that could be achieved by established transport policy and investment measures.

Pro Road: In order to illustrate what extreme changes in the modal split would mean for the infrastructure, we also included two purely theoretical, extreme scenarios. The Pro Road 2030 scenario assumes a 75 per cent loss in rail transport volume. This shifts to road transport, which registers an increase of 15 per cent. Extended to 2050, this scenario leads to an increase of 32 per cent in road transport compared to the BAU 2050 scenario and a marginalisation of rail transport to a share of only 0.6 per cent in the modal split of 2050. At this point, it should be emphasized once again that these are extreme changes, representing a theoretical scenario that cannot be realised.

Pro Rail: On the other hand, the Pro Rail scenario assumes a theoretical development in favour of rail transport. Instead of losing 75 per cent, in this scenario, the share of rail in the modal split increases by 75 per cent, so that the road traffic volume decreases by 15 per cent. For 2050, this means a 28 per cent decrease in road transport compared to the BAU 2050 scenario and a 206 per cent increase in rail transport, so that the rail’s new share of the modal split is 27 per cent. As in the Pro Road case, this is a theoretical scenario, whose extreme changes merely give an overview of purely theoretical developments.

TABLE 1: Definition of the scenarios for traffic development (tkm) until 2030

Scenario	Rail	Road
BAU	= BVWP	= BVWP
Mod Rail	+25% to BAU	−5% to BAU
Mod Road	−25% to BAU	+5% to BAU
Pro Rail	+75% to BAU	−15% to BAU
Pro Road	−75% to BAU	+15% to BAU

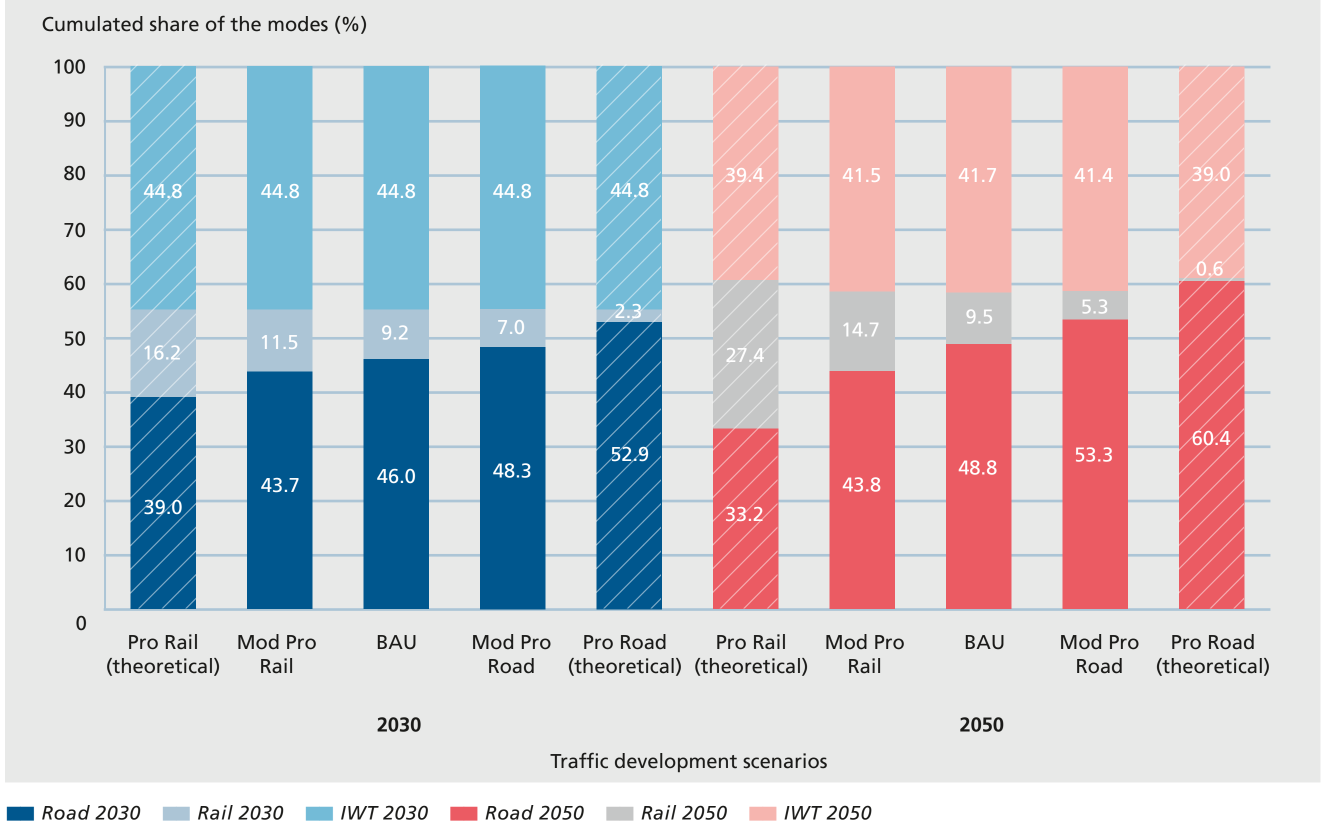
***Source**: Fraunhofer ISI*

The definitions of the scenarios and their implications for transport modes, the modal split and the respective growth rates of ton kilometre are summarized in Table 1 and Figure 4.

As seen in the table above, the scenarios vary widely. This approach allows us to examine the different effects of modal shifts and determine the environmental and social implications. For 2050, the respective growth rates of the scenarios are extended for another 20 years, which amplifies the effects of the scenarios. The Pro Road and Pro Rail scenarios were included in this study as to show the extreme effects of major modal shifts. These two scenarios are only realistic in a hypothetical policy environment exclusively focussed on road or rail, which ignores all financial and organisational restrictions.

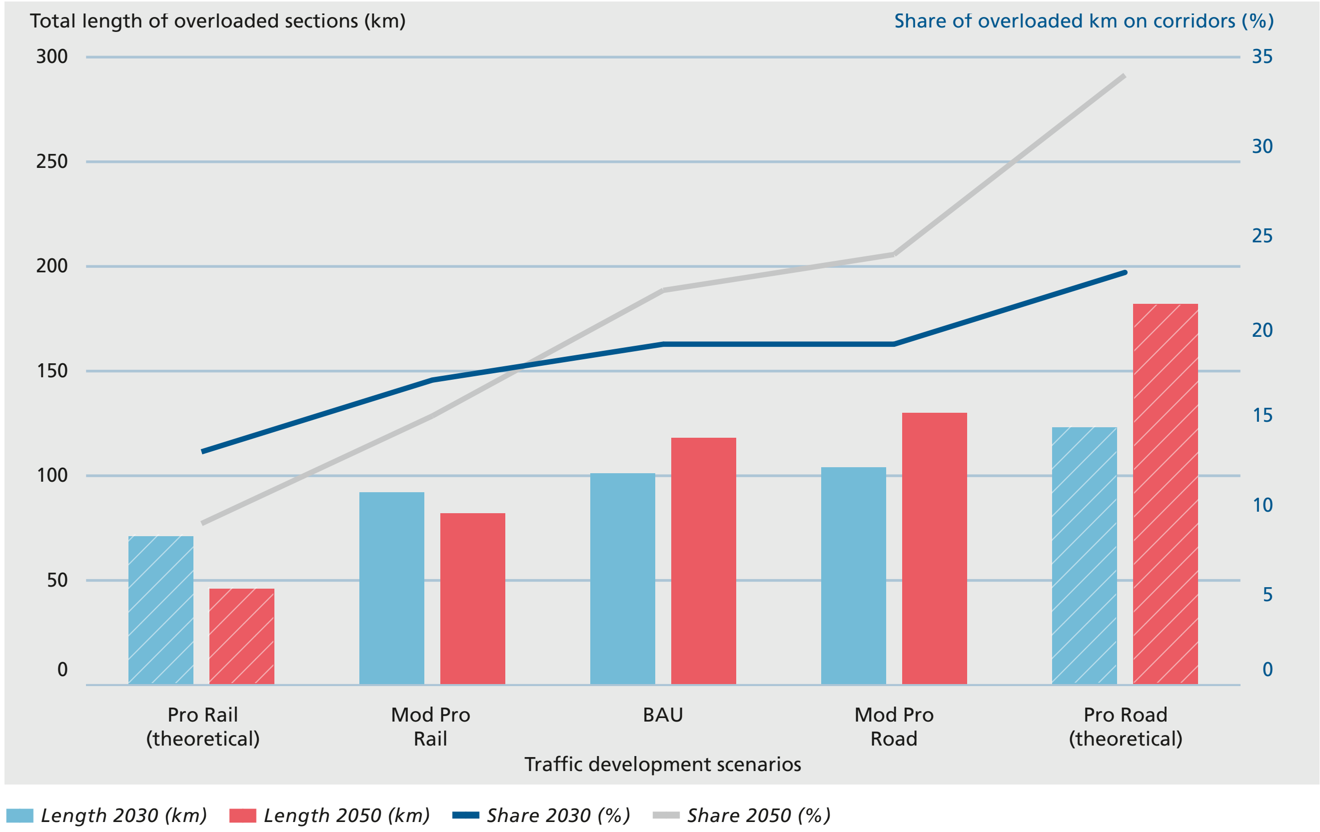
Figure 4 illustrates the effect of the scenarios on the modal split shares of the transport modes in the transport volume on the TEN-T corridors in NRW. The transport shares vary significantly in the different scenarios. Since the study did not examine IWT, its share is nearly the same in every scenario (44.8 per cent in 2030 and 39.0 to 41.7 per cent in 2050), but the rail and road shares differ depending on the chosen infrastructure developments. In 2030, the share of rail transport ranges between 2.3 per cent and 16.2 per cent. This discrepancy increases even further to a range from 0.6 per cent to 27.4 per cent by 2050. Road transport undergoes a similar development but in the opposite direction. In 2030, the share of road transport ranges between 39 per cent and 52.9 per cent. In 2050, a larger range emerges of 33.2 per cent to 60.4 per cent. The extreme scenarios (Pro Road and Pro Rail) highlight that modal share gains or losses of around 15 per cent are possible for road transport under extreme (and highly improbable) measures.

FIGURE 4: Share of the transport modes in transport volume in 2030 and 2050



Source: *Own representation based on BMVI (2015)*

FIGURE 5: Overload of road sections in NRW (only TEN-T corridors) in 2030 and 2050



Source: *Own representation based on BASt (2017)*

3 MODE SHARE AND INFRASTRUCTURE NEEDS ASSESSMENT

3.1 TRAFFIC DEVELOPMENT IN THE SCENARIOS AND IMPACT ON THE INFRASTRUCTURE

For the five scenarios and for the key commodities transported along these corridors, we identified the infrastructure facilities required–or no longer required–as a basis for the investment plan.

Road network load

Before evaluating the load on the roads, planned changes to the infrastructure were taken into account. According to the BVWP, 16 measures are planned for completion by 2030 on the TEN-T corridors in NRW. The following section describes traffic development and its impacts on traffic quality in the different scenarios under these changed circumstances.

The number of critical sections in the scenarios changes in line with the modal split developments. In the Pro Rail scenario, for example, only 18 road sections with a total length of 71 km can be identified as bottlenecks. This corresponds to 13 per cent of the length of all motorways on the corridors in NRW, and this share increases to 23 per cent in the Pro Road scenario, which corresponds to 123 km on 32 sections.

Comparing the developments in 2030 and 2050 shows the intensification of the results. By 2050, the share of overloaded corridor sections on the road decreases to 9 per cent, spread over only 13 sections with a total length of 46 km. The Pro Rail scenario, on the other hand, leads to the maximum of 45 overloaded sections with a total of 182 km. This means that 34 per cent of the total length of the corridors in NRW will be overloaded. A share of 19 per cent of the road corridor kilometres remains critical even in the BAU scenario, where traffic develops as predicted, and which forms the basis of most planning, and considers the measures already planned.

Figure 5 illustrates the different traffic developments described in the scenarios for the critical road infrastructure sections on the TEN-T corridors in NRW. It shows the respective lengths of the sections in kilometres, so that the following development emerges.

Looking at traffic quality in the years 2030 and 2050 reveals that, although an intact infrastructure was assumed, bottlenecks are still expected in some areas despite the planned investments. However, the expansion of the network also improves the situation in some areas. Figure 5 shows that, for the year 2030 in general, the planned projects in the BVWP can only ensure the necessary traffic quality to a limited extent, so there is the need for additional measures.

Rail network load

The infrastructure changes planned in the BVWP were also considered for rail in 2030.

In the year 2030, the extreme Pro Rail scenario implies 24 bottlenecks on the rail corridors in NRW. These extend over a total of 126 km, which corresponds to 14 per cent of the total length of the rail network on the corridors in NRW. Looking at the Pro Road scenario, on the other hand, the share of critical rail kilometres shrinks to one per cent, which means only six kilometres on three corridor sections. In the BAU scenario, however, bottlenecks continue to occur. A total of 64 km on eleven sections, equivalent to seven per cent of the total length, still fall into the critical category despite the planned expansion measures.

If these scenarios are extended to the year 2050, the following distribution of bottlenecks results. In the Pro Rail scenario, the share of critical rail sections on the corridors in NRW doubles to 29 per cent, affecting 41 sections and 256 km. The share of bottlenecks in the Pro Road scenario, on the other hand, is hardly worth mentioning at 0.2 per cent. In the BAU scenario, the situation improves slightly compared to 2030. Only 48 km on nine sections are critical here, which corresponds to a share of five per cent.

Figure 6 illustrates the different traffic developments in the scenarios for the critical sections on the rail infrastructure of the TEN-T corridors in NRW. It considers the respective lengths of the sections in kilometres, so that the following situations emerge.

As was the case for road transport, the results show that the expansion measures already planned for the railways do not adequately meet demand. Particularly in the Pro Rail scenarios, there is a great need for additional measures beyond those already planned in order to be able to handle the growing volume of traffic.

3.2 REQUIRED INVESTMENTS

We estimated the investments required for road and rail transport based on infrastructure needed. Investment cost figures are mainly taken from the Federal Investment Plan 2015 (BVWP) (BMVI, 2015). The investment programme compiles infrastructure measures planned for the TEN-T corridor sections in North Rhine-Westphalia, which are contained in the BVWP.

To determine the required road investments, we calculated the mean of the planned investments in the corridors in NRW. For the years 2011 to 2015, cost figures were taken from the Capital Investment Framework (IRP) (BMVBS, 2012), which totalled 1,266 million euros for the expansion and new construction of lanes along the relevant corridor sections. This means an average investment volume of 17 million euros per kilometre of expansion. In the BVWP covering the years 2015 to 2030, the total costs for expansion and new construction of lanes on the TEN-T corridors in NRW add up to 1,220 million euros, with a mean of 15.6 million euros per km. In both cases, we took extreme outliers into account, which are illustrated by the dotted lines in Figure 7.

Due to the increasing traffic volume, it was equally necessary to consider the expansion of intersections as well as new constructions, e.g. of bridges for renovation purposes. As a simple translation to the number of kilometres did not seem appropriate, these costs were assigned proportionally to the other sections. For both the IRP and BVWP cost rates, this resulted in total average costs of approximately 19.3 million euros per kilometre. We finally assumed this value for the investment requirement per kilometre for the expansion of motorway sections in both directions.

The calculated required investments per kilometre of expansion were transferred to the necessary measures identified for the five scenarios to determine the additionally needed investment volume. In the BAU scenario 2030, for example, there is the need for 58 new lanes totalling 218 km.

Additionally, we must take into account the costs for the already planned measures that also affect traffic quality and contribute to avoiding bottlenecks. These costs have been added to the calculated, additional costs as a designated, fixed part in each scenario and for 2030 and 2050, respectively.

Overall, the Pro Road scenario leads to the highest costs for both 2030 and 2050. This scenario also has the biggest increase in road construction costs between 2030 and 2050 due to the high road loads. The three moderate scenarios have a similar range of costs in 2030 and do not have a major impact on the development of road costs. The Pro Rail scenario is the only scenario in which expansion costs decrease significantly until 2050. The costs in this scenario are less than half the costs for the Pro Road scenario in 2050.

