LowCarb RFC - European Rail Freight Corridors Going Carbon Neutral

Working Paper 7: The assessment of different future freight transport scenarios for Europe and the North Rhine-Westphalia region

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Contents

Table of figures

Table of tables

1. Introduction

Since publication of the EC's Freight Freeway concept in the 1990s, countless model applications have run scenarios on how the overall performance of the European transport sector and in particular the market shares of rail can be enhanced. The present working paper on the one hand remains with that tradition as it computes the mode shift and climate impacts of several road and rail improvement scenarios along two major European corridors. On the other hand, the modelling task goes deeper into freight market characteristics by applying a chain transport model developed at TPR of the University of Antwerp to long distance port hinterland transport flows.

1.1 Context: The LowCarb-RFC project

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

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

- **Stream 1: European Scenarios and Impacts**. For rail, road and waterway transport along the two corridors, cost and quality, scenarios are established and their impact on modal split, investment needs and sustainability are modelled. This stream is the analytical core of the study and shall provide the basis for the subsequent analysis of pathways of interventions.
- **Stream 2: Railway Reforms and Institutional Change**. It 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 down the transport scenarios and intervention pathways to the local conditions in NRW and looks at the implications for investments or de-investments in certain infrastructures, jobs, economic prosperity and the environment.

1.2 Purpose of this working paper

The present working paper feeds into Stream 1 of the LowCarb-RFC study by providing the transport market and basic GHG impact assessment tool. Its main purpose is to provide a method and a set of indicators to assess alternative scenarios against a baseline scenario (business as usual) to study this mode shift potential and its contribution to climate change mitigation. The method needs to be applicable to the main freight corridors crossing Germany and, in particular, the federal state of North-Rhine-Westphalia (NRW). The two main considered European Commission's Rail Freight Corridors in this project are:

- RFC no 1: Rhine-Alpine (RALP) from Antwerp/Rotterdam via Duisburg and Basle to Genova and the southern branch of the RFC.
- RFC no. 8: North –Sea-Baltic (NSB) from the Dutch/Belgian seaports to Poland and the Baltic states. This study only considers its western part to Poland.

The method should allow assessing different scenarios in which conventional rail improvement and policy packages are considered, including emerging industry and technology trends as well as completely new transport solutions. In the project, two scenarios are developed: a Pro road and a Pro rail scenario. As both scenarios go to extremes as concerns cost cuts and quality improvements, a Modest Road and Modest Rail scenario is added.

These different scenarios can have an impact on cost element of either road or rail transport. Also changes in infrastructure (shorter distances when a new railway line is used), different speeds or reliability levels can be one of parameters in a future scenario. Both effects will have an effect on the generalised cost and therefore also on the mode choice. The latter will impact the total preformed ton.km and vehicle.km in NRW.

The main objective of this work package is to:

- Develop a method to assess different scenarios (Business As Usual, Modest rail, Pro rail, modest road and Pro road) for the years 2030 and 2050.
- Determine for the different scenarios and both freight corridors, the change in mode shift, volume and capacity needs on the infrastructure in NRW due to these different scenarios.
- Determine the total greenhouse gas emissions per year for each scenario.

This research paper features seven sub-sections. Section 2 provides a literature review of different freight models. Section 3 describes the developed method. Section 4 shows the used data sources. Section 5 gives the main calculation of the baseline scenario, along with the fitting of the developed model. In section 6 the different calculations are performed to assess the three scenarios in terms of mode shift and GHG saving potentials with constant emission rates. Section 7 gives the conclusions.

2. Literature

The main purpose of this work package is to develop a freight transport model which needs to be able to asses different possible future scenarios. In order to choose or develop such a model an overview of existing freight transport model is given. This section discusses a selected number of references which are relevant for the project.

Tavasszy (2006) gives an overview with a focus on European applications of freight transport modelling. He identifies three main fields:

- Modelling the relationship between transport and economic activity
- Logistics decision-making and processes
- Linking traffic flows and networks.

Meersman and Van de Voorde (2008) deal with the relationship between economic activity and freight transport. They argue that any loss of time due to bottlenecks, coupled with either a temporary or a structural capacity shortage, will affect costs negatively. They conclude that to gain a better understanding of the changing relationship between the economy and freight transport, *disaggregate models are required*. Behavioural models for shippers and carriers can help understand the decision and choice processes determining which goods are moved, in what quantities and by which means (Ben Akiva et al., 2008).

Ben-Akiva and de Jong (2008) state that disaggregate models offer several advantages over aggregate models. Disaggregate models may have a basis in behavioural theory as they may include more detailed policy-relevant variables, while do not suffer from aggregation biases. But there are certain components of a model system that still need to be modelled in an aggregate fashion. Therefore, the authors propose an aggregate-disaggregate-aggregate (ADA) model for freight transport. In the ADA model, the production to consumption (PC) flows and the network model are specified at aggregate level for reasons of data availability. Between these two aggregate components, there is a logistics model that explains the choice of shipment size and transport chain, including mode choice for each leg of the transport chain. *This logistics model is a disaggregate model at the level of the firm, the decision-making unit in freight transport*. (Ben Akiva et al 2008)

Beuthe et al. (2008) present a systematic analysis of stated preference data of alternative freight transport solutions defined by six attributes: frequency of service, transport time, reliability, carrier's flexibility, transport losses, and cost. Nine transport managers from firms in different sectors of industry provided rankings of 25 alternative freight solutions. Four different empirical methods (conjoint analysis, multi-criteria analysis, logit analysis and neural network analysis) were applied separately to each set of rankings. Within this limited cross-section of firms, each of the methods applied shows that seven out of nine transport managers ranked cost factors as the primary consideration in their decision-making process. Although reliability is often considered more crucial than transport time, the relative importance varies from case to case. The other factors played a significant role only in some instances. Altogether, it appears that the better performing methods lead to the conclusion that the utility functions of the decision makers are definitely non-linear. (Ben Akiva et al., 2008)

Tavasszy (2008) states that *time* is a critical input to the process whereby goods and services are delivered to businesses and consumers. In this paper, Tavasszy focuses on the valuation of time gains in transport within the context of social cost-benefit analysis (SCBA) through a "value of time" (VOT) indicator. He addresses the questions of how freight and freight service markets respond to changes in travel time as well as how existing measurement approaches for the VOT can be extended to capture these responses. He argues that the freight logistics system needs to be better understood in order to assess the full effects of transportation improvements. Firstly, a better understanding of freight transport markets (including their imperfections) with perspective to exposing welfare effects additional to those estimated using conventional, travel-time-based SCBA, is required. Secondly, the role of time as a resource, in which time gains can be passed on between agents in the logistics supply chain deserves closer attention. (Ben Akiva et al 2008)

There are many other papers regarding freight modelling. Pauwels (2007) did research on freight transport modelling in Belgium. The author reviews different freight models and develops an application for Belgium. Several papers about freight modeling deal with one single mode of transport (for example Fernández (2004) about rail transport) and about intermodal transport (Vasiliauskas (2002). One main observation is that there are not a lot of papers (research) in which full logistics, including the maritime part, feature.

Tavasszy et al. (2012) give a review of the possibilities of integrating logistics decisions in freight modelling. This is the new upcoming trend in freight modelling. However, it is very difficult to collect the necessary data and to integrate the different sub-models in the main overall model structure.

Aggregated or disaggregated models

One of the main arguments of using more aggregate freight models is that most (inter)national or regional freight transport model systems are lacking logistics elements, such as the determination of shipment size or the use of distribution centres. There are some exceptions: the SMILE and SMILE+ model in The Netherlands (Tavasszy et al., 1998: Bovenkerk, 2005), the SLAM model for Europe (SCENES Consortium, 2000), the EUNET 2.0 model for the Pennine Region in the UK (Yin et al., 2005), the model for Oregon (Hunt, 2003, Hunt et al., 2001, PbConsult, 2002) and the work of Liedtke (2005), which includes an application to German long-distance markets. (Ben-Akiva and de Jong, 2008).

Which model to use?

It can be concluded that a lot of research has been done already on various types of freight models. Each model has its own specific application and purpose. One of the main trends is that the decision making process is at company level. This will imply that the total logistics cost (including shipment size, inventory cost and safety stock) needs to be modelled. Also, in view of the application in the project, the maritime and port phase of the transport must be included. The project focuses on the two main freight corridors crossing NRW (Rhine-Alpine and the North Sea - Baltic). On these corridors, ports can be starting point (or end point) of a transport chain. But also inter-corridor flows (without a direct link to a seaport) are possible in on the considered freight corridors. Therefore, cargo flows originating from the ports (maritime flows) as well as continental flows need to be taken into account. The freight transport modes that need to be taken into account are:

- Road
- Intermodal rail
- Intermodal inland waterway transport (IWT, especially important for the ports of Antwerp and Rotterdam)

In the proposed methodology , the most important attributes must be:

- Out of pocket cost
    - Road
    - Intermodal Rail
    - Intermodal IWT
- Time
    - Road
    - Intermodal Rail
    - Intermodal IWT

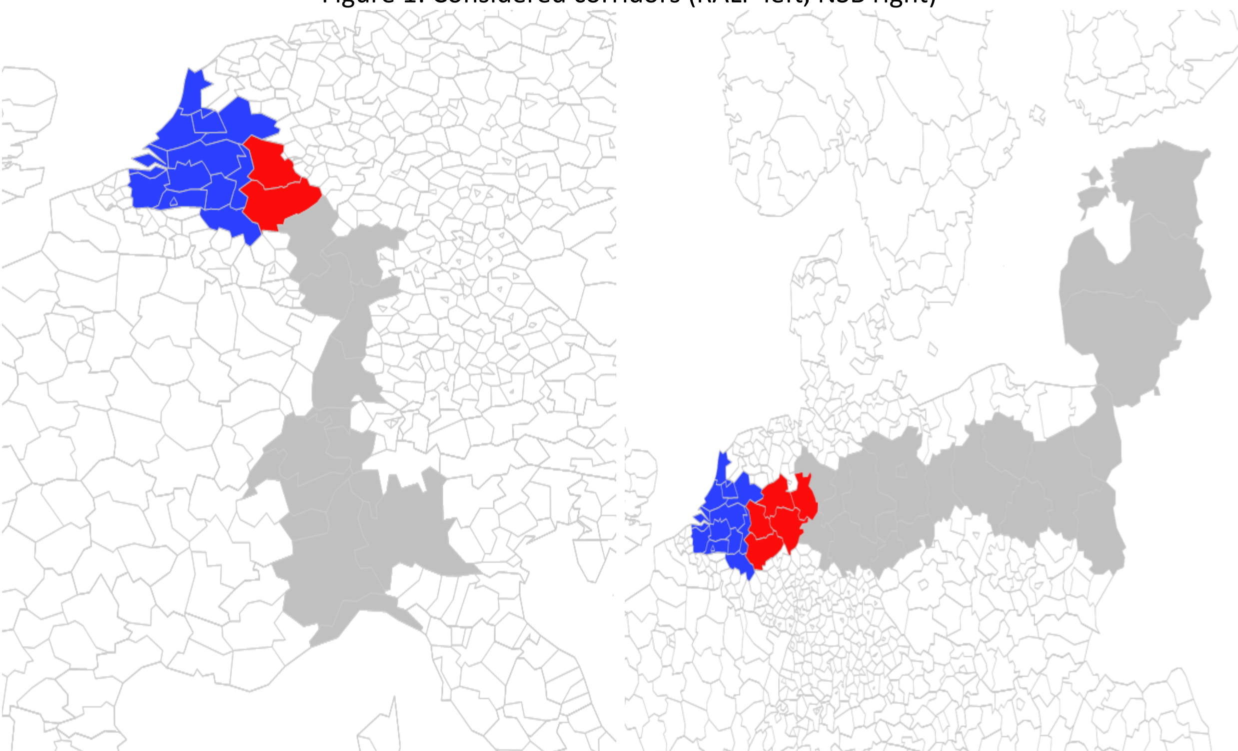
With respect to data needed in the model, data from the ASTRA model can be used. The ASTRA (ASsessment of TRAnsport Strategies) model is a system dynamics model at the European scale developed since 1997 by three partners (Fraunhofer-ISI, IWW Karlsruhe and TRT Trasporti e Territorio) for the strategic assessment of policy scenarios, taking into account feedback loops between the transport system and the economic system. The ASTRA model consists of eight inter-linked modules. For a detailed description of the ASTRA structure, see Schade (2005). (Fiorello et al, 2010)

3. Methodology

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

The two main selected corridors (RALP and NSB) for this project are mapped in Figure 1. In red is NRW, in blue are the analysed zones north or west in the corridor, and in red are the analysed zones south or east in the corridor.

