Local Impacts and Policy Options for North Rhine-Westphalia

Work Package 9 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral

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1 Executive Summary

This working paper is published within the frame of the study “Low Carbon Rail Freight Corridors for Europe” (LowCarb-RFC) co-funded by the Mercator-Foundation and the European Climate Fund. Since greenhouse gas reduction targets are likely to be missed by a significant margin overall and in the transport sector, this study investigated the question of how rail transport can be strengthened, which alternative options for modal shift are possible, what progressive scenarios for rail and road could look like, and what effects on greenhouse gas emissions can be expected for different scenarios.

The purpose of this work package is the examination of the results of the previous work packages using a concrete example and illustrating the resulting effects. Therefore, North Rhine-Westphalia, Germany's most populated federal state, was selected to analyse the infrastructural, environmental and social effects of alternative transport development scenarios. These differ, compared to the business as usual scenario, in the share of modes in the modal split and were assessed for the years 2030 and 2050. Two scenarios in favour of road transport were examined as well as two scenarios illustrating the effects if traffic is shifted to the rail. In addition to proposals for concrete measures, the work package provides an overview of current and future bottlenecks in the road and rail network of the TEN-T corridors in NRW, the necessary investment volume and restrictions regarding infrastructure expansion in the region.

The calculations showed that the traffic situation on the TEN-T corridors will intensify in all scenarios. It can be stated that, even if traffic develops as politicians and scientists are assuming so far, 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 in the case rail is marginalised, i.e. if there is an extreme shift to road transport. The lowest costs can be achieved if a shift to rail is supported, but only selective expansion measures are implemented. By 2050, the costs of expansion will rise in all scenarios due to additional traffic growth. Here, however, a moderate scenario with a lighter positive development of the railways can be implemented most cost-effectively.

Furthermore, we computed carbon emissions and the economic costs of climate change, air pollution, noise and accidents. The carbon mitigation cost and environmental and safety cost efficiency indicators derived in this section draw a positive, but somehow confusing picture. In contrast to the corridor analyses, the results for NRW show that under certain conditions GHG mitigation costs can get negative. Savings in GHG emissions can, in these cases, come along with lower infrastructure investment costs. The same holds true for the environmental and safety cost efficiency: savings against BAU with lower investment costs. In Pro Rail and Pro Road 2050 savings are found nearly twice as high than additional investment costs. Interestingly, in the NRW case the superiority of Pro Road over Pro Rail is way less expressed compared to the corridor analysis.

Policy recommendations arising from the results found in this Working Paper include the early preparation for long term investment plans, the use of the decade ahead to develop and test alternatives to traditional infrastructure programmes and to prepare for the discussion on desired modal shares in a post fossil freight transport world with low costs for trucking. Furthermore, first, intelligent infrastructure planning shall check and prioritise situations where net cost savings meet emission reductions. Second, short-term emission savings are to be even more prioritised over future benefits.

2 Introduction

2.1 Context: The Low Carb-RFC Project

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

The LowCarb-RFC study concentrates on long-distance freight transport along major European corridors, as it is one of the most steadily growing sources of greenhouse gas emissions in Europe and most difficult to address by renewable energies and other standard climate mitigation measures in transport. Starting from the classical suite of approaches - avoid, shift and improve - the LowCarb-RFC methodology concentrates on mode shifts to rail and mitigation measures in all freight modes along the two major transport corridors crossing Germany: The Rhine Alpine corridor (RALP) going from the Benelux countries to Northern Italy and the North-Sea-Baltic corridor (NSB) going 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 transport as a readily available alternative to carry large quantities of goods along busy routes by electric power, and thus potentially in a carbon neutral way. Within this setting, the project pursues three streams of investigation:

- **Stream 1: European Scenarios and Impacts**. For rail, road and waterway transport along the two corridors, cost and quality scenarios are established and their impact on modal split, investment needs and sustainability are modelled. This stream is the analytical core of the study and provides the basis for the subsequent analysis of pathways of interventions.
- **Stream 2: Railway Reforms and Institutional Change**. This stream picks up the slow pace of climate mitigation in the freight transport sector and asks the question how regulatory frameworks, company change management processes or new business models can accelerate them.
- **Stream 3: Case Study NRW**. This step eventually breaks the transport scenarios and intervention pathways down to the local conditions in NRW and looks at the implications for investment or de-investment needs in certain infrastructures, jobs, economic prosperity and the environment.

2.2 Purpose of the work package

North Rhine-Westphalia (NRW) is an important logistics area for Germany as well as for Europe, due to its strategic location in the heart of Europe. North Rhine-Westphalia directly connects Germany to the Netherlands, Belgium and France. Therefore, it assumes an important role within the scope of the harmonization of the European internal market, but also for national transports, as NRW is the most populated region in Germany (Statistisches Bundesamt 2016). Figure 1 illustrates NRWs central position in Europe.

Figure 1: ***Location of NRW in Germany (NRW.Invest 2018a)***

The rapid growth of the global economy (European Commission 2017) and the increase of freight transports as well as commuter flows (Deutscher Gewerkschaftsbund 2016) caused an increasing load on the transport network in NRW in the past years. From 1990 to 2014, traffic on the motorways in NRW increased by 22.8% (MBWSV 2016, p. 87). Apart from regional traffic, the North Rhine-Westphalian transport network is especially charged by transit transport and seaport hinterland traffic originating from the ZARA ports (Zeebrügge, Antwerp, Rotterdam and Amsterdam) (SCI Verkehr and Fraunhofer IML 2015). This development already leads to visible overuse symptoms on some routes indicated through delays of rail transports (Plöchinger and Jaschensky 2013) and frequent congestions on the road (Liebsch 2017). Both, the predicted growth of the region and the continuously increasing global trade indicate a higher future load on the transport infrastructure in NRW.

In order to outline the regional effects of structural changes in the infrastructure, stream 3 of the LowCarb-RFC project transfers the results of stream 1 and 2 to a more detailed level. The results of the other streams are broken down to the local conditions in NRW to outline the structural changes and impacts of significant changes in road and rail transport. NRW was chosen as the reference region as two trans-European transport network (TEN-T) corridors (Rhine-Alpine corridor and North-Sea-Baltic corridor) cross it and as NRW is an interesting area to explore due to its location and population density. Furthermore, the investment and de-investment needs, as well as environmental and social impacts are assessed.

2.3 Scenarios

Five scenarios are used here to examine the traffic development on road and rail and its implications to investments or de-investments in certain infrastructures, jobs, economic prosperity and the environment. These scenarios differ in terms of the share of modes of transport 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 other studies examining the developments in the transportation sector, the other scenarios deal with alternative traffic developments. These scenarios differ from the scenarios used in the preceding work packages, due to the focus on infrastructure of this paper. While the other scenarios were deduced from cost considerations, this work package is based on the loads of the infrastructure in different scenarios and therefrom determines the implications for investment requirements as well as social and environmental impacts on the TEN-T corridors in NRW.

- BAU: The traffic development until 2030 concerning the transport volume on the TEN-T corridors in NRW has been determined using the data from the BVWP. Different from the all-German case (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 total traffic volume. This is due to the great importance of the Rhine and the inland waterway canal system. In addition, almost all waterways in the state belong to the TEN-T corridors, whereas only a fraction of the road and rail infrastructure is located on the corridors. In total, this scenario counts with 42.3 billion tonne-kilometre to be transported on the road and 8.5 billion tonne-kilometre on the rail in 2030. This means a growth of 27% on the road and 23% on the rail compared to 2015. The Transport volume on the inland waterways increases by 15.3% to 41.2 billon tonne-kilometres. Extending this scenario to 2050 leads to a traffic volume of 58.2 billion tonne-kilometre on the road and 11.3 billion tonne-kilometre on the rail. In contrast to the previous Working Papers, the BAU scenario is treated here as an equivalent scenario. The BAU scenario depicts the development if no further measures are taken to promote a mode of transport. As it is based on the BVWP data, this scenario can be classified as most likely. Nevertheless, it will be compared with the other scenarios in the following considerations and evaluated according to its results.

- Moderate Road: This scenario describes an advancement in favour of the traffic development on the road. It assumes that rail transport volume in 2030 will fall by 25% compared to the BAU scenario 2030. Assuming that the growth rate on waterways remains constant at 15% as in the BAU scenario, the corresponding volume shifts completely to road transport. This leads to a 5% growth in total road transport volume until 2030. In the following, the name of this scenario is used in the abbreviated form “Mod Road”. Extending these growth rates until 2050, leads to a “Mod Road 2050” scenario of 53% share of road transport and 5% share of rail transport. Compared to the BAU scenario in 2050, this indicates a 10% increase on the road and a 44% decrease on the rail.

- Moderate Rail: The Moderate Rail 2030 scenario assumes a contrary development. In this case, the transport volume on the rail increases by 25%, so that the share of the road decreases by 5%. Hereinafter, this scenario is referred to as “Mod Rail”. The “Mod Rail 2050” scenario reinforces the development described for 2030. A share of 44% of the transport volume on the road is met by 15% on the rail. The two moderate scenarios describe a more or less realistic development of transport performance that can be justified by concrete measures.

- Pro Road: In order to illustrate what an extreme change in the modal split shares of the transport modes would mean for the infrastructure, two theoretical, extreme scenarios have been examined. Firstly, in the Pro Road 2030 scenario, a 75% loss in rail transport volume is assumed. This volume is transported by the road, which thus registers an increase of 15%. Extended to 2050, this scenario leads to an increase of 32% for road transport compared to the BAU 2050 scenario and a marginalisation of rail transport up to a share of only 0.6% on the modal split of 2050. At this point it should be pointed out once again that, given the extreme changes, this is merely a theoretical scenario that cannot be implemented in that way.

- Pro Rail: On the other hand, in the Pro Rail scenario, a theoretical development in favour of rail transport is assumed. Instead of losing 75%, in this scenario, the share of the rail in the modal split will increase by 75%, so that the traffic volume on the road will fall by 15%. For 2050, this development means a decrease of road transport by 28% compared to the BAU 2050 scenario and an increase in rail transport by 206%, so that the rail´s new share of the modal split will be at 27%. As in the previous case, this is a theoretical scenario whose extreme changes are merely intended to provide an overview of theoretical developments.

The definition of the scenarios and its implications for the transport modes, their shares of the modal split and the respective growth rates, is summarized in the following figures.

Scenario	Rail tkm	Road tkm
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

Table 1: ***Definition of the scenarios for traffic development [tkm] until 2030***

As seen in the table above the scenarios diverge a lot. With this approach different effects of modal shifts can be examined and the implications for environmental and social matters can be defined. For 2050, the respective growth rates of the scenarios are extended to another 20-year horizon, so that the effect of the scenarios is highly intensified. The Pro Road and Pro Rail scenario were included in this study as they exemplary show extreme effects of modal shifts. These two scenarios are only realistic in a hypothetical policy environment, which is totally focussed on road or rail and which is ignoring all associated financial and organisational restrictions.

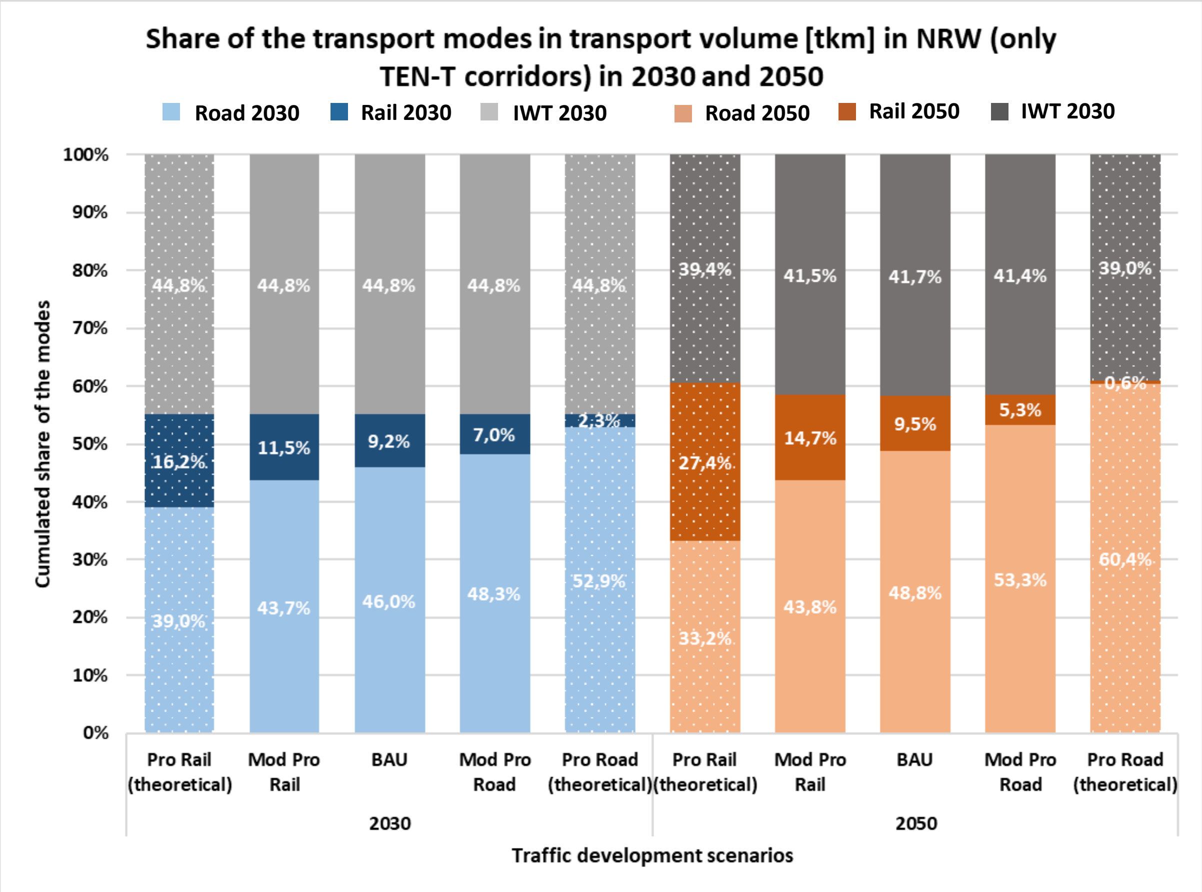

Figure 2: ***Share of the transport modes in transport volume [tkm] in 2030 and 2050***

The development of the transport shares for the different scenarios vary quite a lot. Whilst the IWT share stays nearly the same for every scenario (44.8% in 2030 and 39.0%-41.4% in 2050) the rail and road shares differ depending on the chosen infrastructure developments. The IWT transport share stays the same in this analysis as only transport shifts from rail to road or vice versa are examined.

The following table shows a more detailed overview over the effects and implications caused by the scenarios for 2030 and 2050.

		Road		Rail		IWT	
		2030	2050	2030	2050	2030	2050
Mrd. tkm	Pro Rail	35.9	42.0	14.9	34.5	41.2	49.8
	Mod Rail	40.2	52.5	10.6	17.6	41.2	49.8
	BAU	42.3	58.2	8.5	11.3	41.2	49.8
	Mod Road	44.4	64.2	6.4	6.3	41.2	49.8
	Pro Road	48.7	77.1	2.1	0.7	41.2	49.8
Modal Split	Pro Rail	39%	33%	16%	27%	45%	39%
	Mod Rail	44%	44%	12%	15%	45%	42%
	BAU	46%	49%	9%	10%	45%	42%
	Mod Road	48%	53%	7%	5%	45%	41%
	Pro Road	53%	60%	2%	0,6%	45%	39%
Growth rate 2015-2030/ 2030-2050	Pro Rail	8%	17%	116%	132%	15%	21%
	Mod Rail	21%	31%	54%	66%	15%	21%
	BAU	27%	38%	23%	33%	15%	21%
	Mod Road	33%	44%	-7%	-0,6%	15%	21%
	Pro Road	46%	58%	-69%	-67%	15%	21%

Table 2: ***Transport volume, Modal Split and Growth rate for 2030 and 2050 per scenario***

As shown in Table 2, the percentage shares of the transport modes diverge based on the chosen scenario. Whereas road transport has the highest share by more than double transport volumes in the BAU scenario, the transport share of road transport shrinks for the rail based scenarios. On the other hand the road transport increases both in measures of tonne-kilometres and modal split shares when assuming the scenarios in favour of road transports. As mentioned above, IWT transports are frozen and no volumes were shifted from rail or road to / from IWT in this study, as the aim is to depict the influence of transport volume shifts between rail and road.

3 Status quo

The two TEN-T corridors examined in this study, the Rhine-Alpine and the North Sea-Baltic corridor, both cross North Rhine-Westphalia. As an initial step, the region and its main logistic facilities will be introduced. Furthermore, the roads and rail lines in NRW affected by the corridor flows will be identified and described in detail.

3.1 North Rhine-Westphalia

North Rhine-Westphalia is defined by 1,662 km of borders (IT NRW 2015). It neighbors the Netherlands, Belgium, Lower Saxonie, Hesse and Rhineland-Palatinate. Furthermore, it consists of nine economic regions, which are visualized in the following figure.

Figure 3: ***Economic regions of NRW (NRW.Invest 2018b)***

North Rhine-Westphalia is divided into five administrative districts. These are Detmold and Münster in the north, Düsseldorf in the west, Arnsberg in the southeast and Cologne in the south. Furthermore, it consists of 31 counties and 23 independent towns. (Statistisches Bundesamt 2018)

In 2015, 17.63 million people were living in North Rhine-Westphalia (MBWSV 2016) in an area of 34,110 sq. km (IT NRW 2015). On average, 517 people were living on one square kilometer (IT NRW 2015), which means that it is not only the most populated but in addition, also the most densely populated area in Germany (Statistisches Bundesamt 2016). The following figure provides an overview of the population density in Germany in relation to the federal states.

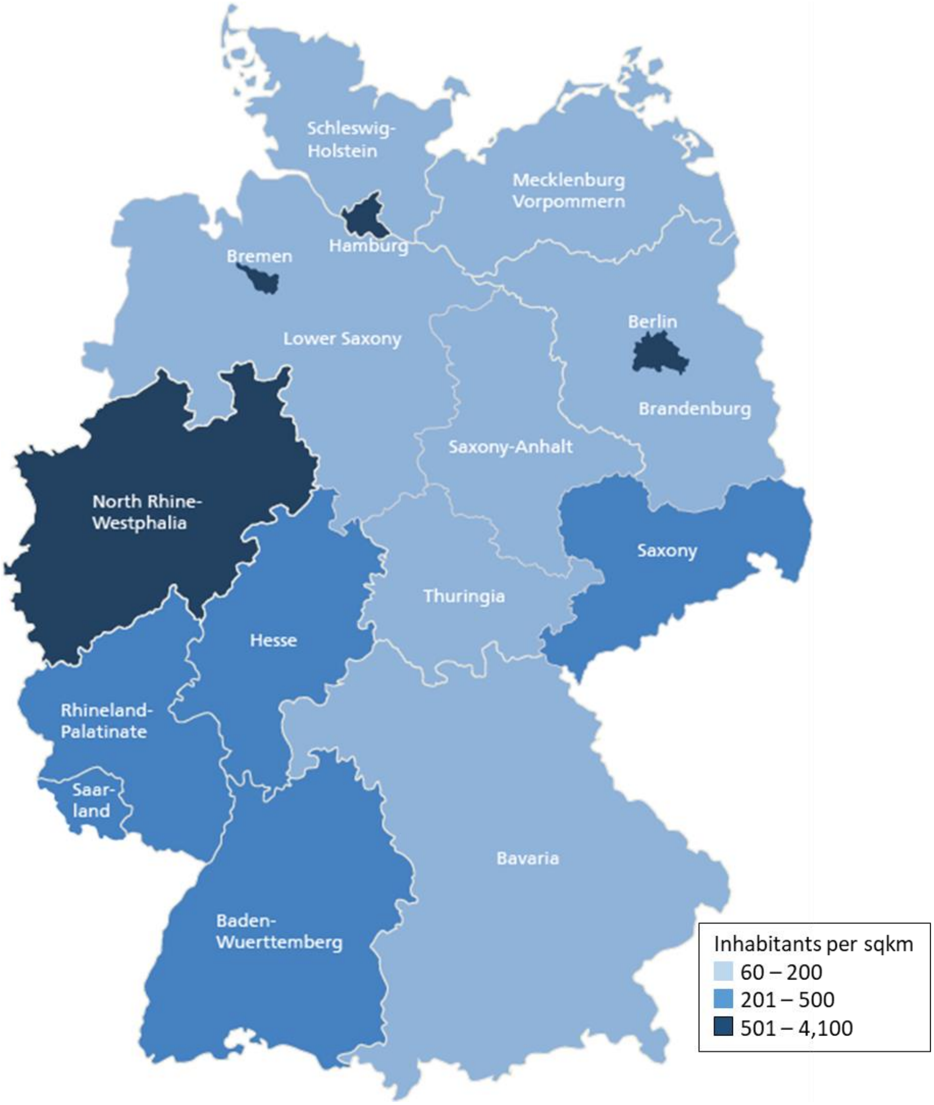

Figure 4: ***Population density in 2015 in Germany per region (Own representation based on Statistisches Bundesamt 2016)***

NRWs 9.1 million employees generated a gross domestic product of EUR 624.7 billion in 2015, which corresponds to a share of 22% of the all-German gross domestic product (Staatskanzlei des Landes Nordrhein-Westfalen 2017). 15.9% of the export goods in Germany originated from NRW. In terms of import NRW held a share of 22.4%, so that in total 250 million tonnes of goods were transported over its borders (LogistikCluster NRW 2015).

9,355 million passenger cars and 530,000 trucks were circulating on the road infrastructure in NRW in the year 2014. Furthermore 139,863 million tonnes of freight have been transported by rail and 127,220 million tonnes via ship (MBWSV 2016).

3.2 Infrastructure in North Rhine-Westphalia

As already stated, North Rhine-Westphalia is the most populous federal state in Germany and an important logistics hub. The following section takes a closer look at the existing infrastructure to meet the demands in NRW.

3.2.1 Road

In 2015, 29,564 km of roads were developed in North Rhine-Westphalia. The road network consisted of 76 % of district roads, whilst 4,467 km federal roads and 2,215 km highways were developed. This corresponds to a share of 17.2 % of the all-German highway network. The majority of 60% of the roads had four lanes (double lane in both directions), while 29% were provided with six lanes. Only 11 km in the Cologne area have been expanded to seven or more lanes (MBWSV 2016). Furthermore, 3,827 bridges and 23 tunnels have been part of the highways in NRW (MBWSV 2016).

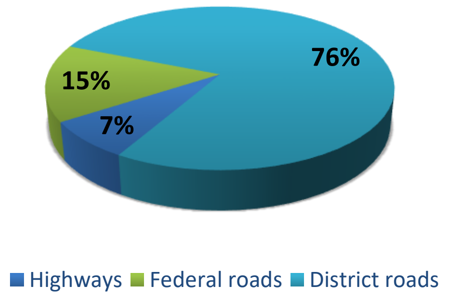

Figure 5: ***Distribution of road types in NRW (Own representation based on MBWSV 2016)***

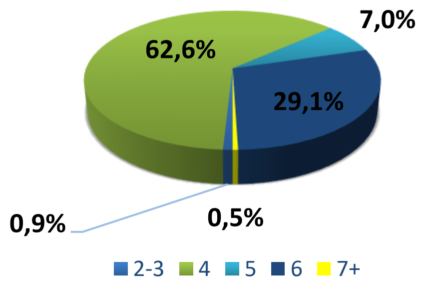

Figure 6: ***Distribution of number of lanes on highways in NRW (Own representation based on MBWSV 2016)***

The road infrastructure in NRW was strained by several factors. On the highways, an average load of 48,375 motor vehicles, principally caused by commuter traffic, was measured. Additionally, the roads were exposed to 10,641 freight transport vehicles (as in 2014). (MBWSV 2016) These strains reflect bottlenecks in the form of congestions. Hence, in 2015 there have been 182,000 traffic jams on highways in NRW with a total length of 323,000 km. This corresponds to 32% of the total German value and sums up to approximately 105,000 hours (ADAC e.V. 2015). The following figure illustrates the development of congestion kilometres in NRW in recent years. It can distinctly be noted that the load situation has continuously increased.

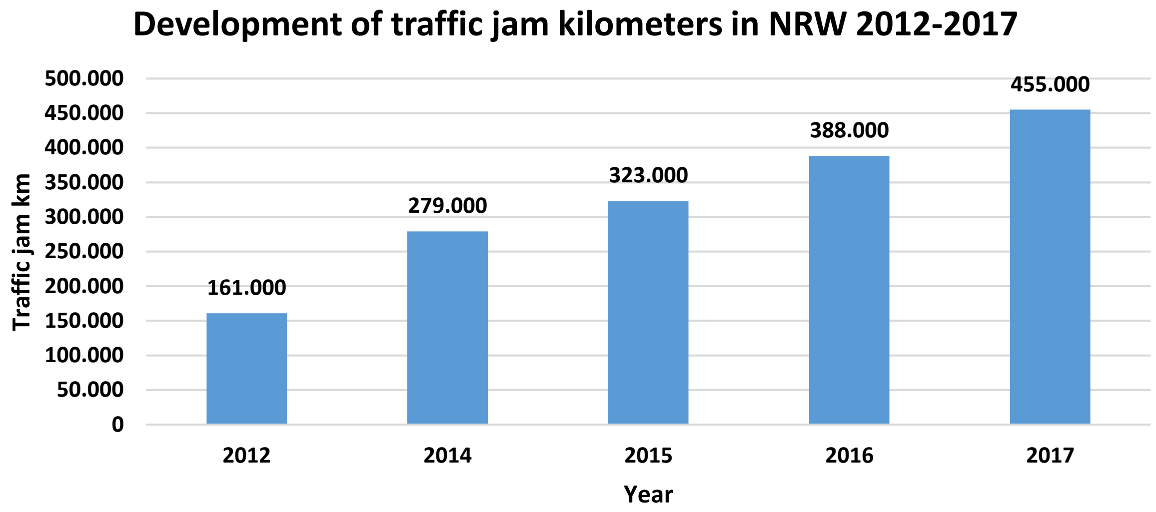

Figure 7: ***Traffic jam development in NRW 2012-2017 (ADAC e.V. 2012, 2014, 2015, 2016, 2017)***

To elaborate the „Logistikkonzept NRW“ (SCI Verkehr and Fraunhofer IML 2015), the data of the transport links, on which the Plan For Federal Traffic Routes (German: Bundesverkehrswegeplan, abbr. BVWP) is based, was evaluated. This led to the result that in North Rhine-Westphalia the road traffic has got the highest volume, whereof the domestic transport holds a share of about 68% (SCI Verkehr and Fraunhofer IML 2015). Transport is called domestic, when source and sink are located in the same region (Kraftfahrt-Bundesamt 2018). In addition, 54.5 million tonnes were transported on the route towards Lower Saxonie, 39.5 million tonnes towards the Netherlands and 27 million tonnes towards Hesse and Rhineland-Palatinate respectively (SCI Verkehr and Fraunhofer IML 2015).