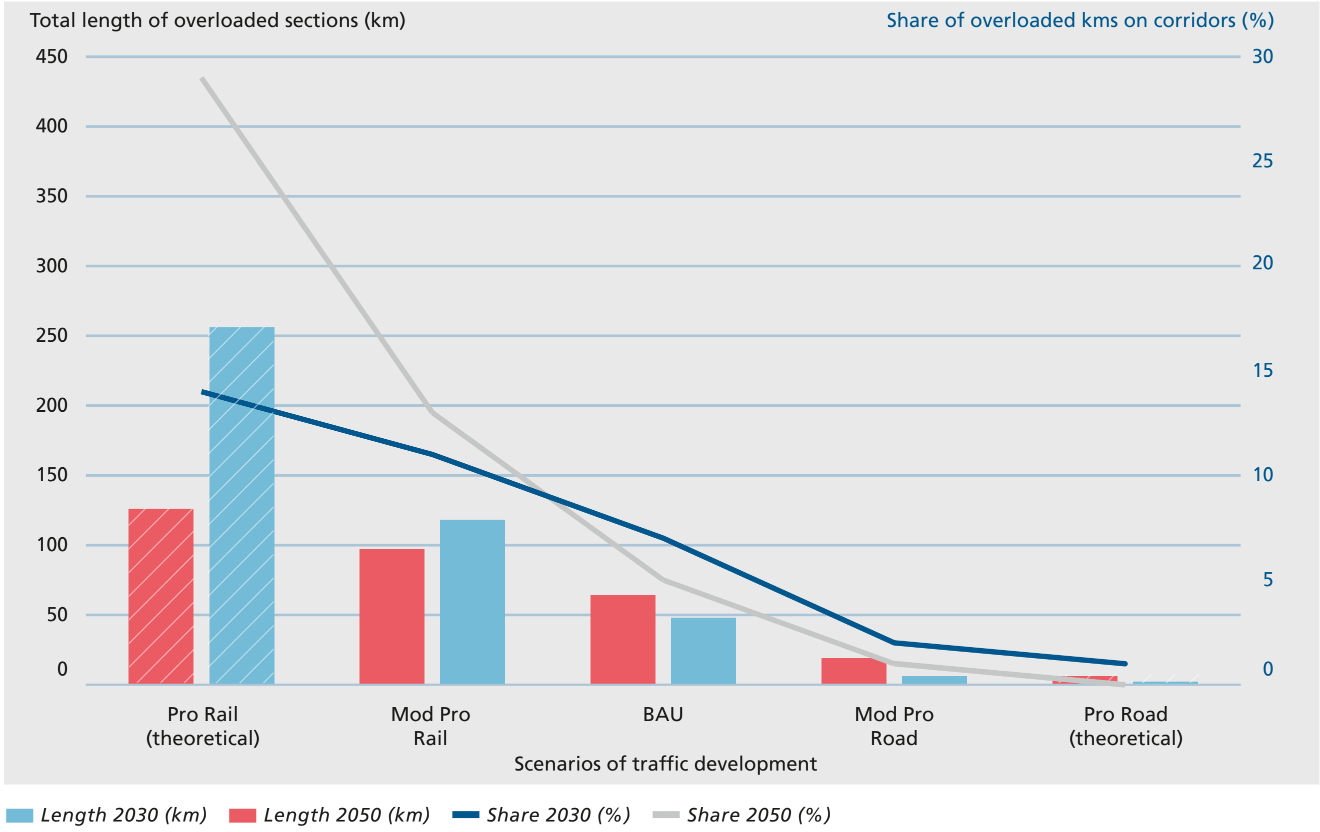
To calculate the total cost of the proposed rail expansion measures, we determined the overall costs of the already planned measures. This data indicated the average cost for the expansion or new construction of tracks. Subsequently, we translated this data into a base value of "cost per kilometre" that we used to estimate the investment costs of the additionally needed measures.

The Federal Environment Agency estimated costs of 12 million euros per kilometre of track for the construction or expansion of sections of line (Holzey, 2010). Calculating the average value of measures planned for NRW in the BVWP (BMVI, 2015) leads to a corresponding value of 12.7 million euros per kilometre (IVM, 2011). This includes all necessary construction measures, such as tunnels and bridges, signalling systems and planning. However, we must emphasize that this is a rough estimate only, and each individual case requires close examination.

The expansion of sidings and passing tracks entails lower costs than the construction of completely new track. Since passing tracks must at least reach the maximum permissible train length of 740 m, costs of 12.7 million euros per passing track are calculated, which is the corresponding value for the construction of one kilometre of track (Deutscher Bundestag, 2018).

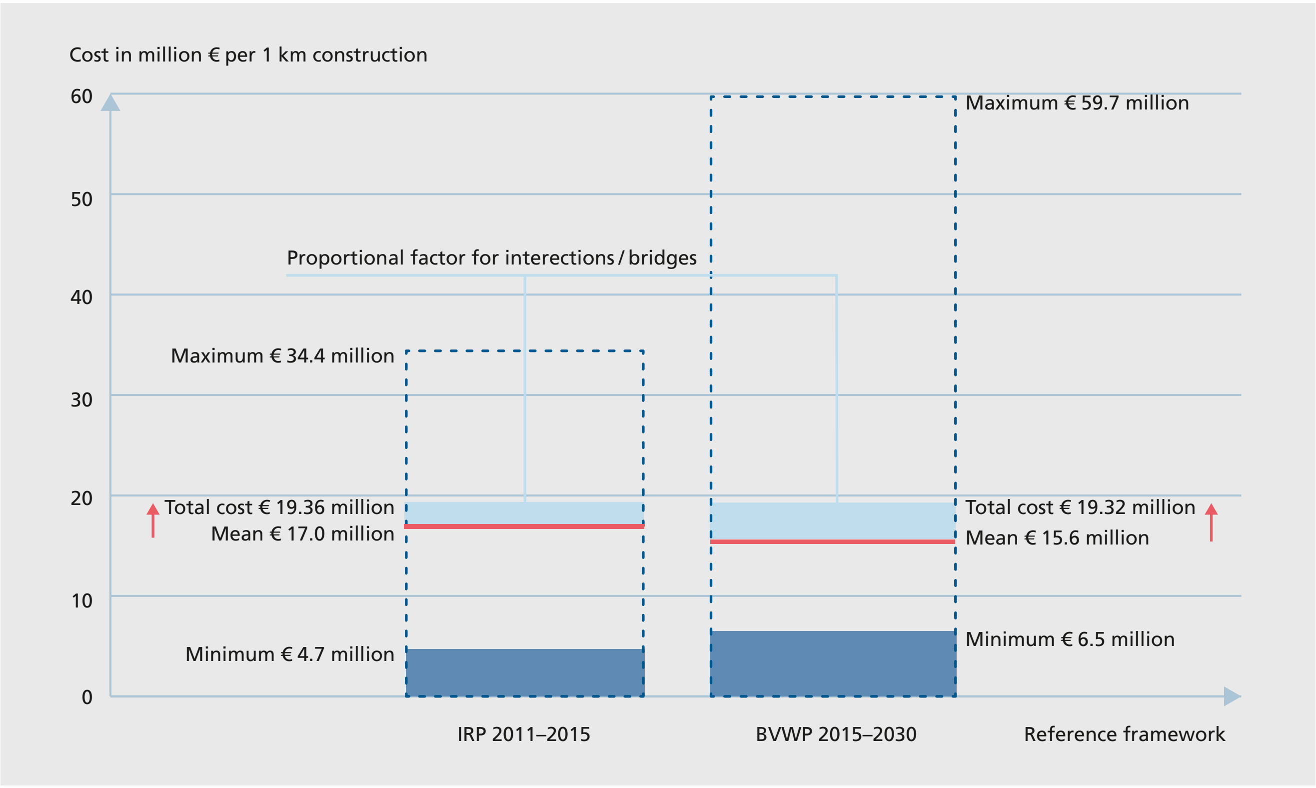
We have to add the designated costs of the already planned measures in the BVWP (BMVI, 2015) to the calculated additional costs for the recommended measures. As precise information on the investment volume of the planned measures on the TEN-T corridors in NRW was not available, we used estimated values based on the previously determined cost per kilometre.

FIGURE 6: Overloaded rail sections in NRW (only TEN-T corridors) in 2030 and 2050



Source: *Own representation based on IVM (2011)*

FIGURE 7: Estimated average cost for one kilometre of road construction on the TEN-T corridors in NRW



Source: *Own representation based on BMVI (2015), BMVBS (2012)*

It is assumed that the European Train Control System (ETCS) expansion in Germany will be completed by 2050 (BMVI, 2018) which is why the corresponding capacity increase was taken into account in this work package. The costs for this comprehensive measure were also included in the assessment and increase the designated costs by 4.5 million euros per corridor kilometre (BMVI, 2018) in NRW by 2050.

As alternative expansion measures to avoid bottlenecks are feasible for some sections, we calculated the case with the highest (upper bound, abbr. UB) and the one with the lowest (lower bound, abbr. LB) costs, based on the general cost rates described above. The total costs of all permissible decision options are then within these bounds. The upper bound represents the most expensive case where capacity increases on overloaded sections are achieved by adding new tracks and not by extending passing tracks. If the passing track option is selected wherever possible to improve the capacity utilisation situation, this is generally the most cost-effective case and represents the lower bound.

In order to evaluate the scenarios, it is not sufficient to consider the influences of transport development on road and rail infrastructure separately. A stronger increase on the roads, which leads to higher investments here, implies a lower increase or even a decrease on the railways, so that fewer investments are necessary here. Figures 8 and 9 show how these effects develop in the five scenarios.

By 2030, the calculated required investment volume is almost twice as high as estimated in the BVWP. Even in the most cost-effective case, the Pro Rail scenario, the necessary investments exceed the designated ones by more than 50 per cent. The Pro Road scenario is the most expensive one in terms of infrastructure costs. This is because only marginal changes are necessary on the railways. The Pro Rail scenario, on the other hand, offers potential cost savings because it has lower road investment requirements. For Pro Rail, however, the range of potential net costs exceeds all other scenarios, so that even higher costs than BAU are possible. When looking at the BAU scenario and the moderate scenarios, no relevant cost changes occur, at least in the most cost-effective variant (LB). The costs for all scenarios converge for expansion based only on new construction (UB), although the Mod Road scenario is narrowly the most cost-effective here.

Figure 9 illustrates the cost effects for 2050. First, BAU investments including full ETCS deployment, over the period 2015 to 2050 are around six billion euros or 50 per cent above the investment needs from 2015 to 2030. Second, the upper limit investment costs in the Mod Rail and BAU scenarios decline relative to the other scenarios. The Mod Rail scenario is then the most cost-effective variant considering lower as well as upper estimates. In the Pro Rail scenario, the possible range between lower and upper bound costs are way more pronounced compared to the 2015 to 2030 investment period. This is because the longer time horizon increases the uncertainty on the number of potential investment measures and on their depreciation periods.

As mentioned above, investments in road and rail are interdependent. Higher investments on the roads usually lead to lower investments on the railways. This effect is more or less noticeable depending on the chosen expansion measures for the railways.

Overall, the two extreme scenarios incur the highest costs, because one mode of transport has to cope with an unexpectedly large volume of traffic, so that a large number of expansion measures are necessary. In contrast, the moderate scenarios featuring more balanced growth have lower expansion costs spread more equally across the different modes of transport.

3.3 REALITY CHECK

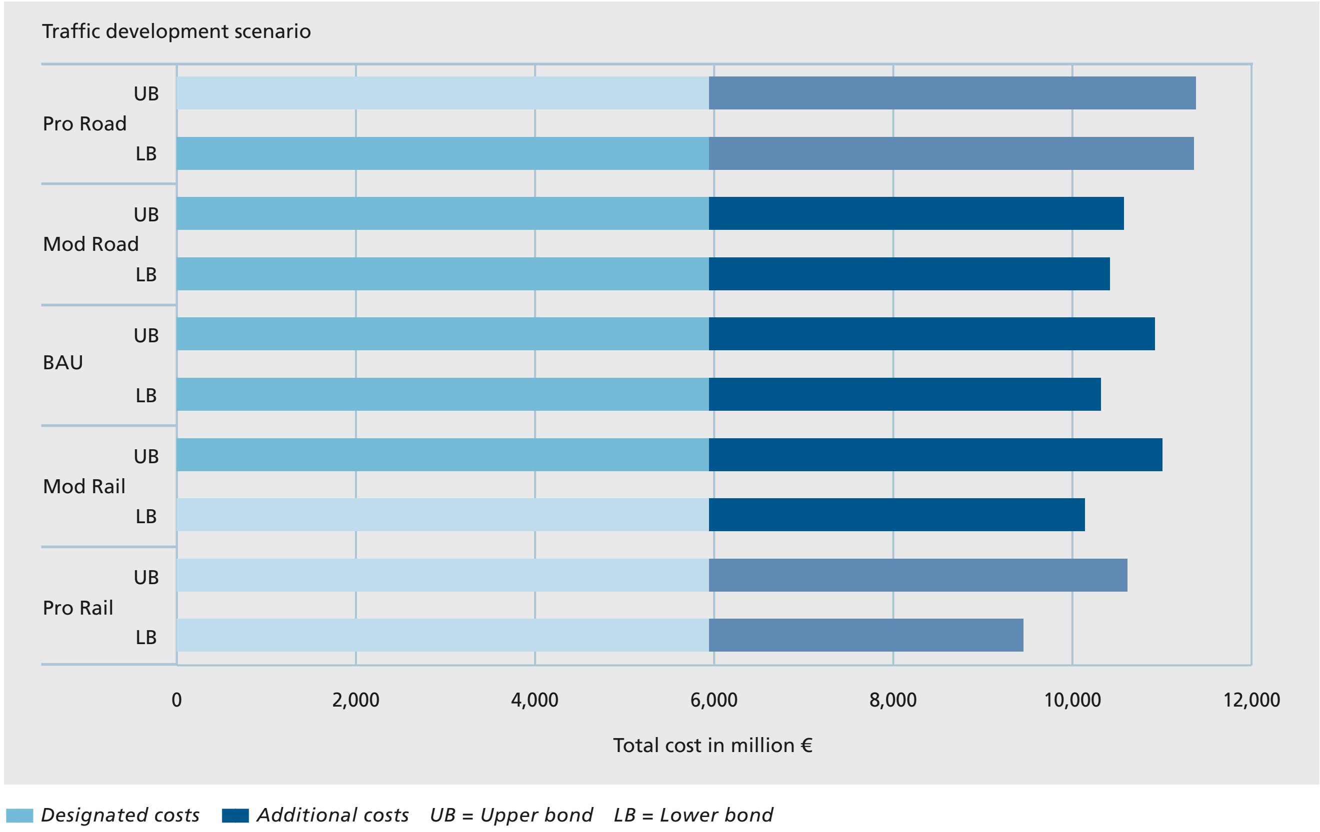
This chapter is characterised by its theoretical nature. If all the developments occur as assumed together with optimal framework conditions, the outlined bottlenecks will emerge and appropriate measures are to be recommended. However, in reality, other factors play a role that can affect, delay or even make the necessary measures impossible.

To illustrate this, we discuss the issue of dense building developments at the edge of existing, but overloaded transport infrastructure. In other words, the case when the theoretically defined measures meet reality.

The analysis identified bottlenecks at the Leverkusen junction (A1 / A3), which are to be countered by increasing the number of lanes. In 2010, the A1 had six lanes from the Wermelskirchen intersection to the Köln-Niehl intersection. The same situation applied to the A3 from the Langenfeld motorway junction to the Köln-Delbrück intersection. Only the section from the Leverkusen-Opladen intersection to the Leverkusen junction has already been widened to eight lanes. In addition, the Leverkusen junction itself has too little capacity due to its clover shape.

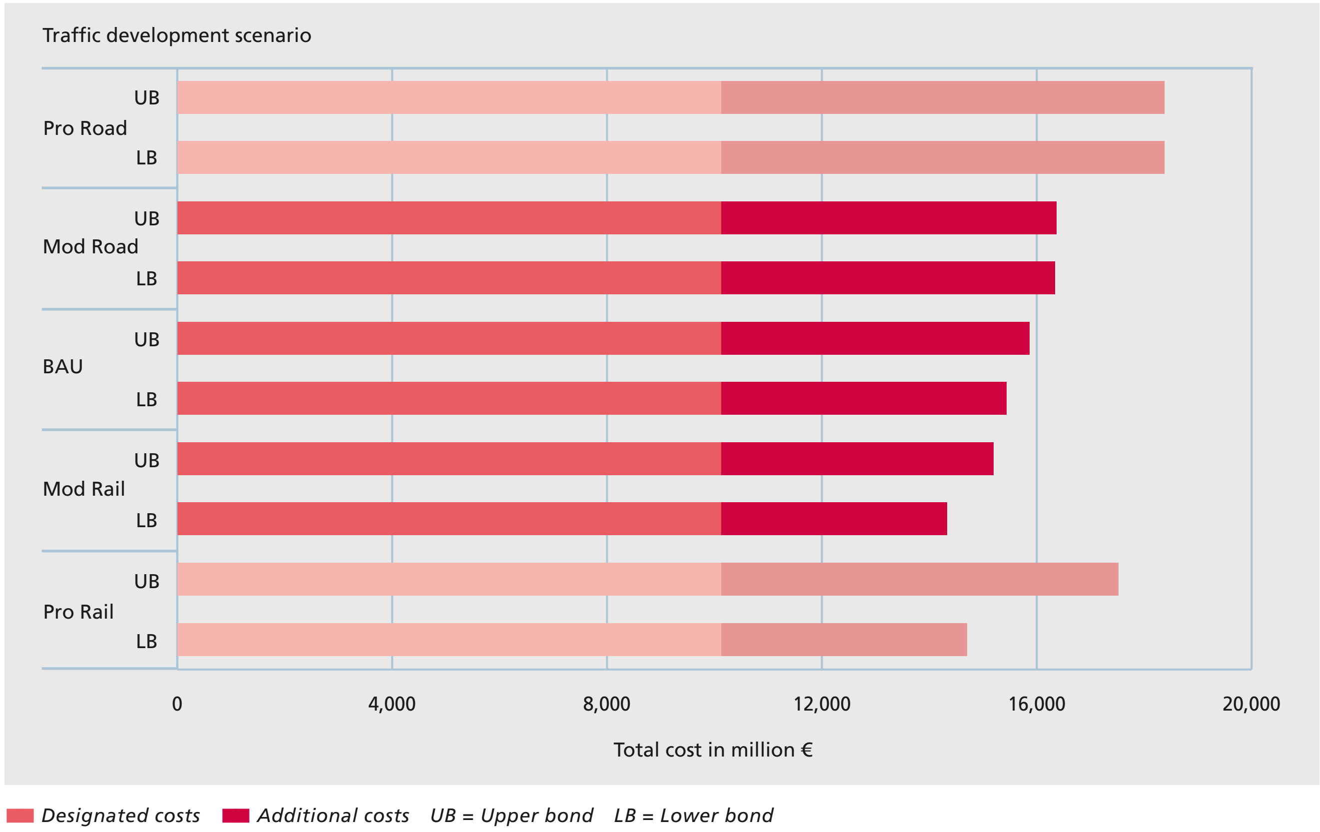
The Federal Transport Infrastructure Plan (BVWP) includes the eight-lane expansion of the Leverkusen junction to the Köln-Niehl intersection on the A1 and the Hilden junction to the Köln-Mülheim intersection on the A3.