Figure 1: Considered corridors (RALP left, NSB right)



For each of the two corridors, there are seven different cargo flows that can be distinguished among (the directions in brackets concern the NSB corridor):

- Transit from North (West) to South (East)[1]
- Transit from South (East) to North (West)[2]
- From NRW to South (East)[3]
- From NRW to North (West)[4]
- From South (East) to NRW[5]
- From North (West) to NRW[6]

[1] From blue to grey
[2] From grey to blue
[3] From red to grey
[4] From red to blue
[5] From grey to red
[6] From grey to blue

- Internal NRW flows

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

- Ton.km (Road, Rail, IWT)
- TEU.km (Road, Rail, IWT)
- (Loaded) vehicle kilometres (Road, Rail, IWT)
- Modal split (TEU, tonne)

Table 1 and Table 2 show the total main output parameters.

Table 1: Total output indicators of the model (TEU.km, tonne.km and veh.km)

	All cargo flows								
	TEU.km			tonne.km			Loaded veh.km		
	Road	Rail	IWT	Road	Rail	IWT	Road	Rail	IWT
TOTAL Transit NRW (North - South)	x	x	x	x	x	x	x	x	x
TOTAL Transit NRW (South - North)	x	x	x	x	x	x	x	x	x
TOTAL NRW (NRW - North)	x	x	x	x	x	x	x	x	x
TOTAL NRW (NRW - South)	x	x	x	x	x	x	x	x	x
TOTAL NRW (North - NRW)	x	x	x	x	x	x	x	x	x
TOTAL NRW (South - NRW)	x	x	x	x	x	x	x	x	x
TOTAL NRW (NRW - NRW)	x	x	x	x	x	x	x	x	x
TOTAL	x	x	x	x	x	x	x	x	x

Table 2: Total output indicators of the model (modal split, in TEU and tonnes)

	Modal split					
	TEU			tonne		
	Road	Rail	IWT	Road	Rail	IWT
TOTAL Transit NRW (North - South)	x	x	x	x	x	x
TOTAL Transit NRW (South - North)	x	x	x	x	x	x
TOTAL NRW (NRW - North)	x	x	x	x	x	x
TOTAL NRW (NRW - South)	x	x	x	x	x	x
TOTAL NRW (North - NRW)	x	x	x	x	x	x
TOTAL NRW (South - NRW)	x	x	x	x	x	x
TOTAL NRW (NRW - NRW)	x	x	x	x	x	x

For each corridor, an O-D matrix is set up which contains the total outgoing and incoming cargo flows for each zone (NUTS-2) (Trip generation). Also the cargo flows between the different zones are collected (trip distribution). This data is taken from the ASTRA model (Schade, 2004). The cargo flows are given in 10 NST classes (0 to 9) for the years 2010 up to 2030.

These cargo flows are transformed into four different main cargo flow groups:

- Containers (unitised)
- Bulk
- Liquid bulk (commodity group 3)
- General cargo

These cargo flows are linked to the 10 commodity groups via the following table (Table 3).

Table 3: Overview of different commodity types and cargo flow groups

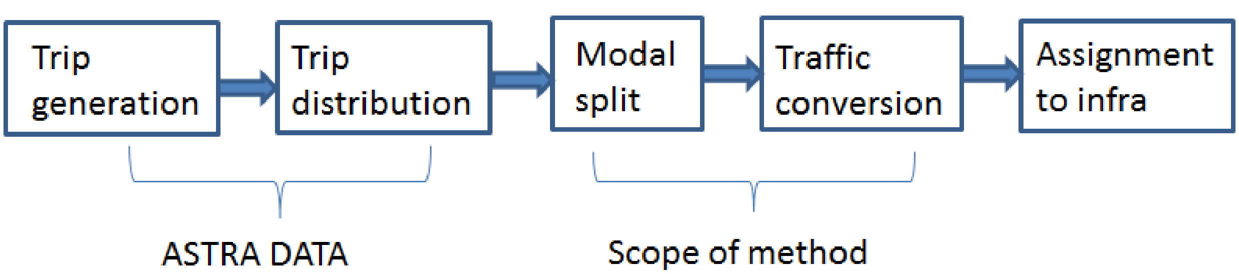
ASTRA flow group	Shares	Commodity group (Number)	Commodity Group (Name)
General cargo	100 %	0	Agricultural products
Unitised	100 %	1	Foodstuffs
Bulk	100 %	2	Solid mineral fuels
Bulk	100 %	3	Petroleum products
Bulk	100 %	4	Ores, metal waste
General cargo	100 %	5	Metal products
Bulk	77 %	6	Building minerals & material
Unitised	23 %	6	
General cargo	100 %	7	Fertilisers
Bulk	100 %	8	Chemicals
Unitised	83 %	9	Machinery & other manufacturing
General cargo	17 %	9	

Source: Schade, 2005

From Table 3, it can be concluded that, for instance, for commodity group 6, 77% can be assigned to bulk cargo and 23% to unitised cargo. Commodity group 1 is completely unitised.

After the trip generation and distribution, the modal split of different cargo flows and the traffic conversion are determined. This can also be seen in Figure 2.

Figure 2: Scope of the method



For the first two steps in Figure 2, ASTRA data is used, while the other steps are modelled within this project in order to determine the main project output indicators.

3.1 Trip generation and distribution

Based on the data from the ASTRA model, the total cargo flows (container, dry bulk, liquid bulk and general cargo) are determined. For each of the considered corridors, the flowing O-D matrices are constructed (see Figure 3).

Figure 3: Overview of O-D matrix freight corridor

	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2
BE25															9,270	9,075
BE23															11,492	11,572
BE21															20,513	20,075
BE22															8,208	8,377
BE24															3,626	3,468
BE10															970	1,015
BE33															7,997	8,037
NL34															9,118	7,043
NL33															38,688	31,125
NL32															12,217	9,730
NL31															5,866	4,849
NL22															22,176	17,709
NL41															39,207	32,275
NL42															25,780	21,797
DEA1	12,768	13,958	29,614	13,462	6,706	2,465	9,470	9,075	43,000	13,779	9,742	38,404	55,524	42,330	2,735,948	614,806
DEA2	11,240	11,895	25,853	11,588	5,774	2,178	7,986	5,590	26,900	8,445	6,233	23,117	34,956	28,979	568,742	2,265,333
DEB1	2,661	3,004	6,157	3,053	1,449	560	2,105	1,648	7,439	2,384	1,766	6,442	9,360	7,941	74,843	194,353
DEB3	1,770	1,671	4,333	1,612	843	345	1,387	940	5,278	1,452	1,236	4,139	6,455	5,161	4,125	14,232
DE71	2,298	2,608	5,721	2,346	1,288	427	1,577	1,143	6,516	1,852	1,513	5,045	7,611	5,717	11,190	34,196
DE12	3,741	4,227	8,716	3,496	1,877	650	2,673	1,632	8,876	2,636	2,102	7,481	11,466	8,461	1,134	3,987
DE13	4,341	4,855	10,231	4,283	2,134	738	3,294	1,948	9,912	2,994	2,294	8,607	12,470	9,620	50	219
CH03	698	784	1,613	484	405	107	330	132	804	193	156	509	795	509	4,189	3,780
CH02	462	588	1,023	308	257	91	274	101	540	135	107	362	571	368	2,520	2,319
CH01	453	512	1,037	303	266	74	217	73	470	108	92	297	464	289	1,566	1,497
CH06	388	553	849	266	217	80	254	77	400	102	82	278	432	273	1,993	1,873
CH07	77	124	154	47	44	22	63	12	64	14	13	42	67	42	291	261
ITC2	15	14	30	10	5	2	7	2	7	2	2	5	9	7	51	55
ITC4	2,687	2,259	5,369	1,637	1,047	449	1,759	760	4,617	1,106	979	3,124	4,500	2,775	14,934	12,828
ITC1	1,745	1,646	3,393	1,044	638	292	1,124	318	1,678	452	374	1,221	1,839	1,160	7,650	7,399
ITC3	246	187	444	131	80	37	145	58	340	83	70	234	360	218	1,170	955

	DEB1	DEB3	DE71	DE12	DE13	CH03	CH02	CH01	CH06	CH07	ITC2	ITC4	ITC1	ITC3
BE25	1,845	1,429	2,563	2,867	3,008	372	284	268	146	15	37	4,320	2,000	37
BE23	2,268	1,771	3,331	3,863	3,772	355	390	355	184	18	39	4,890	2,432	205
BE21	4,185	3,329	6,562	6,586	6,781	903	582	688	309	35	77	9,399	3,966	392
BE22	1,819	1,243	2,357	2,583	2,802	262	181	194	91	10	29	2,864	1,252	113
BE24	703	528	1,026	1,097	1,144	134	98	100	50	6	11	1,570	669	57
BE10	237	151	262	250	249	20	14	15	8	0	2	251	118	10
BE33	1,714	1,538	2,220	2,553	2,790	239	212	185	99	9	30	3,108	1,547	125
NL34	1,396	1,278	1,853	2,248	2,406	267	202	187	104	13	10	1,282	516	38
NL33	6,794	7,510	10,625	10,485	11,332	1,679	1,183	1,269	633	69	49	7,139	2,781	221
NL32	2,094	1,758	3,039	3,142	3,474	467	346	348	173	21	16	2,253	903	66
NL31	1,064	923	1,580	1,591	1,729	232	172	181	91	11	33	1,093	444	33
NL22	3,810	3,188	5,668	5,821	6,560	791	584	602	305	38	28	3,995	1,617	120
NL41	6,632	6,470	9,752	10,525	11,314	1,346	1,050	1,075	559	65	51	6,978	2,960	222
NL42	4,535	3,881	6,364	7,003	7,536	823	622	635	334	44	29	3,786	1,570	117
DEA1	74,444	6,237	20,367	2,951	277	6,801	5,032	3,249	2,213	238	190	19,703	8,606	758
DEA2	167,695	17,346	41,838	6,363	609	5,431	4,052	2,726	1,768	172	139	13,151	6,113	491
DEB1														
DEB3														
DE71														
DE12														
DE13														
CH03														
CH02														
CH01														
CH06														
CH07														
ITC2														
ITC4														
ITC1														
ITC3														

In Figure 3 different colours can be distinguished among. In green are those cargo flows which transit through NRW (both ways). In blue are those cargo flows that have an origin in NRW. In yellow are those flows with a destination in NRW. In red finally are the internal NRW cargo flows.

These matrices are constructed for the four different cargo flow groups and for each mode of transport[7] and for the years 2010, 2020 and 2030.

3.2 Modal split

In order to calculate the modal split, the generalised cost for each mode of transport will be determined. The main purpose of having four different cargo flows is that each of these cargo flows features different cost structures. IWT cargo flows for dry and liquid bulk are almost always unimodal (without pre and post haulage), while for containers and general cargo, there is much more inter- or multimodal transport[8]. This can be seen in Table 4.

[7] Astra gives the cargo flows at mode level (Road, Rail, IWT).

[8] Intermodal transport refers to container transport, while multi-modal transport is much more linked to general cargo.

Table 4: Different forms of transport for the considered commodity types.

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

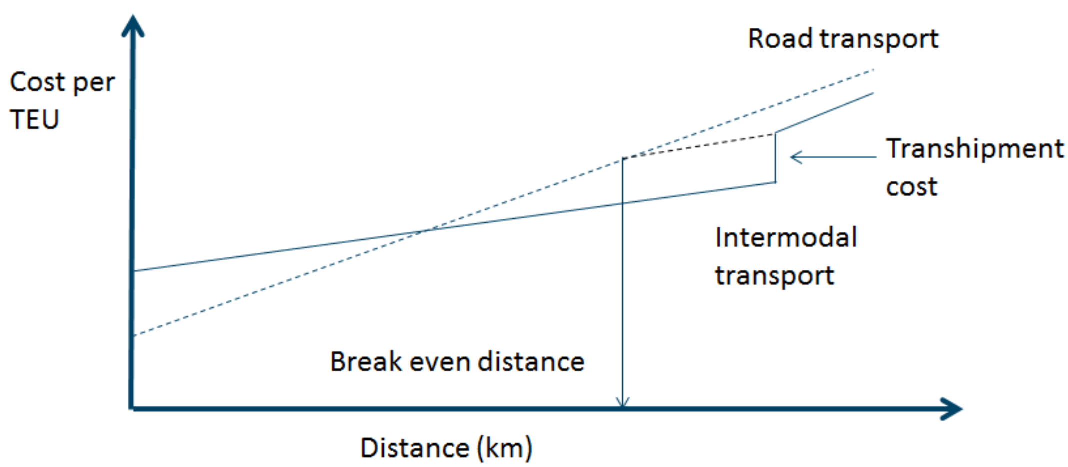
With respect to intermodal and multi-modal transport, we can distinguish among two alternatives:

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

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

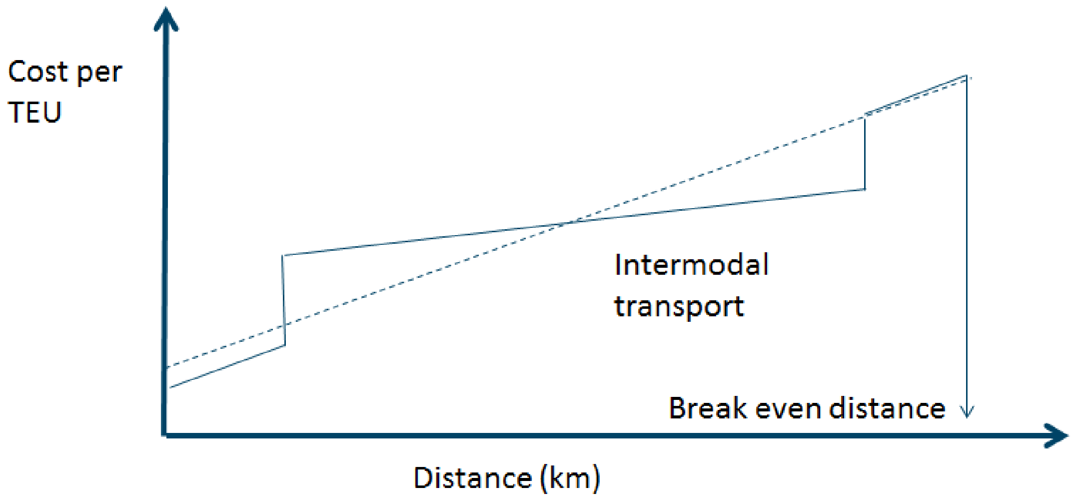
In Figure 4, the general cost structure of maritime intermodal cargo flows can be seen. For the maritime flows, the origin (or destination) of the cargo flow is in a sea port. This means that there is only post- (or pre-) haulage and a handling cost.