3.2.2 Rail

In 2014 the rail infrastructure in North Rhine-Westphalia consisted of 11,965 km of tracks with 1,087 railway stations and stops. Via these tracks 75.7 million tonnes were send and 75.4 million tonnes received by NRW. This results in a total turnover of 150.9 million tonnes, which means an all-German share of 26 % (MBWSV 2016). Furthermore, the rail infrastructure serves to transport passengers, as long as the routes are not functioned as mere freight transport routes, as e.g. the connection Duisburg-Cologne.

According to the „Logistikkonzept NRW“, the highest volume (in rail traffic) is registered along the Rhine and partly in the Ruhr area, mostly in Recklinghausen and Dortmund. In 2010, 89 million tonnes have been transported in domestic traffic, followed by the route towards the Netherlands with 6.8 million tonnes, towards Lower Saxonie with 6 million tonnes and Italy with 4.9 million tonnes. (SCI Verkehr and Fraunhofer IML 2015)

3.2.3 IWT

The most important waterway in NRW is the Rhine with a length of 226 km. Moreover, there are several other rivers and canals, as the Dortmund-Ems Canal, the Weser, the Mittelland Canal or the Wesel-Datteln Canal. The freight traffic by ship is concentrated on the routes towards the Netherlands and Belgium. Jointly 87.6 million tonnes have been transported on these relations. Within NRW transport was limited to 17.8 million tonnes. (SCI Verkehr and Fraunhofer IML 2015)

3.3 Trans-European Networks

The Trans-European Networks are a strategy of the European Commission to strengthen the economic and social cohesion within the European Union (EU). In addition to the trans-European transport network (TEN-T), which will be discussed in more detail, the development and improvement of the telecommunications network (eTEN) and energy infrastructure (TEN-Energy) are part of this priority programme. (EU-Info.Deutschland 2018)

The Trans-European transport network aims to establish a single pan-European network of roads, railways, waterways and CT terminals. Two planning phases are distinguished: the core network and the overall network. The core network represents the most important connections within the overall network by linking the most important nodes and is to be completed by 2030. The expansion of the overall network, also known as comprehensive network, is planned to be completed in 2050, and should then link all regions of Europe extensively, so that by this time no citizen of the 28 member states lives more than 20 minutes away from a core corridor (Sünner and Wedemeier 2014). The central objectives of the transport network the the closing of gaps, the reduction of bottlenecks and the removal of technical barriers between the transport networks of the individual countries so that a single, efficient European transport network is created (Sünner and Wedemeier 2014).

In 2013, the TEN-T were revised and the core network as well as its priority treatment were defined (s. Figure 8). Following this, in addition to the objective of priority implementation, European support for infrastructure development concentrates on the core network. Nine core corridors have been defined, each with its own European coordinator, corridor forums and working groups. These multimodal transport axes cover a total of approx. 15,000 km (Sünner and Wedemeier 2014) and connect the European capitals and important logistics nodes, so that a large part of the transports of the European internal market is or will be carried out via these corridors.

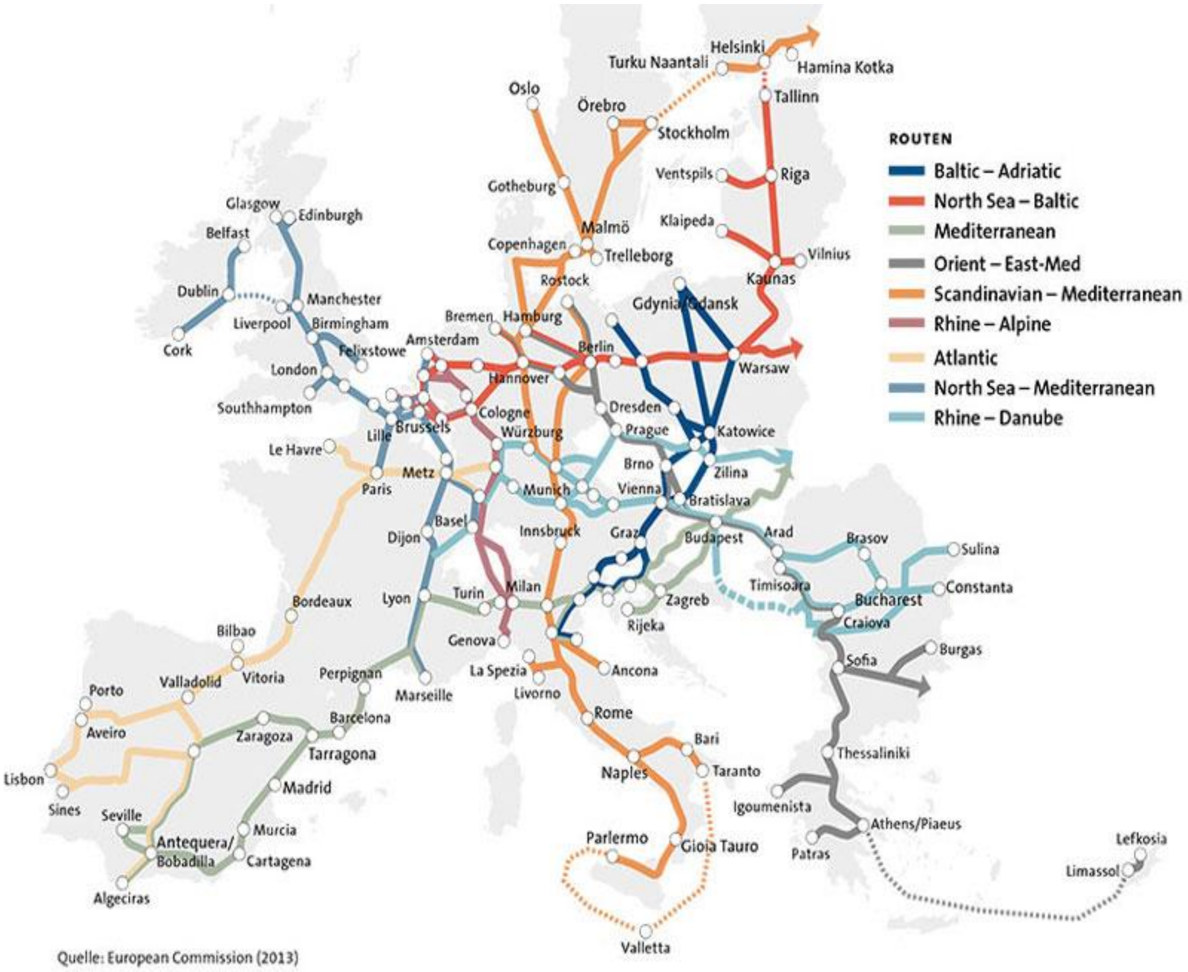

Figure 8: ***Overview of the nine core corridors of the TEN-T (European Commission 2013)***

The main financial burden for the implementation of TEN-T projects is borne by the Member States. The distribution of European Union funds is regulated by the TEN Financing Regulation “Connecting Europe Facility (CEF)”. It defines which measures can be funded and to what extent. In order to receive this support of up to 50%, an application must be submitted, after which it will be verified whether the planned measures meet the objectives of the transport network as defined in the guidelines. (BMVI 2018b)

3.4 Rhine - Alpine Corridor

The Rhine-Alpine corridor connects the Belgian and Dutch seaports of Zeebrugge, Amsterdam, Rotterdam and Antwerpen, in short ZARA, with the Italian Mediterranean port of Genoa. It passes through five countries (Netherlands, Belgium, Germany, Switzerland and Italy) and has a total length of approx. 1,300 km (UECC 2014) (s. Figure 8).

The road infrastructure of the Rhine - Alpine corridor spreads on three highways in NRW. The A3 starts at the border crossing between the Netherlands and Germany in „Elten” and leads towards the motorway exit “Bad Honnef/Linz”. At the interchange “Köln-Heumar”, it additionally branches in addition into the A4, which forms part of the corridor until the junction “Aachen”.

Starting from this point, it follows the A44 unitl the German-Belgian border in "Lichtenbusch" (European Commission 2018). In total, these highway sections add up to 286 km (European Commission 2018).

The rail infrastructure in NRW takes a similar route. Starting from the German-Dutch border in Elten the tracks lead across Emmerich, Oberhausen and Duisburg towards Düsseldorf, where they continue to Cologne and Aachen. In Aachen, the infrastructure divides to the German-Belgian border near Montzen on the one hand and to the same border at Hammerbrücke on the other hand. Furthermore, the route from Oberhausen across Ratingen West, Köln-Mülheim and Bonn is part of the Rhine - Alpine corridor. It ends at the border with Rhineland-Palatinate at Rolandseck or Buchholz. The routes are distinguished between their classification into the high speed or conventional network (European Commission 2018).

The inland waterway infrastructure of the Rhine - Alpine corridor follows the rail and road infrastructure in great parts. It is defined by the Rhine starting in Lobith at the German-Dutch border and running along Emmerich, Duisburg, Düsseldorf, Cologne and Bonn until reaching the border to Rhineland-Palatinate at Bad Honnef (European Commission 2018).

3.5 North Sea - Baltic Corridor

The North Sea – Baltic corridor runs from the Estonian capital and port of Tallinn via the capitals of Latvia, Lithuania, Poland and Germany to Hanover, where it divides and branches towards the Dutch capital Amsterdam and the Belgian capital Brussels. In total, it passes eight countries and has a length of approx. 3,200 km (Euregio 2018) (s. Figure 8).

The road infrastructure of the North Sea - Baltic corridor in North Rhine-Westphalia amounts to 363 km (European Commission 2018). It mainly includes the A1, which starts at the junction "Lotte/Osnabrück" and defines the corridor until the junction "Köln West". Starting there the North Sea – Baltic corridor merges geographically with the Rhine – Alpine corridor, so that the 55 km of the A4 until the junction "Aachen" as well as the 24 km of the A44 until the national border are part of both corridors. Furthermore, a 24 km long section of the A2, from the border with Lower Saxonie at "Bad Eilsen" until the junction "Bad Oeynhausen" is assigned to the North Sea – Baltic corridor. At this junction, the corridor follows the A30 for 29 km until reaching the border with Lower Saxonie near "Bünde" once more. The last section in North Rhine-Westphalia, that is included in the corridor, is another part of the A30 from the junction "Lotte/Osnabrück" until the border with Lower Saxonie at "Rheine Nord" (European Commission 2018).

The rail infrastructure of the North Rhine-Westphalian part of the North Sea – Baltic corridor starts at the border to Lower Saxonie between Haste and Minden. Then it leads to Löhne, where it branches in two directions. On the one hand, it leads on to the German-Dutch border at Hengelo, on the other hand the corridor is defined by the route across Bielefeld, Hamm, Schwerte (Ruhr), Hagen and Wuppertal until Opladen, where it merges with a part of the

Rhine-Alpine corridor. In Cologne-Mülheim it branches a second time, to lead around Cologne both northward and southward, and join together once again in Cologne-Ehrenfeld. Afterwards it follows the tracks across Langerwehe towards Aachen and the German-Belgian border at Hammerbrücke or Montzen. The routes are distinguished again between their classification into the high speed or conventional network (European Commission 2018).

The inland waterways of the North Sea Baltic corridor correspond to the routes of its road and rail infrastructure only in little parts. As in the case of the Rhine – Alpine corridor, the Rhine defines the first part of the corridor starting at the German Dutch border in Lobith until Duisburg. However, unlike the RALP corridor, it then takes the route along Ruhr until reaching the Rhine-Herne Canal, which it follows until Datteln, where it passes over to the Dortmund-Ems Canal until Ibbenbüren. Starting there it takes the Mittelland Canal until the border to Lower Saxonie (European Commission 2018).

The following figure visualizes the courses of the TEN-T core corridors in NRW in terms of road infrastructure. The corridors are distinguished by colours. The Rhine-Alpine corridor is depicted in red, the North Sea-Baltic corridor in contrast in green. If the courses of the two corridors overlap, the corresponding route is shown alternately in red and green.

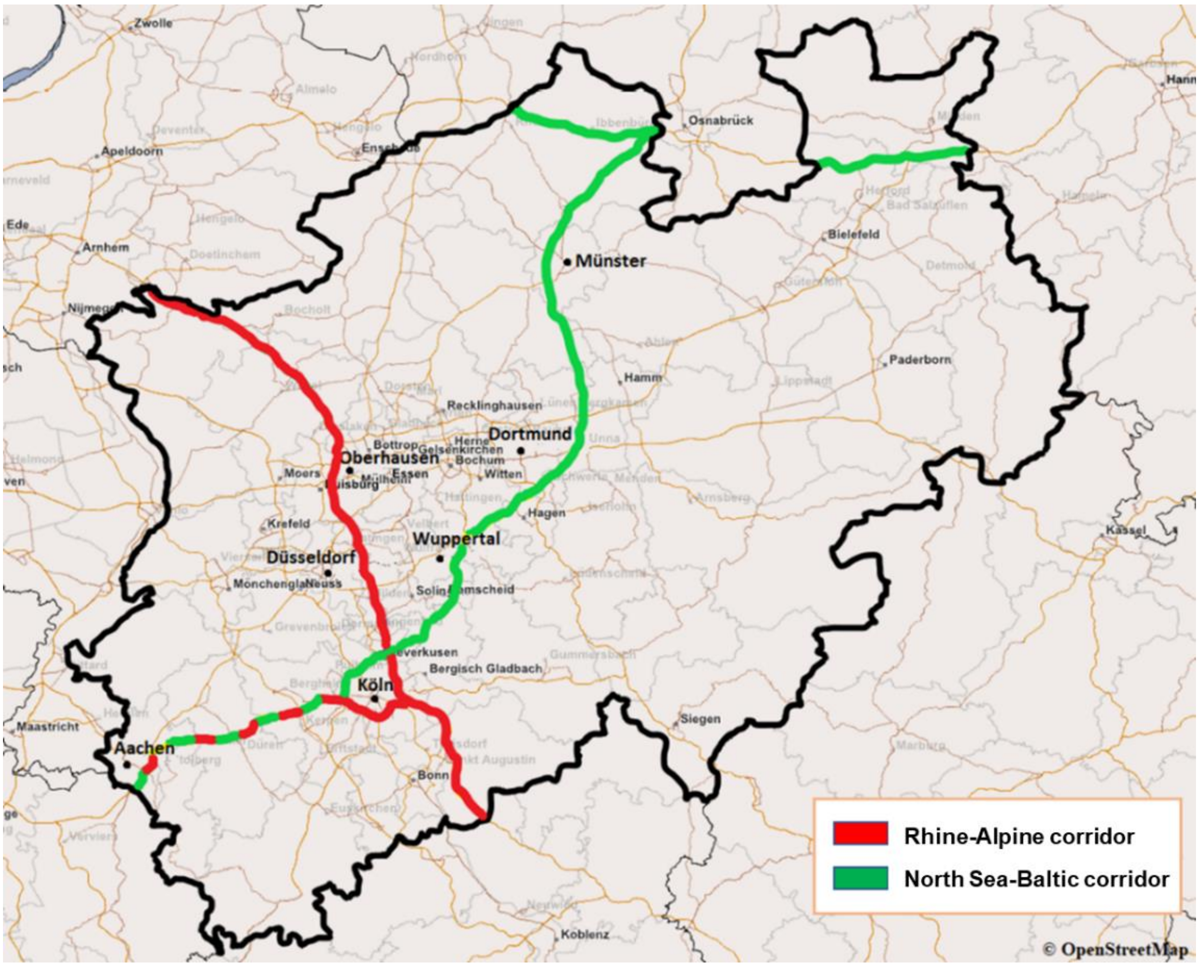

Figure 9: ***Course of the road infrastructure on the TEN-T corridors in NRW (Own representation based on European Commission 2018; Openstreetmap.de)***

Figure 9 shows the road infrastructure of the TEN-T corridors in NRW for the road infrastructure. As described in chapter 3.4 the Rhine-Alpine corridor enters NRW in the west (Netherlands) and leaves towards Belgium and southern Germany at the southern border of NRW. The North Sea - Baltic corridor on the other hand crosses NRW from the north to the south-west and also has one string going through the northern part of NRW. Between Cologne and Aachen both corridors overlap.

In comparison, the second figure visualizes the course of the rail infrastructure of the TEN-T corridors in NRW.

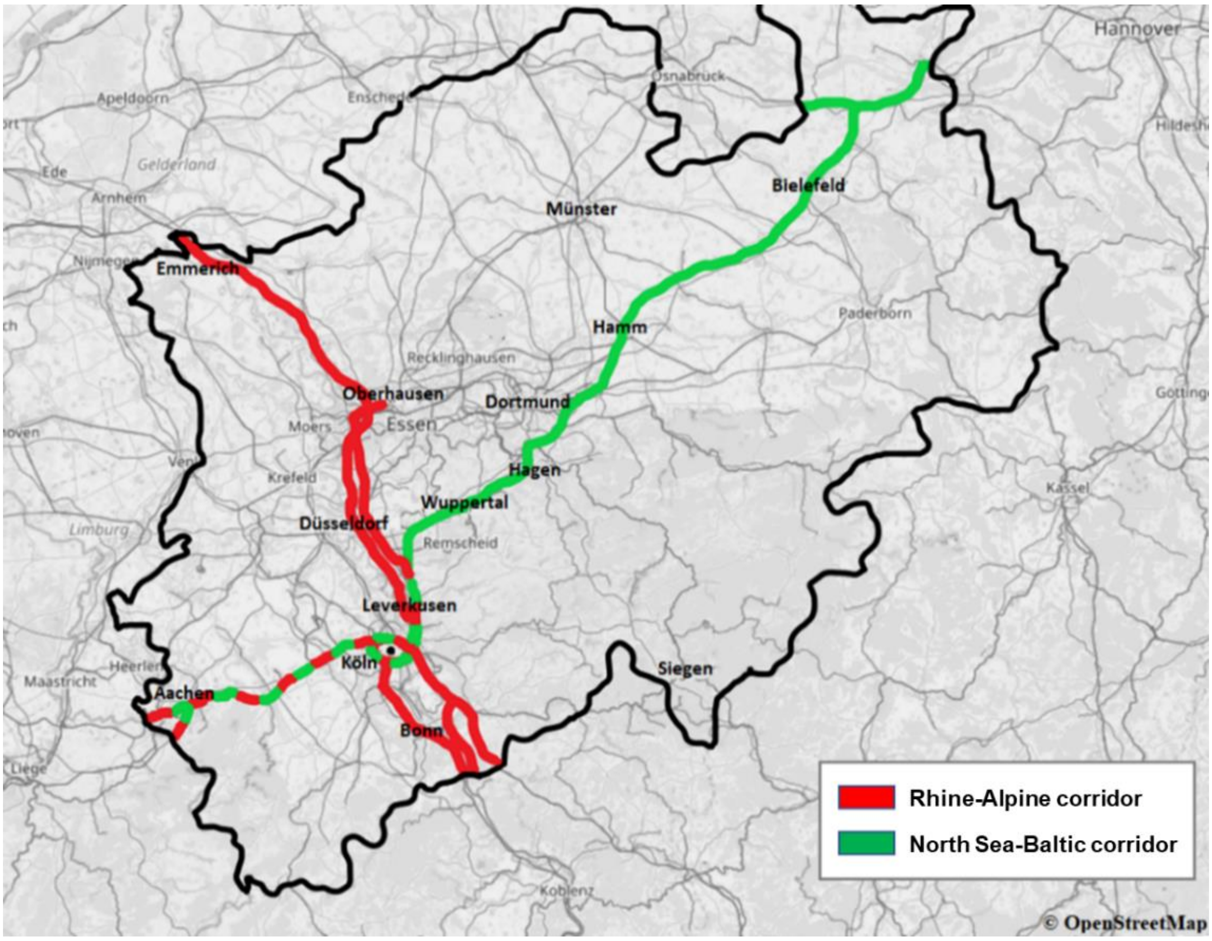

Figure 10: ***Course of the rail infrastructure on the TEN-T corridors in NRW (Own representation based on European Commission 2018; Openstreetmap.de)***

Figure 10 shows that the rail infrastructure routes for both corridors are mostly alike to the road infrastructure shown in the figure before. Especially the section between Cologne and Aachen is alike for road and rail infrastructure. The North-Sea-Baltic corridor takes a different route from the north of NRW to the south-western part than the road infrastructure for the rail infrastructure.

Additionally, the course of the inland waterway canal system depending to the TEN-T corridors in NRW is visualized in the third figure.

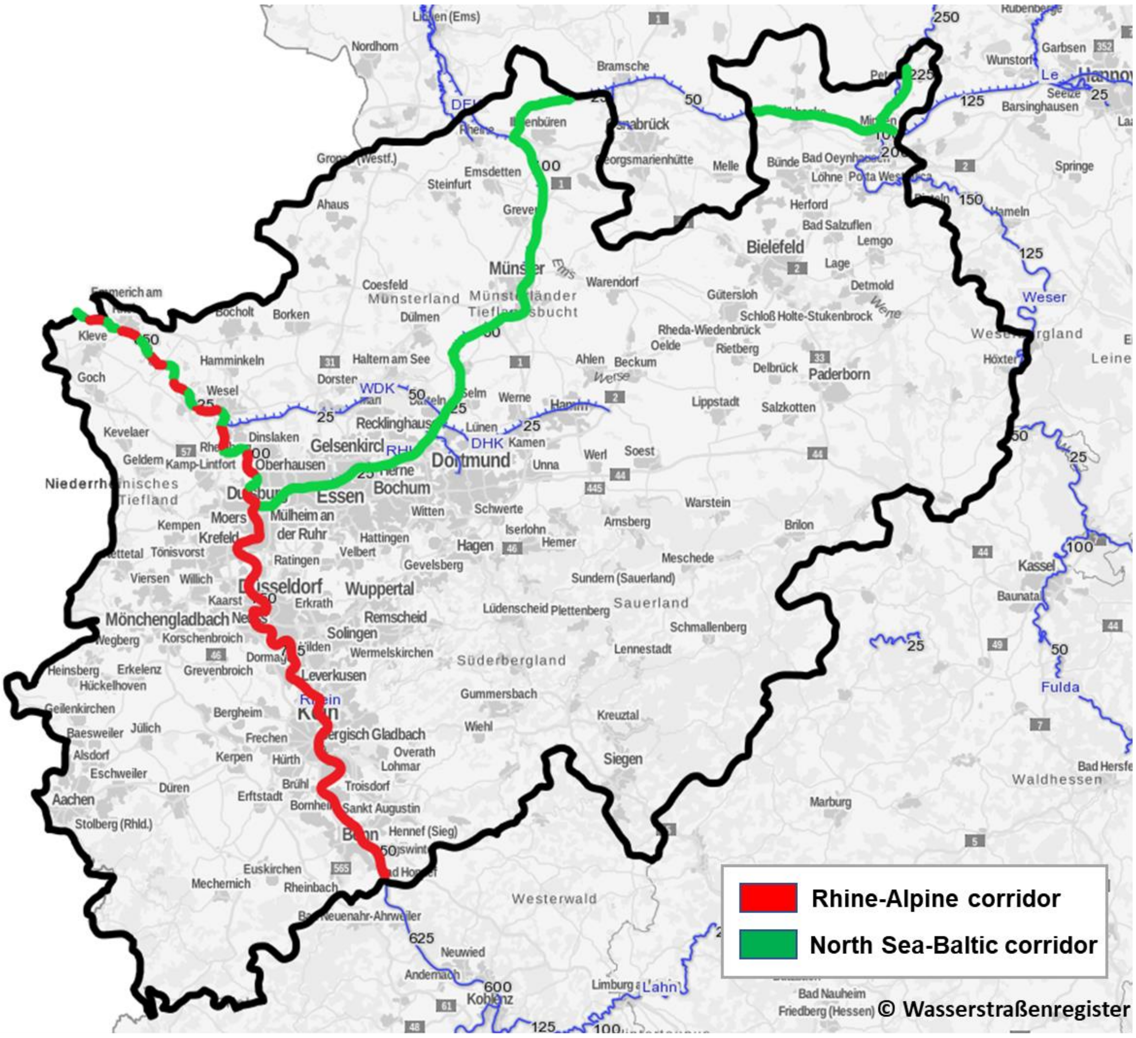

Figure 11: ***Course of the IWT infrastructure on the TEN-T corridors in NRW (Own representation based on European Commission 2018; WSV 2018)***

The IWT infrastructure on the TEN-T corridors in NRW (see Figure 11) shows that the Rhine-Alpine corridor proceeds completely along the Rhine whilst the North-Sea-Baltic corridor uses the German canal system from Duisburg to northern NRW.

4 Methodology

The following chapter provides an overview over the methodology used in this work package. It explains the way the results have been collected in more detail. In a first step, the load on the road and rail infrastructure in NRW has been determined in the different scenarios before evaluating the results by using different methods of classification. Subsequently, measures for the identified bottlenecks have been defined and the investment volume has been determined.

The IWT infrastructure is neglected in the following methodology, as the load shifts only regard road to rail shifts and vice versa. Therefore, the IWT transports were frozen and no loads have been shifted from and to IWT. The same procedure was implemented for passenger transport. The load of passenger transport was included for road and rail infrastructure, but no increases in this sector were included in the methodology and the implications for the scenarios.