FIGURE 8: Estimated total investment needed on the road and rail infrastructure in NRW 2015 until 2030



Source: *Own representation (based on own calculations)*

FIGURE 9: Estimated total investments needed on the road and rail infrastructure in NRW 2015 until 2050



Source: *Own representation (based on own calculations)*

In all traffic development scenarios presented for 2030 two extra lanes are needed on the A3 from the Leverkusen junction to the Köln Heumar motorway intersection. This means that a total of ten lanes are required for the predicted traffic load. By the year 2050 and if traffic develops according to the BAU scenario or the Pro Road scenarios, a total of 12 lanes will be required from the Leverkusen junction to the Leverkusen-Zentrum intersection to absorb the traffic load without disruptions.

Looking at an aerial photograph of the Leverkusen motorway junction (see page 21), it quickly becomes apparent that unlimited expansion will not be possible here without considerable additional efforts. The surrounding residential and industrial buildings, some of which are located directly along the route, cause costs that have not yet been taken into account.

As this issue has become apparent in the last years, several extension measures have already been discussed. For the A1 exemplarily, 14 proposals have been compared and evaluated, whereof nine contained a tunnel solution (Grassl et al., 2018). Furthermore, seven proposals have also been drawn up for the extension of the A3 around the junction Leverkusen. The costs range between 150 million euros and 910 million euros (Straßen.NRW, 2018).

This problem is not related exclusively to road infrastructure. Rail also has framework conditions that complicate infrastructure expansion and significantly increase its cost. For example, the tracks between Köln Messe / Deutz and Cologne Central Station cross the Hohenzollern Bridge. At this point, the rail infrastructure was already overloaded in 2015, at least one additional track indispensable. However, the capacity of the bridge is already fully utilised, so that any expansion will involve a great effort in terms of time and money.

The theoretical measures face further obstacles that can cause delays and higher costs. These include the current condition of the infrastructure in Germany, the long duration of approval procedures, the limited funds available, and the lack of skilled personnel.

3.4 DISCUSSION

The case study of North Rhine-Westphalia focuses on the implications of modal shifts and road decarbonisation at the local level. In contrast, the European corridor analyses started from the technical and efficiency potentials of ways to decrease transport's GHG emissions. These normative modal shift scenarios are deliberately much more cautious than the corridor model results for NRW. This compromise supports the acceptability of our results in the political discussion. However, we acknowledge that climate protection is an urgent issue and requires actions that are more stringent.

The investment cost assessment used the standard cost values for investments from the BVWP, excluding land purchase and large parts of maintenance. We also omitted costs for vehicle production and servicing and the real estate sector associated with transport infrastructures. Thus, even the upper bound cost estimates presented here constitute a relatively cautious estimate of the costs associated with different freight transport scenarios. Nevertheless, the figures do indicate the direct financial burden on public budgets and the railway sector.

The calculations showed that the traffic situation on the TEN-T corridors intensifies in all scenarios. Even if traffic develops as assumed by many politicians and scientists, numerous expansion measures are lacking on the roads and railways in NRW in order to be able to handle the increasing load. By the year 2030, the highest costs will emerge if rail is marginalised, i.e. if there is an extreme modal shift to road transport. A shift to rail achieves the lowest costs, but only if this is achieved with selective expansion measures. By 2050, the costs of expansion will rise in all scenarios due to additional traffic growth. The most cost-effective scenario here is a moderate one with a positive, but less extreme development of the railways.

Policy recommendations based on the results in this section include preparing for long-term investment plans in good time, using the coming decade to develop and test alternatives to traditional infrastructure programmes, and preparing for the discussion about desirable modal shares in a post-fossil freight transport world with low costs for trucking. More detailed policy recommendations are elaborated in Chapter 8.

.

4 WIDER ECONOMIC AND LABOUR MARKET IMPACTS

Investments in transport infrastructures and changes in transport activities will have impacts on various economic sectors. In terms of infrastructure investments, this is primarily the construction sector, but also its upstream suppliers. Freight transport activities affect numerous economic sectors because transport largely constitutes an intermediate sector linking different parts of value chains. Changes in the costs and performance of freight movements therefore have effects on virtually all types of economic activity. In turn, changes in economic activities directly influence employment in terms of the number and quality of jobs. Insofar, economic impacts directly entail social effects. We focus on infrastructure investments and their wider economic impacts.

We analyse the financial and employment impacts by sector using a dynamic input-output model for Germany. This allows the quantification of complex inter-sectoral net effects, and goes beyond the commonly used mono-causal gross effect analyses. However, the approach is limited because it does not look at real employment conditions and the types of jobs and qualifications created or lost in the transport policy scenarios.

Model structure

In macroeconomic terms, changes in investments are changes in the final demand for a certain product, service and industry. Changes in demand not only influence the production or supply of the service itself but also the productions / supply of intermediates, as well as their intermediates and so on. These interrelations can be captured by an input-output analysis based on an input-output table (IOT), which divides the German economy into 72 industries. Changes in production or the supply of services can have effects on the socio-economic environment and different indicators can measure these effects. We chose employment in full-time equivalents (FTE) and gross value added (GVA) in order to obtain further insights into how the estimated investments affect the economy in North Rhine-Westphalia. Since the input-output table (IOT) contains values for Germany as a whole, a direct interpretation of regional effects is not possible. We use the ISI-Macro analysis tool, which contains a regionalization option in order to study both aggregated German as well as North Rhine-Westphalian effects.

From the estimated future investments, we derive investment impulses, i.e. gross expenditures by economic sector and year. We assign these impulses to three industries: civil engineering, manufacturing of electrical equipment, and architectural and engineering activities. Civil engineering covers the construction of rail and road infrastructure and thus accounts for the major share of investments.

The investment impulses exclude rolling stock construction and servicing. We limit the consideration to infrastructures in order to demonstrate the impacts of the scenarios on public budgets rather than on the national or North Rhine-Westphalian economy.

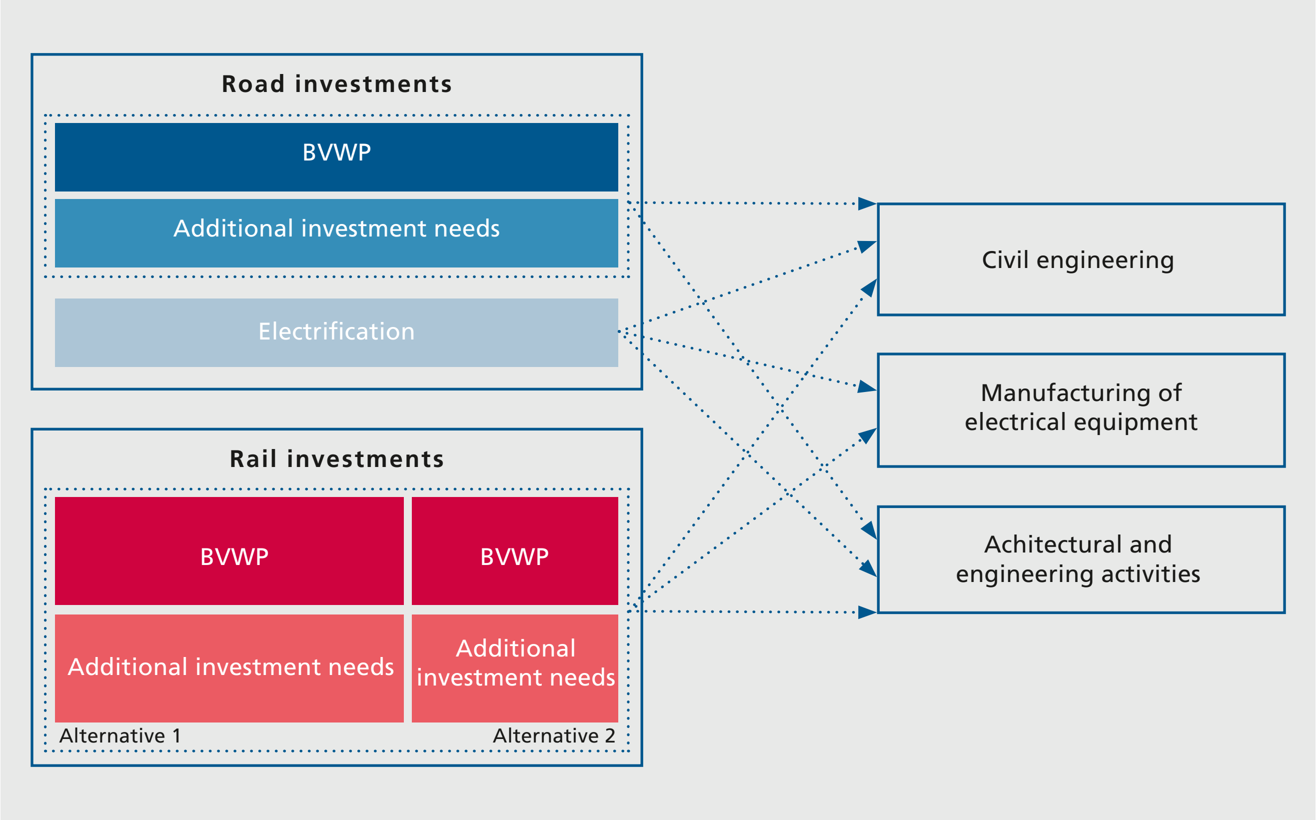
The investment impulses include all measures to meet the infrastructure demand underlying the freight transport scenarios for North Rhine-Westphalia. Whereas the proportion of imported products and services is given by the factors of the input-output table, it remains unclear whether firms based in North Rhine-Westphalia or in other German regions carry out the domestic activities. We therefore calculated a minimum and a maximum effect. The minimum effect assumes that NRW companies only receive a national proportion of investment programmes, while the maximum effect assumes that all non-NRW companies are excluded from funding and thus NRW workers with NRW intermediates carry out all the activities.

Temporal and sectoral allocation of investments

The estimated investments include planned measures by the BVWP plus the additional investments calculated in the preceding chapters for the periods 2015 to 2030 and 2015 to 2050. The economic impacts of future investments in North Rhine-Westphalia are modelled separately for road and rail investments as well as for aggregated investments. The resulting impulses affect three industries. Figure 10 outlines the allocation of road and rail investment impulses to the different industries.

In order to assess the economic impacts of the estimated investments, the annual investments in the BAU scenario are spread equally over the period 2015 to 2050.

FIGURE 10: Allocation of rail / road investments to industries



***Source**: Fraunhofer ISI*

Concerning investments in rail infrastructure, the preceding chapters differentiated between two possible types of investments. Major rail network capacity increases can be achieved either by large-scale investments in new tracks or lines, or by upgrading the existing network via a multitude of smaller measures. These may include passing lanes, industry sidings, gap closures, level-free crossings, etc. From a literature survey, we conclude that in large-scale capacity expansions, 89 per cent are large-scale investment measures.

The estimated investments in road infrastructure include the development and construction of new lanes, nodes and parking facilities, as well as reinforcing bridges for higher traffic volumes. Possible motorway electrification is considered as well. The investments needed for motorway electrification are split into new investments and replacement investments:

New investments: Wietschel et al. (2017) estimate the costs of electrification at 2.2 million euros per motorway-km. A full roll-out of overhead wires for trolley trucks on the German motorway grid would mean the electrification of 5,000 motorway kilometres, which leads to total investment costs of 11 billion euros (without discounting, price increases and expansion of the motorway network). Since motorways must be equipped with overhead wires before the vehicle fleets of logistics companies switch to electric vehicles, we assume the necessary work is finalised by 2030. The annual investments amount to 1.1 billion euros for the entire German network and 188 million euros for NRW in the period 2020 to 2030.

Replacement investments: Given its lifetime of 30 years (Wietschel et al., 2017), the infrastructure must be partly overhauled before 2050. We assume reinvestment needs of 50 per cent. Spread equally over the 20-year period 2030 until 2050, this leads to annual investment impulses of 175 million euros for Germany and 47 million euros for NRW.

Maintenance and servicing: According to German experiences with rail electrification (Müller, 2017), maintenance costs of catenaries range between 13 per cent and 17 per cent of capital investments. We apply this ratio to the estimated investment and replacement costs in the periods 2020 to 2030 and 2030 to 2050 for Germany and for NRW. Apart from electrification costs, we ignore roadside facilities for autonomous driving and the provision of appropriate mobile communication standards. These are either insignificant or the costs are borne by private undertakings.

TABLE 2: Rail and Road investment deltas to BAU per year

Scenario	Cost item	Period 2020–2030 (million € per year)		Period 2030–2050 (million € per year)	
		Diff. to BAU rail invest.	Diff. to BAU road invest.	Diff. to BAU rail invest.	Diff. to BAU road invest.
Pro Rail	Civil engineering	98.9	–87.7	98.9	–87.7
	Manufacturing of electrical equipment	24.7	0	24.7	0
	Architectural and engineering activties	30.9	–21.9	30.9	–21.9
Mod Rail	Civil engineering	18.6	–41.8	18.6	–41.8
	Manufacturing of electrical equipment	4.6	0	4.6	0
	Architectural and engineering activties	5.8	–10.5	5.8	–10.5
Mod Road	Civil engineering	–9.5	60.5	–9.5	34.5
	Manufacturing of electrical equipment	–2.4	34.6	–2.4	8.6
	Architectural and engineering activties	–3.0	23.8	–3.0	10.8
Pro Road	Civil engineering	–10.2	156.3	–10.2	98.2
	Manufacturing of electrical equipment	–2.5	77.8	–2.5	19.5
	Architectural and engineering activties	–3.2	58.6	–3.2	29.4

***Source**: Fraunhofer ISI*

Merging the different investments required in each of the scenarios leads to the total annual rail and road investment deltas shown in Table 2 relative to the BAU case by period. The total investment delta (rail plus road investment) is positive in all scenarios apart from the Mod Rail scenario, because the moderate additional investments in the rail network here are compensated by lower road investments due to the modal shift to rail. The Pro Road scenario requires the highest additional investments of all the scenarios with a positive investment delta. The peaks in the Mod Road and Pro Road cases 2020 to 2030 are caused by the upfront investments needed for motorway catenary systems.

The drops in 2030 in the Mod Road and Pro Road scenarios are due to the changing costs of road electrification before and after 2030. We first estimate the annual investments needed for the periods 2020 to 2030 and 2030 to 2050 for Germany as a whole. These are then broken down to NRW based on the state's 17 per cent share of the motorway infrastructure (VIZ, 2018). A more detailed breakdown of the investment impulses to industries is given in Working Paper 9 of the LowCarb-RFC study (Eiband et al., 2018).

4.1 MODELLING RESULTS

Figure 11 shows the effects of the combined investment impulses in road and rail networks on employment, aggregated over all industries. The numbers are given in full-time equivalents (FTE) for 2030 and 2050 in all four scenarios. The bars on the left represent 2030 figures, while those on the right show the figures for 2050. Blue indicates the minimum effect for NRW and red the maximum effect for NRW. When calculating the minimum effects, it was assumed that North Rhine-Westphalian firms carry out construction and upstream activities according to their average participation in German activities. Since construction works are likely to be carried out by regional firms or at least by firms employing regional workers, the FTE as well as the gross value added (GVA) figures for NRW will probably be above the average NRW participation. The sum of the stacked bars displays the for Germany as a whole, which can be interpreted as the maximum effect in NRW, assuming that all measures and upstream activities are implemented by regional firms. The percentage points displayed above / below the bars indicate the maximum percentage increase or decrease of employment in NRW.

Figure 11 shows that the Pro Road scenario has the biggest effect on employment. In 2030, up to 3,350 additional jobs are needed, which corresponds to about 0.055 per cent of total employment in NRW. In 2050, the delta to BAU drops to a maximum of 1,320 additional jobs. Pro Rail requires up to 464 additional jobs in 2030, and 350 jobs in 2050. Both values are below the additional employment demand created in the Mod Road scenario, which emphasizes the strong impact of varying investments in road infrastructure. Comparing the investment deltas for road and rail infrastructure in the different scenarios shows that rail investment deltas in road-oriented scenarios are close to or under zero, while road investment deltas in rail-oriented scenarios are strongly negative. This results in strong negative employment effects of road investment deltas in rail-oriented scenarios. These negative employment effects could be offset by positive employment effects from rail investment deltas. However, the additional rail investment deltas are only high enough in the extreme Pro Rail scenario to compensate the losses and result in positive employment effects of up to 500 FTE in 2030. The Mod Rail scenario has absolute negative employment effects compared to BAU.

Apart from employment effects, the model ISI-Macro can also estimate the impacts of investment impulses on gross value added (GVA). Figure 12 shows these effects in million euros. The results for GVA are similar to those for FTE effects. Again, the Pro Road scenario in 2030 has the biggest effects. Mod Road as well as Pro Rail have smaller positive values, while the Mod Rail scenario results in negative values compared to BAU. The diagrams for separate rail and road investments resemble Figure 11 and Figure 12 and are not shown.