Figure 4: Maritime intermodal flows



In Figure 5 the cost structure of continental cargo flows can be seen. Here, there are two transhipments because both pre- and post-haulage transport is included.

Figure 5: Continental intermodal flows



3.2.1 Generalised cost

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

- Calculate the generalised cost
- Calculate performed ton.km and vehicle.km

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

3.2.1.1 Road transport

The generalised cost function of road transport can be seen in equation 1.

$$GC_{road,i} = C_{road,i} + 2.C_{handling,i} + T_{road}.VoT_i \qquad (1)$$

In which

$GC_{road,i}$ is the generalised cost road transport for commodity type i[9] [EUR/load unit]

$CR_{oad,i}$ is the out-of-pocket cost for commodity type I [EUR/ Load unit]

$C_{Handling,i}$ is the handling cost per commodity type i [EUR/Load unit]

T_{road} is the total transport time via road transport [h]

VoT_i is the value of time for commodity type i [EUR/(unit.h].

Formula 2 gives the equation to calculate the out-of-pocket road transport cost (C_{Road}).

[9] i = Containers, bulk cargo and general cargo

$$C_{Road,i} = \frac{D_{road}.DC_{road,i}.(1+P_{DCR\_VAR,i})+(T_{Road,driving}+T_{cong}+T_{handle}).HC_{road,i}.(1+P_{HCR\_VAR,i})+T_{Road,resting}.\frac{1}{2}.HC_{road}.(1+P_{HCR\_VAR,i})}{Cap_{Road}.(1+P_{CR\_VAR,i})} \quad (2)$$

In which
D_{Road} is the road distance between origin and destination [km]
$DC_{road,i}$ is the road distance cost [EUR/km] for commodity type I
$P_{DCR\_VAR,i}$ is the add-on for the cost per kilometre for road transport dependent on a future scenario for commodity type i [%],
$P_{HCR\_VAR,i}$ is the add-on for the cost per hour for road transport dependent on a future scenario for commodity type i [%]
$P_{CR\_VAR,i}$ is the add-on for the load capacity for road transport dependent on a future scenario for commodity type i [%]
$T_{road,\ driving}$ is the total driving time [h]
T_{cong} is the congestion time on the road [h]
T_{handle} is the handling time [h]
$HC_{road,i}$ is the hour cost component for commodity type i [EUR/h]
$T_{road,resting}$ is the total resting time [h]
$Cap_{Road,i}$ is the load capacity of a truck for commodity type i [TEU or tonne] and
PSD_VAR,i is a scenario dependent factor for commodity type i

The total road time (T_{Road}) can be calculated with formula 3.

$$T_{road} = T_{road,driving} + T_{road,resting} + T_{cong}.(1+P_{CTR\_VAR,i}) + T_{handle} \quad (3)$$

The road driving time can be calculated with formula 4. In which $P_{CTR\_VAR,i}$ is the add-on for the congestion time for road transport dependent on a future scenario for commodity type i [%].

$$T_{road,driving} = \frac{D_{road}}{V_{road}} \quad (4)$$

V_{road} is the driving speed of a truck [km/h] and can be calculated with formula 5 (van Dorsser, 2006).

$$V_{road} = C_1 + C_2.TANH(D_{road}.C_3) \quad (5)$$

In which C_1 = constant at 37.274 , C_2 = constant at 45.638 and C_3 = constant at 0.01189

The calculation also includes the resting times. This is done because some road distances are over 1,000 kms. This implies that the maximum driving time allowance per day will be breached if no resting is included. In formula 6, the function to determine the resting time (per 24 hours) is given.

$$(T_{road,driving} < 4.5h \rightarrow T_{road,resting} = 0) \wedge (T_{road,driving} < 9h \rightarrow T_{road,resting} = 0.75) \wedge (T_{road,driving} > 9h \rightarrow T_{road,resting} = 13.5) \quad (6)$$

3.2.1.2 Rail transport

For rail transport, we distinguish among three options: unimodal transport, maritime intermodal transport and continental intermodal transport.

Unimodal transport

The generalised cost of unimodal rail transport is given in formula 7.

$$GC_{rail,i} = C_{rai,il} + C_{Handling\_Rail,i} . (1+P_{HCR\_VAR,i}) + T_{UM\_Rail} . VoT_i \tag{7}$$

In which

$GC_{rail,i}$ is the generalised rail cost for commodity type i [EUR/Load unit]

$C_{rail,i}$ is the out-of-pocket cost of rail transport for commodity type i [EUR/Load unit]

$C_{Handling,i}$ is the handling cost for rail transport for commodity type i [EUR/Load unit]

$P_{HCR\_VAR,i}$ is the add-on for the handling cost of rail transport dependent on a future scenario for commodity type i [%]

T_{UM_Rail} is transport time of unimodal rail transport [h].

The transport time of unimodal rail transport is determined by formula 8.

$$T_{UM\_Rail} = (T_{Rail} + T_{Handling}) . (1+P_{RT\_VAR,i}) \tag{8}$$

T_{rail} is the total rail transport time [h] and can be calculated with formula 9 while $T_{handling}$ is the total handling time [h]. $P_{RT\_VAR,i}$ is the add-on for the rail transport time dependent on a future scenario for commodity type i [%].

$$T_{rail} = \frac{D_{rail}}{V_{rail}} \tag{9}$$

D_{rail} is the rail distance in km and V_{rail} is the average rail speed [km/h]. The out-of-pocket rail transport cost is can be calculated with formula 10.

$$C_{rail,i} = \frac{FC_{Rail,i} . (1+P_{FCT\_VAR,i}) + HC_{Rail,i} . (1+P_{HCT\_VAR,i}) . T_{Rail} + DC_{Rail,i} . (1+P_{DCT\_VAR,i}) . D_{Rail}}{Cap_{Rail,i} . (1+P_{CT\_VAR,i}) . CF_{rail,i}} \tag{10}$$

In which

$FC_{Rail,i}$ is the fixed cost of rail transport (shunting cost) for commodity type i [EUR]

$P_{FCT\_VAR,i}$ is the add-on for the fixed cost for train transport dependent on a future scenario for commodity type i [%]

$HC_{Rail,i}$ is the hour cost of rail transport for commodity type i [EUR/h]

$P_{HCT\_VAR,i}$ is the add-on for the hour cost for train transport dependent on a future scenario for commodity type i [%]

$DC_{Rail,i}$ is the distance cost of rail transport for commodity type i [EUR/km]
$P_{DCT\_VAR,i}$ is the add-on for the distance cost for train transport dependent on a future scenario for commodity type i [%]
$Cap_{Rail,i}$ is the load capacity of a freight train for commodity type i [load unit]
$P_{CT\_VAR,i}$ is the add-on for the load capacity for train transport dependent on a future scenario for commodity type i [%]
CFRail is the correction factor for rail transport for cargo type i when a shipment is in-between a single region. This is the case for cargo flows in NRW region (red blocks in figure 3). For this region, large block trains are available but the shipment size is normally not large enough to fill a complete train. Therefore a correction factor of 25% is applied.

Maritime transport

The generalised cost for rail transport for maritime cargo flows ($GC_{IM\_RAIL\_m}$) can be calculated with formula 11.

$$GC_{IM\_rail\_M,i} = C_{rail,i} + C_{Handling\_Rail,i}.(1+P_{HCR\_VAR,i}) + C_{road,PH,i} + T_{IM\_Rail\_M}.VoT_i \quad (11)$$

In formula 11 ,$C_{road,PH,i}$ is the post haulage cost of road transport for commodity type i [EUR/load unit] and this cost is calculated with formula 12.

The same cost function of unimodal road transport is used but now with a different distance input and only one handling cost (see also function 1).

$$C_{Road,PH,i} = C_{Road,i}(D_{PH,Rail}) \quad (12)$$

The total transport time for maritime cargo flows is calculated with formula 13.

$$T_{IM\_Rail\_M} = (T_{Rail} + T_{Handling}).(1+P_{RT\_VAR,i}) + T_{Dwell}.24 + T_{PostH\_Road} \quad (13)$$

T_{Dwell} is the dwell time of cargo on an inland terminal [days] and T_{postH_Road} is the duration of the post haulage movement [h].

Continental transport

For continental rail transport, formula 14 is used to calculate the generalised cost ($GM_{IM\_Rail\_C,i}$).

$$GC_{IM\_rail\_C,i} = C_{rail,i} + 2.C_{Handling\_Rail,i}.(1+P_{HCR\_VAR,i}) + C_{road,PostH,i} + C_{road,\ PreH,i} + T_{IM\_Rail\_C}.VoT_i \quad (14)$$

In formula 14, two handling movements are included, as well as pre-haulage ($CR_{oad,PH,i}$). These costs are calculated with formula 15.

$$C_{Road,PH,i} = C_{Road,i}(D_{PH,Rail}) \quad (15)$$

The total transport time of intermodal transport for continental flows ($T_{IM\_Rail\_C}$) is calculated with formula 16.

$$T_{IM\_Rail\_C} = (T_{Rail} + 2.T_{Handling}).(1+P_{RT\_VAR,i}) + 2.T_{Dwell}.24 + T_{Road,PostH} + T_{Road\_PreH} \quad (16)$$

3.2.1.3 IWT transport

For IWT transport, we again distinguish among three options: Unimodal transport, maritime intermodal transport and continental intermodal transport.

Unimodal transport

The cost structure to calculate generalised cost of IWT transport is given in formula 17.

$$GC_{IWT} = C_{IWT}(CEMT) + C_{Handling\_IWT} + T_{UM\_IWT}.VoT \quad (17)$$

This cost structure is the same as for rail transport. However, the cost structure of the IWT out-of-pocket cost depends on the maximum allowable dimensions of the inland vessel. These dimensions are determined by the CEMT classes (ranging from II to VI[10]). In the model the CEMT classes are taken into account for the different OD relations. The total transport time for unimodal barge transport can be calculated with formula 18.

$$T_{UM\_IWT} = T_{IWT} + T_{Handling} \quad (18)$$

The IWT transport time (T_{IWT})is determined by the sailed distance (D_{IWT}) and the speed (V_{IWT})of the inland vessel.

$$T_{IWT} = \frac{D_{IWT}}{V_{IWT}} \quad (19)$$

The total out-of-pocket cost for IWT transport will be calculated with formula 20.

[10] From 400 tonnes (20 TEU) to 5,000 tonnes (350 TEU)

$$(D_{IWT} < 1000 \rightarrow C_{IWT}(CEMT) = \frac{HC_{Sailing}.T_{IWT\_Sailing} + KC_{Sailing}.D_{Sailing} + HC_{Waiting} + T_{IWT\_Waiting}}{Occ_{IWT}.Cap_{IWT}.CF_{IWT}}).(1+P_{IWT\_VAR,i}) \wedge$$

$$(D_{IWT} > 1000 \rightarrow C_{IWT}(CEMT) = \frac{(HC_{Sailing} + HC_{Sailing\_empty}).T_{IWT\_Sailing} + (KC_{Sailing} + KC_{Sailing\_empty}).D_{Sailing} + HC_{Waiting} + T_{IWT\_Waiting}}{Occ_{IWT}.Cap_{IWT}.CF_{IWT}}).(1+P_{IWT\_VAR,i}) \qquad (20)$$

In which

$HC_{SAILING}$ is the cost for sailing one hour for IWT vessel of a certain CEMT level [EUR/h]

$HC_{WAITING}$ is the cost per hour for an IWT vessel that is waiting [EUR/h]

$HC_{SAILING\_EMPTY}$ is the hour cost for a vessel sailing in empty condition [EUR/h]

$KC_{sailing}$ and $KC_{Sailing\_empty}$ are the kilometre cost for a fully loaded and empty barge

$P_{IWT\_VAR,I}$ is the add-on for the different IWT cost elements dependent on a future scenario for commodity type i [%]

OCC_{IWT} is the occupancy rate of an inland vessel

CAP_{IWT} is the load capacity of an IWT vessel

CFIWT is the correction factor for the occupation rate of inland vessels for transport flows in the same region. As for rail transport also here a correction factor of 50% is applied.