	Road	Rail
1. Determination of the load	• Results of road traffic census 2015 • Translation into unit vehicles considering heavy traffic • Projection to the years 2030/2050 with predicted growth rates	• Data from report „Fahrplan 2025 für das Schienennetz NRW“ (University of Münster) • Base year 2011 • Projection to the years 2030/2050 with predicted growth rates
2. Assessment of the load	• Classification of sections into Traffic quality grades • From level E („inadequate“) critical: Classification as bottleneck • Consideration of the already planned measures from IRP/BVWP • General increase in capacity until 2030 by 10% assumed	• Occupancy rate as quotient from load and capacity data • Methodology from BVWP: Overloaded (critical) from occupancy rate over 110 % • Consideration of the already planned measures from IRP/BVWP • General increase in capacity until 2030 by 10% assumed
3. Definition of potential measures	• For all critical sections • Determination of number of additionally needed lanes • Comparison of the scenarios: Determination which measures needed in all or which ones can/have to be omitted/added	• Identification of potential measures for capacity increase • Selection: Extension of another track or construction of a passing track • Definition of two alternative measures, if possible
4. Determination of the investment volume	• Average of investments from IRP/BVWP on TEN-T corridors in NRW • Consideration of bigger measures as e.g. at intersections/bridges • Ø investment costs of EUR 19.3 Mio. per km of extension	• Average of investments from IRP/BVWP on TEN-T corridors in NRW for new construction/extension: EUR 12.7 Mio. € per km • Passing track with length 1 km: costs of EUR 12.7 Mio. per track • Calculation of highest/lowest costs: cost range

Figure 12: ***Methodology overview and used databases***

4.1 Road

To determine the load, the road infrastructure has to deal with, the results of the 2015 road traffic census published by the Federal Highway Research Institut (BaSt) (Bundesanstalt für Straßenwesen 2017) were used. For this purpose, in an initial step all sections that belong to one of the relevant corridors have been identified. Furthermore, the percentage of heavy traffic has been taken into account. In this case, heavy traffic means busses, trucks with a permissible total weight over 3.5 tonnes and semitrailers. As heavy traffic charges the capacity of the road infrastructure disproportionate, it has been decided to translate into unit vehicles. Passenger cars have been defined as one unit vehicle, heavy traffic has been counted as two unit vehicles respectively (Intraplan Consult GmbH 2012, p. 4). The given share of heavy traffic in the traffic census has facilitated this distinction. This approach does not consider the road abrasion generated by trucks, it only considers the vehicle amounts on the roads.

To identify the load in the scenarios for 2030, the load of the base year on the road as well as on the rail infrastructure has been projected to 15 years based on the predicted growth rates, assuming a linear growth of the traffic load on all sections. It is important to consider, that the data of both transport modes (road and rail) was sourced in different years so that the growth rates were translated accordingly. The road infrastructure data was available for 2015, therefore no translation needed was done, but the rail infrastructure data was updated. The data update to 2015 enables a comparison possibility for the scenarios.

The load in the year 2050 has been determined analogically, relying on the predicted growth rates concerning the years 2030 – 2050.

To evaluate the load on the road in the initial year 2015 a classification into traffic quality grades has been chosen. These quality grades are defined in the Guidelines for dimensioning road traffic facilities (HBS) (Forschungsgesellschaft für Straßen- und Verkehrswesen 2015) and were developed according to the demands of the traffic situation in 2010 by the Intraplan Consult GmbH in their study on traffic quality at German highways for the ADAC (Intraplan Consult GmbH 2012). The six resulting traffic quality grades lead from A/B, which indicates a very good or good traffic quality with a mean daily load of 0 to 11,530 vehicles per lane to grade F-, which is the worst situation with a mean daily load of more than 26.135 vehicles per lane (Intraplan Consult GmbH 2012). From grade E (“inadequate”, 18,920-20,990 vehicles per day and lane) traffic quality has been assumed critical, so that the concerned sections have been identified as bottlenecks. Furthermore, corresponding measures have been defined for these bottlenecks. Figure 13 summarizes the quality grades described above.

Traffic quality		Mean load on one lane 2010 [Vehicle Units/24h]	
Grade	Explanation	Lower bound	Upper bound
A/B	very good/good	0	11,530
C	satisfactory	11,530	15,725
D	adequate	15,725	18,920
E	inadequate	18,920	20,990
F	unsatisfactory	20,990	26,135
F-		26,135	-

Figure 13: ***Classification of traffic quality grades (Based on Intraplan Consult GmbH 2012)***

Before classifying the sections in 2030, all fixedly scheduled or planned measures for preservation, expansion or new construction of highways along the corridors in NRW have been identified. The measures were extracted from the Federal Transport Plan 2030 (BVWP) (BMVI 2015). It has been assumed that the projects classified as FD, VB and VB-E[1] of BVWP (running projects or priority needs) will be completed by the year 2030. Thus, for the analysis of the situation in 2030 a modified road infrastructure according to BVWP is presumed.

The Intraplan Consult GmbH assumed that the capacity of road infrastructure would increase from 2010 to 2025 by 10 % due to traffic control systems and improved automotive technology. This assumption has been adopted for the period 2015 – 2030 in this report, because the study also works with a time horizon of 15 years, and led to a shift in the limits of the traffic quality grades and consequently to an adjusted classification into the grades.

Subsequently, the road sections have been classified into the traffic quality grades according to the data from the three scenarios so that potential bottlenecks could be identified.

After identifying the potential bottlenecks, measures defining for all critical sections in the BAU scenario to improve the traffic quality to at least grade D (“sufficient”) have been chosen. For this aim, the amount of lane additionally needed on the sections were determined.

Finally, the bottlenecks identified in the other scenarios have been compared with the results from the BAU scenario to identify measures that will additionally or no longer be necessary in these scenarios.

The same methodology was applied for the prognosis for 2050. The 2030 data was updated until 2050.

[1] FD: Fest disponiert – firmly scheduled, VB: Vordringlicher Bedarf – priority need, VB-E: Vordringlicher Bedarf mit Engpassbeseitigung – priority need with bottleneck elimination, s. BMVI (2015), p. 11 f.

4.2 Rail

Since the data concerning the load of the rail infrastructure in 2010 has been provided by the Federal Statistical Office merely at a very high level of aggregation and not in detailed form, because of which they are not definitely assignable to the particular sections, the database published in a study by the University of Münster, which only regards NRWs rail infrastructure, has been used (Institut für Verkehrswirtschaft an der Universität Münster 2011). Based on the operational data of the rail traffic 2005 provided by the Federal Statistical Office (Statistisches Bundesamt 2007) as well as using the route timetables 2011 and the respective growth rates, the load of the individual sections has been translated to the year 2011 in this study. To facilitate a translation to a daily level, an amount of 304 operative days has been used. Assuming that passenger and freight transport grow on a constant level, it is possible to project the load in 2011 to 2015 based on the predicted growth rates, so that the initial situation will be comparable to the one in the analysis of the road infrastructure.

In order to permit a reliable forecast for the railways in NRW, which gives an adequate future prognosis, the theoretical capacity of the individual sections of the rail infrastructure was determined. Even though the DB AG collects data on capacity and occupancy rates of the network, they do not publish these data. For this reason, the report refers to the results of the study “Schedule 2025 for the rail network in NRW” (Institut für Verkehrswirtschaft an der Universität Münster 2011) again, which provides detailed data about all railways in NRW for the year 2011. The insignificant increase in capacity until 2015 has been neglected, as no major improvements in the rail infrastructure capacity were evolved in this period of time.

On this basis, the individual occupancy rate was determined as the quotient from the given load and capacity data.

To evaluate the occupancy rate, the methodology used in the BVWP has been applied. This method classifies a section with an occupancy rate over 110 % as “overloaded” (BMVI 2015. p. 23). For this reason, every section with an occupancy rate over 110 % has been assumed critical.

For the rail infrastructure all fixedly scheduled or planned measures from the BVWP for preservation, expansion or new construction of highways on the corridors in NRW have been identified and taken into account before evaluating the occupancy rate in 2030.

Furthermore, an increase of the capacity through organizational measures as an improved train occupancy or an increase of the maximum permissible or medium train length is possible.

Analogically to the assumption concerning the capacity on the road, these improvements have led to the assumption that the capacity on the rail will increase by 10 % until the year 2030 (Deutsche Bahn AG 2007, p. 12). This is a conservative assumption which can be exceeded.

Nevertheless, it provides a sufficient description of the effects on the capacity utilisation of the network.

Subsequently, based on the load data of the three scenarios and the new capacities, the occupancy rates have been calculated so that potential bottlenecks could be identified and possible measures defined.

There is more than one opportunity to increase the capacity of rail infrastructure. After identifying different potential measures the most effective have been chosen. These are the expansion of another track and the construction of passing track. The first possibility, the expansion by another track, increases the capacity proportionally to the amount of tracks, whilst a passing track at the optimal position can increase the capacity by up to 40 % (Holzhey 2010). Additionally, the conversion to ETCS can offer significant increases in capacity without expanding a single track. But since this development will not be completed until 2040 in Germany, this option has been excluded in the first instance. For the analysis of the year 2050, this option has been taken into account as ETCS leads to an increase in capacity of up to 20% (Seibt 2018).

Finally, the two expansion alternatives that increase the capacity in the presented way have been defined for every critical section if possible. The decision which one of the two measures should be preferred has to be assessed in every particular case taking into account additional criteria and cannot be determined generally. These additional criteria can be development restrictions due to already existing infrastructure or peripheral structures, the time required for necessary planning procedures, environmental or social aspects or simply the available investment capital.

5 Initial situation

This chapter introduces the situation of traffic on the TEN-T corridors in NRW in the year 2015 as it was measured by the means of the presented methods. It focusses on loads and capacities of the road and rail infrastructure as these are the two main concepts to be examined in this paper. With regard to inland waterways, no serious capacity bottlenecks could be identified on the TEN-T corridors in NRW, so that the analysis focusses on the modes of transport road and rail.

5.1 Road

Using the methodology described above (see 4.1), the traffic quality grades for the individual sections have been calculated. Thus, to calculate the loads in 2015, the following formula was used:

$$L_i = (MDT * NT * 0.01 + 2 * MDT * HT * 0.01)$$

L_i = *Load [Vehicles/24h] in the year i*
MDT = Mean daily traffic intensity [Vehicles/24h], rounded up to 100 vehicles
NT = Share of normal transport [%]
HV = Share of heavy transport [%]

By multiplying the average daily traffic intensity with the share of the normal or heavy transport and a factor of 0.01 the daily vehicle load of each affected section was calculated. With this information the loads of the roads on the TEN-T corridors were visualized. The example below shows the calculation for an exemplary road section between “Lotte/Osnabrück” and “Lengerich”.

$$L_{2015} = 59{,}300 * 81.8 * 0.01 + 2 * 59{,}300 * 18.2 * 0.01$$

$$= 70{,}093\ [Vehicles/24h]$$

The calculation shows that, on average, over 70,000 vehicles cross the section between “Lotte/Osnabrück and “Lengerich” each day. The data used for the mean daily traffic intensity was generated using the 2015 road traffic census published by the Federal Highway Research Institut (BaSt) (Bundesanstalt für Straßenwesen 2017). Figure 14 visualizes the results of the calculations for each section on the two TEN-T corridors in NRW and shows the difference in the mean daily traffic intensity.

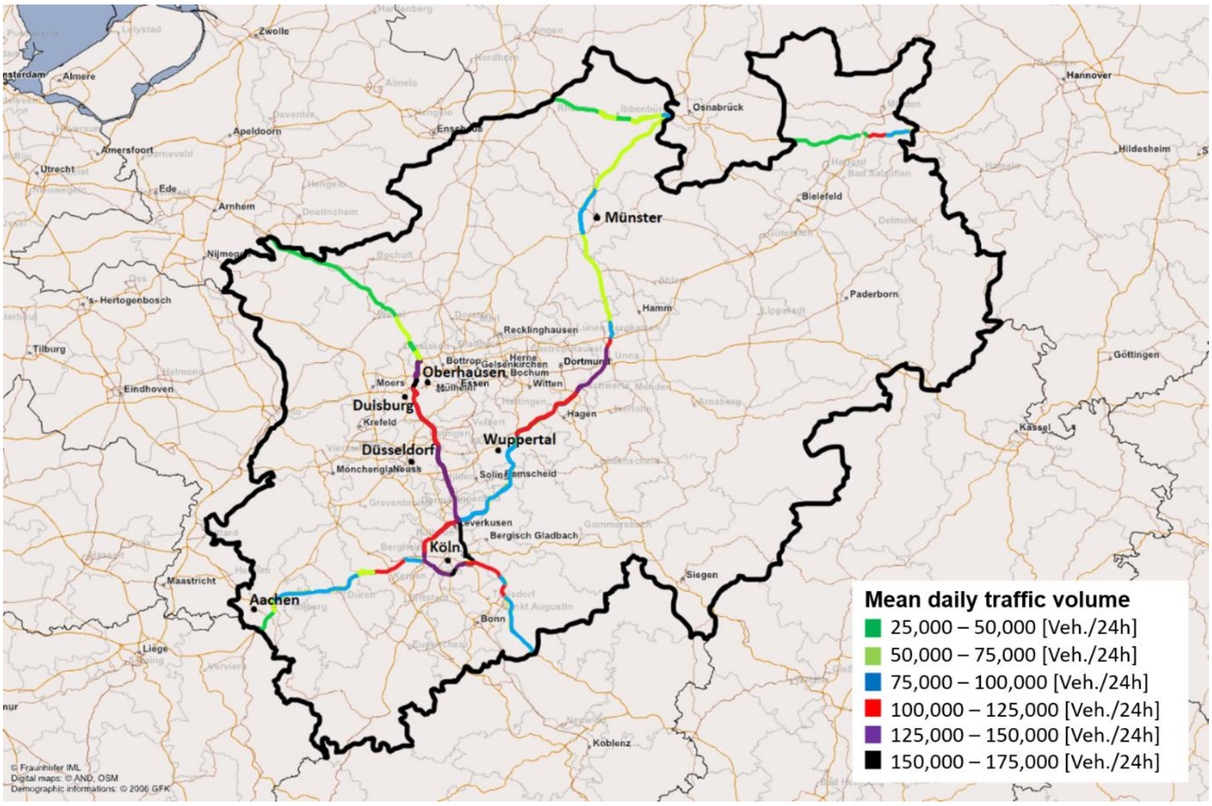

Figure 14: ***Mean daily traffic volume on the road infrastructure on the TEN-T corridors in NRW in 2015 (Own representation based on Bundesanstalt für Straßenwesen 2017; Openstreetmap.de)***

To evaluate the calculated daily traffic volumes, the loads have been separated to every lane. Therefore the quotient of the already known total load and the number of lanes on this section was calculated. Consequently the following formula was used:

$LL_{2015} = L_{2015} / NL$

LL_i = *Load of Lane [Vehicles/24h] in the year i*
L_i = *Total Load [Vehicles/24h] in the year i*
NL = Number of lanes

Using the information for the given example "Lotte/Osnabrück" until "Lengerich" this means:

LL_{2015} = *70,093 / 4*

= *17,523 [Vehicles/24h]*

Therefore, the section between "Lotte/Osnabrück" and "Lengerich" is classified into the quality grade D ("sufficient"). The calculation was executed for each section on the two TEN-T corricors for road transport.

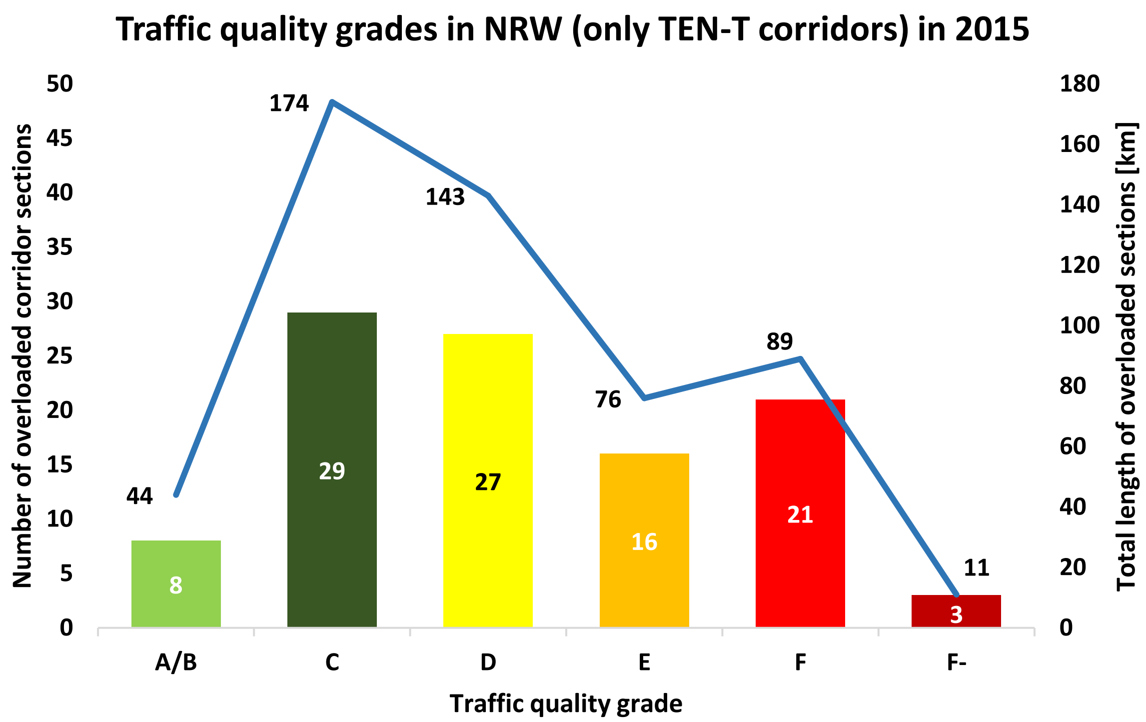

Figure 15: ***Distribution of traffic quality grades in 2015 (Own representation based on Bundesanstalt für Straßenwesen 2017; Intraplan Consult GmbH 2012)***

The blue line in Figure 15 shows the total length of overloaded sections in kilometers. In summary, in 2015, 40 of in total 104 sections in NRW on the two corridors have been allocated to traffic quality grade “E” or worse which means a critical traffic quality as traffic in this area is saturated. These 40 sections have a length of 176 km of 534 km in total. Only 8 sections, with a total length of 44 km, could be assigned to traffic quality grade “A/B” so that a free, fluent traffic flow is possible along the TEN-T corridors.

One of the three sections assigned to 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 are part of the A3. Starting at the intersection “Leverkusen” and crossing “Leverkusen Zentrum” the traffic quality stays critical until “Köln-Mülheim”.

5.2 Rail

For the rail infrastructure, the mean daily load in the year 2011 has been determined by the University of Münster as shown in the following figure:

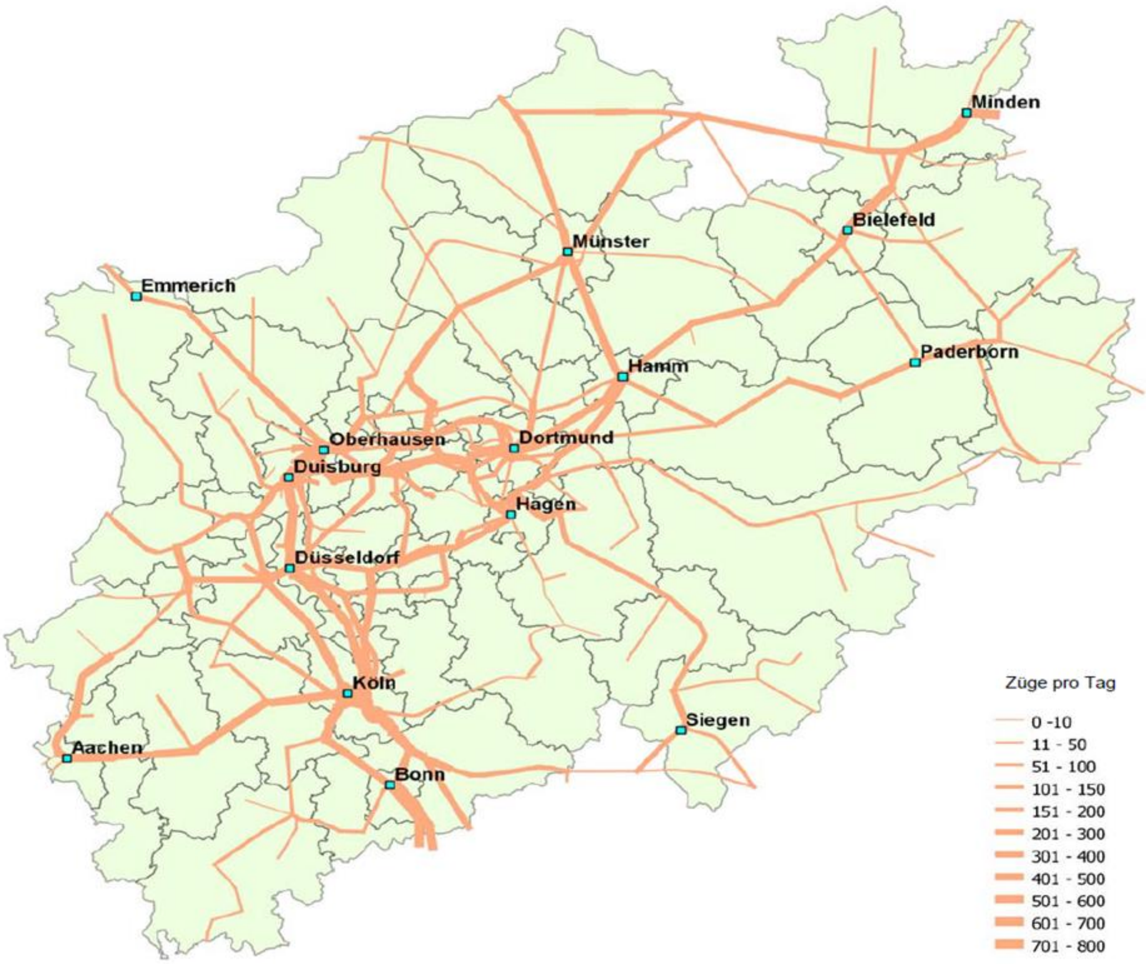

Figure 16: ***Load on the rail in NRW 2011 (Institut für Verkehrswirtschaft an der Universität Münster 2011, p. 29)***

Projected to 2015 the mean daily loads fluctuate between 0 and 770 trains, whereat 65 out of 118 sections have been strained by more than 200 trains per day. On average, this implies 227 trains per day. Detailed data for each railway section was taken from the study by the University of Münster (Institut für Verkehrswirtschaft an der Universität Münster 2011).

To determine the occupancy rate for every section, the quotient from the given load and capacity data was calculated.

$OR_i = L_i / C_i$

OR_i = *Occupancy rate in the year I [%]*
L_i = *Load [trains/section]*
C_i = *Capacity [trains/section]*

Applied to the section “Aachen Hbf” until “Aachen West” for example, the following occupancy rate has been calculated:

$$OR_{2015} = 285 / 196$$

$$= 1.45$$

As the occupancy rate exceeds 110%, it indicates an overload on this section, so that measures have to be defined.

In summary 93 sections remain with idle capacity so that traffic in these sections can flow without restrictions. On 20 sections capacity is used between 85 and 110 %, which indicates an economic occupancy rate and a traffic flow without bigger impacts (Institut für Verkehrswirtschaft an der Universität Münster 2011). The remaining five sections have been classified as overloaded so that delays are a daily problem. Figure 17 illustrates the distribution of the occupancy rates in the initial situation.

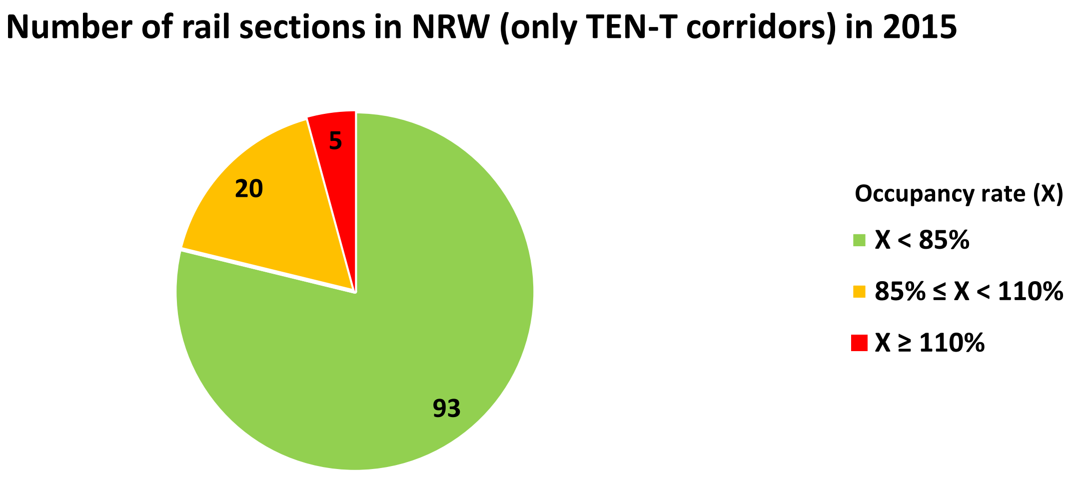

Figure 17: ***Distribution of the occupancy rate in 2015***

The overloaded sections on the TEN-T corridors in NRW and their corresponding line deficiencies, which result from the difference between load and theoretical capacity, are indicated in Table 3.

Taking the given example “Aachen Hbf” to “Aachen West” the line deficiency has been calculated as “285 – 196 = 89 [trains]”.

In the following, the five sections that have been classified as overloaded and their calculated lane deficiency in 2015 are listed.

Track number	Section	Length (in km)	Line deficiency [Trains/Day]
2630	Köln Hbf – Köln West	2	174
2633	Köln Messe Deutz – Köln Hbf	1	119
2550	Aachen Hbf – Aachen West	3	89
2550	Westhofen - Schwerte	4	50
2630	Bonn Hbf – Bonn Mehlem	9	41

Table 3: ***Overloaded sections in 2015***

As Table 3 shows, 19 km of rail tracks are overloaded in 2015 along the TEN-T corridors in NRW. This leads to line deficiencies between 41 and 174 trains per day.

6 Traffic development in the scenarios and impact on the infrastructure

For the five scenarios and for the key commodities transported on these corridors the logistics facilities required – or not required any more – will be identified as a basis for the investment plan in Task 10.

As an initial step, the traffic development following the different scenarios was evaluated. The corresponding consequences for the road and rail infrastructure are summarized in the following chapter.

6.1 Road

Before the evaluation of the load on the road, the changed infrastructural situation was taken into account. According to the BVWP, on the TEN-T corridors in NRW 16 infrastructural measures are planned in the categories FB, VD and VD-E (see p. 22). These are supposed to be finished until 2030. Under these changed circumstances, the traffic development and its impacts to the traffic quality in the different scenarios are presented in the following paragraphs.