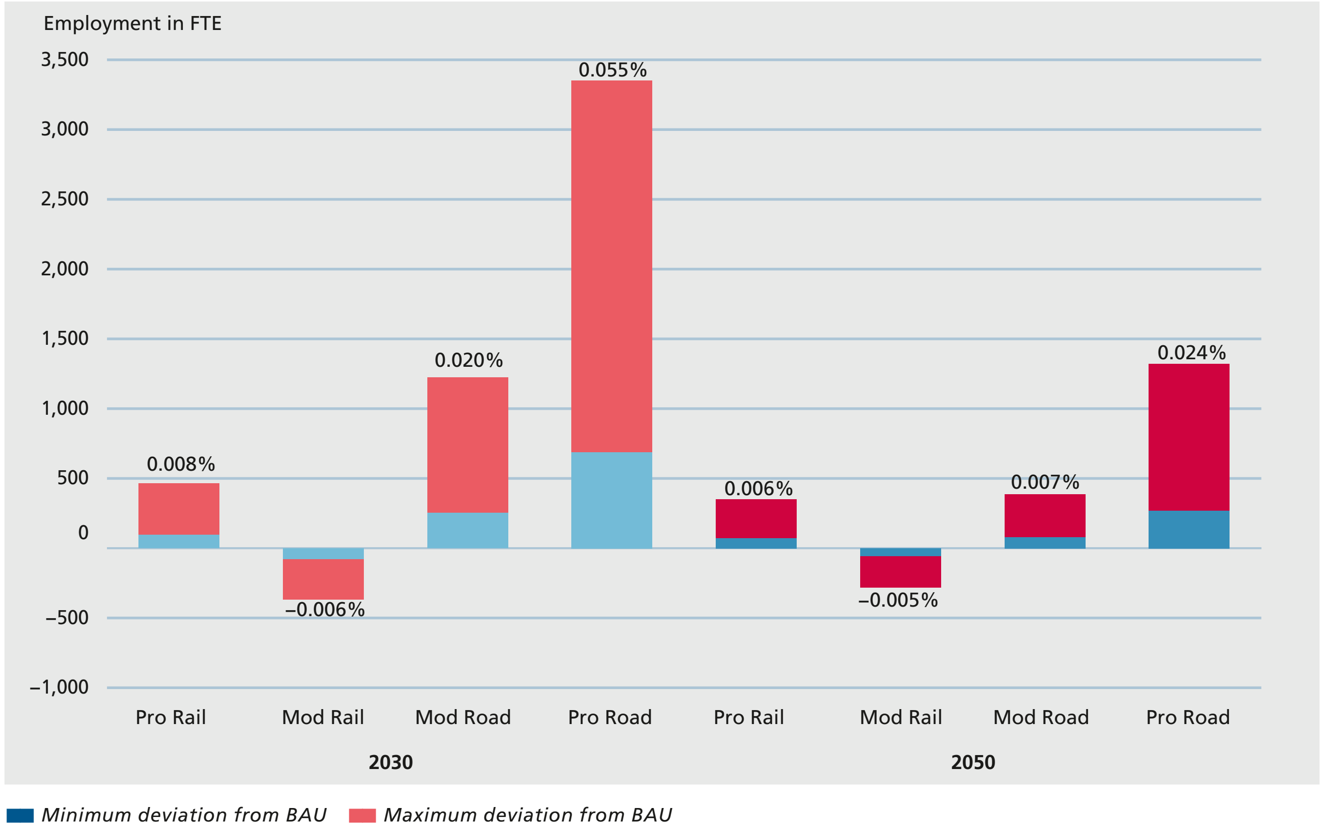
Effects on sectoral employment

So far, the presented figures showed the possible effects of investment impulses in infrastructure on FTE and GVA for all industries in total. However, shifting between modes of transport and investing in new technologies will have a greater effect on the types of jobs and the qualifications needed than on the total workforce required. Figure 13 maps the sectoral effects of rail and road investments in the Pro Road scenario in 2030. The industries listed in the Input-Output Tables are aggregated into 13 industry-groups. We chose the Pro Road scenario because the effects here are bigger and therefore more visible than in the other scenarios. However, the results are similar for the other scenarios albeit on a smaller scale.

The additional employment demand from investments in road infrastructure in Pro Road occurs not only within the directly affected industries but also within those industries providing intermediate inputs. In Figure 13, the biggest additional demand of FTE is in the industry-groups "Manufacturing", "Construction", "Trade, transport, gastro", "Commercial services" and "Public education, health". The industry-groups "Manufacturing", "Construction" and "Commercial services" include industries manufacturing electrical equipment, civil engineering and architectural and engineering activities, respectively, so that much of the change in absolute FTE demand can be related directly to the investment impulses. A majority of effects in the industry-group "Trade, transport, gastro" is usually due to trading activities. All the industries require traded intermediates, which can explain parts of the shift. The industry group "Public education, health" includes public services and thus the administrative processes of planning, approval and others. Since this service plays an important role in the planning and implementation of large construction projects, construction work impulses affect public services as well. In all cases, higher aggregated demand levels due to higher investments in the economy result in higher employment, even though the effects are expected to be relatively small.

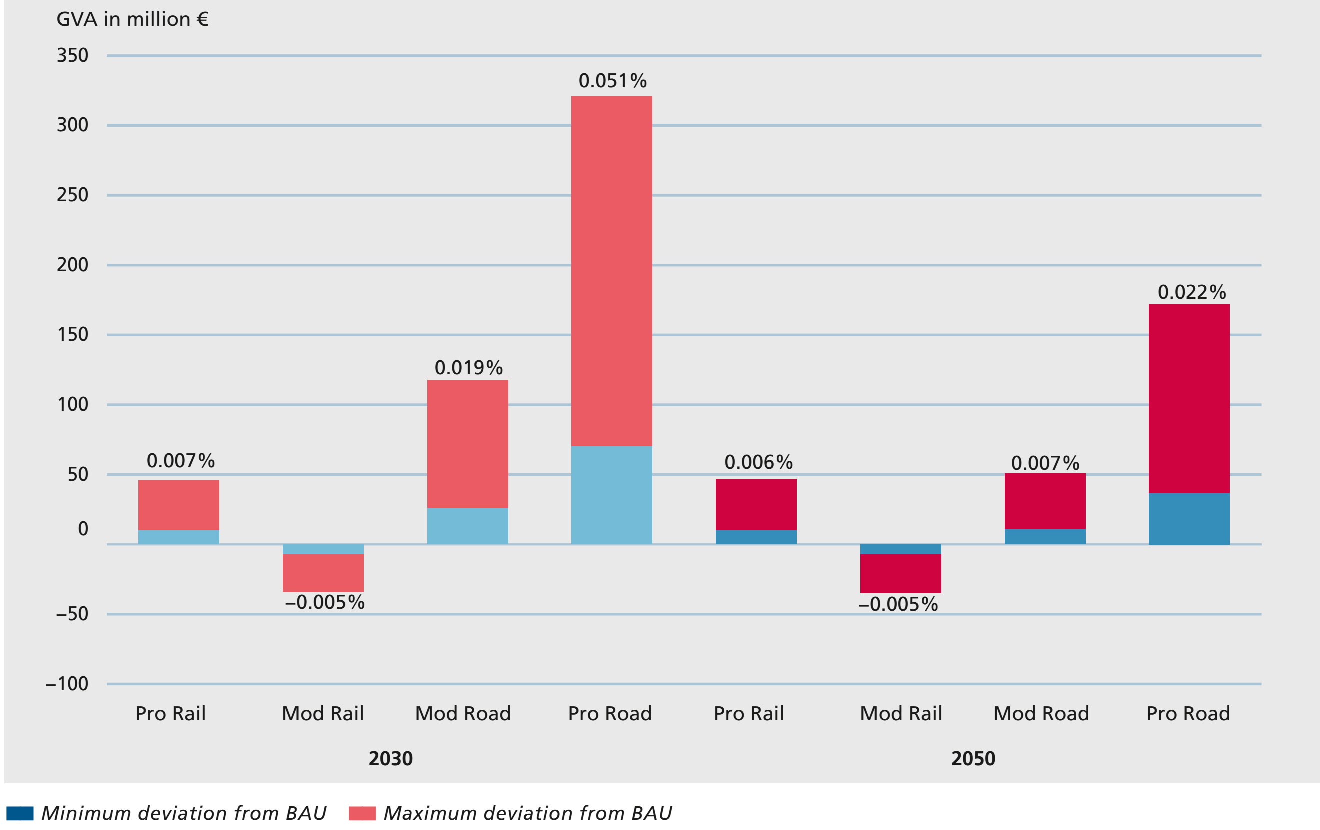
In all industry-groups, the 2050 values are below the 2030 effects. For reasons of clarity, Figure 13 only maps the bigger 2030 values. For the impacts of road investments on FTE, the lower 2050 figures can be explained partly by decreasing investments for road electrification post 2030. For both road and rail investments, the increasing labour productivity assumed in the macroeconomic core of the model ISI-Macro is responsible for lower FTE effects in 2050. Figure 13 also shows the negative effects of rail investments on FTE in the Pro Road scenario in comparison to BAU. The biggest absolute effects occur in the same industry-groups as the effects of road investments and the explanations are the same. However, rail investments have much smaller absolute effects than road investment measures do.

FIGURE 11: Minimum and maximum effects of total investment on FTE 2030/2050 in NRW



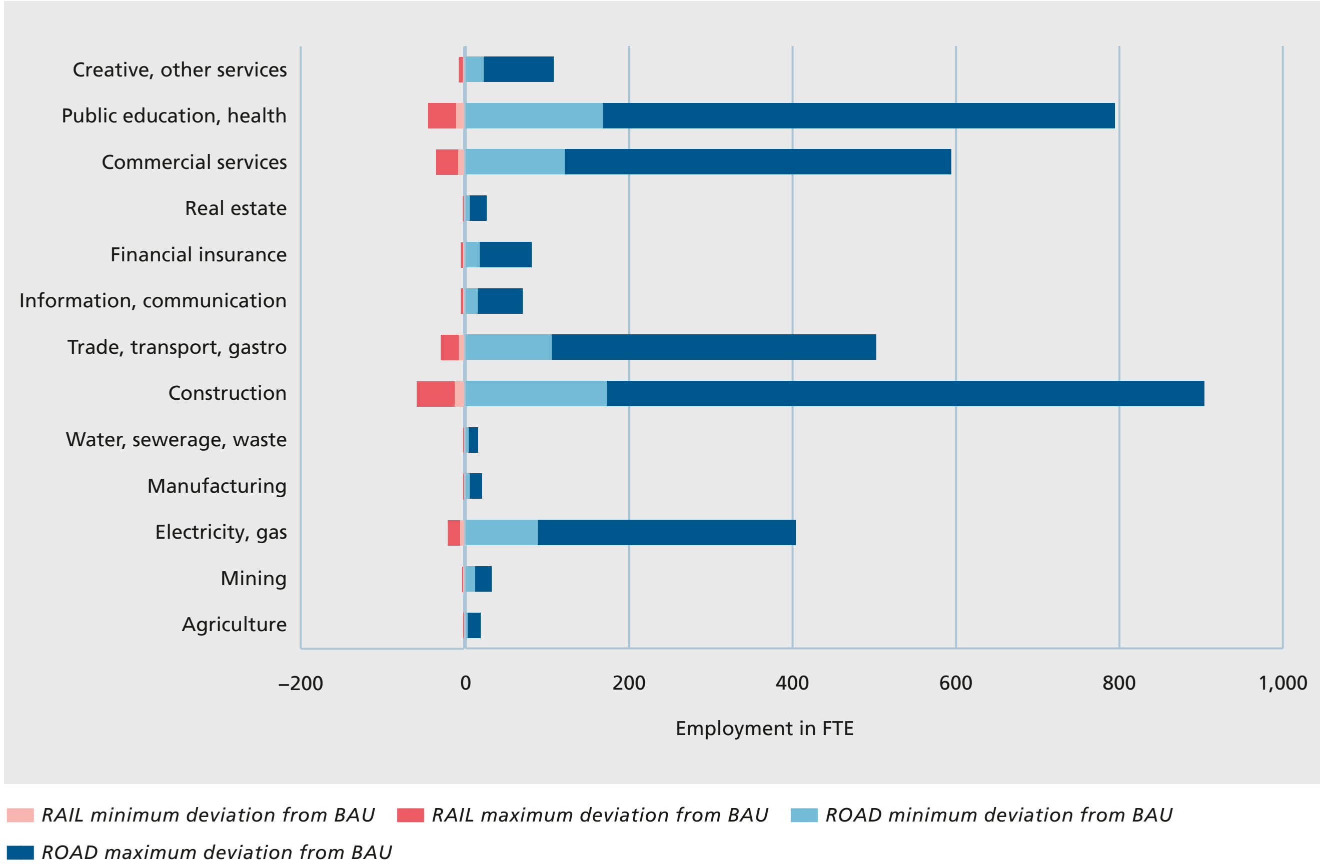
Source: *Fraunhofer ISI*

FIGURE 12: Minimum and maximum effects of total investment on GVA 2030/2050 in NRW



Source: *Fraunhofer ISI*

FIGURE 13: Minimum and maximum effects of rail/road investment on FTE in the Pro Road scenario 2030 per industry group in NRW



***Source**: Fraunhofer ISI*

4.2 INTERPRETATION

For all scenarios and across all industry sectors, the macroeconomic assessment shows employment and gross value added impacts of below 0.1 per cent of current levels. However, there will be distortions in job profiles, qualification requirements and wage levels when shifting priorities from road to rail and possibly waterborne transport, and towards decarbonisation technologies. Even when considering the uncertainties and omissions in investment scenarios and sectoral analyses, we conclude that economic and labour market impacts are not a valid argument for delaying or withholding strong measures to cut freight transport's climate emissions.

The conclusions based on the economic impact assessment are that modal shift and road decarbonisation programmes do have impacts on the labour market and economic sectors, but these are generally small, especially when compared to the impact of growing global markets. Concerns about market disruptions are therefore not a reason to refrain from pushing freight transport towards carbon neutrality. Chapter 8 of this report features a more in-depth discussion.

5 ENVIRONMENTAL AND SAFETY IMPACTS

5.1 SCOPE

The preceding sections estimated the planning and funding efforts needed to implement a major modal shift or decarbonisation strategies in the German federal state of North Rhine-Westphalia. In this section, we look at the benefit side of the equation. This concerns primarily reduced carbon emissions from freight transport, but also air pollution, noise and traffic accidents. We apply the methodology for greenhouse gas emissions and external costs developed and described in the LowCarb-RFC Working Paper 8 (Sieber et al., 2018) with some updates where appropriate.

We focus on the main drivers of the external costs of transport:

- Negative climate impacts from fuel combustion, oil extraction, transport and processing, and electricity generation.
- Air pollution due to nitrogen oxides (NO$_X$) and particulate matter (PM$_{10}$, PM$_{Coarse}$ and PM$_{2.5}$).
- Noise due to engines, tyres and wheels on roads and rail tracks.
- Traffic accidents, including fatalities, and severe and slight injuries inflicted by trucks. Due to their very low numbers, rail and shipping accidents are considered to be and to remain negligible.
- We exclude biodiversity and habitat losses as well as infrastructure-related externalities from the construction phase.

We consider two levels of impacts: physical impacts and environmental / safety costs. Physical impacts are computed as tons of emissions for climate gases only. The physical amount of CO$_2$ emissions are then used to compute the GHG mitigation costs. For climate impacts and all other cost categories, we compute their economic costs in euros per year. Economic and safety costs are then used as input into investment cost efficiency indicators.

5.2 UNIT VALUES FOR EMISSIONS AND INCIDENTS

Climate change impacts

The Special Report on Global Warming of 1.5 degree Celsius by the International Panel on Climate Change (IPCC, 2018) highlights the huge investments of 2.5 per cent of global gross domestic product (GDP) needed to reduce net emissions substantially by 2030 and completely towards 2050. Simultaneously, the German Environment Agency (UBA) issued the third edition of its "Methodology Convention on Estimating Environmental Costs" (UBA, 2018). The report updates unit cost estimates for CO$_2$, other climate gases, air pollutants and noise based on recent literature.

For CO$_2$, UBA (2018) nearly doubled its recommendations compared to the Methodology Convention 2.0 (UBA, 2012). Values are largely based on the avoidance cost approach, because damage estimates show much wider uncertainty ranges. Given that low-cost adaptation measures become scarcer over time, the cost values per ton of CO$_2$ rise considerably between now and 2050. However, the development less steep than in the Methodology Convention 2.0. Table 3 presents the unit values from UBA (2018) used here alongside the previous estimates used in Sieber et al. (2018).

TABLE 3: Unit costs for climate and air pollution emissions

Assessment category	Specific category	Unit value 2018 (€ per ton)[1]	Unit value 2012 (€ per ton)[2]
Climate change	CO_2 2015	180	80
	CO_2 2030	205	145
	CO_2 2050	240	260
Air pollution	NO_X	15,000	15,400
	PM_{10}	6,800	11,000
	PM_{Coarse}	1,000	2,900
	$PM_{2.5}$	59,700	122,800

***Source:** 1) UBA (2012), 2) UBA (2018)*

Emission factors were taken from the model developed in Sieber et al. (2018) for conventional trucks, hybrid overhead wire trucks (HO trucks), diesel and electric rail and barges. For diesel-based CO_2 emissions, an additional 15 per cent of up- and downstream emissions were added for oil extraction, transportation and refinery. For electricity-based emissions, the power plant mix and respective emission factors presented in Wietschel et al. (2018) were used as proposed in Sieber et al. (2018). Projections of 2015 load factors to 2030 considered vehicle efficiency improvements according to the EC's PRIMES model, and dynamic truck, train and barge load factors as defined in the LowCarb-RFC scenarios in Working Papers 5 (Doll and Köhler, 2018) and 6 (Mader and Schade, 2018).

Air pollution costs

Air pollution unit costs for NO_X, PM_{10}, PM_{Coarse} and $PM_{2.5}$ were taken from the current version of the German Methodology Convention 3.0. The values remain constant over time, but differ according to location and type of emitter. Road transport contributes direct exhaust emissions as well as abrasion from tyres and brakes from heavy trucks above 3.5 t of gross vehicle weight on motorways. Apart from NO_X, the unit cost values per ton of emission are considerably lower than in the 2012 edition, which is largely due to different definitions of the spatial context. We used the road category "unknown", which is positioned between suburban roads and motorways. The unit values used are given in Table 3.

For power production, the composition and development of the power plant mix in Germany are used to determine both, the per ton emission costs and the respective emission factors. Emission factors for direct exhaust emissions and for power generation were taken from Sieber et al. (2018) and corrected for load factors as described above.

Noise impacts

Noise costs are very sensitive to traffic volume and composition, time of day and distance to affected inhabitants. Emission factors are thus difficult to apply in the aggregated approach applied here. The Methodology Convention 3.0 (UBA, 2018), moreover, does not provide unit costs per vehicle kilometre. Therefore, and given the minor overall importance of noise costs in an interurban context, we apply the vehicle-kilometre-specific average cost values from UBA (2012). These are 0.54 euros per train-km, 0.0126 euros per HGV-km for diesel trucks and 0.0116 euros per HGV-km for HO trucks.