The total out-of-pocket cost depends on the sailed distance. If the transport distance is over 1,000 kms, it is assumed that there is no return cargo, while for short distances there is a higher probability of return cargo (especially for container transport).

Maritime transport

For maritime cargo flows, the same cost structure is used as in the case of rail transport (formula 21).

$$GC_{IM\_IWT\_M} = C_{IWT}(CEMT) + C_{Handling\_IWT} + C_{road,PH} + T_{IM\_IWT\_M}.VoT \qquad (21)$$

The total intermodal IWT transport time for maritime flows ($T_{IM\_IWT\_M}$) can be calculated by using formula 22.

$$T_{IM\_IWT\_M} = T_{IWT} + T_{Handling\_IWT} + T_{Dwell}.24 + T_{PostH\_Road} \qquad (22)$$

Continental transport

Also for continual transport, the same cost structure is used as in the case of rail transport (formula 23).

$$GC_{IM\_IWT\_C} = C_{IWT}(CEMT) + 2.C_{Handling\_IWT} + C_{road,PostH} + C_{road,\ PreH} + T_{IM\_IWT\_C}.VoT \qquad (23)$$

The same goes for the total transport time of IWT continental transport.

$$\mathrm{T}_{\mathrm{IM\_IWT\_C}} = \mathrm{T}_{IWT} + 2.\mathrm{T}_{\mathrm{Handling\_IWT}} + 2.\mathrm{T}_{\mathrm{Dwell}}.24 + \mathrm{T}_{\mathrm{Road,PostH}} + \mathrm{T}_{\mathrm{Road\_PreH}} \tag{24}$$

3.2.2.Modal split calculation

Based on the calculated generalised cost, the modal split can be calculated, for each commodity type, by making use of the logit model as shown in formulae 25 to 30.

Unimodal transport

$$P_{road,i} = \frac{e^{-\mu.GC_{road,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{Rail,i}} + e^{-\mu.GC_{IWT,i}}} \tag{25}$$

$$P_{Rail,i} = \frac{e^{-\mu.GC_{Rail,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{Rail,i}} + e^{-\mu.GC_{IWT,i}}} \tag{26}$$

$$P_{IWT,i} = \frac{e^{-\mu.GC_{IWT,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{Rail,i}} + e^{-\mu.GC_{IWT,i}}} \tag{27}$$

Inter-/multimodal transport (maritime and continental flows)

$$P_{road,i} = \frac{e^{-\mu.GC_{road,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{IM\_Rail,i}} + e^{-\mu.GC_{IM\_IWT,i}}} \tag{28}$$

$$P_{IM\_Rail,i} = \frac{e^{-\mu.GC_{IM\_Rail,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{IM\_Rail,i}} + e^{-\mu.GC_{IM\_IWT,i}}} \tag{29}$$

$$P_{IM\_IWT,i} = \frac{e^{-\mu.GC_{IM\_IWT,i}}}{e^{-\mu.GC_{road,i}} + e^{-\mu.GC_{IM\_Rail,i}} + e^{-\mu.GC_{IM\_IWT,i}}} \tag{30}$$

In these formulas, there is an unknown parameter µ which needs to be fitted. From the data of ASTRA, it is possible to determine the modal split for each O-D pair. The parameter µ will be fitted, per freight group, on the Astra data (see section 5.1).

3.3 Traffic conversion

Based on the calculated modal split, the cargo flow data and the travelled distances it becomes possible to calculate the total TEU.km , ton.km and vehicle.km that are passing through NRW for each commodity type i. For road transport also the post haulage impact of both rail and IWT on the territory in NRW is taken into account.

$$TK_{O,D,Road,i} = [P_{O,D,Road,i} . D_{O,D,Road\_NRW} + P_{O,D,Rail,i} . D_{O,D,Rail\_PH\_NRW} + P_{O,D,IWT,i} . D_{O,D,IWT\_PH\_NRW}] . Cargo_{O,D,i,2015} . (1+GF) \quad (31)$$

In which
$TK_{O,D,Road,i}$ is the ton.km (or TEU.km) performed in NRW for commodity type i
$P_{O,D,Road,i}$ is the modal share of road transport on a given OD pair for commodity type i
$D_{O,D,Road\_NRW}$ is the distance travelled by road on that OD pair in NRW
$P_{OD,RAIL}$ and $P_{OD,IWT}$ are the modal shares of rail and IWT transport for commodity type i
$D_{Rail\_PH\_NRW}$ and $D_{Rail\_PH\_NRW}$ are the distances of road transport for both the intermodal rail and IWT on the territory of NRW
$Cargo_{O,D}$ is the total amount of cargo transported for commodity type i between an OD pair in the base year 2015
GF is the growth factor of the cargo flow on a given OD pair for the future scenarios (growth from 2015 to 2030 and 2050) [%].

For Rail and IWT, similar formulas are used (32 and 33).

$$TK_{O,D,Rail,i} = P_{O,D,Rail,i} . D_{O,D,Rail\_NRW} . Cargo_{O,D,i,2015} . (1+GF) \quad (32)$$

$$TK_{O,D,IWT,i} = P_{O,D,IWT,i} . D_{O,D,IWT\_NRW} . Cargo_{O,D,i,2015} . (1+GF) \quad (33)$$

The main reason of this approach is that the modal split is calculated by making use of the total distances of the main OD pair, while only the part in NRW is taken into account in the main output indicators. This puts some additional requirements on the distance data needs.

Secondly, based on formulas 31 to 33, both effects of changes in generalised cost and cargo flow forecast can be taken into account.

The total transit ton.km (TK) for road, rail and IWT are determined by equation 34, in which all the TK_{Road}, TK_{Rail} and TK_{IWT} are summed for those OD pairs (m)that have an origin, destination, transiting NRW or are staying in the NRW region[11] and for all commodity types (n).

$$TK_{Transit\_NRW,Road} = \sum_{i=1}^{n} \sum_{O=1}^{m} \sum_{D=1}^{m} TK_{O,D,Road,i} \quad (34)$$

Based on the calculated TK for the three considered modes of transport, it is also possible to determine the vehicle kilometres per mode of transport of each OD pair (formula 35 to 37).

$$VK_{O,D,Road,i} = \frac{P_{O,D,Road,i} . D_{O,D,Road\_NRW} . Cargo_{O,D,i,2015} . (1+GF)}{Cap_{Road,i}} \quad (35)$$

[11] These four cargo different cargo flows corresponds with the different colors in Figure 3

$$VK_{O,D,Rail,i} = \frac{P_{O,D,Rail,i}.D_{O,D,Rail\_NRW}.Cargo_{O,D,i,2015}.(1+GF)}{Cap_{Rail,i}.(1+P_{SD\_VAR,i})} \quad (36)$$

$$VK_{O,D,IWT,i} = \frac{P_{O,D,IWT,i}.D_{O,D,IWT\_NRW}.Cargo_{O,D,i,2015}.(1+GF)}{Cap_{IWT,i}.(1+P_{SD\_VAR,i})} \quad (37)$$

In the analysis, we consider four different cargo types (containers, dry bulk, liquid bulk and general cargo) so this means that we have four main outputs in TEU.km, ton.km and veh.km. The total output indicators are the summation of these four cargo groups. Because container transport is expressed in TEU and not in tonne, the TEU.km are treated separately from the tonne.km of the other cargo types.

3.4 Greenhouse gas emissions

The total greenhouse gasses (GHG) can be determined by the following formula:

$$GHG_{Transit\_NRW\_Total} = \frac{TK_{Transit\_NRW,Road}.GHG_{Road} + TK_{Transit\_NRW,Rail}.GHG_{Rail} + TK_{Transit\_NRW,IWT}.GHG_{IWT}}{10^6} \quad (38)$$

In this formula, GHG_{Total} are the total GHG emitted for all considered transport modes and cargo types linking to the NRW region in tonne CO_2. GHG_{Road}, GHG_{Rail} and GHG_{IWT}[12] are the average GHG emission factors in g CO_2/tonne.km.

[12] In the calculations the average emission factors are kept constant, also for the calculations for 2030 and 2050. Therefore vehicle improvements (energy efficiency) are not taken into account.

4. Data

In this section, the different data sources are described. Firstly, there is the cargo data. Secondly, the distance data are given. Thirdly, the cost data of the different transport options are given.

4.1 Cargo flow data

4.1.1. Commodity types

In the analysis, we distinguish among different main cargo groups:

- Containers (unitised)
- Bulk cargo
  - Dry bulk
  - Liquid bulk
- General cargo

The data is taken from the ASTRA model.

4.1.2 Corridors

In this research, we consider two main freight corridors that pass NRW: RALP and NSB.

4.1.2.1 Rhine Alpine corridor

For the RALP corridor, the following NUTS-2 regions are included:

- BE25 (Zeebruges), BE23 (Ghent), BE21 (Antwerp), BE22, BE24, BE10 (Brussels) and BE33
- NL34, NL33 (Rotterdam), NL32 (Amsterdam), NL31,NL22, NL41 and NL42
- DEA1 and DEA2 (NRW)
- DEB1, DEB3, DE71, DE12 and DE13 (South-West Germany)
- CH03, CH02, CH01, CH06 and CH07 (Switzerland)
- ITC1, ITC,2 ITC3, ITC4 (Northern Italy)

In total, the OD matrix is a 30 by 30 matrix, which is composed of four cargo groups. The matrix is too large to be added in the report.

4.1.2.2 North Sea - Baltic Corridor

In the NSB corridor, the following NUTS-2 regions are included:

- BE25 (Zeebruges), BE23 (Ghent), BE21 (Antwerp), BE22, BE24, BE10 (Brussels) and BE33
- NL34, NL33 (Rotterdam), NL32 (Amsterdam), NL31,NL22, NL41 and NL42
- DEA1, DEA2, DEA3, DEA4 and DEA5 (NRW)
- DE73, DEG0, DED1, DED2, DED3, DEE0, DE91, DE92, DE30, DE41, DE42 (Eastern Germany)
- PL43, PL41, PL11, PL12, PL61,PL34and PL31 (Poland)
- EE00, LV00, LT00 (Baltic States)

In total, the OD matrix is a 40 by 40 matrix, which is composed of four cargo groups. The matrix is again too large to be added in the report.

4.2 Distance data

4.2.1 Road transport

The road distance data is determined by making use of Google maps. The distance is calculated from the centres of the NUTS-2 regions.

The road distance data is determined for the following cases:

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

4.2.2 Rail Transport

For rail transport, the distance data is determined between different rail terminals (containers and bulk), for the following cases:

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

For the rail distances, Openstreetmap data is used (OpenStreetMap, 2015).

4.2.3 IWT Transport

For IWT transport, the distance data is determined between different IWT terminals (containers and bulk, using Blue Road Map[13] (2017), for the following cases:

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

4.3 Cost Data

4.3.1 Cargo data

The value of time data (VoT) is taken from ASTRA (Schade, 2005) and is updated to 2015 values with an index of 2% per year. In

[13] http://www.blueroadmap.nl/

Table 5 the data can be found to determine the value of time for the different cargo types.

Table 5: Data to estimate the value of time for different

	VoT (1990) [EUR/TEU] or [EUR/tonne]	VoT (2015) [EUR/TEU.h] or [EUR/tonne.h]
Containers	14,800	1,142[14]
Dry Bulk	0,160	0,017[15]
Liquid Bulk	n.a.[16]	0,00114[17]
General Cargo	0,810	0,034[18]

4.3.2 Road transport

Table 6Table 6 presents the unit data for the road transport cost calculation for the base case (2015 values).

Table 6: Data for road transport cost calculation (2015 values)

Load units		Container (long distance) [TEU]	Container (pre and post haulage) [TEU]	Bulk [tonne]	General Cargo [tonne]
Load capacity	[Load unit]	1.5		17	15
Loading cost	[EUR/load unit]	40		1	1
Cost					
Cost per km	[EUR/km]	0.83	1.65	0.97	0.87
Cost per h	[EUR/h]	35.4	n/a	35.4	35.4
% cost per hour while resting	[%]	50%	n/a	50%	50%
Time					
$T_{congestion}$	[h]	1			
T_{handle}	[h]	0.5			
$T_{waitPort}$	[h]	1			
Resting time					
Max driving time	[h]	4,5			
Resting time (in operation)	[h]	0.75			
Max driving time per day	[h]	9.0			

14 The ASTRA VoT for container cargo was found to high after testing this value (modal share of rail transport was close to zero). Therefore, a new VoT for container cargo is estimated based on an average value of the cargo of €100.000 per TEU with a depreciation of 10%.