- **BAU:** Traffic development on the road is calculated for the TEN-T corridors in NRW using data from the BVWP 2030. The evaluation leads to a growth rate of 27% in road transport from 2015 to 2030, which corresponds to a 46% share of the modal split. Taking the expansion measures of the categories FD, VB and VB-E from the BVWP, which are assumed to be completed by 2030, into account this will lead to a changed load situation. Instead of previously 40 critical sections, only 27 sections will need to be expanded in 2030 corresponding to the BAU scenario. The proportion of critical sections thus drops from 39% to 27%. In 2050 the share of the modal split of the road increases to 48.8% due to a growth rate of 37.5%. Furthermore, 32 sections are classified as critical, with a total amount of 118 km.

- **Moderate Rail:** In the "Moderate Rail scenario", the growth rate from 2015 to 2030 on the road is 20.6%, so that the road's share of the modal split is reduced to 43.7%. This leads to a drop in the proportion of critical sections to 24%, in absolute terms three critical sections less than in the BAU scenario. This situation remains nearly constant in 2050, as the road´s share of the modal split amounts to 43.8% with a growth rate of 30.6% and the same amount of critical sections which is 24.

- **Pro Rail:** The "Pro Rail scenario" indicates only a slight increase in transport volume for the road with a growth rate of only eight percent over 15 years until 2030. Regarding this scenario, the share of the modal split then falls to 39%. The consequence is a significant reduction of critical sections on the road, so that in this scenario the traffic quality in 2030 must be assessed as critical at only 18 sections. These correspond to a share of 17%. This development is still enforced until 2050, as the road´s share of the modal split falls to 33.2% with a growth rate of only 16.7% over 20 years. Due to this, the amount of critical sections also decreases to 13 that sum up to 46 km.

- **Moderate Road:** The "Moderate Road scenario" is the first scenario that describing an increase in the road's share of the modal split. With a growth rate of 33.4% from 2015 to 2030, the share of the road modal split in this scenario is 48.3%. However, the effect on the critical sections is rather small, since here, in comparison to the BAU scenario, a critical traffic quality results only on one further section. With a growth rate of 44.4 % from 2030 to 2050, the road´s share of the modal split still increases to 48.3 % until 2050, which indicates three more critical sections than in 2030 and seven kilometers more identified as bottlenecks.

- **Pro Road:** The strongest shift in transport performance to the road is represented by the "Pro Road scenario". In this scenario, the road share in the modal split in 2030 is 52.9%, which is caused by a growth rate of 46.2% over fifteen years. This results in another section falling into the critical stage, resulting in 32 sections with critical traffic quality. In 2050, the highest share of the modal split for the road is achieved. A growth rate of 58.3% leads to a share of 60.4% of total transport. Due to this development, the highest amount of critical sections can be found. Compared to 2030, 13 more sections are classified as critical and 34% of the roads on the TEN-T corridors in NRW are identified as bottlenecks.

The road shares in the modal split for 2030 resulting from the respective traffic growth in the scenarios and the corresponding growth rates compared to 2015 are summarized in the following table. Furthermore, the amount and total length of sections with a traffic quality of E or worse in 2030 (bottlenecks) is added to the table.

Scenario for 2030	Modal Split 2030	Growth rate 2015-2030	Sections identified as bottleneck	Length of these sections (in km)	Share of bottleneck kms of total length
Pro Rail	39.0%	+8.0%	18	71	13%
Mod Rail	43.7%	+20.6%	24	92	17%
BAU	46.0%	+27.0%	27	101	19%
Mod Road	48.3%	+33.4%	28	104	19%
Pro Road	52.9%	+46.2%	32	123	23%

Table 4: ***Impact of traffic development on the road in 2030***

The extension of the scenarios to the year 2050 leads to the following growth rates, shares of the modal split and distribution of bottlenecks results. A comparison of the developments in

2030 and 2050 shows that the results from 2030 will be intensified until 2050. Whilst the road traffic increases by only 0.1% for the Mod Rail scenario from 2030 to 2050, the influence of the Mod Road scenario on road transport is more significant. In the Mod Road scenario road transport would increase from 48.3% up to over 50%. The theoretical extrem scenarios (Pro Road and Pro Rail) show that with extreme (and unlikely realizable) methods road transport can either gain or lose around 15% of its modal split share.

Scenario for 2050	Modal Split 2050	Growth rate 2030-2050	Sections identified as bottleneck	Length of these sections (in km)	Share of bottleneck kms of total length
Pro Rail	33.2%	+16.7%	13	46	9%
Mod Rail	43.8%	+30.6%	24	82	15%
BAU	48.8%	+37.5%	32	118	22%
Mod Road	53.3%	+44.4%	35	130	24%
Pro Road	60.4%	+58.3%	45	182	34%

Table 5: ***Impact of traffic development on the road in 2050***

The meaning of the different traffic developments as described in the scenarios for the amount of critical sections on the road infrastructure of the TEN-T corridors in NRW is shown again in Figure 18.

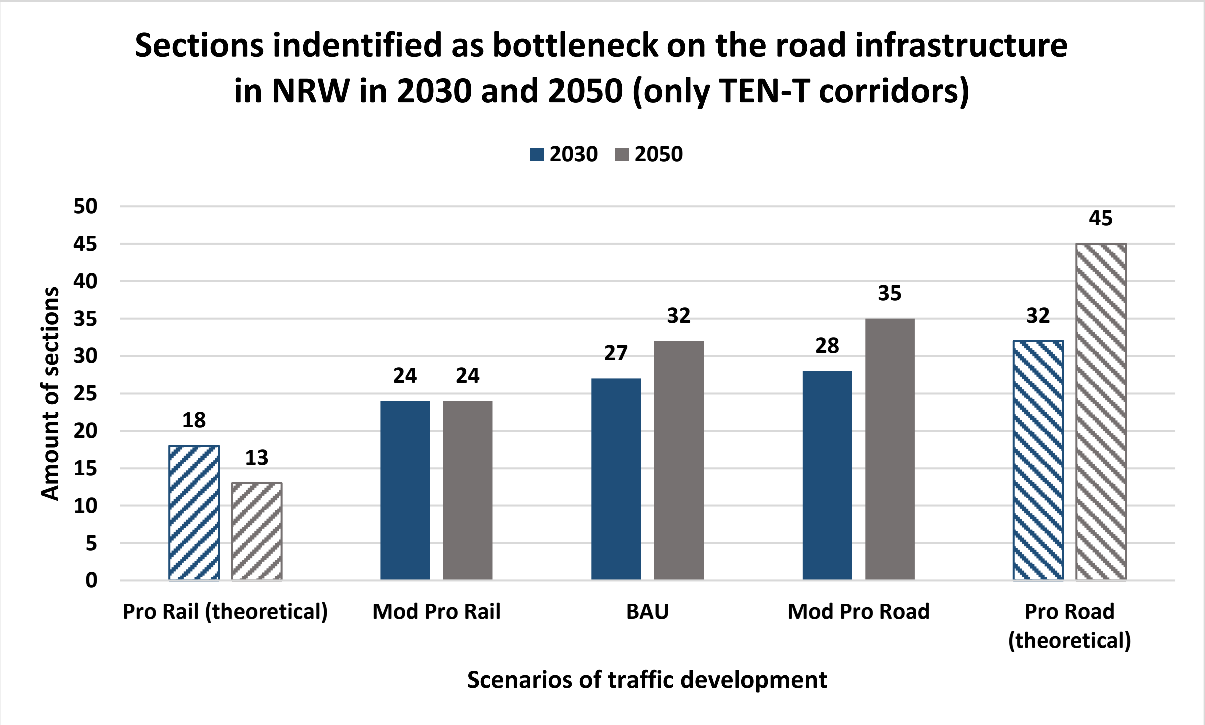

Figure 18: ***Amount of critical sections on the road in the traffic development scenarios***

Considering the respective lengths of the sections in kilometres, the following development emerges, which illustrates the significance of the scenarios for the proportion of critical sections even stronger.

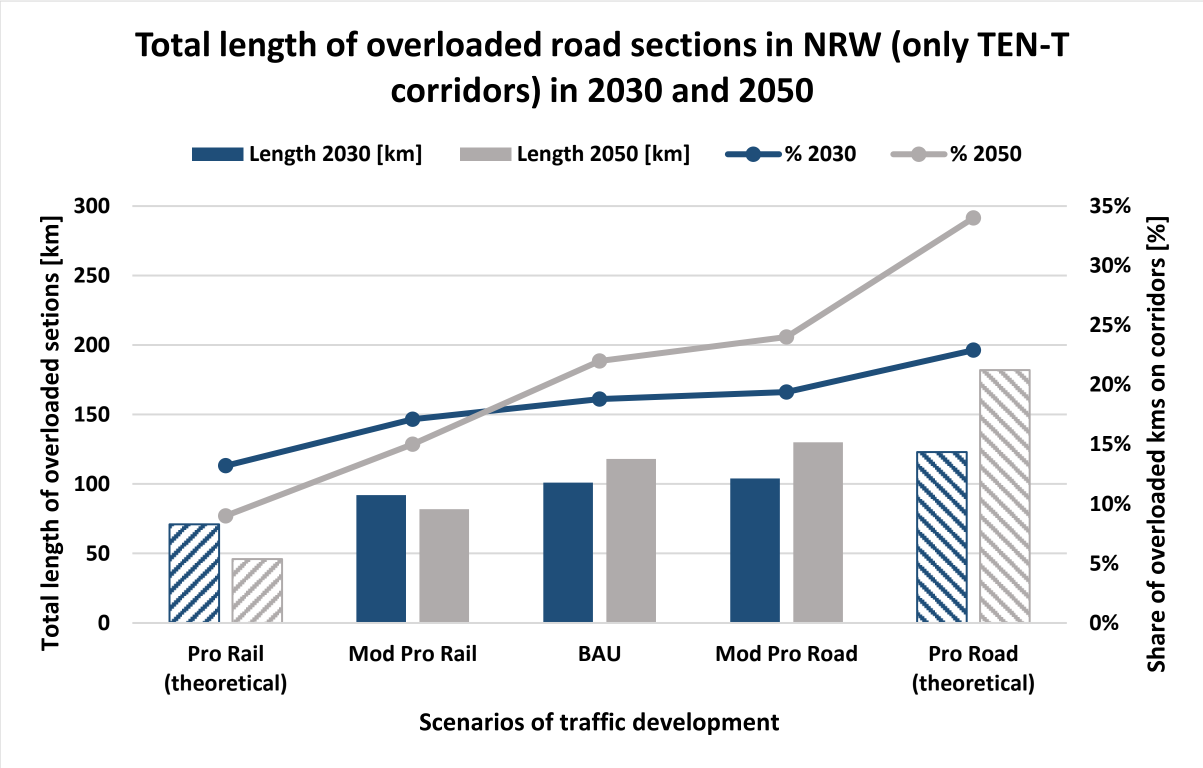

Figure 19: ***Overloaded road sections in NRW (only TEN-T corridors) in 2030 and 2050 [km]***

The examination of the traffic quality in the years 2030 and 2050 led to the result, that although a completely intact infrastructure was assumed, bottlenecks are to be expected in some areas despite the planned investments. However, the expansion of the network is also leading to an improvement in the situation in some areas.

For the year 2030 in general, it can be seen that the projects of urgent need in the BVWP can ensure the maintenance of the necessary traffic quality only to a limited extent, so that there is need for additional measures, which will be presented in chapter 7.

6.2 Rail

Just as in case of the road, the changed infrastructural situation on the rail in 2030 has to be taken into account. Considering the planned measures from categories FB, VB and VB-E in the BVWP as finished in 2030, the traffic development from the different scenarios has been examined with regard to the infrastructure of the rail as well.

- **BAU:** For the rail in 2030, the BAU scenario means a 9.3 % share of the modal split of the modes of transport. Compared to 2015, the share thus increases by 24 %. All in all, this development will lead to 11 overloaded and thus critical sections in 2030 that sum up to 64 km. In 2050, the rail´s share of the modal split will increase insignificantly to 9.5 % in this scenario. However, mainly due to the growing capacity resulting from the use of ETCS, the number of overloaded sections is reduced to 9 on totally 48 km.

- **Moderate Rail:** In the “Mod Rail” 2030 scenario the share of the rail increases to 12%, which means a growth rate of 54% from 2015 to 2030. As traffic volume on the rail increases, so does the amount of critical sections, so that in this scenario 18 out of 118 sections are identified as overloaded. Until 2050, the rail´s share of the modal split increases to 15%. Hence, four more sections and 21 more kilometres are classified as critical. In this scenario, 13% of the kilometres on the corridors in NRW are identified as bottlenecks in 2050.

- **Pro Rail:** Reinforcing this development, the “Pro Rail” scenario leads to a share of the rail in the modal split of 16 % in 2030, so that the traffic volume has grown by 116% compared to 2015. This development leads to 24 critical sections, which means that 14% of all sections will be overloaded in 2030. The most extreme development is expected in the “Pro Rail” 2050 scenario. Based on a growth rate of 132% from 2030 to 2050, the rail's share of the modal split is 27% in this case. Despite the implementation of ETCS, this results in 41 critical sections, which stand for 256 km of bottlenecks.

- **Moderate Road:** The “Mod Road” scenario means a share of 7% of the modal split for the rail, which is caused by a decrease of 7% from 2015 to 2030. Considering this traffic volume, 5 sections have been identified as overloaded and thus critical in 2030. In 2050, the share of the rail of the modal split decreases to 5%, so that only 3 sections are classified as critical, which means that only 1% of the kilometres on the corridors in NRW are identified as bottlenecks.

- **Pro Road:** In the “Pro Road” scenario the share of the rail decreases by 69% to only 2% in the year 2030. As traffic volume is now less than half as high as in 2015, the amount of critical sections falls to 3, which means that in this scenario in 2030 only 1% of the kilometres on the corridors in NRW will be overloaded. Until 2050, the rail´s share of the modal split is marginalized to 0.6% in the “Pro Road” scenario. For this reason, just two sections are identified as critical, representing only a fraction (0.2%) of the total corridor kilometres in NRW.

The shares of the rail in the modal split resulting from the respective traffic growth in the scenarios and the corresponding growth rates compared to 2015 are summarized in the following table. Furthermore, the amount of sections with a traffic quality of E or worse, for this reason identified as bottlenecks, is added to the table.

Scenario for 2030	Modal Split 2030	Growth rate 2015-2030	Sections identified as bottleneck	Length of these sections (in km)	Share of bottleneck kms of total length
Pro Rail	16.2%	116%	24	126	14%
Mod Rail	11.6%	54,3%	18	97	11%
BAU	9.3%	23.5%	11	64	7%
Mod Road	6.9%	-7.4%	5	19	2%
Pro Road	2.3%	-69.1%	3	6	1%

Table 6: ***Impact of traffic development on the rail in 2030***

If these scenarios are extended to the year 2050, the following distribution of bottlenecks results.

Scenario for 2050	Modal Split 2050	Growth rate 2030-2050	Sections identified as bottleneck	Length of these sections (in km)	Share of bottleneck kms of total length
Pro Rail	27.4%	131.8%	41	256	29%
Mod Rail	14.7%	65.6%	22	118	13%
BAU	9.5%	32.47%	9	48	5%
Mod Road	5.3%	-0.6%	3	6	1%
Pro Road	0.6%	-66.9%	2	2	0.2%

Table 7: ***Impact of traffic development on the rail in 2050***

The meaning of the different traffic developments in the scenarios for the amount of critical sections on the rail infrastructure of the TEN-T corridors in NRW is shown again in the following figure.

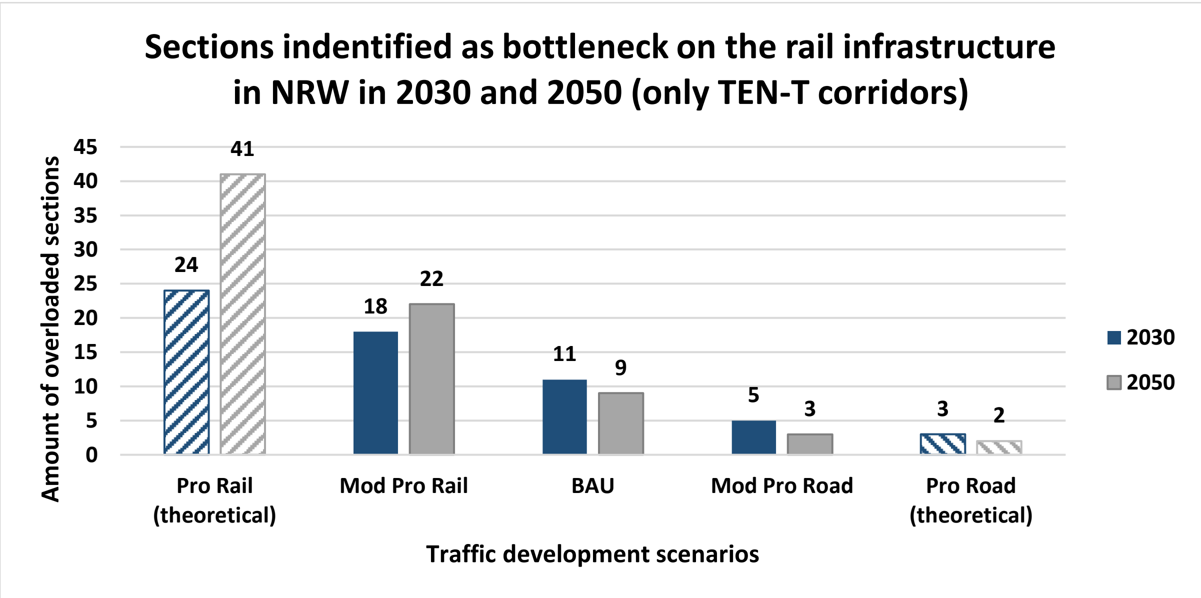

Figure 20: ***Amount of critical sections on the rail in the traffic development scenarios***

Considering the respective lengths of the sections in kilometres, the following development emerges, which illustrates the significance of the scenarios for the proportion of critical sections even stronger.

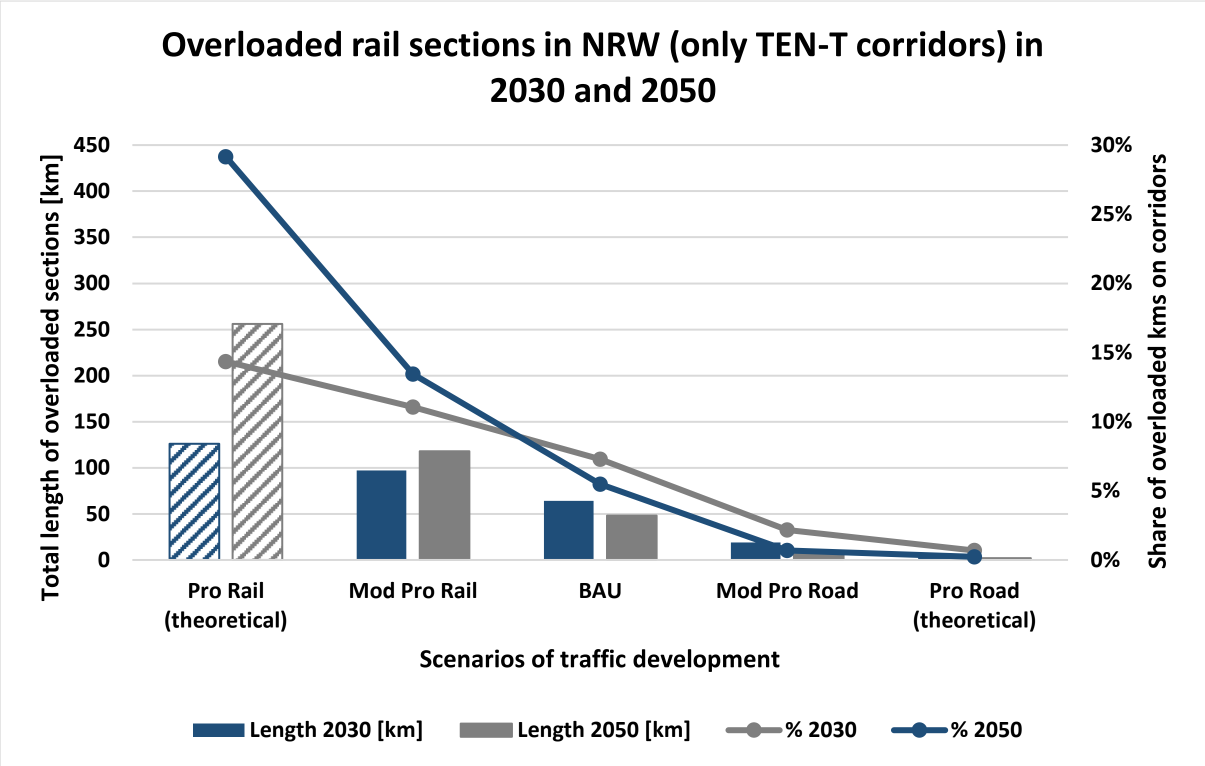

Figure 21: ***Overloaded rail sections in NRW (only TEN-T corridors) in 2030 and 2050***

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

7 Derivation of concrete action recommendations

Despite taking the already planned measures into account, the analysis still reveals road and rail sections on the TEN-T corridors with bottleneck situations in 2030 and 2050. The following chapters present additionally needed measures for the assumed development of traffic volume exemplary.

7.1 Road

The affected sections need an increase in capacity in order to increase the traffic quality on the road and thus to classify the sections into an uncritical traffic quality grade. The expansion of new lanes achieves this objective by reducing the load on each lane. Depending on the predicted traffic quality in the corresponding scenarios for 2030 and 2050, the construction of two or four new lanes per section will be necessary.

The example below explains the situation above with the example of the A1 from "Hagen Nord" to "Hagen West" (3km). In 2015 an inadequate traffic quality (grade E) has been identified at this corridor section. If the traffic load develops according to the BAU scenario, the section remains at the same level, thus is still considered a bottleneck. Therefore, the section needs to increase its capacity. The expansion of two new lanes (outward and return), distributing the load from six to eight lanes, leads to an uncritical traffic quality (grade C). The Pro Road scenario reveals a similar situation. Although the load on the road increases in this scenario, no further need is identified beyond the expansion already identified for the BAU scenario. The situation is different in the Pro Rail scenario. Due to the shift of transport volumes to the rail, the section does not reach a critical traffic quality in this scenario. Therefore, no expansion measures are necessary.

Scenario	Year	Load per lane	Traffic quality without extension	Recommended measure
Initial situation	2015	18,995	E	-
BAU	2030	20,939	E	2 additional lanes
	2050	24,533	F	2 additional lanes
Pro Road	2030	21,846	E	2 additional lanes
	2050	27,217	F	2 additional lanes
Pro Rail	2030	20,041	D	-
	2050	22,238	D	-

Table 8: ***Expansion needs on the corridor section "Hagen Nord" to "Hagen West" (A1) in the traffic development scenarios 2030 and 2050***

On the A4 between “Köln-Poll” and “Köln-Gremberg” (2 km), traffic quality is also critical in 2015.

In order to significantly improve traffic quality by 2030 and not to classify the section as a bottleneck any longer, two additional lanes have to be built in case of a traffic development according to the BAU or Pro Rail scenario, so that the load is distributed over eight lanes. Assuming a development according to the Pro Road scenario, even four additional lanes will be necessary. By 2050, the need for additional lanes will be intensified. If planning is done within this time horizon, four additional lanes will already be required in the BAU scenario.

Scenario	Year	Load per lane	Traffic quality without extension	Recommended measure
	2015	24,083	F	-
BAU	2030	26,661	F	2 additional lanes
	2050	31,413	F	4 additional lanes
Pro Road	2030	27,909	F	4 additional lanes
	2050	35,106	F-	4 additional lanes
Pro Rail	2030	25,426	F	2 additional lanes
	2050	28,255	F	2 additional lanes

Table 9: ***Expansion needs on the corridor section “Köln-Poll” to “Köln-Gremberg” in the traffic development scenarios 2030 and 2050***

7.2 Rail

To increase the capacity on the rail infrastructure, there are different potential measures.

The first way to relieve congested sections of track is usually to use suitable alternative routes. However, this only makes sense until the affected bypasses themselves are in danger of reaching a critical load condition. In addition, this alternative is questionable from an economic point of view as soon as the alternative routes lead to a significant increase in travel time compared to a free optimum route. As soon as this is the case, the capacity of the overloaded sections must be increased.

Probably the most obvious solution to achieve this goal is to expand the number of tracks. In this way, the capacity of the line section is increased in proportion to the number of tracks. A previously single-track line thus doubles its capacity by extending another track.

On mixed traffic routes, it is also advisable to extend a passing track so that a reduction in speed due to a slower train ahead is prevented. Freight trains can assume both roles in relation to passenger trains. Compared with regional passenger rail transport, the freight train is normally the faster one and is slowed down if there is no passing track. Thereby train path capacity is destroyed. On the other hand, the freight train is an obstacle to faster long-distance passenger rail services (Holzhey 2010). With the help of a passing track, instead of forcing a deceleration, a higher cycle sequence is made possible in this way, which in turn increases the capacity of the line by up to 40% (Holzhey 2010).

Furthermore, the improvement of control and safety technology (LST) can lead to an increase in capacity. A track is divided into several sections, so-called blocks. The LST has a decisive influence on the block spacing to be maintained, in other words on the length of the train sequence times and thus on the capacity of a train path. Line capacity is increased by block densification by increasing the number of blocks in a line section so that trains can follow each other at closer intervals. A study carried out by RWTH Aachen University (RWTH Aachen 2009) has shown that the conversion of conventional systems to ETCS (European Train Control System) Level 3 in particular leads to an increase in capacity. The introduction of ETCS Levels 1 and 2, which currently predominate in Europe, has only a minor effect on capacity. "The introduction of the European train control system makes a significant increase in performance possible. However, the time of implementation, which has to take place in an EU-wide process, is still unclear" (Aberle 2005). The study by RWTH Aachen describes the effects of ETCS on rail capacity in a theoretical optimum case. A study by the management consultancy McKinsey for the Ministry of Transport (Seibt 2018), on the other hand, indicates an increase in capacity of 20% under normal circumstances. This is to be rolled out throughout Germany by 2040.

Increased automation through electronic interlockings increases operational quality and enables 24-hour operation time. Another advantage, which does not affect capacity though, is the reduction of personnel costs. A study commissioned by the Federal Environment Agency (Holzhey 2010) concludes, however, that this technology can only be used cost-effectively on main routes and in nodes.