No noise costs were assumed for barges. Average noise costs per vehicle kilometre will most probably decline towards 2050 due to higher traffic volumes and noise reduction measures. We have not factored in these improvements to provide an upper bound estimate in this very uncertain cost category.

Traffic accidents

Fatalities as well as severe and slight injuries were assessed using international studies of the willingness-to-pay for preserving human lives and health. We take the values in Sieber et al. (2018) by severity category for 2015 to 2050: 2.22 million euros per fatality, 307,100 euros per severe injury and 24,800 euros per slight injury.

Accident rates for 2050 are based on the statistics of the German Highway Institute and consider incidents on motorways, mainly inflicted by heavy trucks. Accident rates are assumed to decline to 20 per cent of their 2015 values by 2050 in all scenarios and over all severity categories due to automation and driver-assistance technologies. For rail and shipping, accident rates are so low that we excluded them from the external cost estimation model used here.

5.3 RESULTS

Climate gas emissions

Applying the traffic scenarios in Chapter 2 and the emission factors discussed above, we find that the total CO_2 emissions of the two corridors Rhine-Alpine (RALP) and North Sea-Baltic (NSB) in North Rhine-Westphalia equal 2.6 Mt in 2015, and rise to 2.8 Mt in BAU 2050. Across all scenarios, emissions are dominated by road and inland waterway transport (IWT). Figure 14 presents the results of calculating the CO_2 emissions by mode for all scenarios in 2015, 2030 and 2050.

We find the following results:

- In the BAU scenario, efficiency improvements and modal shift effects limit the overall increase in CO_2 emissions to +9 per cent between 2015 and 2050.

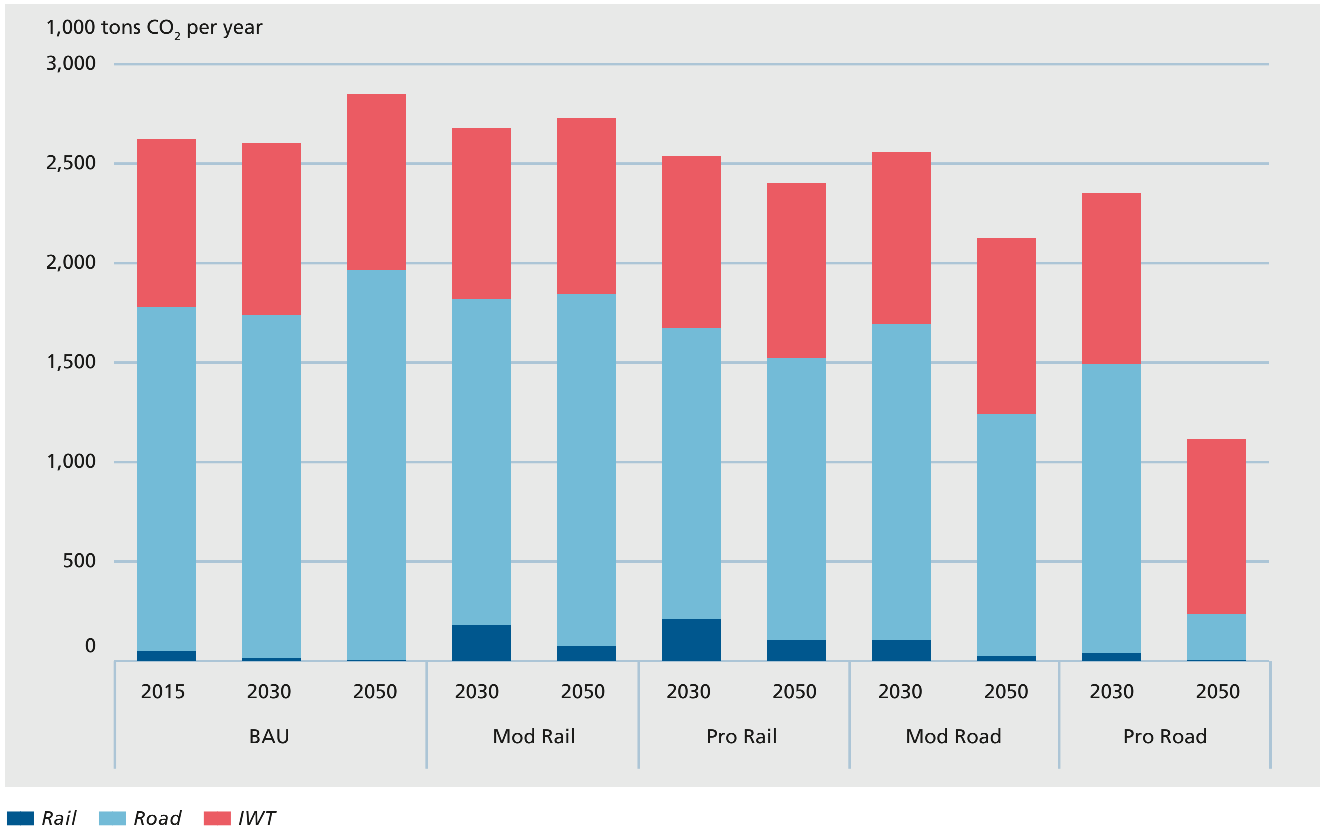
- Total CO_2 emissions in the Rail scenarios range within a +/– 10 per cent corridor around 2015 emissions. This finding is critical as it suggests that we cannot expect major cuts in carbon emissions with conventional policies. At the same time, this is a positive result because it indicates that we can at least stabilize emissions around current levels with conventional transport systems and technologies.

- The Mod Road and Pro Road scenarios show the deepest CO_2 cuts in 2050 with –19 per cent –57 per cent, respectively. Similar to the results for the international corridors, this indicates that substantial CO_2 mitigation is only possible if the major emission contributor, i.e. road haulage, is addressed.

- Inland waterway transport is a major CO_2 emitter. IWT emissions become more relevant as road and rail emissions decline. Their share increases from 32 per cent in 2015 to 79 per cent in Pro Road 2050. Addressing barge emissions with carbon-neutral fuels and more efficient engines could therefore reduce CO_2 levels by –60 per cent to –70 per cent by 2050 compared to 2015 levels.

- The results also indicate that a modal shift to rail helps. The Pro Rail 2050 scenario cuts emissions by 8 per cent compared to 2015 and 16 per cent compared to BAU 2050. This is achieved by standard rail technologies without electrification of HGVs. Therefore, a scenario combining a modal shift to rail, road decarbonisation and IWT improvement should manage deep GHG emission cuts on freight transport corridors with well-developed rail and waterway infrastructures.

FIGURE 14: Carbon emissions NRW by mode, scenario and year



***Source:** Fraunhofer ISI*

Environmental and safety costs

The RALP and NSB corridors caused environmental and social costs of 750 million euros on NRW territory in 2015. The annual costs climb to 891 million euros (+19 per cent) in BAU 2050 due to rising traffic volumes, efficiency improvements and unit cost developments. Details across all scenarios are shown in Figure 15.

The costs of carbon emissions dominate the environmental and safety costs. Apart from the Pro Road scenario, the share of the climate change cost category ranges between 63 per cent in 2015 and 77 per cent in 2050. This is because climate change unit costs per ton of CO_2 rise over time.

In 2015, air pollution accounts for 27 per cent of total costs, falling to 15 per cent in BAU 2050. The sum of noise and accident costs remains marginal as their share declines from 10 per cent in 2015 to 8 per cent of total costs in BAU 2050.

Road accounts for the largest share of environmental and safety costs in the BAU, Pro Rail and Mod Rail scenarios. This is in line with the estimated carbon emissions in Figure 14. In 2015, environmental and safety costs are allocated to the transport modes as follows: 2 per cent rail, 52 per cent road and 46 per cent IWT. In BAU 2050, the share of road increases to 61 per cent of total costs. In Pro Rail 2050, HGVs still contribute 48 per cent of environmental and social costs, while rail accounts for 7 per cent of the cost burden, due to massive modal shifts from road and IWT. In the Pro Road scenario 2050, road's share of environmental and safety costs is expected to shrink to 28 per cent with no measurable cost share of rail.

Cost efficiency ratios

The calculated savings in terms of climate gas emissions and social costs due to environmental and safety impacts are now compared with the investment impulses needed to adapt NRW networks to the expected traffic volumes. We look at CO_2 mitigation costs and at the proportion of environmental and safety costs avoided by investments for the years 2030 and 2050. We differentiate the two periods, because the investment impulses develop between the periods as well. Table 4 presents the results for environmental and social cost efficiency (= cost savings by investments) and climate mitigation costs (= investments per ton of CO_2 saved).

TABLE 4: Environmental/safety cost and climate mitigation efficiency, NRW, 2030–2050

Scenario		**Mod Rail**		**Pro Rail**		**Mod Road**		**Pro Road**	
Year	**Unit**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Investments (diff. to BAU)	Million €	–23.2	–23.2	45	45	104.1	39.2	277.1	131.2
Environmental/safety costs (savings to BAU)	Million €	–12.4	36.3	35.2	85.8	–10.0	57.5	41.4	236.9
Environmental/safety benefit ratio[1]	%	54	–157	78	191	–10	147	15	181
CO_2 emissions (savings to BAU)	1,000 t	–78.2	123.1	142.8	322.0	–19.2	281.2	203.0	1,006.1
CO_2 mitigation costs[2]	€/t CO_2	297	–188	315	140	–5,427	139	1,365	130

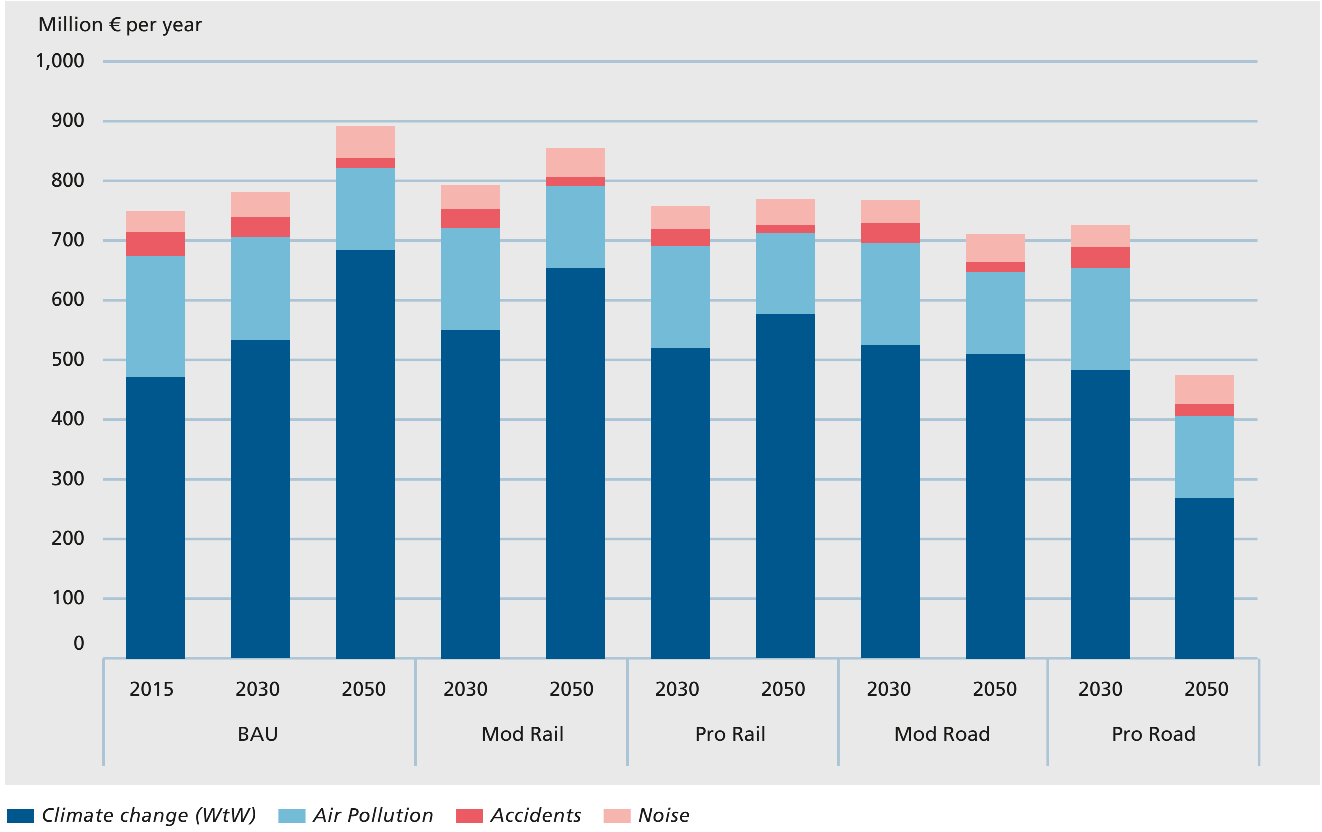
1) Environmental and safety costs by investments (difference to BAU); 2) Investments by CO_2 emissions (difference to BAU)

Source: *Fraunhofer ISI*

Unlike the corridor studies, investment impulses are negative in some scenarios for NRW compared to BAU. This holds true for the Mod Rail cases in 2030 and 2050, where joint investments in road and rail do not exceed the already considerable rail extension programmes in the BAU case. In Mod Rail 2050 and Mod Road 2030, on the other hand, CO_2 emissions and environmental and safety cost savings are negative, i.e. total costs in the scenario exceed the BAU costs in the respective years. Different signs for investments, emissions and environmental / safety costs then imply negative mitigation costs and benefit efficiency indicators in Mod Rail 2050 and Pro Rail 2030.

Apart from negative indicators, environmental and safety cost efficiency tends to be below 100 per cent for rail projects and above 100 per cent for road projects. CO_2 mitigation costs, in contrast, vary widely with no clear tendencies. The highest positive values by far are observed for Pro Road 2030: 1,365 euros per ton CO_2. Pro Road 2050 provides the lowest positive value: 130 euros per ton CO_2.

FIGURE 15: Environmental and safety costs NRW by cost category and scenarios



Source: *Fraunhofer ISI*

We can conclude that the order of magnitude of CO_2 mitigation costs is in line with the findings trans-European corridor studies, but its structure needs further interpretation. Negative signs with mitigation costs and benefit efficiencies demonstrate that, under some circumstances, savings in infrastructure costs can go hand in hand with environmental protection and increased safety. The results also suggest that this only occurs with comparatively small changes in investment activities. For both Pro Rail and Pro Road, declining burdens seem to be coupled with higher investments.

5.4 DISCUSSION

This chapter computed carbon emissions and the economic costs of climate change, air pollution, noise and accidents using the methodology applied to the European freight corridors in Sieber et al. (2018) but with updated values. The updated unit costs taken from the newly published Methodology Convention for Environmental Costs 3.0 of the German Environment Agency assigned higher costs to carbon emissions now compared to lower climate costs towards 2050 and lower economic impacts of particulate emissions.

The shift in unit values is in line with the recent IPCC report on the 1.5°C target (IPCC, 2018). Given the long-term global relevance of climate warming and the high likelihood of failing to meet the agreed targets, the upwards correction of mainstream GHG unit values is appreciated as it promises more favourable benefit-cost-ratios for climate mitigation policies and measures.

In terms of air emissions, the applied methodology takes some shortcuts. First, the emission rates of fuel combustion remain constant at Euro-VI emission standards. The reasoning behind this simplification is that political priorities will shift towards greater CO_2 reduction and vehicle manufacturers will curb research on engine development in the light of powertrain electrification.

The second shortcut when estimating air pollution costs is to exclude CO_1, SO_2, NMVOC and other substances. We do not consider this a major problem as NOx and PM are commonly acknowledged lead substances for environmental impact assessments.

The carbon mitigation cost and environmental and safety cost efficiency indicators derived in this section draw a positive, but somewhat confusing picture. In contrast to the corridor analyses, the results for NRW show that, under certain conditions, GHG mitigation costs can become negative. Saved GHG emissions can, in these cases, be accompanied by lower infrastructure investment costs. The same holds true for the environmental and safety cost efficiency: savings compared to BAU with lower investment costs. In Pro Rail and Pro Road 2050, the savings are nearly double the additional investment costs. Interestingly, in the NRW case, the superiority of Pro Road over Pro Rail les pronounced than in the corridor analysis.

The policy conclusions drawn from these results are that intelligent infrastructure planning should check and prioritise situations where net cost savings and emission reductions coincide. In addition, with regard to recent IPCC warnings and the adjusted unit values by UBA (2018), greater priority should be given to short-term emission savings than to future benefits. Detailed recommendations are given in Chapter 8.

5.5 CLIMATE RESILIENCE AND NEW TECHNOLOGIES

This section limits the scope of investment activities to infrastructures. Widening the perspective to include systemic railway technologies such as digital automated coupling and electro-pneumatic braking could unveil further synergies between climate gas mitigation and the competitiveness of rail freight services. Clean fuels for shipping is another highly relevant field of action to lower GHG emissions and combat environmental problems in freight transport. Moreover, rail and waterborne transport both need to be incorporated into digital networks for the handling, supervision and tracing of consignments in order to retain current markets or gain new ones.

Freight transport is not only a cause of climate change, but is also its victim at the same time. This applies to rail and shipping more than to road haulage. More flexible and data-based fleet handling procedures could serve three purposes at the same time: increasing rail and shipping business opportunities, mitigating GHG emissions by curbing road traffic volumes, and adapting the sector to cope with climate impacts. Vertical cooperation between rail and shipping would support such a flexibility strategy.