15 The ASTRA VoT for bulk cargo was found to high after testing this value. Therefore, a new VoT for bulk cargo is estimated based on an average value of the cargo of €500 per ton.

16 There is no value for the VoT for liquid bulk in Schade (2005).

17 The VoT is estimated on the value of the cargo (€100 per ton) and a depreciation of 10% per year.

18 The ASTRA VoT for general cargo was found to high after testing this value (modal share of rail transport was close to zero). Therefore, a new VoT for general cargo is estimated based on an average value of the cargo of €10.000 per ton with a depreciation of 10%.

Source: van Hassel et al. (2016a) and LowCarb Project working group (cost data)

4.3.3 Rail Transport

Table 7 presents the data used for the calculation of the rail cost for the base case (2015 values).

Table 7: Data for rail transport cost calculation (2015 values)

Load units		Container [TEU]	Bulk [tonne]	General Cargo [tonne]
Load capacity	[Load unit]	70	700	500
Loading cost	[EUR/load unit]	40	0.90	0.90
Cost				
Fixed cost	[EUR]	1,950	1,098	1,098
Cost per km	[EUR/km]	5.49	7.74	4.99
Cost per h	[EUR/h]	2,192	2,298	2,123
Time				
V_{rail}	[km/h]	50		
T_{handle}	[units/h]	40	200	
$T_{waitPort}$	[h]	20		
T_{dwell}	[days]	2		

Source: Flemish Traffic Centre (2017) (Cost data) and LowCarb Project working group

4.3.4 IWT Transport

Table 8 and Table 9 present the cost data for the calculation of IWT transport for the base case (2015 values).

Table 8: General data for IWT transport cost calculation (2015 values)

Load units		TEU	tonne
Loading cost	[EUR/load unit]	40	0,90
Cost			
Occupation rate	[%]	90	
Time			
T_{handle}	[units/h]	30	200
$T_{waitPort}$	[h]	7	
T_{dwell}	[days]	2	

Source: Based on van Hassel et al. (2016a)

Table 8 gives the general data for all IWT vessels, while Table 9 shows the cost and load capacity for the different vessel classes.

Table 9: IWT class dependent data for cost calculation (2015 values)

CEMT	Time Cost					Load capacity	
	Sailing		Waiting	Empty		Container	tonne
	EUR/veh.km	EUR/Veh.h	EUR/Veh.h	EUR/veh.km	EUR/Veh.h		
2	2..64	63.06	49.72	1.73	63.06	20	400
3	3.49	83.36	66.59	2.29	83.36	28	650
4	5.47	130.57	104.31	3.59	13..57	60	1,350
5	12.05	287.55	224.88	7.90	287.55	200	3,000
6	21.06	502.46	292.95	13.81	502.46	350	5,000

Source: Based on van Hassel et al. (2016)

4.4 GHG emissions factors

This paper applies a fixed rate GHG emission approach. This reports the emissions per mode from now to 2050 using constant 2015 emission factors. We apply this approach in order to isolate the impact from mode shift from other effects, including the de-carbonisation of rail traction power. This implies that the GHG emission calculations in this paper constitute a theoretical value only, which is not applicable to policy decisions. A full-scale assessment will be carried out in other parts of the LowCarb-RFC project.

In Table 10, the average emission factors are given for road, rail and IWT, 2015.

Table 10: GHG emission factors

Transport mode	**g CO2/tonne.km**
Road	62
Rail	22
Barge	31

Source: ECTA & Cefic (2011)

In the developed method, four main freight categories are used. For containers and general cargo, the shipments are modelled as intermodal transport, while for dry and liquid bulk, only unimodal rail or IWT is used. In the conversion to ton.km per transport mode, the additional road ton.km (as a result of the intermodal transport) is already taken into account in the road ton.km. Therefore, the unimodal transport mode values can be used.

5. Fitting of the model and results of the base line calculations

In this chapter, the developed model will be fitted to the available ASTRA data, and the main output for the base case is calculated.

5.1 Fitting the model to ASTRA data

In order to fit the developed model, for each of specific cargo flows, to the ASTRA data, and to determine the spreading factor μ, the calculated modal split needs to be compared to modal split values in the ASTRA model.

For each of the three considered transport modes, the following formulas will be applied.

$$D_{\mathrm{Road}} = \sum_{i=0}^{n}\sum_{j=0}^{k}\left[\left(\mathrm{P}_{\mathrm{Road,i,j}} - \mathrm{P}_{\mathrm{Road,i,j,ASTRA}}\right)^2 \cdot \frac{\mathrm{VOL}_{\mathrm{Road,i,j,ASTRA}}}{\sum_{i=0}^{n}\sum_{j=0}^{k}\mathrm{VOL}_{\mathrm{Road,i,j,ASTRA}}}\right] \tag{38}$$

$$D_{\mathrm{Rail}} = \sum_{i=0}^{n}\sum_{j=0}^{k}\left[\left(\mathrm{P}_{\mathrm{Rail,i,j}} - \mathrm{P}_{\mathrm{Rail,i,j,ASTRA}}\right)^2 \cdot \frac{\mathrm{VOL}_{\mathrm{Rail,i,j,ASTRA}}}{\sum_{i=0}^{n}\sum_{j=0}^{k}\mathrm{VOL}_{\mathrm{Rail,i,j,ASTRA}}}\right] \tag{39}$$

$$D_{IWT} = \sum_{i=0}^{n}\sum_{j=0}^{k}\left[\left(\mathrm{P}_{\mathrm{IWT,i,j}} - \mathrm{P}_{\mathrm{IWT,i,j,ASTRA}}\right)^2 \cdot \frac{\mathrm{VOL}_{\mathrm{IWT,i,j,ASTRA}}}{\sum_{i=0}^{n}\sum_{j=0}^{k}\mathrm{VOL}_{\mathrm{IWT,i,j,ASTRA}}}\right] \tag{40}$$

In which

D_{Road} is the difference for road transport between the calculated mode share and the mode share given in ASTRA for a certain transport corridor

$P_{\mathrm{Road,I,j,ASTRA}}$ is the mode share of road transport from origin i to destination j given in ASTRA

$VOL_{\mathrm{i,j,ASTRA}}$ is the volume road transport from origin i to destination j. By applying the ratio more value is given to those O-D relations with a high transport volumes.

For the other transport modes the same logic is used. Because there are three modal shares, we need to determine a single parameter (fitting parameter, FP). The function is given in formula 41.

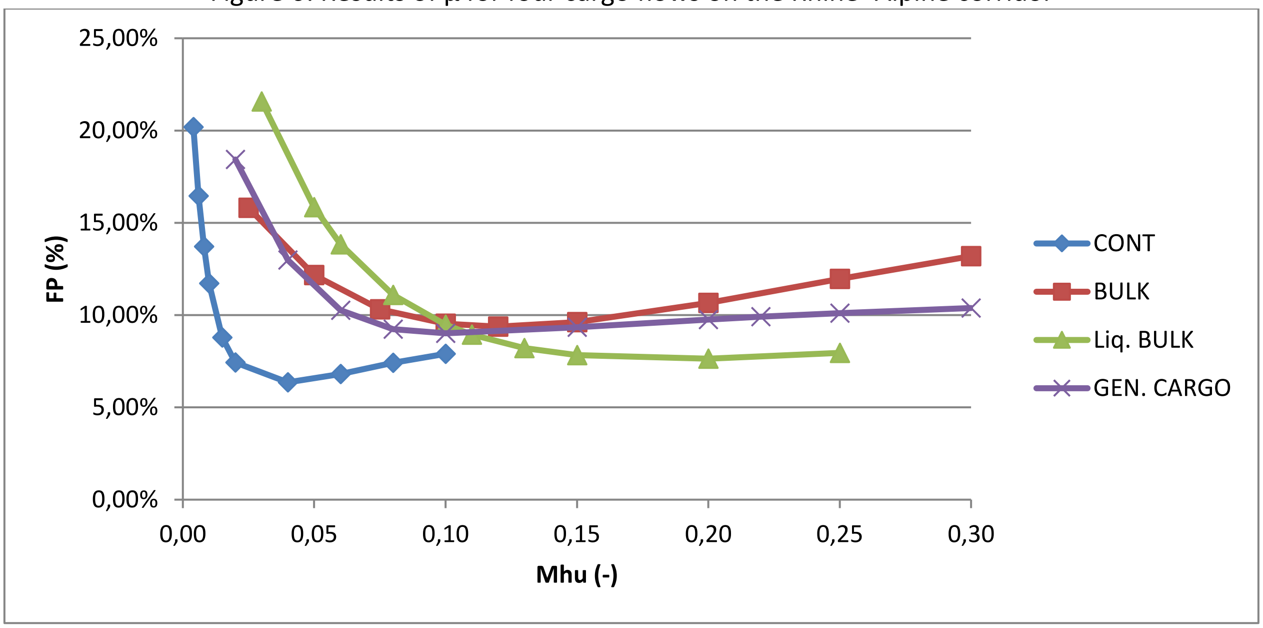
$$FP = \frac{\sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{Road,i,j,ASTRA}.D_{Road} + \sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{RAIL,i,j,ASTRA}.D_{Rail} + \sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{IWT,i,j,ASTRA}.D_{IWT}}{\sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{Road,i,j,ASTRA} + \sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{Rail,i,j,ASTRA} + \sum_{i=0}^{n}\sum_{j=0}^{k} VOL_{IWT,i,j,ASTRA}} \quad (41)$$

For each cargo type (container, dry bulk, liquid bulk and general cargo), a value for µ will be determined. Each µ will be determined by applying function 42.

$$\underset{\mu}{MIN}\ FP(\mu), \text{ subjected to } \mu \in [0,1] \quad (42)$$

For the Rhine Alpine corridor, we get the following results when applying formula 42.

Figure 6: Results of µ for four cargo flows on the Rhine- Alpine corridor



From Figure 6, it can be concluded that there are different values of µ for each of the different cargo flows. All container and general cargo have the best fits with a fitting parameter below 10%. From Figure 6 it can also be concluded that there is a clear minimum value for all types of cargo (except for general cargo).

In Figure 7 the results for the North Sea Baltic corridor can be found.

Figure 7: Results of μ for four cargo flows on the North Sea Baltic corridor

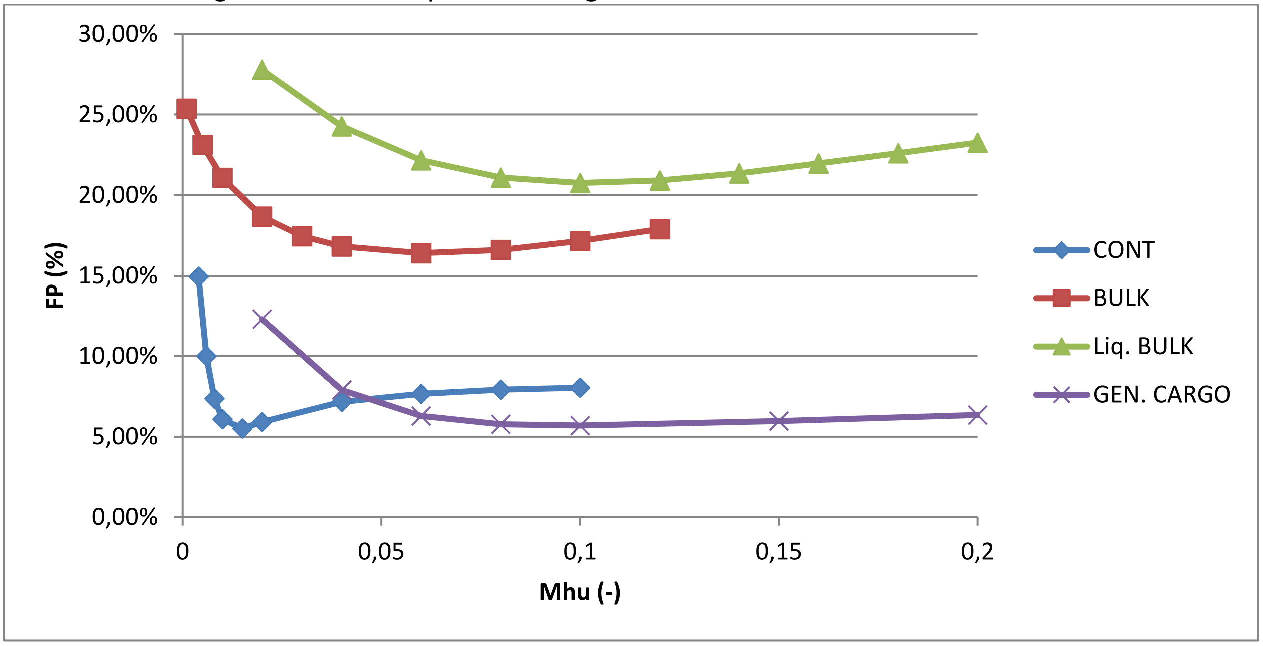


Figure 7 shows a similar pattern as Figure 6 The main difference is that the FP for dry and liquid bulk is larger for the North Sea Baltic corridor compared to the Rhine Alpine corridor.