In addition, DB AG estimates the capacity increase potential only through organisational optimization of container train capacity utilization at up to 20%. Moreover, an increase in the permitted train length from currently 740 m in regular operation would increase the loading capacity by 28% and thus reduce the number of trains, which would reduce the demand for train paths at the same transport volume (Deutsche Bahn AG 2007). Due to numerous restrictions, however, the extension to 835 m has so far only been applied on individual routes (e.g. from Padborg (DK) to Maschen (SH)) or, in the version of 1,000 m, tested on test routes (e.g. from Kijfhoek (NI) to Oberhausen). Nevertheless, in the long term, DB AG plans to run freight trains up to 1,500 m (Bardua 2013).

In order to determine the necessary expansion measures, the introduction of ETCS and the resulting capacity effects were assumed to be completed by the year 2040. In addition, a general capacity increase of 10% through organisational measures was assumed, analogous to the evaluation of the road infrastructure. After considering these effects, two alternative measures remain, the new construction of a complete track or the extension of an overtaking track, which increase the capacity as described. For this reason, if possible two expansion alternatives have been defined for every critical section. Which one of the two measures should be preferred has to be assessed in every particular case taking into account additional criteria and cannot be determined generally. These additional criteria can be development restrictions due to already existing infrastructure or peripheral structures, the time required for necessary planning procedures, environmental or social aspects or simply the available investment capital.

7.3 Reality check of infrastructural plans

The previous examination is characterised in particular by its theoretical character. If all developments occur as they have been assumed and if optimal framework conditions are assumed, the outlined bottlenecks will emerge and appropriate measures are to be recommended.

However, it has to be considered that in reality other factors play a role which affect, delay or even make impossible the necessary measures. This chapter addresses some of these issues and their impact on infrastructure development.

7.3.1 Ailing bridges

Aside from increasing capacity by expanding road and rail infrastructure, financial and personnel capacities must be used to maintain the existing infrastructure. In particular, the poor condition of the bridges is currently dominating the headlines. According to a Spiegel report published on the 18.07.2018 (Pauly and Stotz 2018), the proportion of ailing bridges in NRW has fallen over the past ten years, but 9% of the bridges still remain in poor condition.

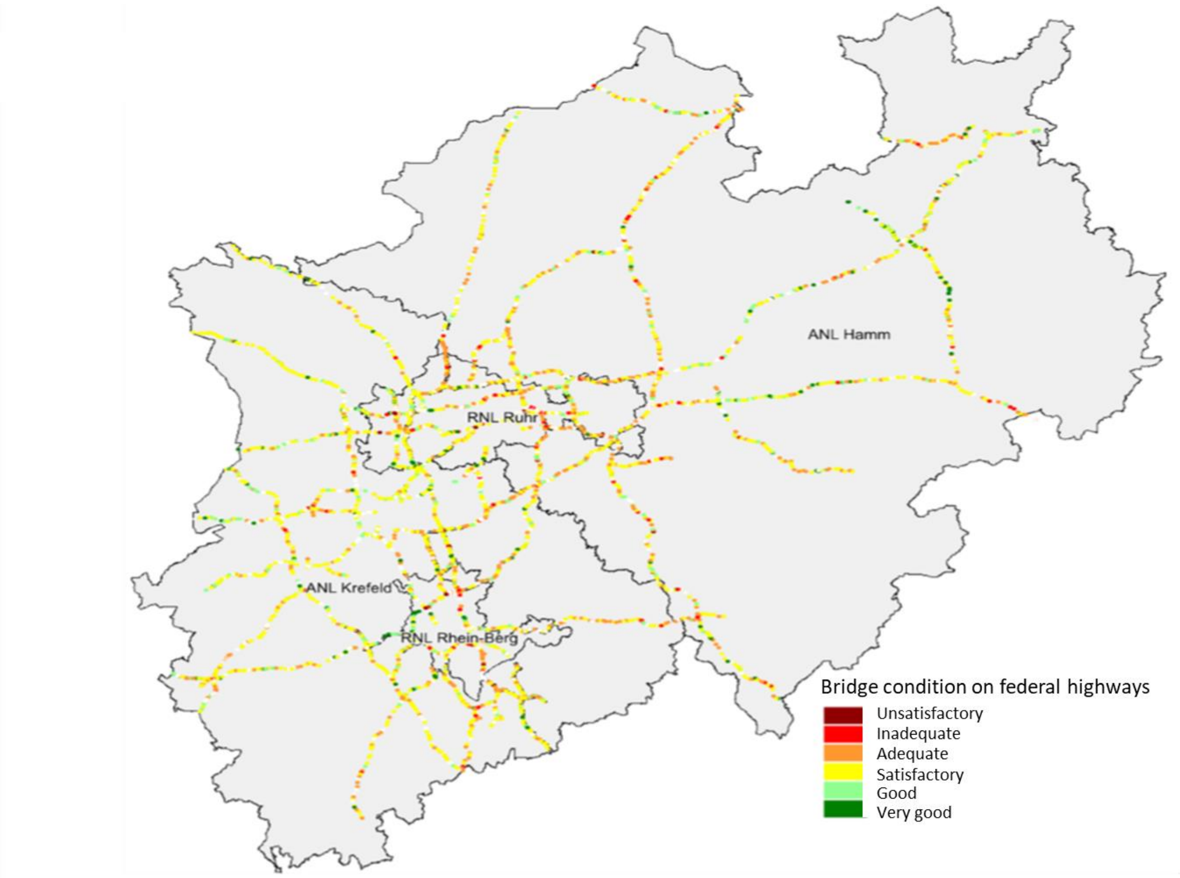

Figure 22: ***Condition of bridges on highways in NRW in 2015 (Straßen.NRW 2017, p. 51)***

One of the reasons why bridges in Germany are in a poor condition is the financing and missing investments. In 2018, 3.9 billion euros were provided for maintenance. However, experts estimate the costs for the necessary modernization measures to be significantly higher (Altmann 2018). Another problem is that although the funds for bridge renovations were increased in the last legislative period, the money could not be fully called up. This is mainly due to an acute shortage of skilled professionals and lengthy approval procedures (Pauly and Stotz 2018).

7.3.2 Implementation of expansion and new construction measures

After their inclusion in the Federal Transport Infrastructure Plan and the requirement plans, federal transport infrastructure projects generally undergo a regional planning and then a planning approval procedure, which concludes with the granting of building rights. By European standards, these processes take an above-average amount of time in Germany (BMVI 2018a). Regional planning procedures are used to determine the compatibility of a measure with regional planning. It must meet the requirements of regional planning and be coordinated with other measures of regional significance (FIS 2011). The aim of the subsequent planning approval procedure is to examine all legal issues relevant to the construction and to weigh the construction project against the public and private interests involved (Straßen.NRW 2018c). This can lead to considerable delays. The total duration of a planning approval procedure on rail infrastructure is usually one to three years (EBA 2018). Nevertheless, the planning duration of a new construction or expansion project depends strongly on the individual case. For example, the expansion of the B224 to the A52 in Gladbeck has dominated local headlines since 2012, but the planning has not yet been completed by 2018 as a result of citizens' petitions and court proceedings (Lokalkompass 2018).

In this area, however, the Federal Government is currently also making efforts to speed up the process. On July 18th 2018, the Planning Acceleration Act (Planungsbeschleunigungsgesetz) was passed to streamline the planning and approval procedures for the expansion and construction of transport infrastructure. The core objectives here are to avoid duplicate inspections, to reduce the number of interfaces, to increase the efficiency of procedures, to create more transparency and digitisation in public participation, and to speed up court proceedings (BMVI 2018c).

In addition, on July 25th 2017, the agreement on the implementation of the requirements plan was signed between the Federal Government and Deutsche Bahn, which aims to make the planning of new construction and expansion measures on rail more rapid and cost-effective (BMVI 2017b).

7.3.3 Financing/Funding

In addition to the long planning phases, there are other obstacles to the timely expansion of infrastructure in Germany. On the one hand, these result from a shortage of skilled professionals who can plan and implement the measures and, on the other hand, from financial aspects.

First of all, the available public budget funds are not sufficient to provide a transport network that meets the demand. According to the report of the Daehre Commission, € 7.2 billion per year are missing for 15 years for the modes of transport road, rail and waterway for maintenance and to reduce the backlog in order to avoid further economic damage and not to endanger Germany as a business location (Daehre et al. 2012).

In addition, the financial planning security in Germany is relatively low due to the strong dependence on budgets to be approved annually. Reliable, stable finance planning over a medium-term, multi-year time horizon, as is typical for large-scale projects, is made considerably more difficult by this system (Roland Berger Strategy Consultants 2013).

Finally, the principle of preservation and renovation before the expansion and new construction of the Conference of Transport Ministers means an obstacle for the swift implementation of further measures necessary to expand capacity (Verkehrsministerkonferenz 2015).

7.3.4 Infrastructure wear

When this work package refers to the load on a road section, it refers to the average number of vehicles using that section on a daily basis. A distinction is made between passenger cars and heavy goods vehicles by taking into account the proportion of heavy goods vehicles with a double weight. In this way, the disproportionate influence of heavy goods traffic on the capacity of a section is considered.

At the same time, it should be noted that the term "load" is not used in this study in the sense of infrastructure wear and tear. In this context, the influence of heavy traffic is of course considerably higher. Road engineers assume that road wear increases almost with the fourth power of the axle load. A truck with a permissible axle load of 9 tonnes per single axle puts 5,000 times more strain on the road than a passenger car with an axle load of 0.9 tonnes (Kopper et al. 2013). Other studies calculate with a factor of 40,000 if comparing the load of a light car with that of a fully loaded truck with 40 tonnes. However, it is also confirmed that this factor can fall below 10,000 if the weight ratios change (Bundesanstalt für Straßenwesen 2006).

7.3.5 Expansion restrictions

Another issue that arises when the defined measures meet reality is the density of buildings on the edge of the highway.

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

The federal traffic route plan includes the eight-lane expansion of the sections junction Leverkusen to intersection Köln-Niehl on the A1 and junction Hilden to intersection Köln-Mülheim on the A3.

In all presented traffic development scenarios for 2030, two more lanes are missing on the A3 from junction Leverkusen to triangle Köln-Heumar. This means that a total of 10 lanes are required for the predicted load. By the year 2050 and a traffic development according to the BAU scenario or the Pro Road scenarios, a total of 12 lanes will be required from the junction Leverkusen to the intersection Leverkusen-Zentrum to be able to absorb the traffic load without disruption.

However, due to the location of the junction in the immediate vicinity of buildings and company premises an unlimited extension will not be possible here without considerable additional effort.

The residential and industrial buildings, some of which are located directly along the route, are causing costs that have not yet been taken into account.

Straßen.NRW has been dealing with this problem for quite some time. For the extension of the A1, 14 variants were compared and evaluated. There are five variants at elevated level, eight at low level and a combination of both. According to the exclusion principle, only three variants were examined in detail: the variants H02 "high site south offset with transverse displacement", T01 "tunnel south offset" and T04 "tunnel south offset with partial dismantling" (Grassl et al.).

Seven proposals have also already been drawn up for the expansion of the A3 around the Leverkusen AK. The costs range between €150 million and €910 million, whereby the effects on local residents and the environment were also examined (Straßen.NRW 2018b).

Since the motorway junction in the form of a cloverleaf will no longer be able to handle the increasing load in the future, various options for expansion are also being discussed here. A decision is made between a Maltese cross or two different forms of a modified windmill. When making the choice, it must be taken into account that the motorway extension variant is suitable for the new shape of the junction (Straßen.NRW 2018a).

In order to extend the existing analysis of the expansion requirements of the TEN-T corridors in NRW, additional costs incurred due to the given infrastructural restrictions were investigated. First of all, the legal basis in case of expropriation was consulted in order to estimate the costs. However, as these are basically individual case decisions that are strongly dependent on the local situation and the type of development, the determination of an exact cost value is only possible to a very limited extent. For this reason, a framework within which the costs move has been specified. It was set up with the standard land value around the junction Leverkusen and the corresponding values for residential and industrial buildings. In addition, a differentiated utilization of the area has been investigated. Potential additional process costs were estimated on the basis of former proceedings.

Additionally, a tunnel alternative was considered, of which the average cost per kilometre is estimated at around € 20 million in various average calculations (Walther 2018; BVFD Graubünden and Autonome Provinz Bozen/Südtirol 2006). Furthermore, additional costs of 20% for the equipment, e.g. lighting and ventilation, and emergency routes were included (Burbaum et al. 2005). In this case, additional annual costs of one million euros incur for the maintenance of the tunnel. However, in this case there are some roughly divergent cost calculations as well. Straßen.NRW, for example, charges € 900 million for a 2.2 km tunnel solution (Straßen.NRW 2018b), since, in addition to relocating supply and disposal lines, the Dhünn would also have to be relocated and, here too, at least during the construction period, interventions in the ownership structure will be indispensable. A precise statement about the costs can therefore only be made on the basis of detailed data, which are not yet available. The following figure visualizes therefore only a rough overview of the problems and a general assessment of the cost effects.

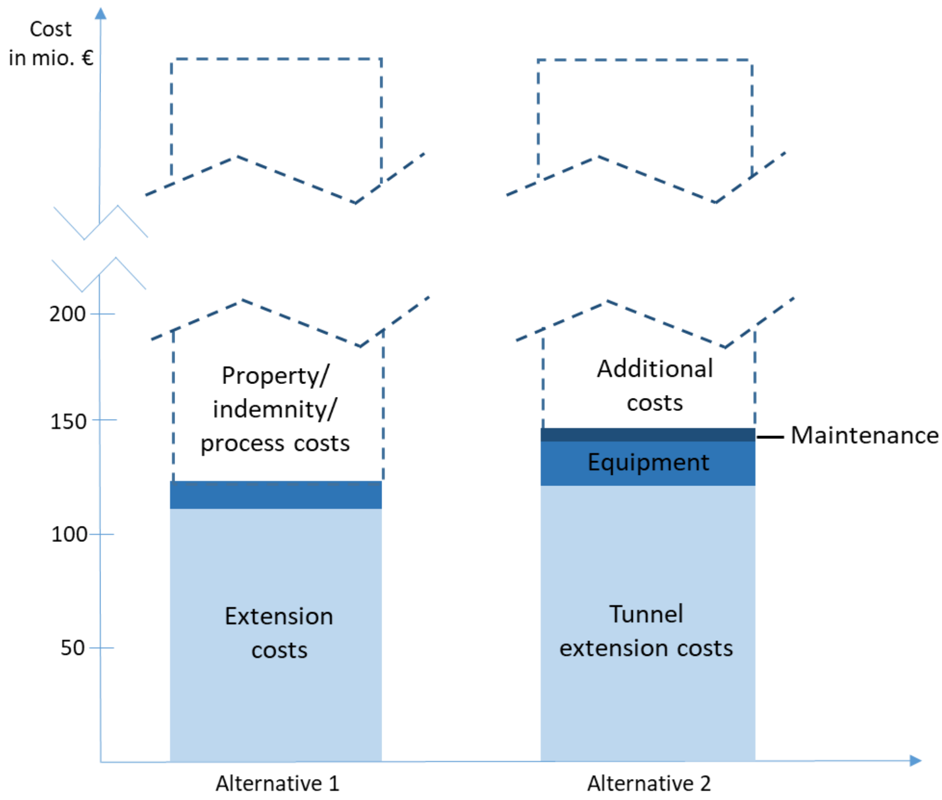

Figure 23: ***Cost calculation for different extension alternatives at junction Leverkusen (Own representation based on BMVI 2015; Bundesanstalt für Straßenwesen 2017; Walther 2018; Burbaum et al. 2005)***

The problem described does not relate exclusively to road infrastructure. Rail transport also provides framework conditions that complicate further infrastructure expansion and increase its cost significantly. For example, the tracks between Cologne Messe/Deutz and Cologne Central Station cross the Hohenzollern Bridge. At this point, the rail infrastructure is already overloaded in 2015, making the expansion of at least one additional track indispensable. However, the capacity of the bridge is fully utilised, so that an expansion will require a great effort in terms of time and money.

7.3.6 Passing tracks

In order to increase capacity on the rail, the extension of a passing track has been considered as an alternative. Theoretically, this leads to an increase in capacity of up to 40% and is faster to realize than building a complete new track. Nevertheless, it has to be taken into account, that the extension of passing tracks is not possible or useful at every point of the network. Within the framework of this study, only a general assessment of the effects of such a measure has been carried out without assessing the actual feasibility for each individual case. In this context, the additional expansion measures required for every section were determined purely on the basis of the loads and existing capacities. It must therefore be made clear that further constructive restrictions with regard to new overtaking tracks are quite conceivable.

Considering the restrictions on infrastructure extension presented above, it quickly becomes clear that a purely theoretical approach such as the one used in the study is not sufficient to fully grasp the manifold interactions to overcome capacity bottlenecks. Nevertheless, this study should serve as a basis for further discussion as it identifies possible developments and addresses potential barriers.

8 Investment needs

Based on the requirements for the infrastructure identified in Chapter 6 and 7 an estimation of the investment needs is established for road and rail transport. Investment cost figures are mainly based on the costs in the Federal Investment Plan (BVWP) 2015 (BMVI 2015) and focused on measures planned for the TEN-T corridors in North Rhine-Westphalia.

8.1 Road

To determine the capital expenditure to realize the additionally needed measures, the mean of the fixedly planned investments at the corridors in NRW has been calculated. For expansion and new construction of lanes at the relevant corridor sections, in the capital investment framework 2011-2015 (IRP) (BMVBS 2012) have been estimated in total € 1,266.1 million. This amount leads to an average investment volume of € 16.98 million per kilometer of expansion. The values vary between € 4.73 million per km (at the A4 between Düren and Kempen) and € 34.36 million per km (at the A3 between Köln-Delbrück and Köln-Mülheim).

In BVWP (BMVI 2015) the total costs for expansion and new construction of lanes on the relevant corridors have been added up to € 1,220.1 million. Using these given plans of the measures in the BVWP a mean of € 15.6 million per km, with a range between € 6.51 million per km (at the A3 between Hilden and Ratingen-Ost) and an extreme outlier of € 59.68 million (at the A1 between Köln-Niehl and Leverkusen), has been calculated. The next lower value has been € 20.34 million (at the A3 between Königsforst and Köln-Heumar). This extreme outlier is explained by the reconstruction of the Rhine bridge with a simultaneous increase of the amount of lanes. However, since this kind of exceptional measure is expected to occur frequently in the course of major corridor uprades, the respective cost figures have to be taken into account when estimating average road expansion costs. Increases of per kilometer costs against BVWP figures are also expected concerning land values.

Due to the increasing traffic volume it is 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 amount of kilometers did not seem appropriate, these costs have been translated proportionally to the other sections. In the IRP, further € 225 million have been planned for the expansion of four intersections. When translating these costs to the 110 km of highway, which have to be expanded, the cost for the expansion of a single kilometer of highway increases by 14 % to € 19.356 million. In comparison, in the BVWP six measures with an overall volume of € 384.5 million have been planned. These had to be translated to 100 km that have to be extended. This has resulted to an increase in the cost for one kilometer of expansion by 24 % to € 19.32 million. On this basis, an investment need of € 19.3 million per kilometer of expansion has been assumed, in which the reverse direction has been included respectively.

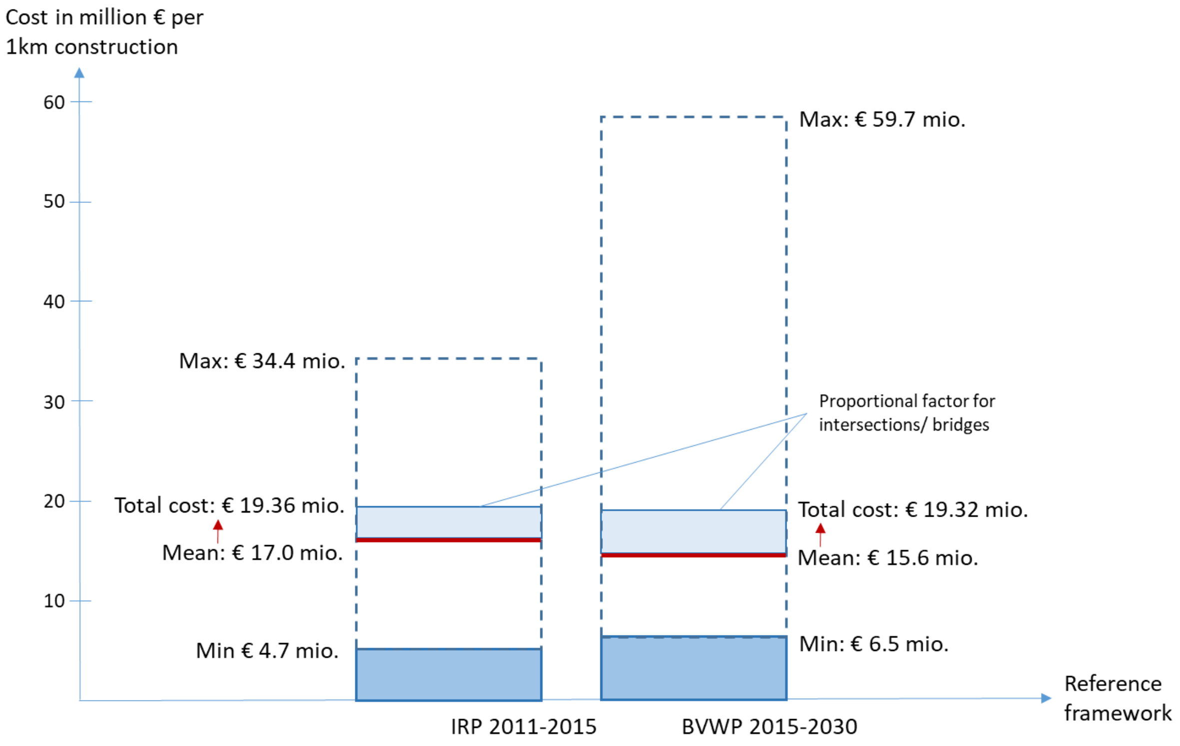

Figure 24: ***Determination of average cost for one kilometre of road construction on the TEN-T corridors in NRW (Own representation based on BMVI 2015; BMVBS 2012)***

The calculated investment need per kilometer of expansion has been translated to the necessary measures identified for the five scenarios, to determine the additionally needed investment volume. In the BAU scenario 2030, 58 new lanes have to be built, which amount to a total of 218 km. Based on the calculated € 19.3 million per kilometer of extension, this results in an investment requirement of € 4,207.4 million in order to avoid all bottlenecks by 2030.

Additionally, the costs for the already planned measures, that also effect the traffic quality and contribute to avoiding bottlenecks, have to be taken into account. Until 2030, the measures from the BVWP that are planned on the TEN-T corridors in NRW amount to € 3,567.4 million on 125.2 km. In each scenario, these costs have been added to the calculated, additional costs as a fixed part.

For 2050, the fixed costs are insignificantly higher and amount to € 3,793.7 million, due to four new measures on 26.9 km. As in the BAU scenario 76 lanes, spread over 268 km (instead of 58 lanes and 218 km in 2030) have to be built, the additional investment requirement sums up to € 5,172.4 million, so that a total cost of € 8,966.1 million results.

The following table gives an overview over the estimated investment needs on the road in the scenarios for 2030 and 2050.

		Pro Rail (theoretical)	Mod Rail	BAU	Mod Road	Pro Road (theoretical)
Total new lanes	2030	36	52	58	62	76
	2050	26	54	76	88	110
Total km	2030	142	200	218	228	278
	2050	92	184	268	320	426
Additional costs [Mio. €]	2030	2,740.6	3,860.0	4,207.4	4,400.4	5,365.4
	2050	1,775.6	3,551.2	5,172.4	6,176.0	8,221.8
Total cost [Mio. €]	2030	6,308.0	7,427.4	7,774.8	7,967.8	8,932.8
	2050	5,569.3	7,344.9	8,966.1	9,969.7	12,015.5

Table 10: ***Investment need for road infrastructure in NRW (only TEN-T corridors)***

All in all, the theoretical Pro Road scenario leads to the highest costs for both 2030 and 2050. It is also the scenario with the highest increase in road construction costs between the two dates due to the high road load. The costs for the three middle scenarios range in a similar amount in 2030. Thus, by 2030, the moderate scenarios 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, so that the costs for this scenario are less than half of the costs for the Pro Road scenario at this point in time. The calculated total costs in the scenarios by 2030 and 2050 are shown again in the following figure.

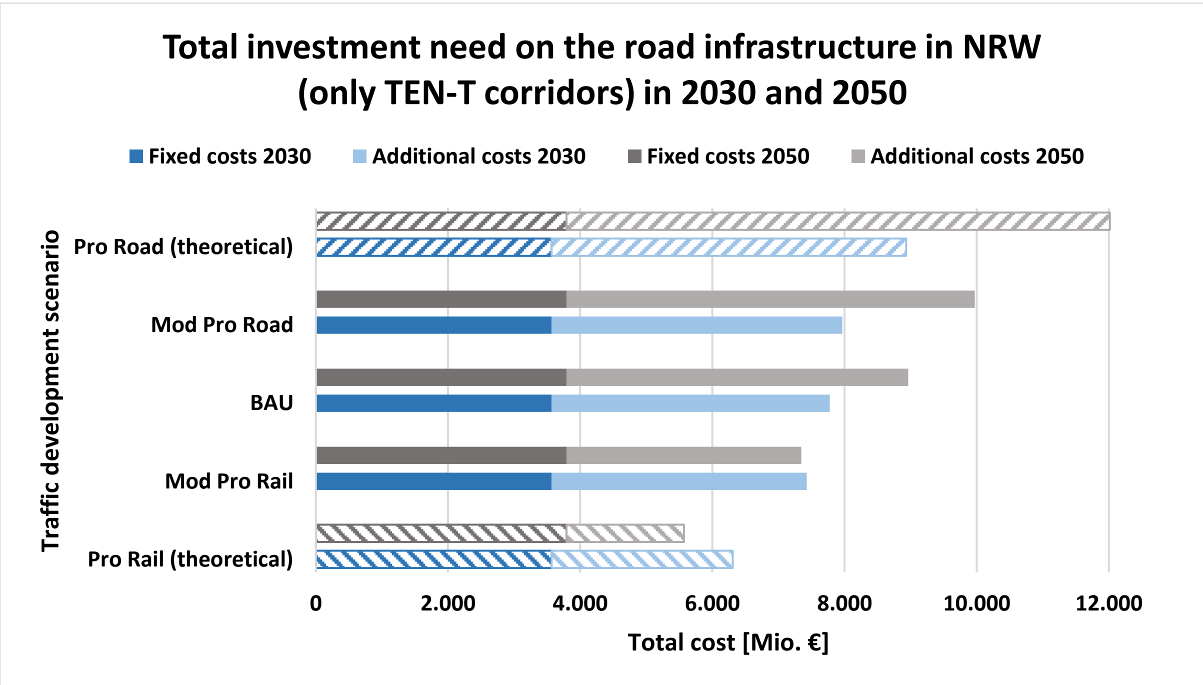

Figure 25: ***Roughly estimated total investment need on the road infrastructure in NRW until 2030 and 2050***

In addition to the conventional expansion measures, the introduction of hybrid overhead line trucks is currently being discussed in Germany. Test tracks in Hesse, Baden-Württemberg and

Schleswig-Holstein are currently under construction or in the approval phase (WirtschaftsWoche 2018).