6 COMPARING THE NRW CASE TO TRANS-EUROPEAN FREIGHT CORRIDORS

The first phase of the LowCarb-RFC project investigated the long-distance European freight corridors Rhine-Alpine from Rotterdam to Genova and North Sea-Baltic from Antwerp to north-eastern Poland. In four working papers, we defined cost and technology pathways towards 2050 for business-as-usual and railway scenarios (Doll and Köhler, 2018), Road scenarios (Mader and Schade, 2018), set up and applied a transport chain model (Van Hassel et al., 2018) and performed an environmental and safety cost assessment (Sieber et al., 2018). The results are summarised in Summary Report 2 of the LowCarb-RFC study (Doll et al., 2018). In this chapter, we briefly review the findings and compare them to the NRW findings.

The second summary report of the LowCarb-RFC study presents extreme scenarios of cost cuts in rail freight and the electrification of road haulage for two European freight corridors by 2050. The Pro Rail scenarios for competitive freight railways and Pro Road scenarios for greenhouse gas-neutral road transport aim at quantifying the potential contributions these two different transport and climate policy approaches could make to climate protection and sustainability.

6.1 DIFFERENT TRANSPORT SCENARIOS

The NRW case features different assumptions and methods. We use the same scenarios (BAU, Pro/Mod Rail and Pro/Mod Road) as in the corridor analyses but different definitions for NRW.

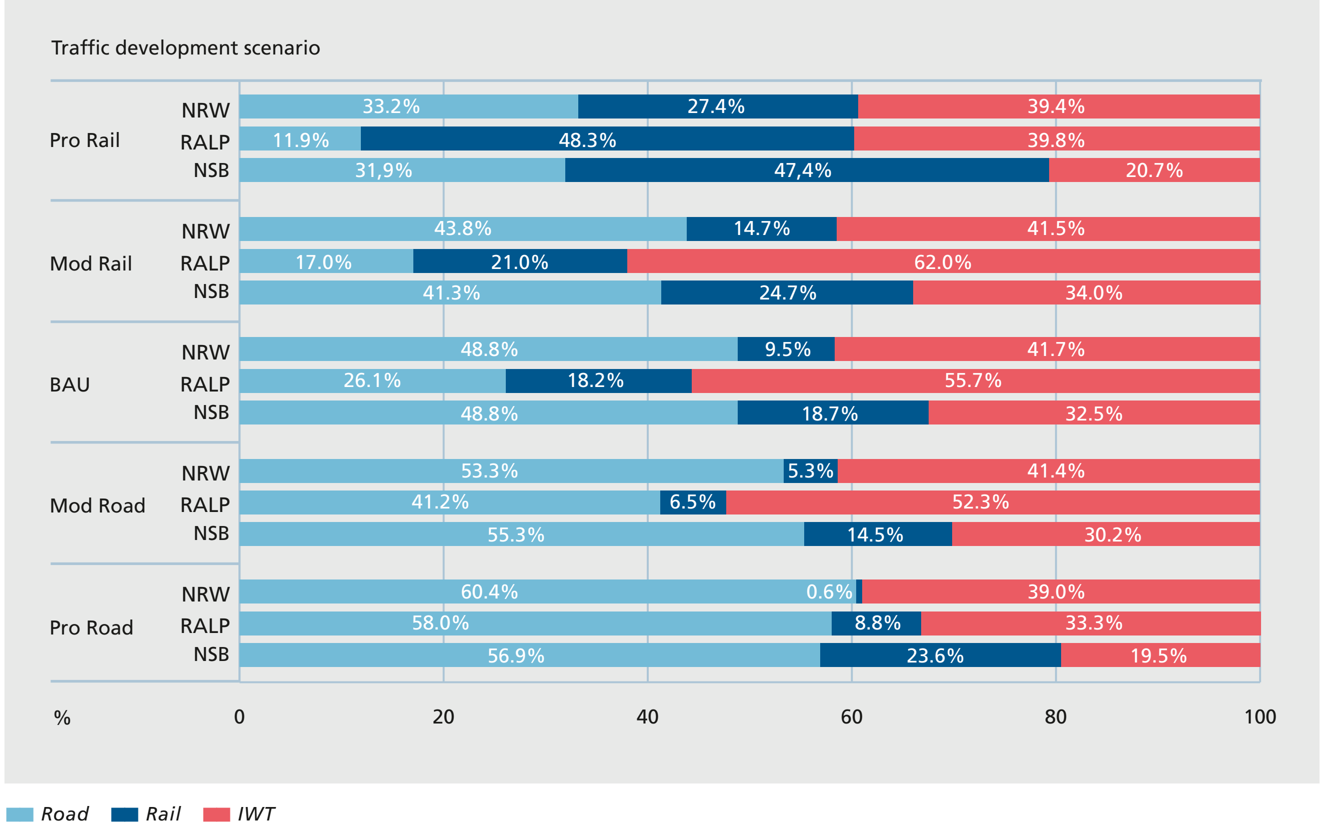
The transport market scenarios for the European corridors are derived from assumptions on cost and performance changes along five cost categories in road, rail and inland waterway (IWT) transport. Pro Rail drafts a future in which rail transport costs decline by 66 per cent due to the effect of regulatory frameworks, entrepreneurial measures and the comprehensive and consistent application of digitalisation and automation. At the same time, road haulage costs increase by 25 per cent as the result of taxes, charges and regulation. In contrast, Pro Road describes a future in which road transport operates carbon neutrally using overhead power-catenary systems, batteries and fuel cells. The modal shares of road, rail and IWT in 2030 and 2050 are computed using an extended version of the TRP logistics chain model created within the LowCarb-RFC project. Rail's market share triples in the Pro Rail scenario compared to the reference case in the year 2050. This is partly at the expense of trucks, but also at the expense of inland shipping.

In contrast, the NRW case study considers fixed changes by scenario in the market shares of all three modes of transport. The assumptions made are much less extreme than those suggested by the TRP chain model. This was done to align the study more closely to the figures and assumptions of the German Federal Transport Infrastructure Plan (BVWP), and make the results more comparable to national assessments.

The results of the three cases, NRW, and the RALP and NSB corridors, differ considerably. Firstly, this is due to the role of inland waterway transport. While IWT shares remain stable around 41 per cent at ton kilometres in the NRW case study, the sector reacts quite sharply to changes in scenario assumptions in the European corridor studies. Secondly, the role of rail in the road scenarios is much more dynamic in the NRW case study than along the RALP and the NSB corridors.

Rail maintains its market share in both corridor studies, but particularly along the axis from the North Sea ports to Poland. Together with the generally higher market share of rail along the European corridors, this finding is in line with the cost advantages of rail over long distances. In contrast: in the NRW case study is fully marginalised to 0.6 per cent at ton kilometres in the NRW case in 2050. Figure 16 shows the estimated modal shares for the three cases by scenario for the year 2050.

FIGURE 16: Comparison of modal shares 2050 in NRW to the European corridors



Source: *Fraunhofer ISI*

6.2 DIFFERENCES IN SUSTAINABILITY ASSESSMENT

Along the Rhine-Alpine Corridor 2050, annual GHG emissions decline from 60 Mt to 35 Mt (–42 per cent) CO_2-equivalents in the Pro Rail scenario and to 22 Mt (–63 per cent) in the Pro Road scenario. Combining both scenarios could achieve a further reduction to 16 Mt (–73 per cent). Because these extreme scenarios of rail enhancement and road electrification are unlikely to be realised as proposed, climate policy needs to exploit all the emission reduction potentials in all modes and push suitable low-emission and low-cost combinations of road, rail and inland waterway transport.

The GHG emissions in the NRW case study are about half those calculated for the RALP corridor and about a third of the emissions computed for the NSB corridor. This ratio is in line with the relative traffic volumes.

The assessment model finds no systematic differences between the corridor studies and the NRW case for the emissions relative to the BAU case in 2050. The biggest reduction of –61 per cent is found for the Pro Road scenario, while the Pro Rail scenario only achieves –16 per cent of total freight emissions. This is significantly below the Pro Rail scenario assessment for RALP (–43 per cent) and for NSB (–28 per cent). This finding reflects the lower dynamics of the railways in the NRW case study. The limited size of the federal state's territory compared to the long-distance lines along the two European corridors might explain part of the results. Table 5 provides the relative GHG reductions estimated for 2050.

GHG mitigation costs have been estimated for the corridors as well as for NRW. In both case studies and for all scenarios, we compared the total additional infrastructure investments relative to the BAU scenario needed to meet actual demand in 2050 to the total CO_2-equivalents saved. We only estimated disinvestments for the corridors if demand levels in the scenarios were below the BAU case.

Comparing NRW to the RALP and NSB corridors reveals similar mitigation cost estimates for the road sector. The NRW value (130 euros per ton CO_2-eq.) is midway- between the values for the two corridors. The cost estimates for rail, however, differ widely. While the corridors suggest mitigation costs that are four to six times higher than those for roads, the NRW case study's figure of 140 euros per ton CO_2-eq. is very similar to that for rail. A possible explanation could be the different transport demand assumptions in the scenarios. In Pro Rail 2050, rail volumes were limited to +75 per cent relative to BAU in the NRW case, while the RALP and NSB scenarios assumed a tripling of volumes. From these observations we can conclude that a programme of dedicated small to medium sized investment measures entails lower GHG mitigation costs than highly effective but expensive large investment projects.

The approach assumes that all the investments in infrastructure capacity, ICT systems (ETCS level 2 and 3 for rail) and electrification (motorway catenary infrastructures) were made only to reduce GHG emissions. This does apply to motorway electrification, but infrastructure investments serve other purposes, including accessibility, service quality, and market acquisition or maintenance. Therefore, only parts of the costs should be attributed to CO_2 reduction.

TABLE 5: Comparison of GHG emissions compared to BAU 2050 by scenario

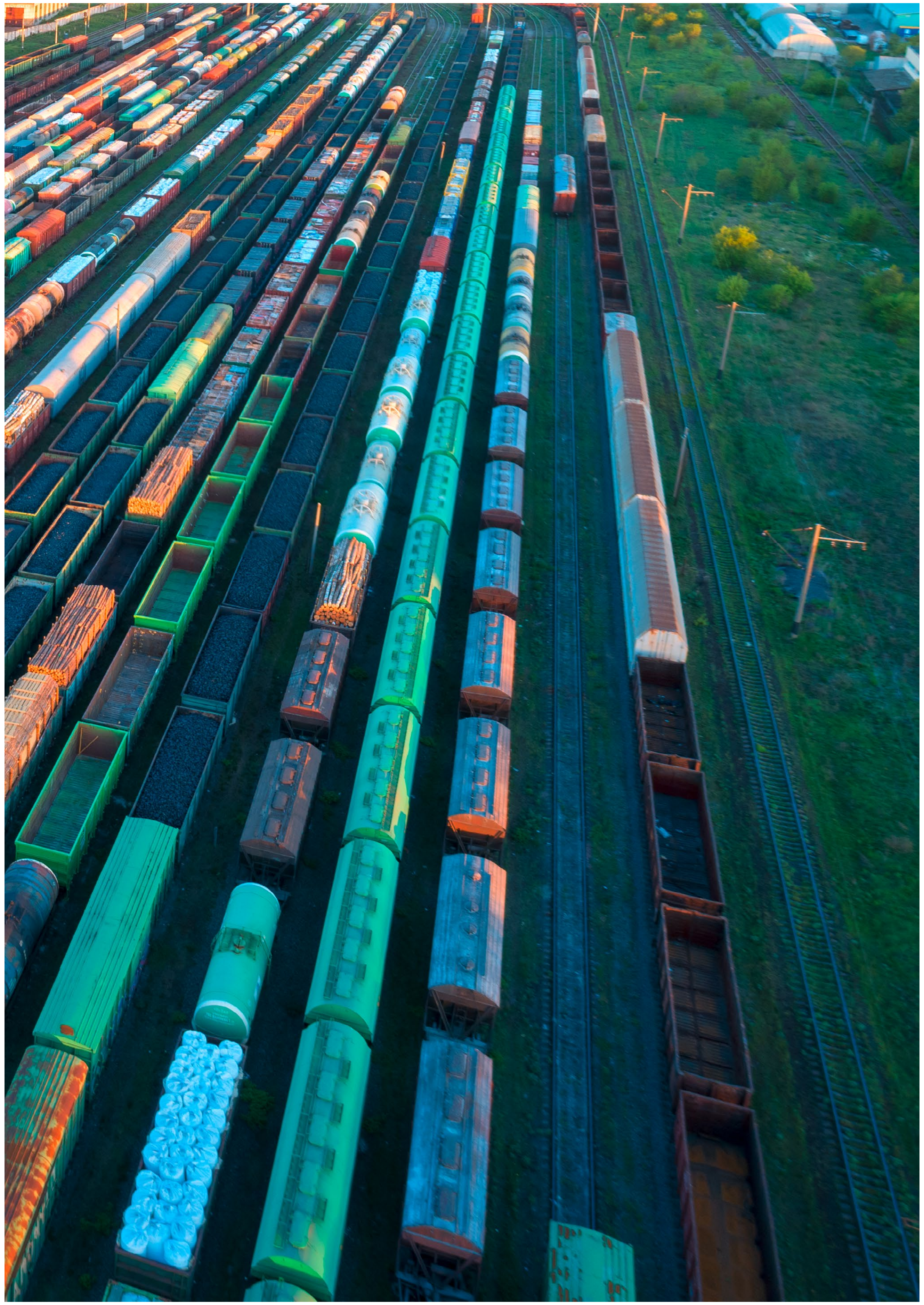
Scenario	CO_2 reduction potential 2050/2015 in %			GHG mitigation costs (€ per ton CO_2-eq)		
	NRW	**RALP**	**NSB**	**NRW**	**RALP**	**NSB**
Pro Rail	–16	–43	–28	140	566	616
Mod Rail	–4	–15	–10	140	566	616
Mod Road	–25	–8	–20	130	172	108
Pro Road	–61	–64	–60	130	172	108

Source: *Fraunhofer ISI*

6.3 THE ROLE OF LOCAL RAIL FREIGHT TRANSPORT

We looked exclusively at the main freight lines in both cases: along the European corridors and in the specific case of North Rhine-Westphalia. Even in the NRW case, we did not consider regional or local distribution networks. This is partly because we focus on high freight volumes with all the entailed GHG emissions and other sustainability problems, and partly because rail is commonly considered a long-distance mode only. In this tradition, the European Commission's 2011 Transport White Paper (European Commission, 2011) refers to shipments over 300 kilometres to enhance rail modal shares.

However, examples from the Swiss retail sector show that concerted efforts including local businesses and the railways can provide attractive services even for distances of less than 100 kilometres. Other examples from across Europe demonstrate good practices in trading vacant container and wagon capacity, in last-mile logistics and in re-vitalising freight lines. The common factors here are the personal engagement and high sustainability standards of the railways' customers. To attract considerable volumes from road-based to rail-based local goods distribution networks, the railways would need to provide powerful and reliable interfaces to supply chain management tools. Automated transhipment, shunting and last-mile rail operation services would need to bring down delivery costs. Local goods distribution networks have significant climate impacts, account for almost 50 percent of freight volumes and are currently almost exclusively based on road transport.



7 TRANSFORMING INSTITUTIONS AND TECHNOLOGY REGIMES

7.1 BASIC APPROACH TO INSTITUTIONAL CHANGE

The first summary report of the LowCarb-RFC study (Petry et al., 2018) combines the regulation and other policies supporting innovation with concepts of change management and the creation of new markets for rail transport and climate mitigation on European freight corridors. Improved competitiveness of the railways requires solving the double challenge of earlier and more extensive liberalisation of road haulage and the dominant role of the incumbents in rail freight.

Rail freight growth requires the reform of complex internal structures, long decision pathways and exaggerated expectations concerning rail. This requires changes in the organisation and institutional setting of rail freight together with infrastructure expansion, digitalisation and modernisation. We find that the current institutional design and adaptation efforts of incumbents, while introducing major changes, do not go far enough for their final customers. Deeper institutional reform processes, as planned for DB, would require greater political pressure in order to materialise.

In the longer term, new operators could improve rail's competitiveness with respect to road transport. Success factors include equivalent working conditions across modes, standardisation of rail systems and innovation support. A survey of business models in other sectors finds common developments including predictive logistics, use- and results-oriented product service systems, horizontal cooperation and bundling. These may well complement traditional company strategies.

7.2 KEY MESSAGES ON CHANGE MANAGEMENT

Change management literature distinguishes between four perspectives on institutional analysis:

- Adaptation of organisational field to external change (institutional diffusion);
- Actor adapts to external change (institutional adaptation);
- Organisational field triggers institutional change (collective action);
- Actor deliberately triggers institutional change (institutional design)

These perspectives suggest that the current processes and rates of change may not be enough to bring about the far-reaching changes necessary for a large-scale transformation of the modal split of freight transport. The theory of Multi-Level Perspectives (MLP) suggests that the inertia of the rail freight regime could be overcome by new organisations and institutions utilising innovative technologies in internet-based business models and railway operations to drastically improve rail freight competitiveness as a part of intermodal supply chains. The MLP also suggests that such new organisations and institutions may need to be implemented by a range of actors in rail freight and not just DB. (Van Mossel et al. 2018) review organisation theories and their application to the behaviour of regime incumbents. They conclude that if an incumbent adopts the new technologies and organisation of a niche, it has higher chances of survival.

The conclusion from the institutional change literature and business models is that incumbent railway undertakings, such as DB Cargo, may be able to take advantage of the opportunity provided by the supportive political environment due to the sustainability debate. However, they will need to change their organisation to develop new business models and institutions able to lead the internet-based logistics industry of the 21st century. Other actors, whether new rail operators or entrants from the logistics sector, may provide the competitive pressure to DB Cargo and deliver the necessary innovations. They may also grow to become major actors in the sector. A new structure of the industry with a changed business model for DB will be necessary.