Table 11 summarizes the values of μ for each cargo flow and for both considered freight corridors.

Table 11: Determined values of μ

	Rhine Alp.	North Sea Baltic
CONT	0.040	0.015
BULK	0.110	0.060
LIQ BULK	0.130	0.100
GEN. CARGO	0.100	0.150

The values of μ, given in Table 11, are used in the model and based on these values the different calculations will be made.

From the different spreading factors, it can be concluded that the elasticity of container transport is lower than for the other cargo types. This implies that changes in generalised cost impacts on container transport to a lesser extent than for dry bulk, liquid bulk and general cargo.

Secondly, the spreading factors of the North Sea Baltic are smaller than for the Rhine Alpine corridor (except for general cargo). This also implies that the changes in generalised cost also impacts on the North Sea Baltic corridor less than on the Rhine Alpine corridor.

5.2 Result of the Business As Usual (2015) calculations

This section gives the results for the two freight corridors. The main results of the calculations are the ton.km, vehicle.km and the modal split on the NRW territory for both freight corridors[19] [20].

5.2.1 Rhine-Alpine

Table 12 and Table 13 give the results of the calculations for all four cargo flows. Appendix A gives the sub-results per cargo type.

Table 12: TEU.km, tonne.km and veh.km (Rhine-Alpine 2015 business as usual)

	All cargo flows (10^6)								
	TEU.km			ton.km			Loaded veh.km		
	Road	Rail	IWT	Road	Rail	IWT	Road	Rail	IWT
Transit NRW (N - S)	12.86	11.76	161.63	449	180	5,054	37.02	0.44	20.58
Transit NRW (S - N)	14.98	10.92	139.29	281	91	2,627	27.99	0.29	12.77
NRW (NRW - North)	41.60	0.01	60.40	656	33	1,955	67.73	0.05	9.25
NRW (NRW - South)	21.33	2.54	11.05	770	57	634	62.34	0.12	1.94
NRW (North - NRW)	33.24	0.02	60.81	1,231	59	4,233	96.33	0.09	14.74
NRW (South - NRW)	19.82	2.20	8.38	406	40	339	38.21	0.09	1.05
NRW (NRW - NRW)	340.65	0.05	30.10	6,493	435	2,460	620.39	0.64	7.49
TOTAL	**484.48**	**27.51**	**471.66**	**10,286.48**	**895.75**	**17,301.02**	**950.00**	**1.73**	**67.82**

From Table 12, it can be concluded that the biggest contributor to the TEU.km is road transport on the RALP corridor. This is mainly caused by the very large share of road transport in the NRW region itself (origin and destination in NRW). For the cargo flows in tonnes, IWT has a high share on this corridor. Here, the biggest contribution comes from the transit flows going to and from the Dutch and Flemish ports. With respect to the vehicle-kilometres, road transport represents by far the highest amount. This is also due to the fact that the payload of a truck is much less than from a freight train or barge.

Table 13: Modal split, in TEU and tonnes (Rhine-Alpine 2015 business as usual)

	Modal split					
	TEU			tonne		
	Road	Rail	IWT	Road	Rail	IWT
Transit NRW (North - South)	6.9%	6.3%	86.8%	7.9%	3.2%	88.9%
Transit NRW (South - North)	9.1%	6.6%	84.3%	9.4%	3.0%	87.6%
NRW (NRW - North)	40.8%	0.0%	59.2%	24.8%	1.3%	73.9%
NRW (NRW - South)	61.1%	7.3%	31.6%	52.7%	3.9%	43.4%
NRW (North - NRW)	35.3%	0.0%	64.6%	22.3%	1.1%	76.6%
NRW (South - NRW)	65.2%	7.2%	27.6%	51.7%	5.1%	43.2%
NRW (NRW - NRW)	91.9%	0.0%	8.1%	69.2%	4.6%	26.2%

[19] See also chapter 3 table 1 and table 2.

[20] The total preformed TEU.km, ton.km and veh.km for the whole corridor are also available.

For the modal split[21], it can be seen that there is much room of improvement for rail transport. Rail transport never has the highest share while in some cases IWT transport has the highest modal share (especially for bulk flows in transit through NRW).

Table 14 gives the total TEU.km, tonne.km and vehicle kilometres for the whole corridor. It needs to be mentioned that the whole corridor contains all the cargo flows that have a link with NRW. Thus for example, cargo flows going from Antwerp to Amsterdam are not in the data[22].

Table 14: TEU.km, tonne.km, veh.km and modal share for the whole corridor (Rhine Alpine 2015 base case)

	All cargo flows (10^6)								
	TEU.km			ton.km			Loaded veh.km		
	Road	Rail	IWT	Road	Rail	IWT	Road	Rail	IWT
Total corridor	882.34	232.65	1,294.96	17,460.66	3,477.73	42,083.48	1,737.39	8.49	164.71
	Modal split			Modal split					
	36.6%	9.7%	53.7%	27.7%	5.5%	66.8%			

From Table 14, it can be concluded that IWT is the transport mode that has the highest share for both container transport and bulk and general cargo. The share of rail transport is about 9.7% to 5.7% on this corridor.

5.2.2 North –Sea-Baltic

Table 15 and Table 16 give the results of the calculations for all the four cargo flows. Appendix B gives the sub-results per cargo type.

Table 15: TEU.km, tonne.km and veh.km (North Sea – Baltic 2015 base case)

	All cargo flows (10^6)								
	TEU.km			ton.km			Loaded veh.km		
	Road	Rail	IWT	Road	Rail	IWT	Road	Rail	IWT
Transit NRW (W - E)	64.86	23.47	65.12	575.68	151.83	851.56	79.59	0.56	2.29
Transit NRW (E - W)	53.65	19.88	58.36	428.14	101.75	1,757.48	62.98	0.44	2.36
NRW (NRW - West)	102.61	1.46	30.68	1,446.68	230.51	2,285.69	159.02	0.36	1.15
NRW (NRW - East)	95.03	11.29	12.09	2,109.86	178.56	1,480.67	195.99	0.43	1.28
NRW (West - NRW)	152.71	6.02	61.43	4,832.45	975.14	8,797.18	397.20	1.49	3.61
NRW (East - NRW)	97.41	16.02	22.66	1,614.80	125.68	1,241.44	166.98	0.42	1.32
NRW (NRW - NRW)	1,184.71	13.09	79.80	26,256.91	1,447.94	13,404.54	2,469.83	2.31	9.21
TOTAL	1,750.99	91.22	330.14	37,264.52	3,211.41	29,818.57	3,531.60	6.01	21.21

[21] Modal split based on ton.kms and veh.kms

[22] In Figure 3 this can be seen as the white blocks in the OD matrix. These cargo flows are not taken into account.

From Table 15, it can be concluded that road transport is the most dominant mode of transport. This is mainly contributed to by the fact that the region of NRW is much larger in this transport corridor (see also (Figure 1). That is why the inter-regional flows are dominating the total TEU.km, ton.km and vehicle kilometres.

Table 16: Modal split, in TEU and tonnes (North Sea – Baltic 2015 base case)

	Modal split					
	TEU			tonne		
	Road	Rail	IWT	Road	Rail	IWT
Transit NRW (West - East)	42.3%	15.3%	42.4%	36.5%	9.6%	53.9%
Transit NRW (East - West)	40.7%	15.1%	44.2%	18.7%	4.4%	76.8%
NRW (NRW - West)	76.1%	1.1%	22.8%	36.5%	5.8%	57.7%
NRW (NRW - East)	80.3%	9.5%	10.2%	56.0%	4.7%	39.3%
NRW (West - NRW)	69.4%	2.7%	27.9%	33.1%	6.7%	60.2%
NRW (East - NRW)	71.6%	11.8%	16.7%	54.2%	4.2%	41.6%
NRW (NRW - NRW)	92.7%	1.0%	6.2%	63.9%	3.5%	32.6%

For the modal split, it can be seen that there is much room of improvement for rail transport. Rail transport never has the highest share. The biggest potentials could be achieved in the inter NRW flows and for the cargo flows going to the east.

Table 17 gives the total TEU.km, tonne.km and vehicle kilometres for the whole corridor. Also here, only those cargo flows that have a link with NRW are taken into account.

Table 17: TEU.km, tonne.km, veh.km and modal share for the whole corridor (North sea Baltic 2015 base case)

	All cargo flows (10^6)								
	TEU.km			ton.km			Loaded veh.km		
	Road	Rail	IWT	Road	Rail	IWT	Road	Rail	IWT
Total corridor	**2,383.84**	**396.74**	**659.11**	**44,224.64**	**6,087.49**	**49,189.90**	**4,400.43**	**14.63**	**185.16**
	Modal split			Modal split					
	69.3%	11.5%	19.2%	44.4%	6.1%	49.4%			

From Table 17, it can be observed that road transport has the highest modal share for container transport while the share of inland waterway transport has the highest modal share for the transportation of bulk cargo. Most of this modal share comes from cargo flows the Flemish and Dutch ports and NRW. For the cargo flows to the east of NRW the waterway infrastructure is not as well developed as it is from NRW to the south (Rhine). As a result more use will be made of rail and road transport for cargo flows going to the east of NRW.

6 Scenario Analysis

In this section, we will analyse the impact of different scenarios on the modal share on the cargo flows linked to the NRW region. Firstly an overview of the different inputs related to the developed scenarios is given. Secondly, the results of both the Rhine-Alpine and the North Sea Baltic corridor are given. For each scenario, the total performed TEU.km and tonne.km, veh.km and GHG emissions are determined for the whole corridor and on the territory of NRW.

6.1 Inputs for the different scenario analysis

Based on the results of Work Packages 3 and 5, the data related to the relative changes of the different generalised cost elements for the three scenarios are presented. For each scenario, the relative changes in input parameters relative to the data presented in section 4 are given.

6.1.1 Business as Usual scenario (2030, 2050)

For the Business as Usual scenario (BAU), the relative changes to the base inputs can be found in

Table 18. The data in the table is the summary of the work done by WP 3 from the LowCarb project.

Table 18: Relative changes in inputs for the BAU scenario (%)

Tranport mode	Year	Commodity type	Cost and time parameters					
			Fixed cost	Variable Cost(km)	Variable Cost(hour)	Load rate	Shipment time	Handling cost
Road	2030	Cont (L.D.)	4%	8%	-10%	5%	n.a.	0%
		Cont (PP.H.)	n.a.	4%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	4%	10%	-10%	5%	n.a.	0%
		Liq Bulk	4%	10%	-10%	5%	n.a.	0%
		Gen Cargo	4%	10%	-10%	5%	n.a.	0%
	2050	Cont (L.D.)	9%	-11%	-20%	10%	n.a.	0%
		Cont (PP.H.)	n.a.	10%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	9%	-6%	-20%	10%	n.a.	0%
		Liq Bulk	9%	-6%	-20%	10%	n.a.	0%
		Gen Cargo	9%	-7%	-20%	10%	n.a.	0%
Rail	2030	Cont	4%	-8%	-16%	5%	n.a.	0%
		Dry Bulk	4%	-7%	-16%	5%	n.a.	0%
		Liq Bulk	4%	-7%	-16%	5%	n.a.	0%
		Gen Cargo	4%	-8%	-16%	5%	n.a.	0%
	2050	Cont	9%	-19%	-42%	33%	n.a.	0%
		Dry Bulk	9%	-18%	-42%	10%	n.a.	0%
		Liq Bulk	9%	-18%	-42%	10%	n.a.	0%
		Gen Cargo	9%	-20%	-42%	10%	n.a.	0%
IWT	2030	Cont	-4%			10%	n.a.	0%
		Dry Bulk	-4%			10%	n.a.	0%
		Liq Bulk	-4%			10%	n.a.	0%

		Gen Cargo	-4%	10%	n.a.	0%
	2050	Cont	-18%	20%	n.a.	0%
		Dry Bulk	-18%	20%	n.a.	0%
		Liq Bulk	-18%	20%	n.a.	0%
		Gen Cargo	-18%	20%	n.a.	0%

Source: based on the outputs of Doll, C., Köhler, J. (2018)

From Table 18, it can be seen that for both rail and road transport, a decrease in kilometre and hour cost can be achieved. Also the payload of trucks and trains will increase.

6.1.2 Modest Rail scenario (2030, 2050)

For the Mod Rail scenario[23], the relative changes to the base inputs can be found in Table 19.The data in the table is derived from the Pro Rail Scenario by halving all deviations from the Business-as-Usual case.