If considering from the cost perspective also the expansion of the HO, studies speak of a total German investment requirement of approx. 8 to 10 billion € (BMVI 2017a). This is based on the assumption that in the long term approx. 80 % (approx. 250,000 trucks) of the heavy commercial vehicles registered in Germany will be converted to HO trucks. In addition, an evaluation of the route loads of the German motorways with truck traffic showed that only 4000 km of the German motorway network (30% of the entire network) had to be equipped with overhead lines (BMVI 2017a).

For the assessment of the investment volume for the overhead line infrastructure on the TEN-T corridors in NRW, an investment requirement of € 2.2 million/km has been assumed (BMVI 2017a). Depending on the source, the figures range between 1.1 million euro/km (Grontmij 2010), 2.2 million (UBA 2016), 2 to 3 million (den Boer et al. 2013) and 2.5 million (SRU 2012). The figures refer to the electrification of one lane in each direction. The investments include all necessary facilities from the connection to the medium-voltage network of an energy supply company, i.e. in particular transformer stations, lines and masts (BMVI 2017a).

In total, the road part of the TEN-T corridors in NRW amounts to 537 km. These sections are by definition among the busiest and should therefore be fully equipped with overhead contact lines. If one lane in each direction of each corridor section were to be equipped with overhead contact line infrastructure, the cost of this measure would be € 1.1814 billion.

8.2 Rail

To calculate the total cost of the proposed expansion measures at the rail, the overall costs of the already planned measures had to be determined. Based on this data, indications about the average cost of the expansion or new construction of tracks could be established. Subsequently, this data could be translated to a base value of "cost per kilometer" in order to base on it rough estimations concerning the investment cost of the additionally needed measures.

The Federal Environment Agency has estimated costs of € 12 million per km of track for the construction or expansion of sections of line (Holzhey 2010). If the average value of measures planned for NRW in the BVWP (BMVI 2015) is calculated, it leads to a corresponding average value of € 12.7 million per km (Institut für Verkehrswirtschaft an der Universität Münster 2011). This includes all necessary construction measures, such as tunnels and bridges, signalling systems and planning. Nevertheless, it must be taken into account that, due to the wide spread, this is a rough estimate and each individual case requires close examination.

Due to the lower effort involved, the expansion of sidings and passing tracks entails lower costs than the construction of a complete new track. Since a passing track must reach at least the maximum permissible train length of 740 m, costs of EUR 12.7 million per passing track, i.e. the corresponding value for the construction of one kilometer of track (Deutscher Bundestag 2018, p. 2), are calculated.

Furthermore, the fixed costs caused by the already planned measures from the BVWP (BMVI 2015) have to be added 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 has not been available, estimated values based on the previously determined cost per kilometer of extension were used. This approach resulted in a fixed cost share of € 2,376 million for 198 km of expansion by 2030.

It is assumed that the ETCS expansion in Germany will be completed by 2050 (BMVI 2018d). For this reason, a corresponding capacity increase has been taken into account in this work package. At the same time, the costs for this comprehensive measure must also be included in the assessment. For this reason, the fixed costs will increase by € 4.5 million per corridor kilometer (BMVI 2018d) in NRW by 2050, in total € 3,951 million. This means that fixed costs of € 6,327 million are expected in 2050.

As alternative expansion measures to avoid bottlenecks are feasible for some sections, the case with the highest (upper bound) and the one with the lowest (lower bound) costs have been calculated. The total costs of all permissible decision options are then within this interval.

The following table gives an overview over the estimated investment needs on the rail in the scenarios for 2030 and 2050, if the extension of passing tracks is not considered, so that capacity on the overloaded sections is increased by the extension of new tracks. If this alternative is chosen for each critical section, this is in total the most expensive solution (upper bound).

Upper bound		Pro Rail (theoretical)	Mod Rail	BAU	Mod Road	Pro Road (theoretical)
Total new tracks	2030	32	19	11	5	3
	2050	82	25	9	3	2
Total km	2030	161	100	64	19	6
	2050	469	127	48	6	3
Additional costs [Mio. €]	2030	1,932	1,200	768	228	72
	2050	5,628	1,524	576	72	36
Total cost [Mio. €]	2030	4,308	3,576	3,144	2,604	2,448
	2050	11,955	7,851	6,903	6,399	6,363

Table 11: ***Investment need for rail infrastructure in NRW (only TEN-T corridors) calculated for Alternative 1***

If, whenever it is possible to improve the capacity utilisation situation, the extension of passing tracks is chosen, the following situation, which is shown in *Table **12***, results. In general, this is the most cost-effective case.

Lower bound		Pro Rail (theoretical)	Mod Rail	BAU	Mod Road	Pro Road (theoretical)
Total new tracks	2030	8	3	2	1	1
	2050	36	7	2	1	1
Total km	2030	42	12	5	2	2
	2050	197	38	5	2	2
Passing tracks	2030	22	16	9	4	2
	2050	37	17	7	2	1
Additional costs [Mio. €]	2030	768	336	168	72	48
	2050	2,808	660	144	48	36
Total cost [Mio. €]	2030	3,144	2,712	2,544	2,448	2,424
	2050	9,135	6,987	6,471	6,375	6,363

Table 12: ***Investment need for rail infrastructure in NRW (only TEN-T corridors) calculated for Alternative 2***

The resulting total investment need on the rail infrastructure on the TEN-T corridors in NRW, comparing 2030 and 2050 as well as the alternatives with highest and lowest costs, is shown in Figure 18. The most expensive scenario in this case is obviously the theoretical Pro Rail scenario in both 2030 and 2050 and in both alternative cases. The most cost effective scenario is the theoretical Pro Road scenario. In comparison to the costs of road expansion, the costs for rail expansion increase stronger until 2050, which is due to the extensive ETCS expansion. In addition, the difference between the Pro Road and Pro Rail scenarios is somewhat smaller, since alternative one, as in the case of road expansion, almost doubles the costs between the scenarios, but in alternative two only costs increase only by 45%.

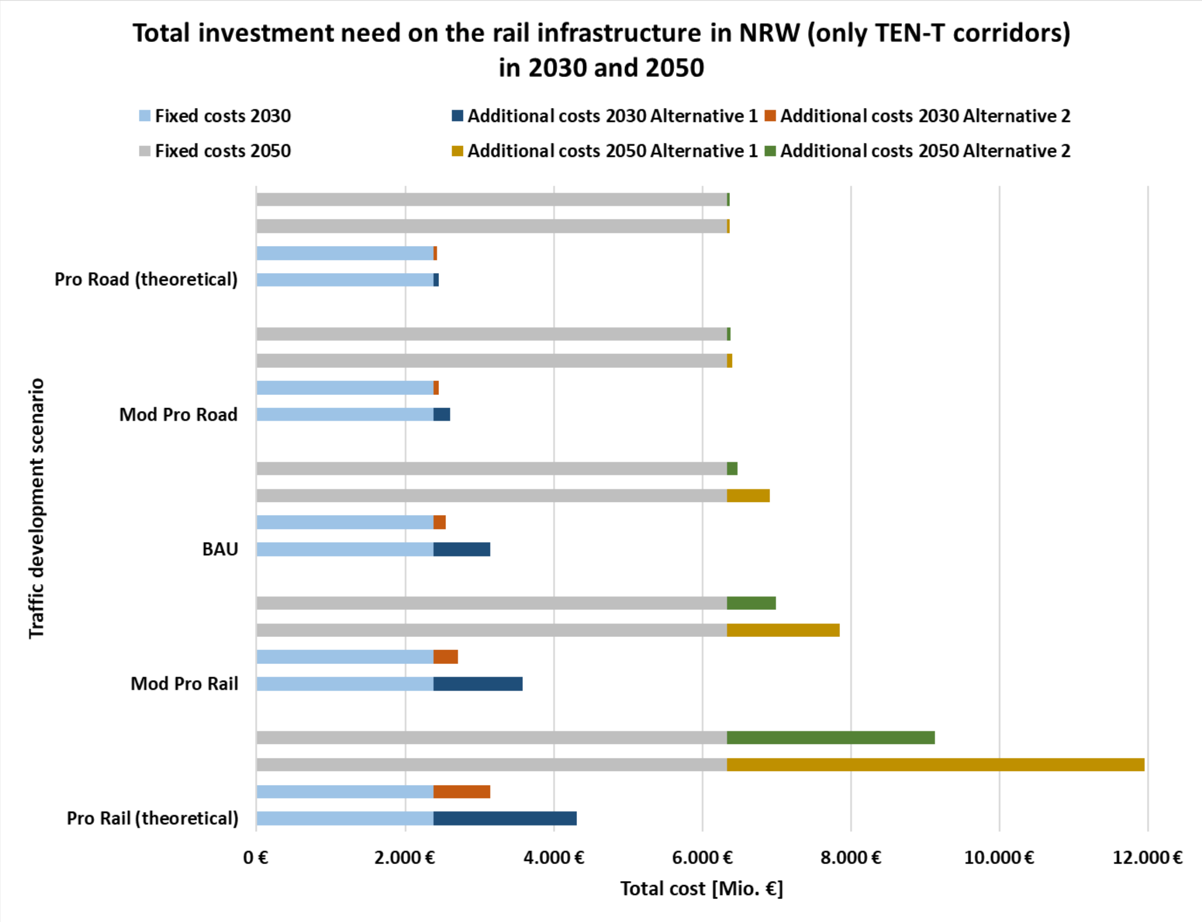

Figure 26: ***Roughly estimated total investment need on the rail infrastructure in NRW until 2030 and 2050***

8.3 Result

In order to evaluate the scenarios, it is not sufficient to consider the influences of traffic development on road and rail infrastructure separately. A stronger increase on the road, which leads to higher investments, implies a lower increase or even decrease on the railways, so that less investments are necessary here. Figure 27 and Figure 28 show how these effects develop in the five scenarios.

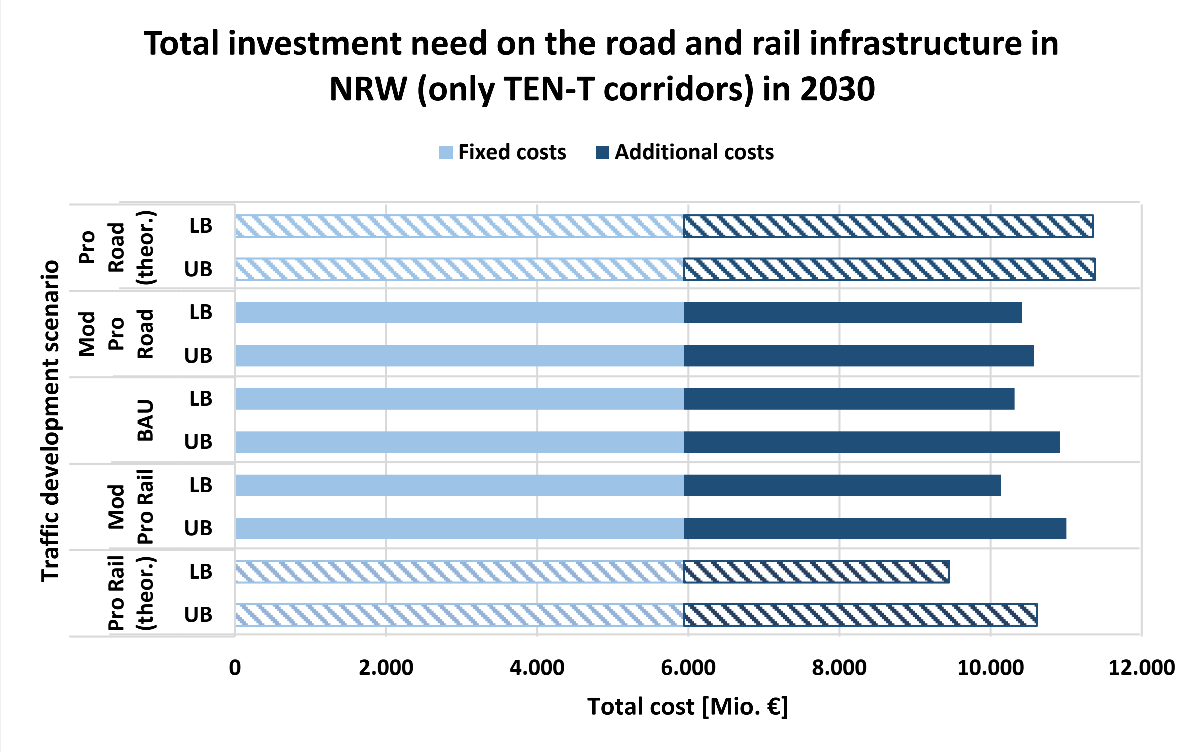

Figure 27: ***Roughly estimated total investment need on the road and rail infrastructure in NRW in 2030***

In 2030, the Pro Road scenario is the most expensive one concerning the infrastructure cost. This is due to the fact that only marginal changes are necessary on the railways. In the other extreme, although the costs for rail expansion increase, this is offset by lower investment requirements on the road, so that the Pro Rail scenario offers potential cost savings. Here, however, the range of all scenarios is the largest, so that higher costs are also possible. Looking at the BAU scenario and the moderate scenarios, it can be noted that no relevant cost changes occur, at least in the most cost-effective variant (LB). If, in any case, a complete expansion is chosen (UB), the costs for all scenarios converge. In this case, however, the moderate Road scenario is narrowly the most cost-effective.

Figure 30 visualizes the cost effects for 2050. Apart from the fact that higher investments are necessary (also taking into account the ETCS expansion), some important changes compared to 2030 can be observed. These concern the upper limit in the Mod Rail and BAU scenario. In both cases the costs decrease in relation to the other scenarios, so that the Mod Rail scenario is the most cost-effective variant in both alternatives and thus also for each case in between. In the Pro Rail scenario, the possible range increases, which is due to the longer time horizon and thus the number and length of the measures.

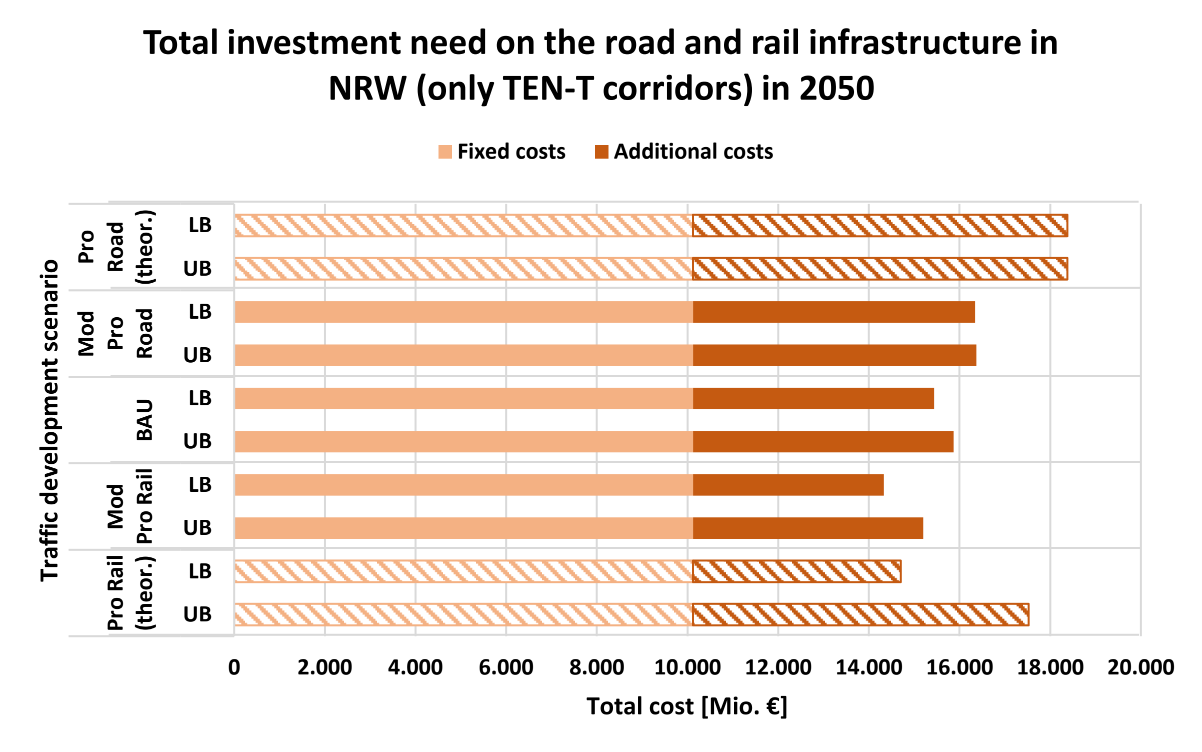

Figure 28: ***Roughly estimated total investment need on the road and rail infrastructure in NRW in 2050***

It may be noted that investments in road and rail are interdependent. Higher investments on the roads, due to a strong increase in the road load, usually lead to lower investments on the railways, as the traffic load decreases. Depending on which expansion measures are chosen for the railways, this effect is more or less noticeable.

All in all, the highest costs incur in the extreme scenarios, as one mode of transport has to cope with an unexpectedly large volume of traffic, so that a great number of expansion measures are necessary. More balanced growth, as in the moderate scenarios, leads to lower expansion costs, which are distributed among the modes of transport.

9 Socio-economic 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 economic branches delivering goods and services to it. Freight transport activities affect various economic sectors as transport to a large extent constitutes an intermediate sector linking various parts of value chains. Changes in the costs and the performance of freight movement thus impose effects on virtually all types of economic activity. Changes in economic activities directly influence employment in terms of the number and the quality of jobs. Insofar, economic impacts directly entail social effects. Hereinafter, we focus on infrastructure investments and their wider economic impacts.

In this section, we turn the attention towards these two layers of wider impacts of transport policy and investment scenarios. We analyse financial and employment impacts by sectors using a dynamic input-output model for Germany. This allows the quantification of complex inter-sectoral net effects, and thus goes beyond commonly used mono-causal gross effect analyses. The approach is, on the other hand, limited in terms of looking into real employment conditions and the types of jobs and qualifications, to be created or lost through the transport policy scenarios.

9.1 Methodology

9.1.1 Model structure

In macro-economic terms, changes in investments are changes in the final demand for a certain product, service and industry. Changes in demand do 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. This interrelation can be captured by an input-output analysis. The analysis is 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, which can be measured by different indicators. We choose employment in full time equivalents (FTE) and gross value added (GVA) in order to get further insights how the estimated investment needs affect North-Rhine Westphalian economy. Since the input-output table (IOT) contains German values, 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, aggregate German as well as North-Rhine Westphalian effects.

From the estimated future investment needs, 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 both, rail as well as road infrastructure and thus receives the major share of investments. A minor part of the investments is undertaken in architectural and engineering activities, which are a prerequisite for construction projects. Another part of investment impulses is assigned to the manufacturing of electrical equipment. Civil engineering includes many types of construction and its share of intermediates from the manufacture of electrical equipment is smaller than the average input into rail and road construction, especially when taking into account the future need of higher electrification. We thus feed part of the investment impulses into the manufacture of electrical equipment in order to fulfil an adequate demand for electrical equipment needed in civil engineering regarding the specified projects.

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 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 Westphalian 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 maximum effects assume that all non-NRW companies are excluded from funding and thus NRW workers with NRW intermediates carry out all activity. The investment impulses are fed into the macroeconomic core of ISI-macro which represents the whole German economy. Modelling results are value added by economic sector accounting for direct, indirect and induced effects of the investment impulses. National value added per economic sector can be assigned to German regions (federal states in this study). The regional distribution takes into account historic shares of sectoral value added as well as projections on regional distribution of future labor potential. Regional employment per sector is calculated from regional value added using regional labor productivities.

9.1.2 Temporal and sectoral allocation of investments

The data from chapter 8 concerning the total investment needs in road and rail infrastructure in all scenarios was collected. The estimated investment needs include planned measures by the BVWP plus additional investment needs, calculated in the preceding chapters for the periods 2015 to 2030 and 2015 to 2050. The economic impacts of future investment needs in North-Rhine Westphalia are modelled separately for road and rail investments as well as for aggregate investments and considered impulses to three industries. Figure 29 outlines the allocation of road and rail investment impulses to the different sectors. The details on the temporal allocation of investments as well as the sectoral allocation are described in the following.

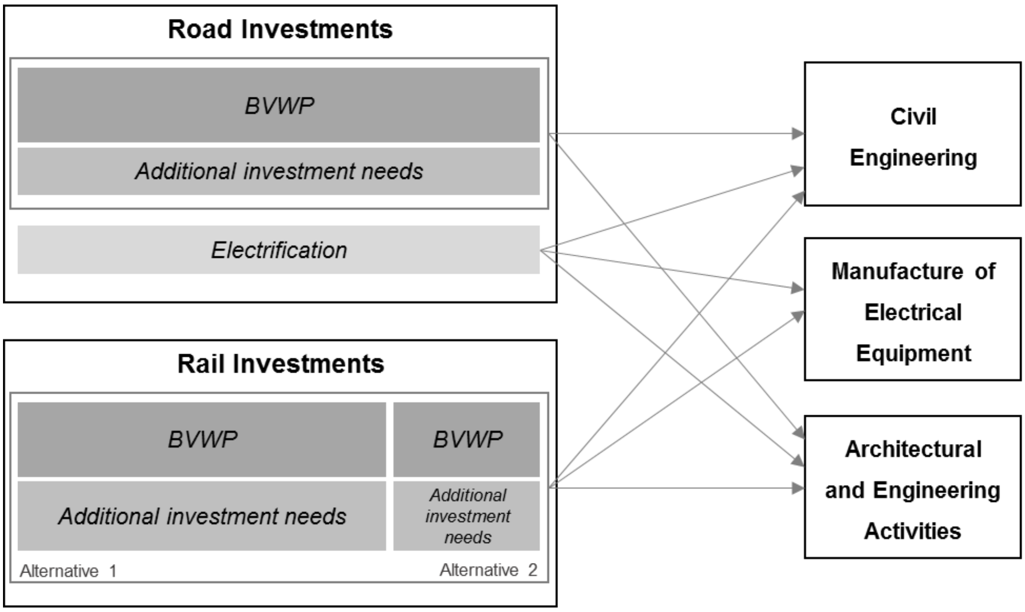

Figure 29: ***Allocation of rail/road investments to Industries***

In order to assess the economic impacts of the estimated investment needs, the annual investments in the BAU scenario are spread equally over the period 2015 to 2050. Assuming additional measures to be implemented from 2020 onwards, the annual investments 2015 to 2019 in the four scenarios Pro Rail, Mod Rail, Mod Road and Pro Road are set equal to the average investments in the BAU Scenario. The remaining, total investment needs in each of the scenarios are then spread equally over the period 2020 to 2050.

Concerning investments in rail infrastructure, the preceding chapters differentiated between two possible types of investments. Major rail network capacity increases can either be achieved through large scale investments in new tracks or lines, or by upgrading the existing network with a multitude of smaller measures. These may include passing lanes, industry sidings, gap closures, level-free crossings, etc. In order to assess the composition of total rail investments regarding the shares of small and large measures, respective estimates of Deutsche Bahn AG reported in Holzhey (2010) are consulted. He estimates that for a doubling of rail capacity in the German network the following measures need to be taken:

- Immediate programme for port hinterland traffic: 305 million euros
- Growth programme (small and medium sized measures): 2 100 million euros
- General investment plan (large scale measures): >20 000 million euros

We can thus conclude, that of the 22 400 million euro investment programme 89% go into large-scale investment measures. The remaining 11% may be spent for small and medium sized upgrading activities. We assume the same proportion of small and large measures for the studied period.

The estimated investments in road infrastructure include the development and construction of new lanes, nodes and parking facilities, as well as the strengthening of bridges for higher traffic volumes. Additional to the estimated investment needs, a possible electrification of the highways is considered. The investment needs for highway electrification are split into new investments and replacement investments.

New investments: Wietschel et al. (2017) figure the costs of electrification at € 2.2 million per highway-km (BAB-km). A full extension of the German highway grid would mean the electrification of 5,000 highway-km which leads to total investment costs of € 11 billion (without discounting, price increases and expansion of the highway grid). Since the equipment of the highways with overhead wires as well as companying measures need to precede the transition of the vehicle fleet of logistics companies, we assume a finalization until 2030. The annual investment needs amount to € 1.1 billion for the entire German grid and € 188 million for NRW in the period 2020 to 2030.

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

Maintenance and servicing: According to a study on rail electrification in Bavaria (Müller 2017), maintenance costs of catenaries may range between 13% and 17% of capital investments. Applying this ratio to the current case of motorway catenary infrastructures, we receive 165 million euros (for Germany) and 28 million euros (for NRW) p.a. for 2020 to 2030. For 2030 to 2050 the figures are 41 (for Germany) and 7 (for NRW) million euros per annum. Maintenance and servicing costs of motorway electrification are taken into account since the real life time of this new type of infrastructure cannot be estimated with sufficient certainty yet.

No roadside facilities or IT infrastructure are considered for fully autonomous driving in 2050, but the system requires 5G data submission standard to be fully available. The respective investment and maintenance costs will be covered by mobile communications companies and thus do not appear in social cost accounting.