The example of railway reform in Germany indicates there will be a strong increase in intermodal competition from domestic and foreign players using business models tailored to promising market segments. This can be described as a disruptive form of institutional change, putting the incumbent freight carriers under pressure and most likely resulting in greater competitiveness of the sector and a stronger orientation towards customer needs. However, these developments and the current Master Plan Rail Freight Transport (BMVI, 2017) alone will hardly drive the rail share upwards unless road haulage has to cover its full social costs. Another important driver of institutional change in the transport sector is technological progress brought about by the digitalisation of the railway freight sector and its customers.

7.3 TECHNOLOGY INVESTMENT PROGRAMMES

Fostering the introduction of systemic railway technologies could unveil synergies between climate gas mitigation and the competitiveness of rail freight services. Examples are digital automated coupling and electro-pneumatic braking. Both technologies are common in passenger rail services. However, they have not yet found their way into the freight market because standard freight wagons are used all across Europe and so the entire fleet would need to be renewed at once. An attempt in the 1980s to introduce automated coupling failed because of the reluctance of some countries.

Investing in digital automated coupling would allow more efficient train composition processes and save resources. Combined with electricity and data lines, it could enable wagons to supervise cargo conditions and connect with data processing platforms at the railway operators or directly at their customers. Electro-pneumatic braking permits longer trains and more dynamic and energy-efficient driving patterns. This technology can improve the overall efficiency, track capacity and energy use of rail freight services.

These are just two examples of where the railways themselves could improve their customer value in a data-driven economy and even incorporate market segments that have been entirely lost to trucking over the past decades. These and similar technologies could be implemented in specific market niches to start with, such as port hinterland container traffic or automotive logistics networks. The decisions, however, need to be taken fast, given the critical development of GHG emissions.

8 POLICY SUGGESTIONS AND RECOMMENDATIONS

8.1 INVESTMENT NEEDS FOR NRW

In Chapters 2 and 3 of this report, we described and assessed infrastructure investment scenarios for North Rhine-Westphalia from today until 2030 and 2050. We derive the following policy conclusions from the findings:

1. *Long-term investment programmes need to prepare for rising investment costs*. We used standard infrastructure investment cost values from the German transport Infrastructure plan (BVWP) 2030 for the rail and road investment scenarios. These may be far too low already and will be in particular in the longer term. Citizens take an increasingly critical view of noise and environmental issues, making planning processes even longer and more costly. Moreover, land scarcity might drive construction costs up as well. Automated construction and maintenance procedures are unlikely to compensate for these effects. Furthermore, even in the moderate scenarios, the planned budget on the TEN-T corridors will not be sufficient to cope with the growth in road and rail traffic. There is the threat of a significant increase in the number of kilometres of congestion, which will place a heavy burden on the economy and the environment. The focus on maintenance measures also leads to too little room for expansion measures. Additionally, bridge construction and the expansion of the TEN-T corridors in densely populated areas will lead to significantly higher costs due to the additional costs of tunnel solutions or high land acquisition costs.

2. *Transport infrastructure planning projects need to be accelerated.* The traffic increases expected in the scenarios in NRW will have to be covered by the infrastructure, which is already partly overburdened at present levels. The building permit procedures are an unnecessary obstacle to the implementation of already financed construction projects. An acceleration is urgently needed here. The shortage of personnel is also a problem that needs to be solved.

3. *The 2020s are needed to prepare the system transition towards a post-fossil freight market*. Up to 2030, total costs between the scenarios do not differ much. This holds true for the upper bound cost estimates, which vary between 10.6 billion euros for Mod Road and 11.4 billion euros for Pro Road. This investment phase shall thus be used best to strengthen the level playing field between all transport modes and to prepare for alternatives to the investment phase post 2030 by innovative technologies and business models.

4. *The attractiveness of the railways must be increased*. In order to achieve the Pro Rail scenario, significant improvements in the area of rail are necessary. Here, the master plan for rail freight transport is a promising first step that should be implemented swiftly (BMVI, 2017). This requires both nationwide programmes and legal adjustments, as well as regional contributions to implementation, such as local strengthening of the railways for land use planning, information platforms, etc., to be made. In this context, a significantly increased willingness on the part of the public sector to adopt the railways is necessary.

5. *Alternative technologies are needed for capacity provision and decarbonisation*. The most expensive scenario, Pro Road, differs to BAU by only 0.4 billion euros until 2030, but by 2.8 billion euros until 2050. For the TEN-T corridors in NRW alone, the latter is considerable. It is thus recommended to look for other options to provide the necessary capacity to meet rail demand in the Pro Rail scenario towards 2050. This is relevant, because the development from 2015 to 2050 alone calls for major investments in both rail and road transport. Affordable solutions could include integrated and multi-modal freight platforms, automated transhipment, dense train schedules due to harmonised speeds, and better use of inland waterway capacities. In order to achieve the CO_2 target, a significant effort is required to finance and implement sustainable solutions such as HO trucks, shifting to rail, etc. This requires an extensive research and development programme, which must be seen in addition to the capacity increases and maintenance investments in the infrastructure.

8.2 ECONOMIC AND SOCIAL IMPACTS FOR NRW

Analysing the macro-economic impacts of modal shift and road electrification measures in North Rhine-Westphalia in Chapter 4 yielded the following encouraging results:

6. *The potential impacts of modal shift and decarbonisation scenarios on labour markets and economic performance appear to be well manageable*. Overall, the investment impulses resulted in small maximum changes below 0.1 per cent to FTE and GVA in NRW. Even these small values represent an upper limit of the infrastructure investments needed since they are based on the assumption that all additional FTE demand / GVA for Germany is generated in NRW. Estimating the full net effects in the macroeconomic input-output model and taking substitution and price effects into account might lead to even lower values. Effects on GVA are either positive or close to zero.

7. *The socio-economic assessment carried out here is based on some simplifications*. First, the analysis did not consider how the investments are funded or whether they substitute other investments. The underlying assumption is that the socio-economic effects are unlikely to change the impacts on FTE / GVA much. Second, we omitted investments in HGVs, trains, and barges, as well as the costs for transport services. Moreover, we did not discuss in detail the costs of shifting jobs between industry sectors. For instance, the qualifications required for road construction may differ widely from those needed for railway facilities.

8. *Policy needs to focus on longer-term sustainability goals*. In the end, we conclude that the comparison and assessment of scenarios should not be based solely on their socioeconomic effects but must include technical, organizational and environmental perspectives as well.

8.3 ENVIRONMENTAL IMPACTS FOR NRW

Chapter 5 picked up the transport scenarios from Chapter 3.2 and computed the social costs of climate gas emissions, air pollution, noise and safety by scenario, mode of transport and period. In 2015, climate emissions from trucking dominate the picture, followed by air pollution from road and waterborne transport. The calculations suggest the following recommendations:

9. *Environmental policy should prioritise the reduction of greenhouse gas emissions when addressing transport*. Apart from in the Pro Road scenario, the share of the cost category climate change ranges between 63 per cent in 2015 and 77 per cent in 2050. This is because the social costs per ton of CO_2 rise over time and because it is easier to tackle air pollution and safety issues through technical measures including clean fuels, electrification and automation.

10. *Initial financial support is needed to manage the transition towards acceptable GHG mitigation costs in the long term*. The Pro Road and Pro Rail scenarios have GHG abatement costs of 130 euros per ton to 140 euros per ton of CO_2-equivalent in the period 2030 to 2050. These costs are below those for solar (700 to 1,000 euros per ton) or heat pumps (up to 500 euros per ton), and similar to wind power (100 to150 euros per ton) (FfE, 2017). The short-term abatement costs might be much higher. Given the urgency of climate protection, the transition towards acceptable mitigation costs should be supported by tax or other funding mechanisms.

8.4 STRATEGIC POLICY RECOMMENDATIONS

Summary Report 2 (Doll et al., 2018) draws the following policy conclusions from the European corridor studies:

11. *Rapid decarbonisation of road transport through electrification is indispensable to achieve the climate targets in transport.* The scenarios for NRW and for the European corridors confirm that modal shifts help to mitigate carbon emissions, but these shifts alone will not meet the agreed reduction targets for the transport sector. This applies even more if we leave the busy corridors with bundled freight flows and look at disperse regional logistics patterns. Therefore, decarbonisation of road transport must be prioritised by transport and climate policy. As greenhouse gases cumulate in the atmosphere, this needs to happen fast to minimise the violation of the 1.5°C or even of the 2.0°C degree targets.

12. *Strong railways are needed to achieve even deeper cuts in GHG emissions and compensate those segments of road haulage that cannot be electrified*. Sieber et al. (2018) reveal that combining various mitigation pathways such as road decarbonisation and modal shift scenarios can achieve GHG reduction targets without going to the extreme of restructuring the transport market. However, the rail sector needs to standardise and simplify operations in any case and needs to adopt new technologies and business models wherever possible.

13. *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*. In NRW as well as along the European corridors, barges accommodate up to half of total ton kilometres shipped. There are no unsolvable capacity limits to shipping and its GHG footprint is comparable to rail. As far as supply chains allow, shipping needs to be supported in the transport mix. However, in order to utilise the available resources of IWT, company philosophies must move beyond the focus on just-in-time and same-day delivery.

14. *GHG reductions of up to 75 per cent are possible by combining rail extension and motorway electrification to their full extend along the European corridors*. Motorway electrification alone could reduce GHG emissions by 60 per cent, while rail mode share along may achieve up to 43 per cent on the Rhine-Alpine corridor. The bulk of the remaining GHG emissions are from IWT and power supply. Using carbon neutral fuels for shipping and 100 per cent renewables-based electricity in the power sector could in principle curb the carbon emissions of freight transport on major routes by 80 per cent.

15. *The business case for GHG mitigation remains open*. GHG mitigation costs along the European corridors range from 570 euros per ton CO2-eq. for decarbonising road transport to 172 euros per ton CO2-eq. in the case of a modal shift policy. We exclude the costs of decarbonising the energy sector, and assume constant costs per road or rail network kilometre. This may not apply in the future. Further cost increases will occur due to the growing scarcity of land and production resources in the coming decades, and maintenance costs may rise with automated and connected vehicles entering the market. Moreover, some parts of the rail expansion costs are not due to climate protection reasons, but for accessibility, safety, resilience and other purposes. Taking these issues into account, the ranking of GHG mitigation costs by policy might reverse.

16. *Uncertainties about the need for infrastructure investments are particularly high for the road network*. Along the European corridors, the annual investments required range between 1.2 billion euros for the electrification and capacity expansion of the motorway network to 3.0 billion euros for rail digitalisation and infrastructure upgrades. In contrast to this finding, the NRW case study suggests that road investments are far higher than rail investments due to the upfront investments in catenary infrastructure and a more detailed consideration of capacity bottlenecks in the highly congested NRW motorway network. In light of the more detailed NRW case study, we need to reconsider the conclusion about the superior business case of road electrification compared to the modal shift to rail in Sieber et al. (2018). Road extension might become more costly than the multiple options for increasing capacity in the rail network.

17. *In a low-carbon freight world, criteria other than the environment are used to determine the desirable mix of transport modes.* Once motorway catenary systems are up and running, the cheaper construction and maintenance costs of roads compared to rail per traffic unit become apparent. However, we must consider the concerns about rising construction costs in the future and potentially higher maintenance and renewal costs of motorway electrification infrastructures. Two of the major cost categories of trucking decline drastically with automated electric trucks; this suggests even larger shifts from rail to road than indicated in the Pro Road scenario. As climate, air quality and safety problems are then largely resolved, other criteria will determine what level of road transport is acceptable, such as working conditions, resilience to environmental impacts and technical failures, transport infrastructure land requirements, nature and habitat preservation or the recreational value of our landscapes. Policy guidelines for this post-fossil phase of investment planning must be prepared in time.

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.

8.5 INDUSTRY STRUCTURES AND BUSINESS MODELS

The promotion of the "new economy" brought about fundamental changes in the relationship between producers, their customers and the final clients. This affects the expected timing and reliability of processes as well as the clients' demand for the transparency and flexibility of transactions. Consequently, the production processes of traditional industries as well as their interfaces to the customer have changed–or still need to change–from a producer- and process-centred perspective to a more customer-oriented philosophy. Here, we summarise our pervious conclusions in Gandenberger et al. (2018) on the respective reform processes in the railway sector.

18. *Drivers of change within large entities like incumbent railway companies need external support and pressure to take effect*. The academic literature on change management stresses that implementation is the most difficult and challenging part of organisational change processes. For instance, opposition from trade unions and employees might result in deviations from the original design and cause considerable time delays. At the same time it can be observed, that the increasing pressure from intramodal competitors trigger transformative

organisational change initiatives at incumbent European railway operators. Even though the success of these initiatives is highly uncertain, in total, these changes are likely to result in a greater competitiveness of the sector and its stronger orientation to customer needs. The environmental and climate policy debate and a stringent regulatory framework could help these processes to bear fruit and to align the railways' strategy with sustainability goals.

19. *Support niche products, players and markets within and outside incumbent rail carriers to adapt the sector to future business cultures and demand structures*. The four perspectives on institutional analysis discussed in Gandenberger et al. (2018) suggest that the current processes and rates of change may not be strong enough to bring about the far-reaching changes needed for a large-scale transformation of the modal split in freight transport. The theory of Multi-Level Perspectives (MLP) suggests that the inertia of the rail freight regime could be overcome by the development of new organisations and institutions, which can utilise new technologies, business models and operations to drastically improve the competitiveness of rail freight. The MLP further suggests that such new organisations and institutions may need to be implemented by a range of actors in rail freight and not just by the incumbent carriers.

20. *Digital transformation and automation have enormous potential in the rail sector*. Digital business models and operational procedures have the potential to unveil enormous capacity reserves in the railway sector, to cut costs and to bring it closer to its customers. Digitalisation and automation can thus improve rail's competitive position against road haulage, they require fundamental the sector's organisation and business culture. These changes are probably way more profound than the challenges of digitalisation and automation in trucking.

21. *Digitalisation and automation in the railway sector need cooperation*. Digitalisation processes cannot be introduced by new train operators alone, because they require fundamental changes to the train control systems that are currently still operated as a monopoly by the incumbent national rail carriers. Key innovations include the automation of marshalling and train disposal, energy efficiency, integrated customer-oriented freight information along the supply chain, and new services like underground freight movement.

22. *Take full advantage of the potential of combined transport using standardised equipment and procedures across transport modes*. The intelligent combination of various means of transport can boost rail freight: To strengthen rail freight in general, we therefore strongly recommend taking full advantage of the possibilities offered by combined transport. This requires further investments in the standardisation of services and products. In order to facilitate combined transport and to accelerate cargo handling, for instance, we propose standardised trailers and automatic terminals.

23. *Carbon-neutral rail freight corridors require Interoperability 2.0*. Cargo handling does not stop at borders. Creating carbon-neutral rail freight corridors requires increased interconnection of cross-border traffic–a kind of "Interoperability 2.0". Different languages should not cause barriers. This is why agreeing on a common language (e.g. English) is an important success factor for international transportation. The same applies with respect to the rolling stock: To facilitate international operations, neighbouring countries should continue to standardise power supply and safety systems.

24. *Client orientation instead of systems orientation*. Cooperating with actors from other countries and investing in a network of personal contacts appears to be very important if new entrants are to be successful on the (international) rail freight market. Direct links to their customers should give the railways an advantage over freight trading platforms, which can force them into playing a carrier-only role. However, this requires not only network-oriented business models, but also flexible–and transparent–access for various actors in the European transport market.

Half of all rail wagons run empty and their average annual kilometre performance is modest in most market segments. A better use of rolling stock and loading space is the key to cost efficient railways (Doll and Köhler, 2018). Smart management of these assets can create new capacity in the rail network without expensive infrastructure investment programmes. For this to be successful, however, attractive business models must integrate existing and potential customers into railway logistics planning processes. Meyer et al. (2018) elaborated several ideas for potential ways forward that are summarised here:

- *Less commonly used types of new business models need to be exploited to enhance the competitiveness of rail and combined transport*. The rail transport sector harbours great potential for business model innovations. Digital transformation, in particular, can be expected to open the door to various innovations, many of which have not yet been developed. Digital transformation can be fostered by including digitalization in national transport Infrastructure plans. A more systematic approach to identifying successful business models is needed to unveil the potentials for making sustainable freight transport more efficient or attractive. Promising areas include predictive logistics, use-oriented and results-oriented product service systems, the facilitation of horizontal cooperation, bundling, and large-scale platform applications.

- *Purely digital business models and digitally upgraded conventional business models can co-exist*. There is a bias towards purely digital business models. Such models promise unlimited scalability and may therefore be more attractive to investors. However, it is also possible to enhance conventional business models with digital technologies. This is particularly important for incumbents. If they fail to respond and adapt to the digital revolution, they may eventually be forced out of business. Moreover, it needs to be acknowledged that the transportation process will always involve physical assets. Digitalisation will never replace the physical movement of goods. That being said, value chains might change and the businesses that are best able to gather and utilise transport-related data might flourish at the expense of others.

- *Further investments in platform models are needed to improve multi-modal access to transport chains and to enhance the efficiency of all modes of transport*. Besides new entrants to the transport sector, new digital business models are required to improve the interface between rail transport companies and their clients. Platform-based business models harbour a huge market potential because they are able to cut transaction costs. At the same time, however, there is the risk that proprietary platforms that are controlled by a single or a limited number of companies will lead to considerable anti-trust issues.