Table 19: Relative changes in inputs for the Mod Rail scenario (%)

Tranport mode	Year	Commodity type	Cost and time parameters					
			Fixed cost	Variable Cost(km)	Variable Cost(hour)	Load rate	Shipment time	Handling cost
Road	2030	Cont (L.D.)	7.5%	9.5%	2.5%	2.5%	n.a.	0.0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	7.5%	16.0%	2.5%	2.5%	n.a.	0.0%
		Liq Bulk	7.5%	16.0%	2.5%	2.5%	n.a.	0.0%
		Gen Cargo	7.5%	16.0%	2.5%	2.5%	n.a.	0.0%
	2050	Cont (L.D.)	12.5%	3.5%	5.0%	5.0%	n.a.	0.0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	12.5%	23.0%	5.0%	5.0%	n.a.	0.0%
		Liq Bulk	12.5%	23.0%	5.0%	5.0%	n.a.	0.0%
		Gen Cargo	12.5%	23.5%	5.0%	5.0%	n.a.	0.0%
Rail	2030	Cont	-10.0%	-15.5%	-12.5%	36.5%	n.a.	-50.0%
		Dry Bulk	-10.0%	-15.0%	-12.5%	20.0%	n.a.	-50.0%
		Liq Bulk	-10.0%	-15.0%	-12.5%	20.0%	n.a.	-50.0%
		Gen Cargo	-10.0%	-16.0%	-12.5%	39.5%	n.a.	-50.0%
	2050	Cont	-16.5%	-28.5%	-34.0%	95.5%	n.a.	-50.0%
		Dry Bulk	-16.5%	-28.0%	-34.0%	51.0%	n.a.	-50.0%
		Liq Bulk	-16.5%	-28.0%	-34.0%	51.0%	n.a.	-50.0%
		Gen Cargo	-16.5%	-29.5%	-34.0%	104.5%	n.a.	-50.0%
IWT	2030	Cont	-2.0%			5.0%	n.a.	-50.0%
		Dry Bulk	-2.0%			5.0%	n.a.	-50.0%
		Liq Bulk	-2.0%			5.0%	n.a.	-50.0%
		Gen Cargo	-2.0%			5.0%	n.a.	-50.0%

[23] The modest rail scenario has halve of the reduction factors of the Pro Rail scenario.

	2050	Cont	-9.0%	10.0%	n.a.	-50.0%
		Dry Bulk	-9.0%	10.0%	n.a.	-50.0%
		Liq Bulk	-9.0%	10.0%	n.a.	-50.0%
		Gen Cargo	-9.0%	10.0%	n.a.	-50.0%

Source: based on the outputs of Doll, C., Köhler, J. (2018)

6.1.3 Pro Rail scenario (2030, 2050)

For the Pro Rail scenario, the relative changes to the base inputs can be found in Table 20. The data in the table is the summary of Doll, C., Köhler, J. (2018).

Table 20:Relative changes in inputs for the Pro Rail scenario (%)

Tranport mode	Year	Commodity type	Cost and time parameters					
			Fixed cost	Variable Cost(km)	Variable Cost(hour)	Load rate	Shipment time	Handling cost
Road	2030	Cont (L.D.)	15%	19%	5%	5%	n.a.	0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	15%	32%	5%	5%	n.a.	0%
		Liq Bulk	15%	32%	5%	5%	n.a.	0%
		Gen Cargo	15%	32%	5%	5%	n.a.	0%
	2050	Cont (L.D.)	25%	7%	10%	10%	n.a.	0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	25%	46%	10%	10%	n.a.	0%
		Liq Bulk	25%	46%	10%	10%	n.a.	0%
		Gen Cargo	25%	47%	10%	10%	n.a.	0%
Rail	2030	Cont	-20%	-31%	-25%	73%	n.a.	-100%
		Dry Bulk	-20%	-30%	-25%	40%	n.a.	-100%
		Liq Bulk	-20%	-30%	-25%	40%	n.a.	-100%
		Gen Cargo	-20%	-32%	-25%	79%	n.a.	-100%
	2050	Cont	-33%	-57%	-68%	191%	n.a.	-100%
		Dry Bulk	-33%	-56%	-68%	102%	n.a.	-100%
		Liq Bulk	-33%	-56%	-68%	102%	n.a.	-100%
		Gen Cargo	-33%	-59%	-68%	209%	n.a.	-100%
IWT	2030	Cont	-4%			10%	n.a.	-100%
		Dry Bulk	-4%			10%	n.a.	-100%
		Liq Bulk	-4%			10%	n.a.	-100%
		Gen Cargo	-4%			10%	n.a.	-100%
	2050	Cont	-18%			20%	n.a.	-100%
		Dry Bulk	-18%			20%	n.a.	-100%
		Liq Bulk	-18%			20%	n.a.	-100%
		Gen Cargo	-18%			20%	n.a.	-100%

Source: based on the outputs of Doll, C., Köhler, J. (2018)

6.1.4 Modest Road scenario (2030, 2050)

For the modest Road scenario[24], the relative changes to the base inputs can be found in Table 21 .The data in the table is derived from the Pro Road-Scenario by halving all deviations from the Business-as-Usual case.

Table 21: Relative changes in inputs for the Mod Road scenario (%)

Tranport mode	Year	Commodity type	Cost and time parameters					
			Fixed cost	Variable Cost(km)	Variable Cost(hour)	Load rate	Shipment time	Handling cost
Road	2030	Cont (L.D.)	5.0%	-18.5%	-15.0%	7.5%	n.a.	-25.0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	5.0%	-25.5%	-15.0%	7.5%	n.a.	-25.0%
		Liq Bulk	5.0%	-25.5%	-15.0%	7.5%	n.a.	-25.0%
		Gen Cargo	5.0%	-24.0%	-15.0%	7.5%	n.a.	-25.0%
	2050	Cont (L.D.)	2.5%	-26.0%	-35.0%	12.5%	n.a.	-25.0%
		Cont (PP.H.)	n.a.	16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	2.5%	-31.0%	-35.0%	12.5%	n.a.	-25.0%
		Liq Bulk	2.5%	-31.0%	-35.0%	12.5%	n.a.	-25.0%
		Gen Cargo	2.5%	-29.5%	-35.0%	12.5%	n.a.	-25.0%
Rail	2030	Cont	-10.0%	-4.0%	-8.0%	15.0%	n.a.	-25.0%
		Dry Bulk	-10.0%	-3.5%	-8.0%	15.0%	n.a.	-25.0%
		Liq Bulk	-10.0%	-3.5%	-8.0%	15.0%	n.a.	-25.0%
		Gen Cargo	-10.0%	-4.0%	-8.0%	15.0%	n.a.	-25.0%
	2050	Cont	-16.5%	-9.5%	-21.0%	50.0%	n.a.	-25.0%
		Dry Bulk	-16.5%	-9.0%	-21.0%	50.0%	n.a.	-25.0%
		Liq Bulk	-16.5%	-9.0%	-21.0%	50.0%	n.a.	-25.0%
		Gen Cargo	-16.5%	-10.0%	-21.0%	50.0%	n.a.	-25.0%
IWT	2030	Cont	-2.0%			5.0%	n.a.	-25.0%
		Dry Bulk	-2.0%			5.0%	n.a.	-25.0%
		Liq Bulk	-2.0%			5.0%	n.a.	-25.0%
		Gen Cargo	-2.0%			5.0%	n.a.	-25.0%
	2050	Cont	-9.0%			10.0%	n.a.	-25.0%
		Dry Bulk	-9.0%			10.0%	n.a.	-25.0%
		Liq Bulk	-9.0%			10.0%	n.a.	-25.0%
		Gen Cargo	-9.0%			10.0%	n.a.	-25.0%

Source: based on the outputs of Mader, S. and W. Schade (2018)

[24] The relative changes for the modest road scenario are half of the pro road scenario.

6.1.5 Pro Road scenario (2030, 2050)

For the Pro Rail scenario, the relative changes to the base inputs can be found in Table 22. The data in the table is the summary of the work done by Mader, S. and W. Schade (2018).

Table 22:Relative changes in inputs for the Pro Road scenario (%)

Tranport mode	Year	Commodity type	Cost and time parameters					
			Fixed cost	Variable Cost(km)	Variable Cost(hour)	Load rate	Shipment time	Handling cost
Road	2030	Cont (L.D.)	10%	-37%	-30%	15%	n.a.	-50%
		Cont (PP.H.)	n.a.	-16%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	10%	-51%	-30%	15%	n.a.	-50%
		Liq Bulk	10%	-51%	-30%	15%	n.a.	-50%
		Gen Cargo	10%	-48%	-30%	15%	n.a.	-50%
	2050	Cont (L.D.)	5%	-52%	-70%	25%	n.a.	-50%
		Cont (PP.H.)	n.a.	-37%	n.a.	n.a.	n.a.	n.a.
		Dry Bulk	5%	-62%	-70%	25%	n.a.	-50%
		Liq Bulk	5%	-62%	-70%	25%	n.a.	-50%
		Gen Cargo	5%	-59%	-70%	25%	n.a.	-50%
Rail	2030	Cont	-20%	-8%	-16%	30%	n.a.	-50%
		Dry Bulk	-20%	-7%	-16%	30%	n.a.	-50%
		Liq Bulk	-20%	-7%	-16%	30%	n.a.	-50%
		Gen Cargo	-20%	-8%	-16%	30%	n.a.	-50%
	2050	Cont	-33%	-19%	-42%	100%	n.a.	-50%
		Dry Bulk	-33%	-18%	-42%	100%	n.a.	-50%
		Liq Bulk	-33%	-18%	-42%	100%	n.a.	-50%
		Gen Cargo	-33%	-20%	-42%	100%	n.a.	-50%
IWT	2030	Cont		-4%		10%	n.a.	-50%
		Dry Bulk		-4%		10%	n.a.	-50%
		Liq Bulk		-4%		10%	n.a.	-50%
		Gen Cargo		-4%		10%	n.a.	-50%
	2050	Cont		-18%		20%	n.a.	-50%
		Dry Bulk		-18%		20%	n.a.	-50%
		Liq Bulk		-18%		20%	n.a.	-50%
		Gen Cargo		-18%		20%	n.a.	-50%

Source: based on the outputs of Mader, S. and W. Schade (2018)

6.2 Rhine Alpine Corridor

For the Rhine Alpine corridor, a growth of 1.7% in transport demand per year is expected (Palacio and Wojciechowski, 2015). For 2030, a growth of 28.7% is expected, while in 2050 the growth will be 80.4%[25].

With these growth figures the future TEU.km, tonne.km and vehicle.km are calculated for the three developed scenarios. Also the GHG emissions with constant emission factors for each scenario are presented. The overview of the modal split data can be seen in Appendix A.

6.2.1 Business As Usual

For the business as usual (BAU) scenario, the results of the calculations are shown in Figure 8 and

Figure 9.

Figure 8: TEU.km (left) and tonne.km (right) (10^6) on NRW territory and the total RALP corridor (BAU scenario)