Scenario	Cost item	Period 2020-2030 (M€/a)		Period 2030-2050 (M€/a)	
		DE	NRW	DE	NRW
Pro Road	*HO trucks catenary investments*	*1100,0*	*188,0*	*275,0*	*47,0*
	HO trucks catenary maintenance	*165,0*	*28,2*	*41,3*	*7,1*
	Total Electric Facilities	1265,0	216,2	316,3	54,1
Mod Road	Total Electric Facilities	632,5	108,1	158,1	27,0
BAU, Pro Rail, Mod Rail	Total Electric Facilities	126,5	21,6	31,6	5,4

Table 13: ***Additional investment costs for electrified motorways (Fraunhofer ISI)***

Merging the different investment needs in each of the scenarios leads to the total investment needs. In order to transform those investment needs into investment impulses, the difference between BAU investments and the investments in the scenarios is taken. Figure 30 shows the investment delta. The investment delta is positive in all scenarios apart from the Mod Rail scenario. Among the others with positive investment deltas, the Pro Road scenario requires the highest additional investment. The delta to BAU is zero which means that the BAU scenario is treated as the usual development path in the ISI-Macro environment. The drops in 2030 in the Mod Road as well as the Pro Road scenario arise from changing costs of road electrification before and after 2030.

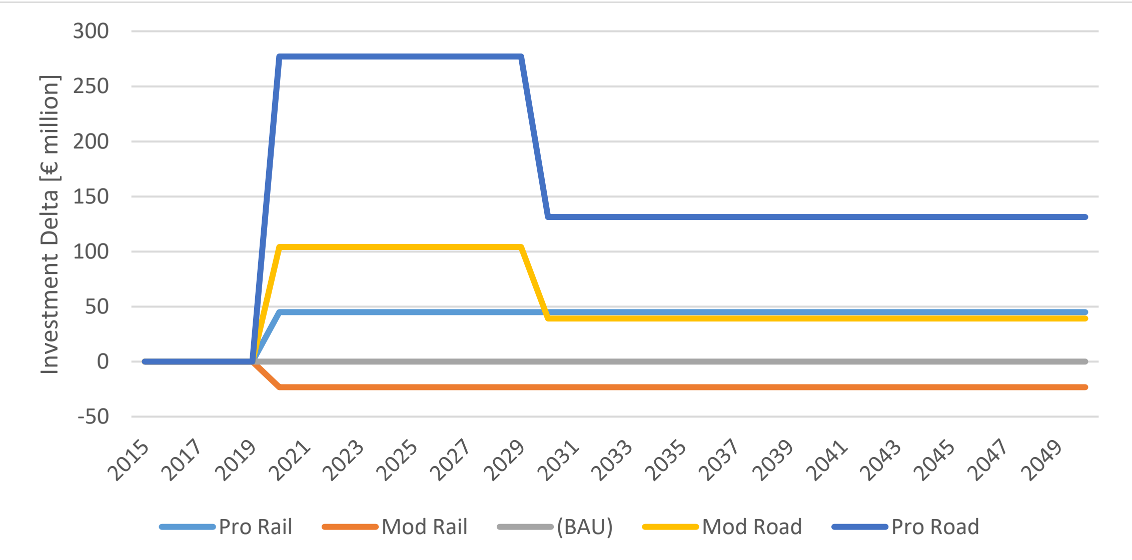

Figure 30: ***Total Investment Delta (Rail+Road Invest) to BAU per Year (Fraunhofer ISI)***

The calculated investment deltas or impulses are fed into the model via split investment impulses to different sectors as outlined in Figure 29. According to the scenario definitions, BAU, Pro Rail and Mod Rail get 10% of additional electrification and IT equipment of Pro Rail and Mod Road receives 50% of it. We first estimate annual investment needs for the periods 2020 to 2030 and 2030 to 2050 for German in total. These are then broken down to NRW by the state's share of motorway infrastructure: 17% (VIZ 2018).

In order to study economic impacts, the investments are considered to behave as impulses to the sectors civil engineering, electric equipment as well as architecture and engineering. As described above, 80% of the initial investment needs are considered impulse to civil engineering while 20% are distributed to architectural and planning activities. The additional investment needs for electrification of the highways are distributed as following: 40% are considered impulses to electric equipment, 40% civil engineering and 20% architecture and planning measures. For rail, Holzhey (2010) estimates the costs of track upgrading at 12 million euros per kilometre and the cost of electrification of 2 million euros per kilometre. ETCS level 2 implementation costs can be estimated with 300,000 euros per km. Electrification and the train control system together make 16% of total investment costs. 20% of the rail investments are assumed to be planning measures as well. 16% go into electric equipment while the remaining 64% are considered impulse to the civil engineering sector.

For the comparison of possible impacts of the realization of the scenarios in socio-economic terms, the difference in investment needs between the looked at scenarios and the BAU scenario was calculated. We choose full time equivalents (FTE) and gross value added (GVA) as indicators of socio-economic performance. The investment delta in each of the years 2015 to 2050 was used as an investment impulse to answer the question what employment effect as well as gross value added effect the scenarios would have in comparison to the BAU scenario.

9.2 Results from modelling

Figure 31 to Figure 33 show the effects of the investments impulses on employment, aggregated over all industries. The numbers are measured in full time equivalents (FTE) for 2030 and 2050 in all 4 scenarios. The pale bars represent 2030 figures while the bars on the right show figures for 2050. Blue indicates the minimum effect for NRW and orange the gap the maximum effect for NRW. For the calculation of the minimum effects, it is assumed that North-Rhine Westphalian firms carry out construction and upstream works 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 gross value added (GVA) figures for NRW will probably be above the average NRW participation. The total of the stacked bars displays the German effect, which can be interpreted as the maximum effect in NRW, assuming that all measures and upstream works are implemented by regional firms. The displayed percentage points above/below the bars indicate the maximum percentage increase or decrease of employment in NRW.

9.2.1 Effects of road investment delta on employment

Figure 31 displays the distinct employment effects of the estimated investment delta in road infrastructure. The two rail-oriented scenarios Pro Rail and Moderate Rail show negative values in both, 2030 and 2050. The decreases in employment range from the minimum of 323 to the maximum of 1578 in the Pro Rail scenario in 2030. The rail-oriented scenarios focus on a strengthening of rail freight transport by, among other measures, weakening road freight transport. The figures show lower employment in road infrastructure construction compared to BAU since road infrastructure investments are lower in the rail-oriented scenarios than they would be in the BAU scenario.

The investments in road infrastructure in the two road-oriented Pro Road and Moderate Road, in turn, show positive employment effects. Estimated, additional investment needs, on top of the measures defined in the BVWP, imply a positive delta to BAU and thus positive investment impulses. In 2030, employment effects range from a surplus of 292 to 1 422 FTE in the Moderate Road scenario and a surplus of 732 to 3 568 FTE in the Pro Road scenario. Assuming that all measures and upstream works are carried out by North-Rhine Westphalian firms and workers, the additional demand of FTE is corresponds to only 0.06% of total employment in NRW. The big difference between 2030 and 2050 effects mainly arises from the drop in investment impulses in 2030 due to lower highway electrification investments as illustrated in Figure 30.

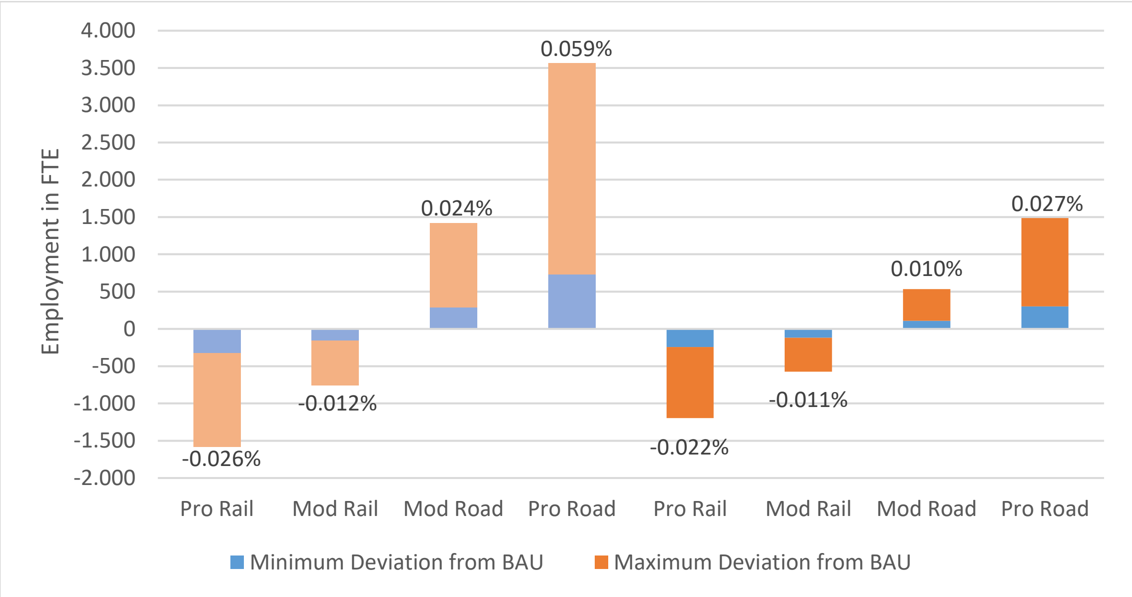

Figure 31: ***Minimum and Maximum Effects of Road Investment on FTE 2030/2050 in NRW (Fraunhofer ISI)***

9.2.2 Effects of rail investment delta on employment

Figure 32 displays the distinct employment effects of estimated additional investment needs in rail infrastructure. It can be seen as the counterpart to the effects of road investments: Rail investments have positive employment effects in the two rail-oriented scenarios Pro Rail and Moderate Rail in 2030 and 2050 and negative employment effects in the two road-oriented scenarios Pro Road and Moderate Road. Estimated additional investments in comparison to BAU create 414 to 2018 additional jobs in the Pro Rail scenario in 2030. In contrast, the employment demand in the Moderate Rail scenario only amounts to a surplus of 78 to 380 compared to BAU. Effects in percentage point remain below the 0.1% mark in both cases. The negative employment effects of the rail investment delta in the two road-oriented scenarios range from -40 to -206 FTE.

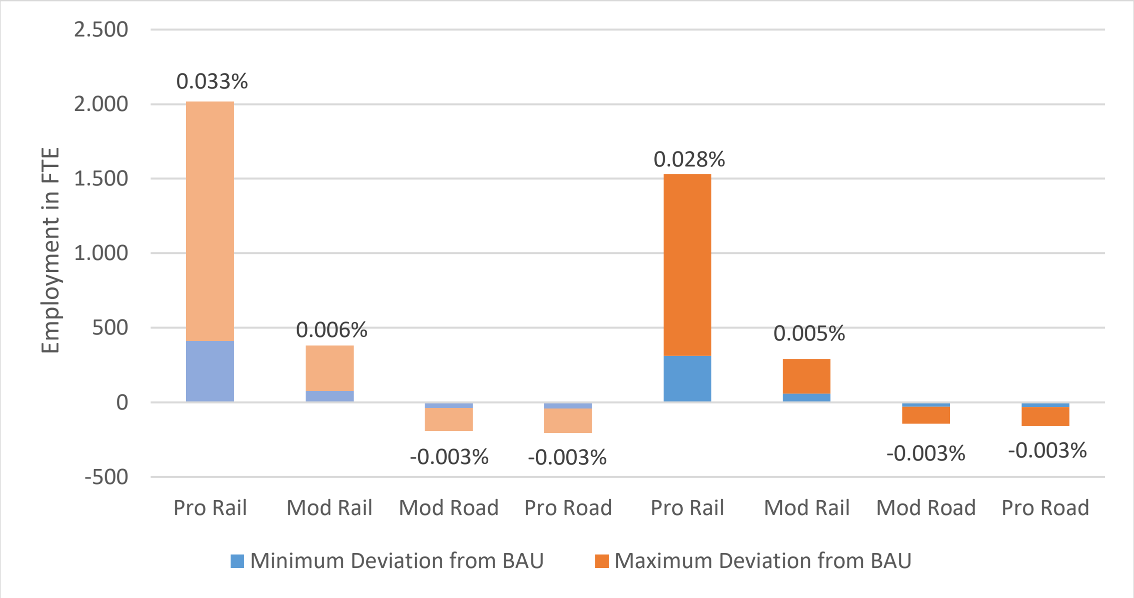

Figure 32: ***Minimum and Maximum Effects of Rail Investment on FTE 2030/2050 in NRW (Fraunhofer ISI)***

9.2.3 Effects of total investment delta on employment and value added

The employment effects of the total investment delta to BAU are provided in Figure 33. Adding up road and rail investment needs and calculating the difference to total BAU investments lead to the investment delta and thus total investment impulse as outlined in Figure 30. Figure 33 shows that employment is affected the most in the Pro Road scenario. In 2030, up to 3 350 additional employees are needed which corresponds to about 0.055% of total employment in NRW. In 2050, the delta to BAU drops to a maximum of 1 320 additional employees. The rail-oriented extreme scenario Pro Rail requires up to 464 additional employees in 2030 and 350 employees in 2050, respectively. Both numbers are below additional employment demand in the Moderate Road scenario, which emphasizes the strong impact of varying road investments due to higher absolute investment impulses. Comparing the investment deltas for road and rail infrastructure in the different scenarios shows, that rail investment deltas in the road-oriented scenarios are close under zero while road investment deltas in the rail-oriented scenarios are far negative. This results in strong negative employment effects from road investment deltas in the rail-oriented scenarios. These negative employment effects could be compensated by positive employment effects from rail investment deltas. However, only in the extreme Pro Rail scenario, the additional rail investment deltas are high enough to compensate for the losses from road investment deltas and result in positive employment effects up to 500 FTE in 2030. The Moderate Rail scenario suggests absolute negative employment effects compared to BAU.

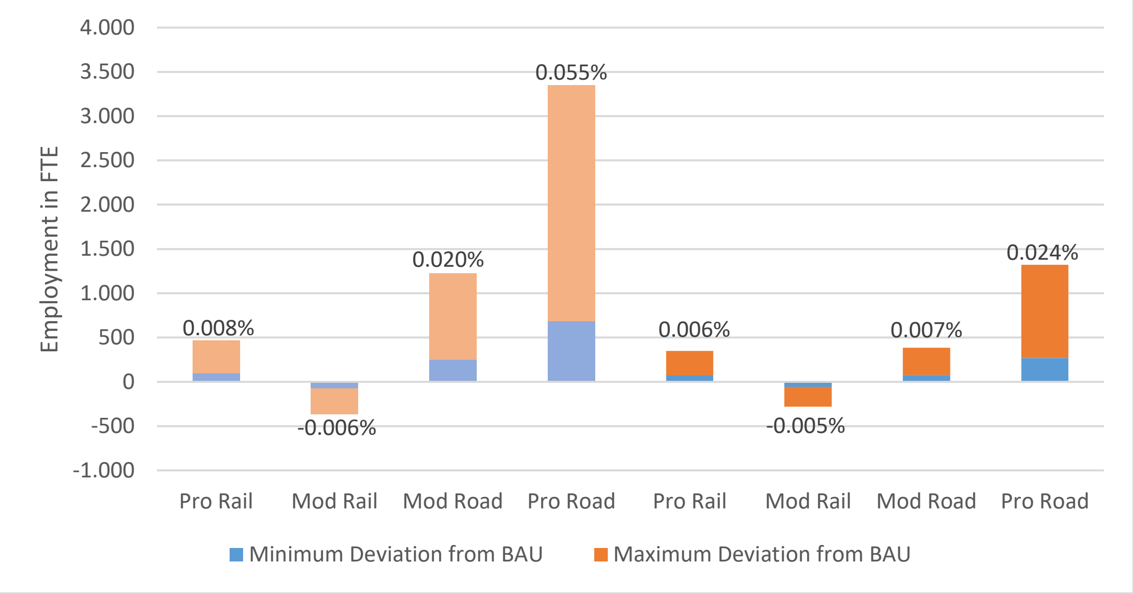

Figure 33: ***Minimum and Maximum Effects of Total Investment on FTE 2030/2050 in NRW (Fraunhofer ISI)***

Apart from employment effects the model ISI-Macro also allows to estimate the impacts of investment impulses on gross value added (GVA). Figure 34 shows the effects in million euros. The figures for GVA have the same characteristics as the figures for FTE effects. GVA in the Pro Road scenario in 2030 gains by far the most surplus. Moderate Road as well as Pro Rail scenarios result in smaller positive values while the effect on GVA in the Moderate Rail scenario results in negative values compared to BAU. The diagrams for distinct rail and road investment also resemble Figure 31 and Figure 32 and are not presented explicitly.

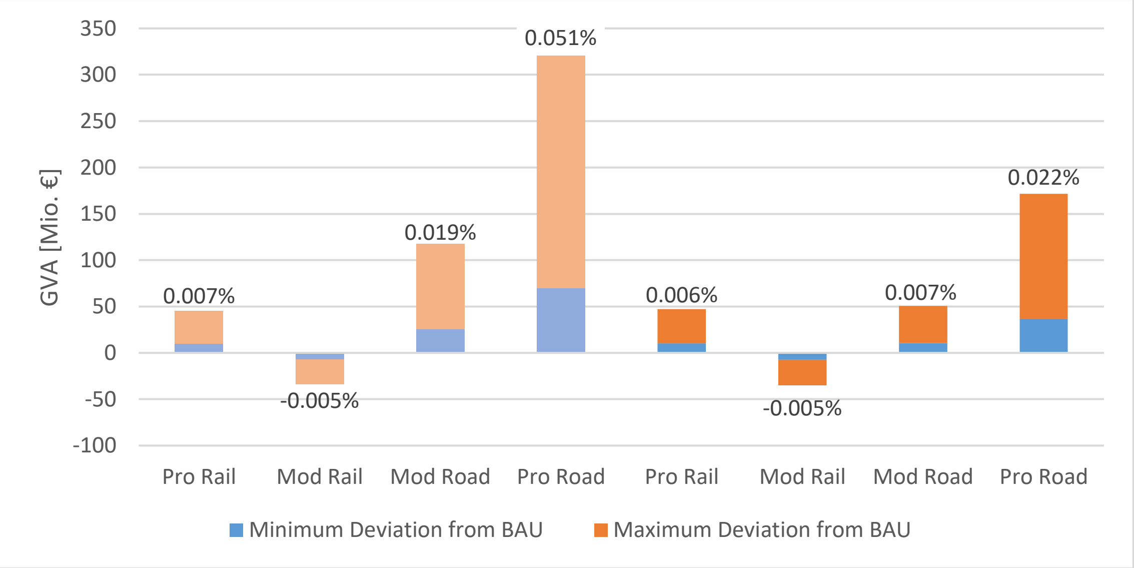

Figure 34: ***Minimum and Maximum Effects of Total Investment on GVA 2030/2050 in NRW (Fraunhofer ISI)***

9.2.4 Effects of sectoral employment

So far, the presented figures showed possible effects of investment impulses in infrastructure on FTE/GVA for total NRW economy. In order to assess the shifts in employment and to identify possible re-employment opportunities, a more detailed illustration might give further insights. Figure 35 and Figure 36 map sectoral effects in the Pro Road scenario, where the industries listed in the Input-Output Tables are aggregated into 13 industry-groups. Figure 35 shows minimum and maximum effects of road investment on FTE in the Pro Road Scenario 2030/2050 per industry-group in NRW while Figure 36 presents the same values for rail investments. We chose the Pro Road scenario for illustration since the effects are the biggest and thus better observable. However, the argumentation fits the other scenarios as well on a smaller scale.

As pointed out in Figure 31 to Figure 33, road investments in the Pro Road scenario lead to higher employment than in the BAU scenario whereas rail investments in the Pro Rail scenario result in lower employment compared to BAU. Added up, the total effect is positive: We can expect a surplus of up to 3 500 additional employees in the Pro Road scenario compared to the BAU scenario. This additional employment demand does not only occur within the directly affected industries but also within those industries that provide intermediate inputs. In Figure 35, the biggest additional demand of FTE is in the industry-groups “Manufacturing”, “Construction”, “TradeTransportGastro”, “Commercial Services” and “PublicEducationHealth”. The industry-groups “Manufacturing”, “Construction” and “Commercial Services” include the industries manufacturing of electrical equipment, civil engineering and architectural and engineering activities, respectively, thus much of the change in absolute FTE demand can be related directly to the investment impulses. A majority of effects in the industry-group “TradeTransportGastro” usually arises from trading activities. All industries require traded intermediates, which can explain parts of the shift. The industry group “PublicEducationHealth” includes public services and thus the administrative processes of approval and others. Since this service plays an important role in the planning and implementation of large construction projects, the impulses to construction works affect public services as well. In all cases, higher aggregate demand levels through higher investments in the economy result in higher employment, even though within this scope the effects are expected to be fairly small.

Compared to the average change in total FTE demand in percentage points compared to the BAU scenario, the industry-groups "Mining", "Construction" and “Commercial Services” show the only higher share. "Construction" and “Commercial Services” are affected directly by the investment impulses. "Mining" is one relatively big supplier of the construction sector, which might be why the investment impulse also induced a comparably high effect on FTE in "Mining". Even though represented by a small bar as well, the subgroup "Real Estate" shows an at least average value for percentage change of FTE.

In all cases, the 2050 values lie below the 2030 effects. For road investments’ impacts on FTE, this can partly be explained by decreasing estimated investment needs for road electrification after 2030. For both types of investments, road as well as rail, increasing labour productivity, assumed in the macroeconomic core of the model ISI-Macro, drives lower FTE effects in 2050.

Figure 36 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 explanation follows the same arguments. In all industry-groups, the negative employment effects from rail investments are more than compensated by the positive effects of road investments, resulting in a surplus of aggregate employment demand in the Pro Road scenario.

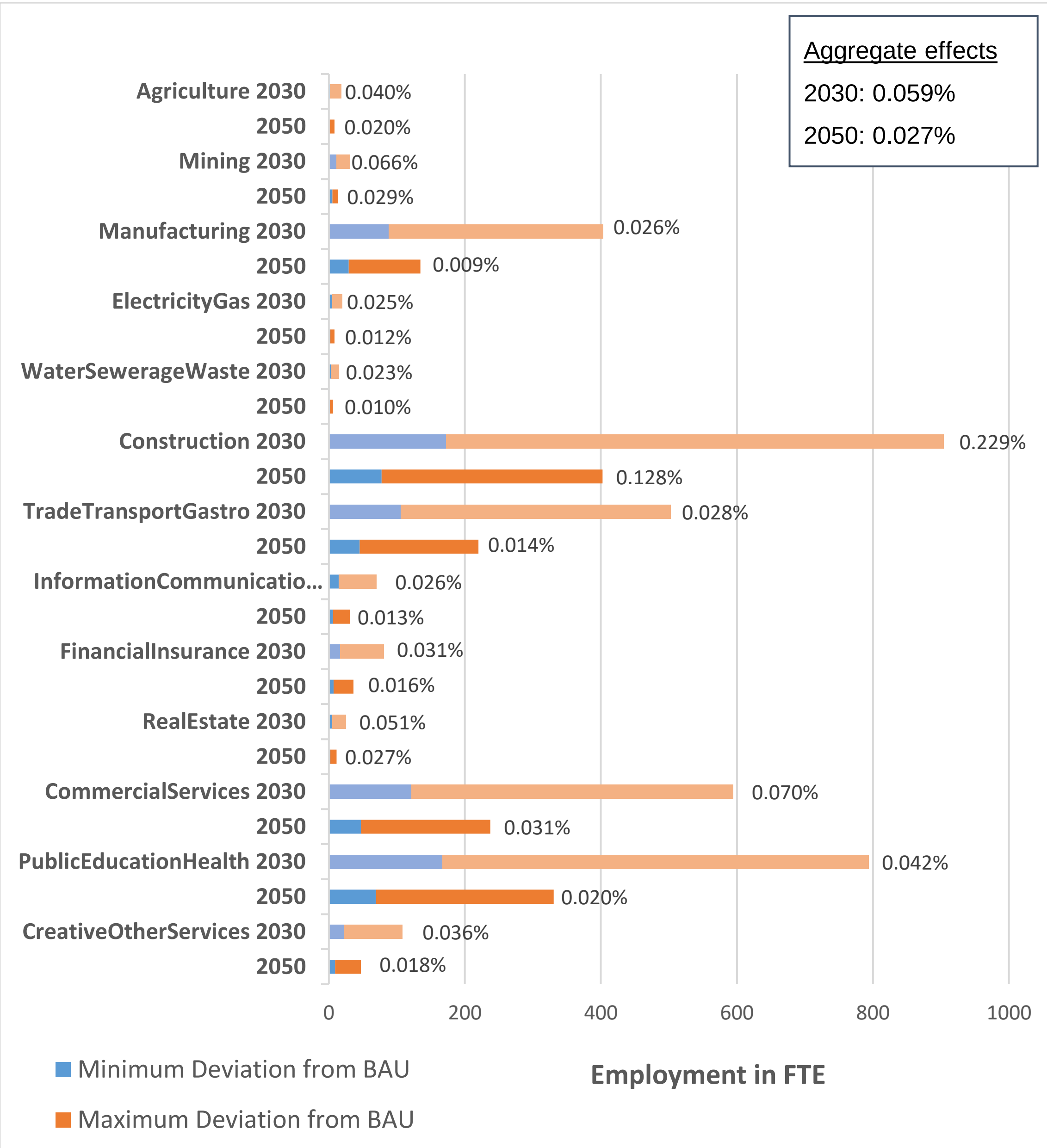

Figure 35: ***Minimum and Maximum Effects of Road Investment on FTE in the Pro Road Scenario 2030/2050 per Industry Group in NRW (Fraunhofer ISI)***

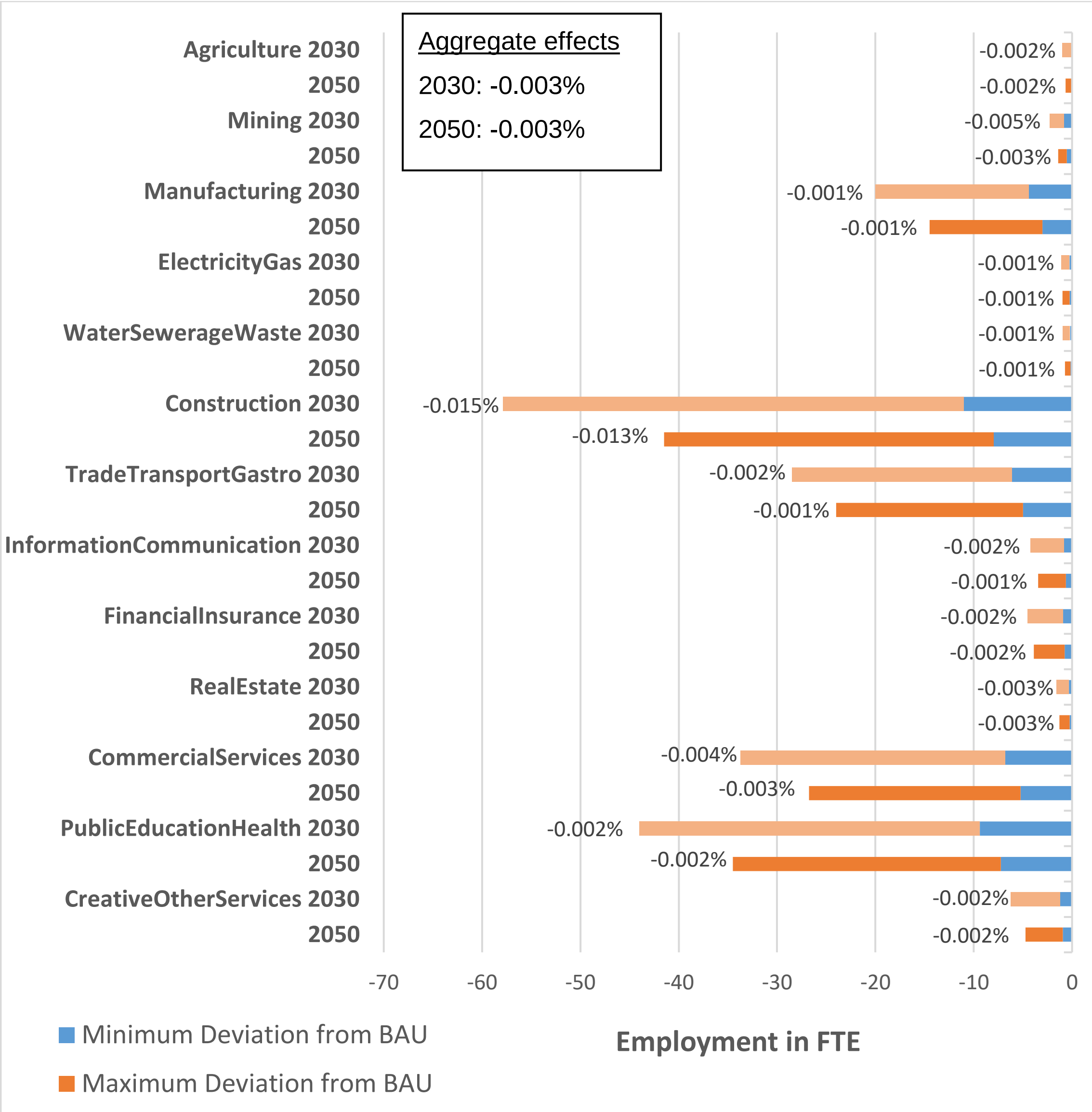

Figure 36: ***Minimum and Maximum Effects of Rail Investment on FTE in the Pro Road Scenario 2030/2050 per Industry Group in NRW (Fraunhofer ISI)***

9.3 Interpretation

This section gives a rough estimation of possible socio-economic impacts through changing investment needs. The effects were assessed via investment impulses, calculated as the delta between the four different scenarios and the BAU scenario. Thus, all figures gave an impression of the additional effects in comparison to BAU and represent a starting point to evaluate the feasibility of the scenarios.