8.6 FINAL REMARKS

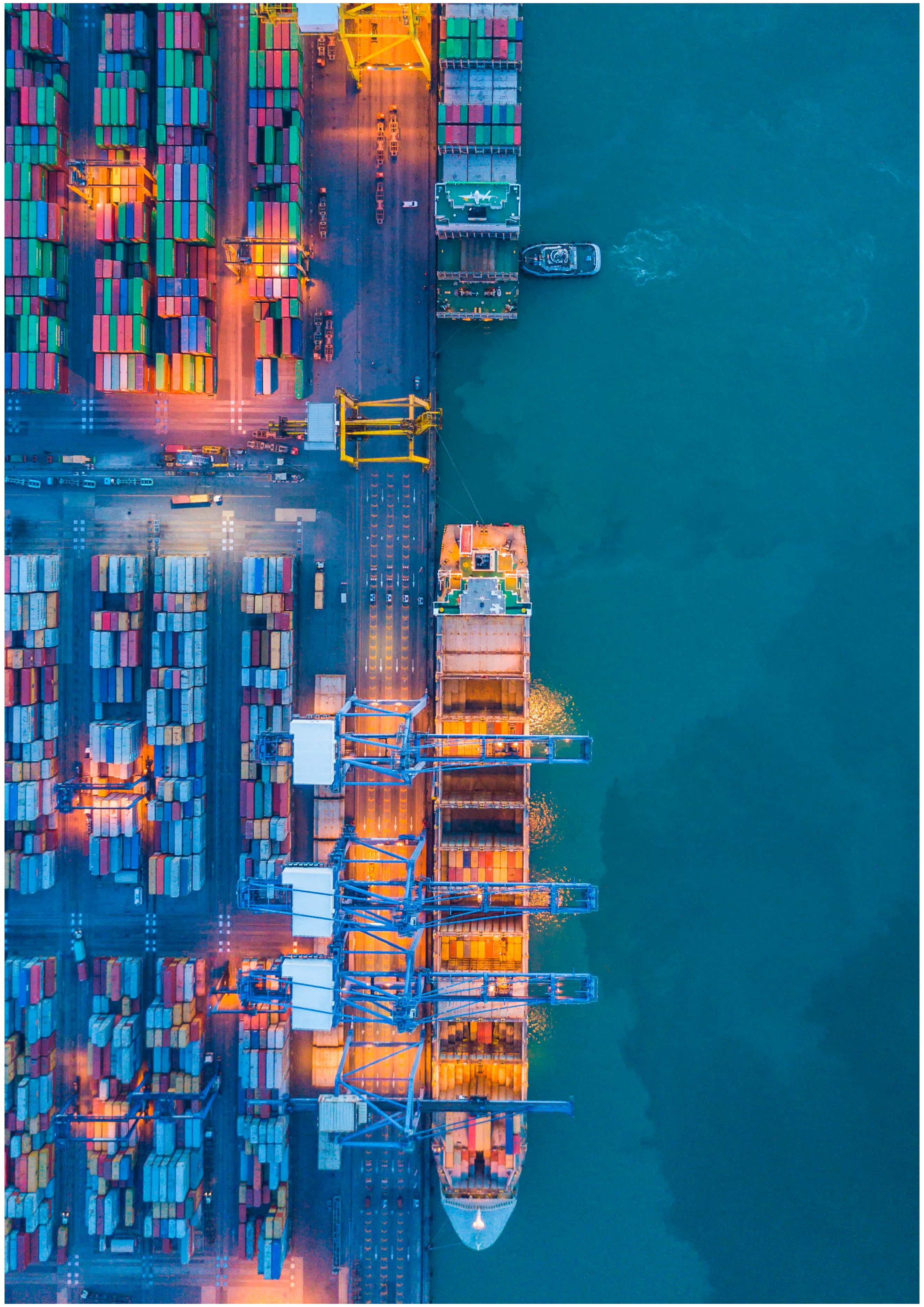
This summary report embraced all the research streams of the LowCarb-RFC study. It started with the North Rhine-Westphalia case study and then briefly reviewed the previous summary reports: SR-2 on European corridors (Doll et al., 2018), and SR-1 on markets, institutions and business models (Petry et al, 2018). We emphasise the urgent need for rapid climate action in the freight sector and for radical policies if the transport sector is to get anywhere near the target of –60 per cent GHG emissions in 2050 compared to 2015. At first sight, it seemed that road electrification is superior to a modal shift to rail in terms of the cost-efficiency of GHG mitigation. However, the superiority of this solution becomes less obvious when considering the available capacity reserves in the rail system and the most likely sharp rise in the costs for infrastructure construction and maintenance. Moreover, the potentials offered by inland and coastal shipping powered by cleaner fuels should not be underestimated. Here, more in-depth research of investment programmes is needed.

To tap into the existing rail capacity reserves, full digitalisation and the application of innovative business models are of the utmost importance. New forms of production and customer relations will not necessarily crowd out existing services, but may emerge in market niches run by incumbent carriers or new market entrants. Stringent and clear policy signals and regulations are key to support change processes in large traditional undertakings; internal processes alone will most likely not develop sufficient force to bring about the fundamental changes required.

For the case of North Rhine-Westphalia, we explored the investments required in road and rail infrastructure when fostering or deliberately neglecting the railway sector. In the latter case, we find that some motorways will need 12 lanes to cope with the extra traffic. This will hardly be possible given the increasing opposition to new infrastructure projects and major upgrades and the fact that most of the area needed for construction is already occupied otherwise. On the other hand, the economic impact analyses suggest that the effects on the labour market and grow indicators are minor in all investment scenarios. This may also apply in the case of significantly higher costs.

We find that costs do not seem to be a prohibitive criterion, but that any freight transport system must have minimal further land use, noise pollution and visual intrusion. These two points lead to two suggestions: the maximum exploitation of existing capacities or the installation of novel systems for transporting goods. Railways, in particular, have excess unused capacity reserves as pointed out above. Spending public money to exploit these should be more efficient and faster than lengthy infrastructure projects. For the second option of a completely new freight system, the Swiss concept of Cargo Sous Terrain could be a suitable blueprint.

Facing the huge challenges of climate mitigation, growing armed conflicts, and globalisation, policy and industry should join forces to help steer Europe successfully through the 21st century. New technologies and collaborative projects could form an important pillar of a policy designed to engage people and showcase Europe's technological power, while taking climate targets seriously at the same time. Decisive policies will almost certainly encounter resistance from several directions as the incumbents try to retain the current business models and technologies. However, if the "pain of change" is overcome, a low-carbon economy could also be very cost-efficient, resilient, and therefore globally competitive. This very generic statement applies to most of the production sector, as well as the transport and logistics market.



9 ANNEX

ABBREVIATIONS

AADT	Average annual daily traffic
BAU	Business-as-usual
BASt	Bundesanstalt für Straßenwesen
BVWP	Bundesverkehrswegeplan (Federal Transport Infrastructure Plan)
CO_2	Carbon dioxide
CO_2-eq.	Carbon dioxide equivalent
DB	Deutsche Bahn AG
DEA	NUTS-1 region North Rhine-Westphalia
ETCS	European train control system
EU	European Union
FTE	Full time equivalent
GDP	Gross domestic product
GHG	Greenhouse gas(es)
GVA	Gross value added
HGV	Heavy goods vehicle (above 3.5t)
HO truck	Hybrid overhead wire truck
ICT	Information and communication technologies
IOT	Input-output table
IRP	Investitionsrahmenplan (Capital Investment Framework)
IWT	Inland waterway transport
LB	Lower bound
LDV	Light duty vehicle (up to 3.5t)
MLP	Multi-level perspective
Mt	Mega-ton(s) (million tons)
NOx	Nitrogeous oxides
NRW	North Rhine-Westphalia
NSB	North Sea-Baltic Corridor
NUTS	Nomenclature of territorial units for statistics
PCU	Passenger car unit
PM_{10}	Particulate matter, diameter less than 10 µm
$PM_{2.5}$	Particulate matter, diameter less than 2.5 µm
PM_{Coarse}	Particulate matter, diameter above 10 µm
RALP	Rhine-Alpine Corridor
[illegible]	ton
TEN-T	Trans-European networks for transport
tkm	Ton kilometre
UB	Upper bound
WtW	Well-to-wheel
ZARA ports	Zeebrügge, Antwerp, Rotterdam and Amsterdam ports

REFERENCES

ADAC e.V. (2012): Staubilanz 2012. München.

ADAC e.V. (2017): Staubilanz 2017. München.

Adam, S. (2014): NRW: Reaktionen zum maroden Autobahnkreuz Leverkusen. URL: https://rp-online.de/nrw/staedte/leverkusen/sperrung-im-autobahnkreuz-leverkusen_aid-20499839 (2018)

BASt (2017): Manuelle Straßenverkehrszählung 2015. Ergebnisse auf Bundesautobahnen. Bundesanstalt für Straßenwesen (BASt), Bergisch-Gladbach.

BMVBS (2012): Investitionsrahmenplan 2011–2015 für die Verkehrsinfrastruktur des Bundes (IRP). Berlin.

BMVI (2015): Bundesverkehrswegeplan 2030. Entwurf März 2016. Bundesministerium für Verkehr und digitale Infrastrukturen (BMVI). Berlin.

BMVI (2017): Masterplan Schienengüterverkehr. Bundesministerium für Verkehr und digitale Infrastrukturen (BMVI). Berlin.

BMVI (2018): Verkehr in Zahlen 2017 / 2018. 46. Aufl. Bundesministerium für Verkehr und digitale Infrastrukturen (BMVI). Berlin.

Deutscher Bundestag (2018): Drucksache 19 / 1609. 740-Meter-Netz für Güterzüge. Berlin.

Deutscher Gewerkschaftsbund (2016): Mobilität in der Arbeitswelt: Immer mehr Pendler, immer größere Distanzen, in: Arbeitsmarkt aktuell.

Doll, C.; J. Köhler; W. Schade; S. Mader; T. Vanelslander; E. van Hassel; N. Sieber (2018): European Freight Scenarios and Impacts. Summary Report 2 of European Rail Freight Corridors for Europe–Storyline and responsibilities, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI, M-Five GmbH, TPR/University of Antwerp and Fraunhofer IML. Karlsruhe.

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.

European Commission (2017): EU-Kommissionsprognose Frühjahr 2018. Wirtschaftswachstum weltweit. Brüssel.

European Commission (2018): Transport in Figures. URL: https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2018_en (2018)

Eiband, A.; A. Klukas; M. Remmert; C. Doll et al. (2018): Local Impacts and Policy Options for North-Rhine-Westphalia. Working Paper 9 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer IML, Fraunhofer ISI. Karlsruhe.

European Commission (2011): Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Brussels.

Eurostat (2019): Eurostat Website, Database. European Commission. Brussels. URL: https://ec.europa.eu/eurostat/data/database (03.01.2019)

FfE (2017): CO_2-Vermeidungskosten erneuerbarer Energietechnologien. Forschungsstelle für Energiewirtschaft e.V. (FfE). URL: https://www.ffe.de/themen-und-methoden/ressourcen-und-klimaschutz/70-CO_2-vermeidungskosten-erneuerbarer-energietechnologien (2019)

FGSV (2008): Richtlinie für die Anlage von Autobahnen (RAA). Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). Köln.

Gandenberger, C.; J. Köhler; C. Doll (2018): Institutional and Organisational Change in the German Rail Transport Sector. Working Paper 3 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI. Karlsruhe.

Grassl, Kocks Ingenierure, SimuPlan (2018): Variantenvergleich: Ausbau der A1 zwischen AK Leverkusen-West und AK Leverkusen. URL: https://www.strassen.nrw.de/files/oe/a-bei-lev/machbarkeitsstudie_abschnitt_2.pdf.

Holzhey, M. (2010): Schienennetz 2025/2030. Ausbaukonzeption für einen leistungsfähigen Schienengüterverkehr in Deutschland. TEXTE 42/2010. Hg. v. Umweltbundesamt (UBA) und KCW GmbH. Dessau-Roßlau (ISSN 1862-4804).

Intraplan Consult GmbH (2012): Verkehrsqualität auf deutschen Autobahnen. München.

IPCC (2018): Global warming of 1.5°C. Summary for Policymakers. Intergovernmental Panel on Climate Change (IPCC). Switzerland.

IVM (2011): Fahrplan 2025 für das Schienennetz in NRW. Korridorbetrachtung und Engpassanalyse. Institut für Verkehrswirtschaft an der Universität Münster. Dortmund.

Liebsch, H. (2017): Immer mehr Staus – nichts geht mehr!. URL: https://www.swr.de/odysso/immermehr-staus-nichts-geht-mehr/-/id=1046894/did=18097610/nid=1046894/u9hvs5/index.html (10.04.2018)

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.

MBWSV (2016): Mobilität in Nordrhein-Westfalen. Daten und Fakten 2015/2016. Straßenverkehr – ÖPNV und Eisenbahn – Binnenschiffsverkehr – Luftverkehr. NRW Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr (MBWSV). Düsseldorf.

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

Müller, A. (2017): Wissenschaftlicher Bewertung von alternativen, emissionsarmen Antriebskonzepten für den bayerischen SPNV. Dresden.

Openstreetmap (2018). URL: https://www.openstreetmap.de/ (2018)

Petry, C.; M. Maibach; C. Gandenberger; N. Meyer; D. Horvat; J. Köhler; C. Doll; 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. Infras, Fraunhofer ISI, T&E. Zurich, Karlsruhe.

Plöchinger, S. and W. Jaschensky (2013): So verspätet ist die Bahn in Ihrer Stadt, auf Ihrer Strecke. URL: http://www.sueddeutsche.de/reise/verspaetungs-atlas-so-verspaetet-ist-die-bahn-inihrer-stadt-auf-ihrer-strecke-1.1651455 (20.09.2018)

SCI Verkehr, Fraunhofer IML (2015): Logistikkonzept NRW. Untersuchung der Rahmenbedingungen für die nordrhein-westfälische Logistikwirtschaft und Verkehrslogistik sowie die Möglichkeiten ihrer Fortentwicklung. Düsseldorf.

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

Statistisches Bundesamt (2016): Bundesländer mit Hauptstädten nach Fläche, Bevölkerung und Bevölkerungsdichte. URL: https://www.destatis.de/DE/ZahlenFakten/LaenderRegionen/Regionales/Gemeindeverzeichnis/Administrativ/Aktuell/02Bundeslaender.html (2018).

Straßen.NRW (2018): Die verschiedenen Varianten: Autobahnausbau bei Leverkusen – Abschnitt 3. URL: https://www.strassen.nrw.de/de/Ausbau-a3.html.

UBA (2012): Ökonomische Bewertung von Umweltschäden - Methodenkonvention 2.0 zur Schätzung von Umweltkosten. Umweltbundesamt (UBA). Dessau-Roßlau.

UBA (2018): Methodological Convention 3.0 for the Assessment of Environmental Costs. Cost Rates. Umweltbundesamt (UBA). Dessau-Roßlau.

Van Hassel, E.; T. Vanelslander; C. Doll (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. TPR / University of Antwerp and Fraunhofer ISI. Antwerp.

Van Mossel, A.; F. van Rijnsoever; M. Hekkert (2018): Navigators through the storm: A review of organization theories and the behavior of incumbent firms during transitions. Environmental Innovation and Societal Transitions 26: p. 44–63.

VIZ (2018): Verkehr in Zahlen 2017 / 2018. Hg. v. Bundesministerium für Verkehr und digitale Infrastrukturen BMVI. Berlin.

Wietschel, M.; T. Gnann; A. Kühn; P. Plötz; C. Moll; D. Speth, et al. (2017): Machbarkeitsstudie zur Ermittlung der Potentiale des Hybrid-Oberleitungs-Lkw. Studie im Rahmen der Wissenschaftlichen Beratung des BMVI zur Mobilitäts- und Kraftstoffstrategie. Fraunhofer ISI, Fraunhofer IML, PTV Transport Consult GmbH, TU Hamburg-Harburg – IUE und M-Five GmbH. Karlsruhe.

LOWCARB-RFC PROJECT PUBLICATIONS

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

Fraunhofer ISI: LowCarb-RFC project website:
https://www.isi.fraunhofer.de/en/competence-center/nachhaltigkeit-infrastruktursysteme/projekte/lowcarb_rfc.html.

Stiftung Mercator, Climate-Friendly Freight Transport in Europe:
https://www.stiftung-mercator.de/en/project/climate-friendly-freight-transport-in-europe/.

Transport & Environment, Low Carbon Freight: http://lowcarbonfreight.eu/.

WORKING PAPERS

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

Petry, C. and M. Maibach (2018): Rail Reforms, Learnings from Other Sectors and New Entrants. Working Paper 2 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Infras. Zurich.

Gandenberger, C.; J. Köhler and C. Doll (2018): Institutional and Organisational Change in the German Rail Transport Sector. Working Paper 3 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI. Karlsruhe.

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

Doll, C.; 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.

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.

Van Hassel, E.; T. Vanelslander and C. Doll (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. TPR / University of Antwerp and Fraunhofer ISI. Antwerp.

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

Eiband, A.; Görtz, D.; Remmert, M.; Klukas, A.; Doll, C.; Sievers, L.; Grimm, A. (2018): Local Impacts and Policy Options for North-Rhine-Westphalia. Working Paper 9 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer IML, Fraunhofer ISI. Karlsruhe.

SUMMARY REPORTS

Petry, C.; M. Maibach; C. Gandenberger; D. Horvat; C. Doll; 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. Infras, Fraunhofer ISI, T&E. Karlsruhe.

Doll, C.; J. Köhler; W. Schade;. S. Mader; T. Vanelslander; E. van Hassel and N. Sieber (2018): European Freight Scenarios and Impacts. Summary Report 2 of the study LowCarb-RFC–European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI, M-Five GmbH, TPR/University of Antwerp. Karlsruhe.

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

IMPRINT

Publisher
Fraunhofer Institute for Systems and
Innovation Research ISI
Breslauer Straße 48 | 76139 Karlsruhe

Editors
Claus Doll (Fraunhofer ISI)

Layout and Typesetting
Jeanette Braun
Sabine Wurst

Language check
Gillian Bowman-Köhler

Karlsruhe, 2019

Photo credits
Cover © NASA
p. 4 © Shutterstock/TTstudio
p. 9 © Shutterstock / IndustryAndTravel
p. 21 © Hans Blossey/Alamy Stock Foto
p. 22 © Shutterstock / Praphan Jampala
p. 38 © Shutterstock / Denis Belitsky
p. 46 © Shutterstock / Avigator Thailand