The straightforward construction of the impulses considers only parts of the interrelation between the involved industries and presents gross effects. The estimation of net effects, taking into account effects of substitution as well as price effects, might lead to even lower values. Overall, the investment impulses resulted in small maximum changes to FTE and GVA in NRW below 0.1%. The values represent an upper limit of infrastructure investment need by assuming that all additional FTE demand/GVA for Germany will be met or generated, respectively, in NRW. Since even the upper limit effects remain small, the additional demand of FTE in the scenarios seems attainable despite the tight job market. Effects on GVA are either positive or proximal zero. None of the both indicators represents a strong argument against the implementation of the infrastructure needs of the LowCarb-RFC scenarios from the socio-economic viewpoint.

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

Eventually we conclude, that the comparison and possible assessment of the scenarios should not be driven by the socio-economic effects but rather from technical, organisational as well as environmental perspectives.

10 Environmental and safety aspects

In the previous sections of this working paper, we have demonstrated which enormous efforts in terms of planning and funding are needed to implement major mode 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 is first of all 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 LowCarb-RFC Working Paper 8 (Sieber et al. 2018). But, taking account of current developments in impact assessment literature, we updated the methods and values where needed. The results are thus not directly comparable to those in working paper 8.

10.1 Scope

As in the impact assessment for the European freight corridors in (Sieber et al. 2018), we focus on the main drivers of the external costs of transport:

- **Climate impacts** from fuel combustion, oil extraction, transport and processing, and from electricity generation. Other climate gases like methane (NH_4) or nitrous oxide (N_2O) are not considered.

- **Air pollution** from nitrogen oxides (NO_X) and from particles of several diameters (PM_{10}, PM_{Coarse} and $PM_{2.5}$). Other substances like sulphur dioxide (SO_2) or non-methane volatile organic compounds (NMVOC) are disregarded due to their limited weight in the exhaust fume cocktail.

- **Noise impacts** from engine emissions and from tyres and wheels on roads and rail tracks. Working noise from loading or unloading of trucks, from transhipment stations or at marshalling yards is not considered.

- **Traffic accidents**, including fatalities, severe and slight injuries inflicted by trucks. Due to their very low number, rail and shipping accidents are considered to be and to remain zero. Non-transport related incidents on company yards or at rail facilities are allocated to the production sector. Material damages are not considered as they are usually fully covered by insurance premiums.

We also exclude infrastructure-related externalities form the construction phase and for biodiversity and habitat losses. To qualify these impacts more detailed infrastructure scenarios as provided here would be needed. Moreover, the overall size of these impacts is limited compared to the four main impacts listed above.

We consider two levels of impacts: physical impacts and environmental 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 finally feed into investment cost efficiency indicators.

10.2 Method and unit values

10.2.1 Climate change impacts

The Special Report on Global Warming of 1.5°C of the International Panel on Climate Change (IPCC 2018) highlights the huge investments of 2.5% of global gross domestic product (GDP) to reduce net emissions substantially to 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 sector literature.

For CO_2 the Methodology Convention 3.0 nearly doubled its recommendations compared to the Methodology Convention 2.0 (UBA 2012). Values are largely based on the avoidance cost approach as damage estimates show much wider uncertainty ranges. Given that cheaper adaptation measures get more scarce over time, cost values per ton of CO_2 considerably rise between now and 2050. The progression of values proposed in the Methodology Convention 3.0 is, however, less steep compared to the Methodology Convention 2.0. The revised 2050 CO_2 emission unit costs are then lower than the central estimates for 2050 in the Methodology Convention 2.0 (UBA 2012). The following values are used (values of the Methodology Convention 2.0 in brackets):

- 2015: 180 €/t (80 €/t)
- 2030: 205 €/t (145 €/t)
- 2050: 240 €/t (260 €/t)

Emission factors have been used 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% of up- and downstream emissions for oil extraction, transportation and refinery have been added. For electricity based emissions the power plant mix and respective emission factors as 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).

10.2.2 Air pollution costs

Air pollution unit costs for NO_X, PM_{10}, PM_{Coarse} and $PM_{2.5}$ have again been 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. This is because atmospheric transmission pathways differ by substance and as emitters vary strongly in the composition of particle in their exhaust fume. In transport, direct exhaust emissions as well as abrasion from tyres and brakes from heavy trucks above 3.5 t of gross vehicle weight on motorways are considered. Besides for NO_X, the values are considerably lower than in the 2012 edition, which is largely due to the spatial context. Here we used the road category “unknown”, which is somewhat between suburban and motorways. For the dense motorway network in NRW this category seems appropriate. As in the section above, the below list shows the unit costs used here, with those used in Sieber et al. (2018) in brackets.

- NO_X: 15 000 €/t (15 400 €/t)
- PM_{10}: 6800 €/t (11 000 €/t)
- PM_{Coarse}: 1000 €/t (2900 €/t)
- $PM_{2.5}$: 59 700 €/t (122 800 €/t)

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

10.2.3 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 an aggregated approach as followed in this work. The Methodology Convention 3.0 (UBA 2018), moreover, does not provide unit costs per vehicle kilometre. Therefore, and given the small overall importance of noise costs in an interurban context, we apply the vehicle-kilometre-specific average cost values from UBA (2012). These are:

- Rail: 0.54 €/train-km (diesel and electric)
- Road: 0.0126 €/HGV-km for diesel propulsion and 0.0116 €/HGV for HO trucks

For barges, no noise costs have been assumed. 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.

10.2.4 Traffic accidents

Fatalities as well as severe and slight injuries are assessed using international studies in 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:

- Fatality: 2 220 000 €/casualty
- Severe Injury: 307 100 €/casualty
- Slight injury: 24 800 €/casualty

Accident rates for 2050 are taken from statistics of the German Highway Institute. Considered are incidents on motorways, mainly inflicted by heavy trucks. Accident rates are assumed to decline to 20% 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 here.

10.3 Results

10.3.1 Climate gas emissions

Climate gas emissions are represented by carbon dioxide (CO_2) in this paper. Applying the traffic scenarios in Chapter 2.3 and the emission factors as discussed above we find that total CO_2 emissions of the two corridors Rhine-Alpine (RALP) and North Sea-Baltic (NSB) on North Rhine-Westphalia territory account for 2.6 Mt in 2015, and climb up to 2.8 Mt in BAU 2050. Across all scenarios, emissions are dominated by road and inland waterway transport (IWT) in all scenarios. Figure 37 presents the results of the CO_2 emission calculation by mode for all scenarios, 2015, 2030 and 2050.

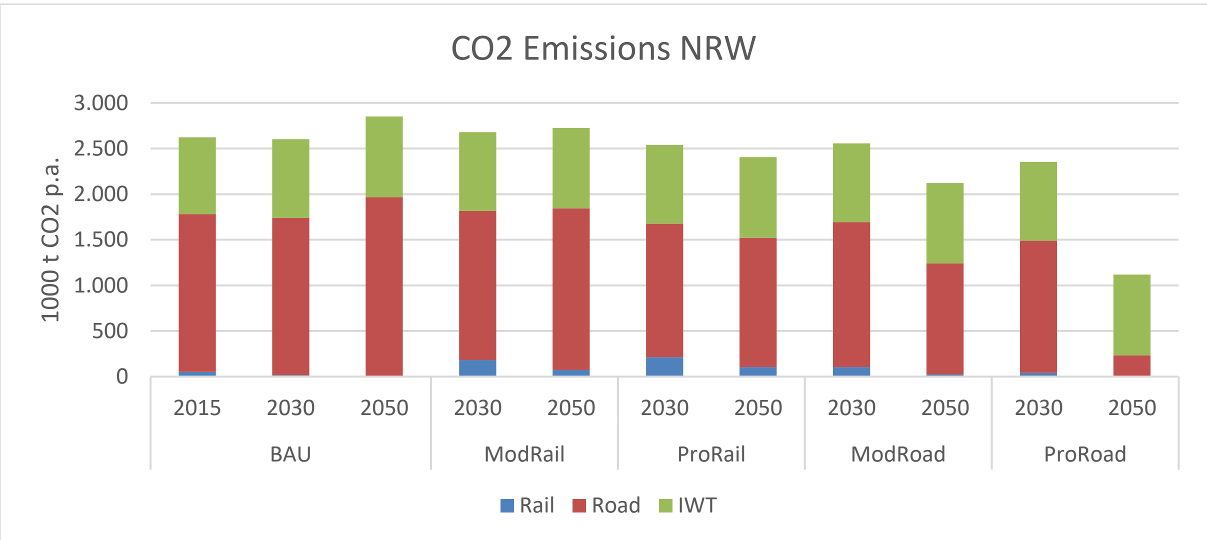

Figure 37: ***Carbon emissions NRW by mode, scenario and year (Fraunhofer ISI)***

We find the following results:

- In the BAU scenario, efficiency improvements and mode shit effects manage to limit total CO_2 emissions to -1% (2030/2015) and +9% (2050/2015).
- Besides the 2050 values of the Mod Road and Pro Road scenarios, total CO_2 emissions in all other cases are found in a +/-10% corridor around 2015 emissions. This finding is critical as it suggests that with conventional policies major cuts on carbon emission cannot be expected. It is, at the same time, positive as it indicates that we can at least stabilize emissions around current levels.
- The cases with deepest CO_2 cuts are the 2050 results for the Mod Road scenario with -19% and for Pro Road with -57%. As for the international corridors, this result indicates that a substantial mitigation of CO_2 emissions is only possible if the major emission contributor itself, i.e. road haulage, is addressed. Indirect measures like shift of demand to more climate friendly modes, seem to be less effective.
- As revealed for the corridor studies in Sieber et al. (2018), also for NRW, inland waterway transport is a major factor of CO_2 emissions. The more road and rail emissions decline, IWT emissions gain weight. Their share increases from 32% in 2015 to 79% in Pro Road 2050. Addressing barge emissions with carbon neutral fuels and more efficient engines could thus reduce CO_2 levels against 2015 levels even below -60% to -70% by 2050.
- The results also indicate that shift to rail helps. Against a 9% increase by 2050 against 2015 in the BAU case, the Pro Rail scenario achieves -8%. This is -16% without any technical improvements of HGVs. A combi scenario out of shift to rail, road decarbonisation and IWT improvement should thus allow to achieve deep cuts on long distance freight transport's carbon emissions in NRW and elsewhere across Europe.

Table 14 shows the CO_2 emission estimates in 2050 by scenario and mode of transport.

Scenario	**Unit**	**BAU**	**Mod Rail**	**Pro Rail**	**Mod Road**	**Pro Road**
Rail	1000 t/a	3.8	72.9	104.9	23.3	3.3
Road	1000 t/a	1 962.8	1 770.5	1 416.4	1 216.9	230.8
IWT	1000 t/a	882.8	882.8	882.8	882.8	882.8
TOTAL	1000 t/a	2 849.4	2 726.2	2 404.2	2 123.0	1 116.9
Diff. to BAU			-4.3%	-15.6%	-25.5%	-60.8%

Table 14: ***Carbon emissions from freight transport in NRW, 2050 (Fraunhofer ISI)***

10.3.2 Environmental and safety costs

On NRW territory, the two corridors RALP and NSB cause environmental and social costs of 750 million euros in 2015. Driven by rising traffic volumes, efficiency improvements and unit cost developments, annual costs climb up to 891 million euros (+19%) in BAU 2050. Details across all scenarios are shown in Figure 38.

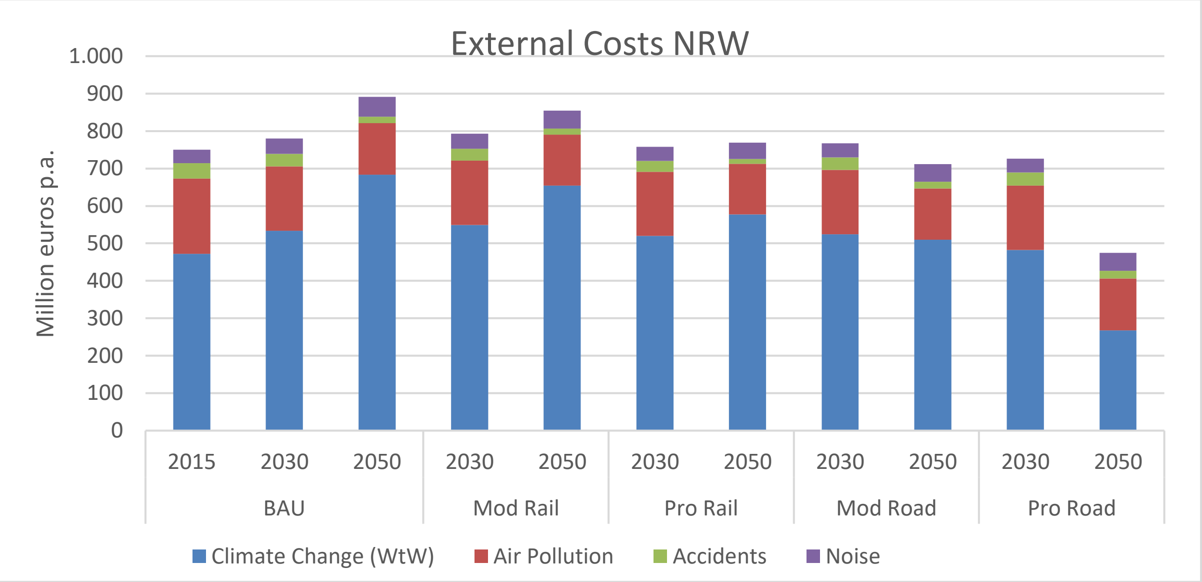

Figure 38: ***Environmental and safety costs NRW by cost category and scenarios (Fraunhofer ISI)***

Across all four cost categories, the dynamics of environmental and safety costs is somewhat less expressed than for CO_2 emissions. Against the 2015 level, rising CO_2 unit costs cannot be compensated by falling accident rates. In the strongest case of declining environmental and safety costs, the Pro Road 2050 case, social costs are 47% below their 2015 level.

The costs of carbon emissions dominate environmental and safety costs. Besides the Pro Road scenario, the share of the cost category climate change ranges between 63% in 2015 and 77% in 2050. This is because climate change unit costs per ton of CO_2 rise over time as discussed in Section 10.2.1. In 2015, air pollution accounts for 27% of total costs, while accidents and noise each contribute 5%. In BAU 2050 the shares evolve to 15%, 2% and 6% respectively.

Road holds the largest share of environmental and safety costs in the BAU, Pro Rail and Mod Rail scenarios. This diagnosis is in line with the estimated carbon emissions in Figure 37. In 2015, environmental and safety costs are attributable to transport modes as follows: 2% rail, 52% road and 46% IWT. In BAU 2050 the share of road increases even to 61% of total costs. In Pro Rail 2050, HGVs still contribute 48% of environmental and social costs, while rail, due to massive modal shifts from road and IWT, takes 7% of the cost burden.

In the Pro Road scenario 2050, road's share at environmental and safety costs is expected to shrink to 28% with no measurable cost share of rail. IWT in this case is then responsible for the lion's share of 72% of costs. This is not surprising as for barges only marginal technical improvements are foreseen, against a nearly complete decarbonisation of trucking and rail transport. Table 15 summarises absolute costs in the 2050 scenarios by mode of transport.

Scenario	Unit	BAU	Mod Rail	Pro Rail	Mod Road	Pro Road
Rail	Mill. €	9.9	26.4	38.0	8.4	1.2
Road	Mill. €	539.7	486.9	389.5	361.6	132.0
IWT	Mill. €	341.6	341.6	341.6	341.6	341.6
TOTAL	Mill. €	891.1	854.8	769.1	711.6	474.7
Diff. to BAU			-4.1%	-13.7%	-20.1%	-46.7%

*Table 15: **Environmental and safety costs from freight transport in NRW, 2050 (Fraunhofer ISI)***

10.3.3 Cost efficiency ratios

After having computed the savings in climate gas emissions and in the social costs due to environmental and safety impacts we now compare these figures to the investment impulses needed to adapt the 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 investment needs for the years 2030 and 2050. We differentiate between the two periods, because the investment impulses develop between the periods as well. Table 16 presents the results for environmental and social cost efficiency (= cost savings by investments) and of climate mitigation costs (= investments per ton of CO_2 saved).

Scenario	Unit	Mod Rail		Pro Rail		Mod Road		Pro Road	
Year		2030	2050	2030	2050	2030	2050	2030	2050
Investments (diff. to BAU)	Mill. €	-23.2	-23.2	45	45	104.1	39.2	277.1	131.2
Env./safety costs (savings to BAU)	Mill. €	-12.4	36.3	35.2	85.8	-10.0	57.5	41.4	236.9
Env./safety benefit ratio [1)]		54%	-157%	78%	191%	-10%	147%	15%	181%
CO2 emissions (savings to BAU)	1000 t	-78.2	123.1	142.8	322.0	-19.2	281.2	203.0	1006.1
CO2 mitigation costs [2)]	€/t CO2	297	-188	315	140	-5427	139	1365	130

*Table 16: **Environmental/safety cost and climate mitigation efficiency, NRW, 2030-2050 (Fraunhofer ISI)***

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

Unlike the corridor studies, investment impulses against BAU are negative in some scenarios for NRW. 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 other cases, namely Mod Rail 2050 and Mod Road 2030, CO_2 emission and environmental and safety cost savings are negative as well. I.e. total costs in the scenario case exceed the BAU costs in the respective years. Different signs for investments, emissions and environmental/safety costs then imply negative mitigation cost 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% for the rail projects and above 100% for the road projects. CO_2 mitigation costs, in contrast, show a very different picture with no clear tendencies. By far the highest positive values is observed for Pro Road 2030: 1365 €/t CO_2. The same scenario, Pro Road 2050, then also provides the lowest positive value: 130 €/t CO_2.

We can conclude, that the average order of magnitude of CO_2 mitigation costs is in line with the corridor findings, but their structure needs further interpretation. Negative signs with mitigation costs and benefit efficiencies in fact demonstrate, that under some circumstances savings in infrastructure costs can come hand in hand with environmental protection and more safety. The results, however, also suggest that this happens only with comparably small changes in investment activities. For both scenarios, Pro Rail and Pro Road, declining burdens and higher investments seem to be coupled.

10.4 Discussion

In this section, we computed carbon emissions and the economic costs of climate change, air pollution, noise and accidents according to the methodology applied for the European freight corridors in Sieber et al. (2018), but with updated values. The update of 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 in the present years, against lower climate costs towards 2050 and lower economic impacts of particle emissions.

This shift in unit values is in line with the recent IPCC report in 1.5°C. Given the long term and global relevance of global warming and the high likelihood to fail agreed targets, this shift in priorities in sustainability assessment can be appreciated.

In terms of air emissions, the methodology applied in this section takes some short cuts. First, emission rates of fuel combustion are kept constant at Euro-VI emission standards. The guiding thought behind this simplification is that political priorities shift wards CO_2 reduction and that vehicle manufacturers curb research activities in engine development in the light of power train electrification. For the shipping sector, this assumption is potentially over-simplistic.

The second short cut in estimating air pollution costs is to exclude CO, SO_2, NMVOC other substances. We do not consider this a major problem as NO_X and PM are commonly acknowledged as lead substances for environmental impact assessment.

The carbon mitigation cost and environmental and safety cost efficiency indicators derived in this section draw a positive, but somehow complex picture. In contrast to the corridor analyses, the results for NRW show that under certain conditions GHG mitigation costs can get negative. Savings in GHG emissions can, in these cases, come along with lower infrastructure investment costs. The same holds true for the environmental and safety cost efficiency: savings against BAU with lower investment costs. In Pro Rail and Pro Road 2050 savings are found nearly twice as high than additional investment costs. Interestingly, in the NRW case the superiority of Pro Road over Pro Rail is way less expressed compared to the corridor analysis.

11 Recommendations

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 report 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 the following.

11.1 Investment needs for NRW

In Chapters 7 and 8 of this report, we described and assessed infrastructure investment scenarios for North Rhine-Westphalia in the periods 2020-2030 and 2030-2050. We found no large differences in the net investment needs until 2030 compared to the BAU scenario, but considerable differences towards 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 too low already, but will be 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 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 high 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. 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 until 2030,

but by €2.8 billion between 2030 and 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.

11.2 Economic and social impacts for NRW

Analysing the macro-economic impacts of modal shift and road electrification measures in North Rhine-Westphalia in Chapter 9 yielded the following encouraging results:

1. **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% 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.
2. **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.
3. **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.

11.3 Environmental impacts for NRW

Chapter 10 picked up the transport scenarios from chapter 2.3 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:

1. **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% in 2015 and 77% in 2050. This is because the social costs per ton of CO2 rise over time and because it is easier to tackle air pollution and safety issues through technical measures including clean fuels, electrification and automation.
2. **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 €/t to 140 €/t of CO2-equivalent in the period 2030 to 2050. These costs are below those for solar (700-1000 €/t) or heat pumps (up to 500 €/t), and similar to wind power (100-150 €/t) (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.

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14 List of abbreviations

ADAC	Allgemeiner Deutscher Automobil Club (General German Automobile Club)
BAB	Bundesautobahn (Federal Highway)
BaSt	Bundesanstalt für Straßenwesen (Federal Highway Research Institut)
BAU	Business-as-usual
BVWP	Bundesverkehrswegeplan (Federal Transport Infrastructure Plan)
CEF	Connecting Europe Facility
CO_2	Carbon dioxide
DB AG	Deutsche Bahn AG
DK	Denmark
ETCS	European Train Control System
eTEN	Trans-European Telecommunications Network
FD	Fest disponiert (Fixedly disposed)
FTE	Full Time Equivalents
GDP	Gross Domestic Product
GHG	Greenhouse Gas(es)
GVA	Gross Value Added
Hbf	Hauptbahnhof (Central station)
HBS	Handbuch für die Bemessung von Straßenverkehrsanlagen (Guidelines for dimensioning road traffic facilities)
HGV	Heavy goods vehicle
HO truck	Hybrid overhead line truck
IRP	Investitionsrahmenplan (Capital investment framework)
IWT	Inland Waterway Transport
LB	Lower bound
LowCarb-RFC	Low Carbon Rail Freight Corridors
LST	Leit- und Steuerungstechnik (Control and safety technology)
Mt	Mega-ton(s) (million tons
NH_4	Methane
NI	Niedersachsen (Lower Saxonie)
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous oxide
NO_X	Nitrogen Oxides
NRW	Nordrhein-Westfalen (North Rhine-Westphalia)
NSB	North Sea-Baltic Corridor
$PM_{2.5}$	Particulate matter, diameter less than 2.5 µm
PM_{10}	Particulate matter, diameter less than 10 µm
PM_{Coarse}	Particulate matter, diameter above 10 µm
RALP	Rhine-Alpine Corridor

SH	Schleswig-Holstein
SO_2	Sulphur Dioxide
TEN Energy	Trans-European Energy Network
TEN-T	Trans-European Transport Network
UB	Upper bound
VB	Vordringlicher Bedarf (Priority need)
VB-E	Vordringlicher Bedarf – Engpass (Priority need – bottleneck)
ZARA	Zeebrügge, Antwerp, Rotterdam and Amsterdam

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