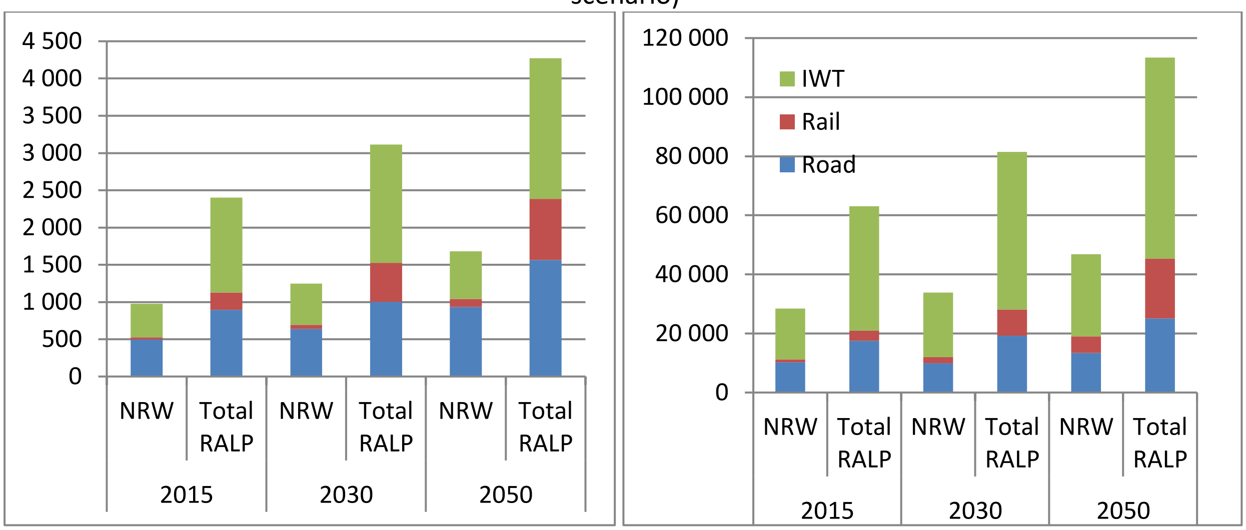
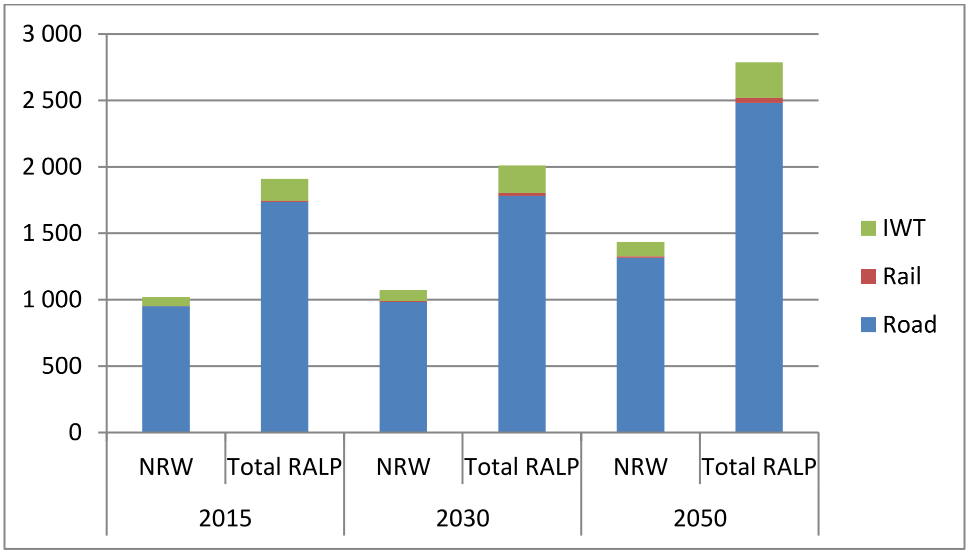


Figure 9: Vehicle kilometers (10^6) on NRW territory and the total RALP corridor (BAU scenario)

[25] A constant growth of 1.7% per year until 2050 is assumed.



Based on the calculations, there will be strong growth in TEU.km and ton.kms up to 2050. Especially the strong growth of road is apparent. The modal share of road transport for container transport even grows from 49% to 56% for the container cargo flows on the territory of NRW . In absolute figures, the growth of rail transport is also quite high (from 900 million ton.km in 2015 to 5.500 million in 2050). In terms of train veh.km this is an increase of a factor 5.24. The question is, if the rail infrastructure in NRW can handle such a strong growth in absolute terms?

6.2.2 Modest Rail

For the modest rail scenario, the results of the calculations are shown in Figure 10 and Figure 11.

Figure 10: TEU.km (left) and tonne.km (right) (10^6) on NRW territory and the total RALP corridor (Mod Rail scenario)

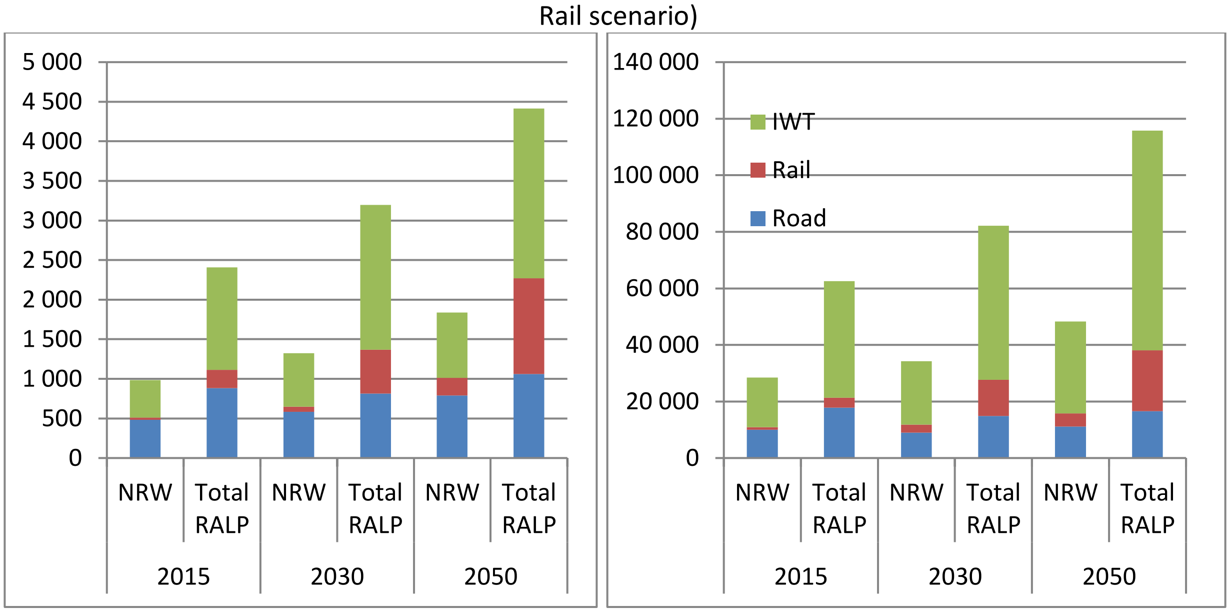
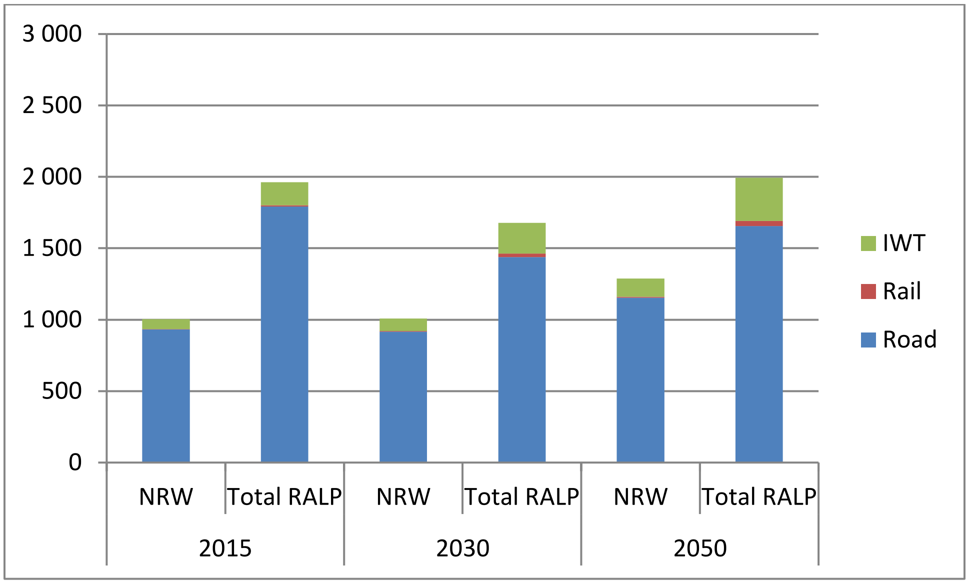


Figure 11: Vehicle kilometers (10^6) on NRW territory and the total RALP corridor (Mod Rail scenario)

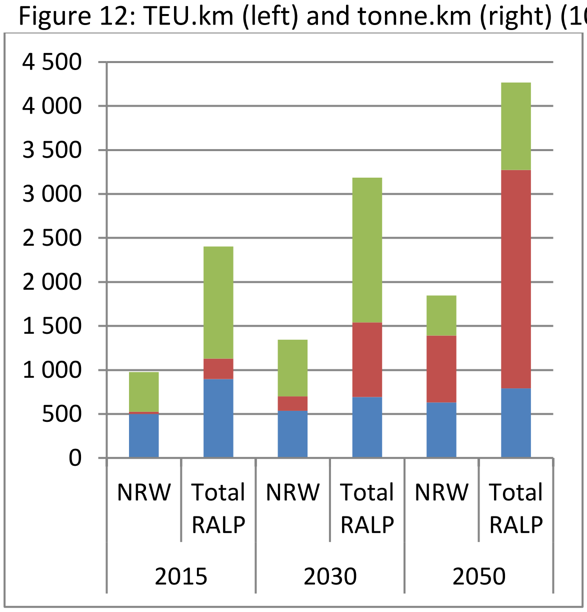


In this scenario the share of rail transport for container will increase from 3%, of cargo flows on the territory of NRW, to 12% in 2050. For bulk transport the rail share will increase from 3% to 10%. The vehicle kilometres on the territory of NRW will increase from 1.0 billion in 2015 to 1.28 billion in 2050. For the whole corridor (for those cargo flows having a link with NRW) there is only a small increase from 1.96 billion to 1.99 billion veh.km for all transport modes. In this scenario, there is an increase in road veh.km on the territory of NRW and a decrease in road veh.km for the whole corridor.

6.2.3 Pro Rail

For the Pro Rail scenario, the same calculations are made. The results of the calculations can be found in Figure 12 and Figure 13.

Figure 12: TEU.km (left) and tonne.km (right) (10^6) on NRW territory RALP corridors (Pro Rail scenario)



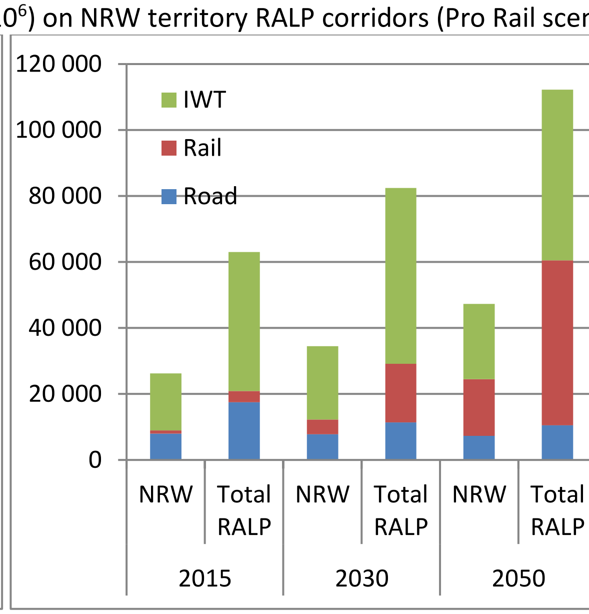
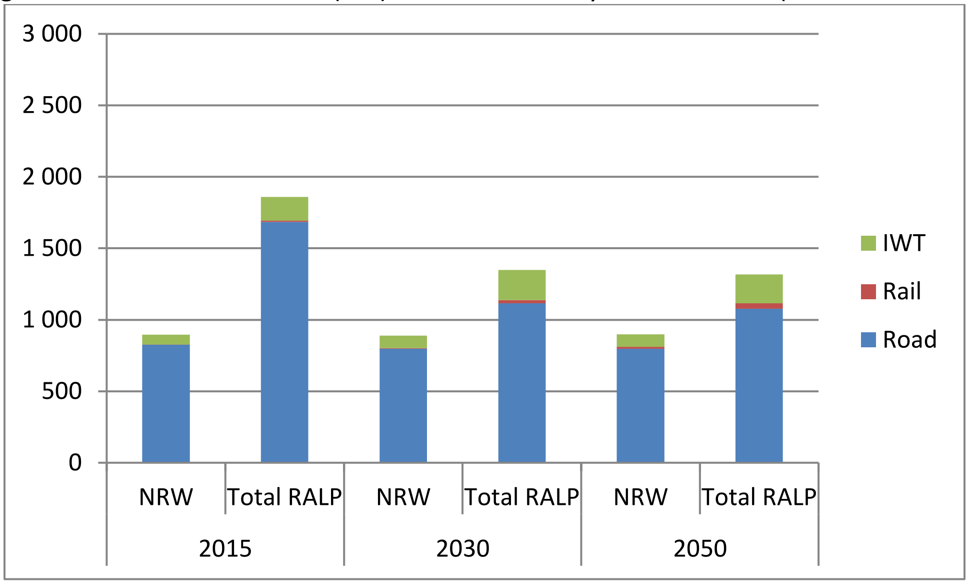


Figure 13: Vehicle kilometers (10^6) on NRW territory RALP corridor (Pro Rail scenario)



With respect to the BAU scenario, a very strong growth in rail transport can be observed. For 2050, the modal share on the NRW territory will increase for container transport from 3% to 41% and for bulk transport from 3% to 36%. Also the number of rail transport vehicle.km is increased on the territory of NRW with a factor of 6.9[26]. So 6.9 as much train.km capacity needs to be handled on the rail infrastructure[27] (see also Figure 13). This means that the rail infrastructure needs to be able to deal with this strong increase. If that is the case, the total TEU.km and ton.km is reduced quite a lot compared to the BAU scenario (-37% for those cargo flows with link to NRW and -52.8% for the whole corridor).

6.2.4 Modest Road

With respect to the Mod Road scenario, the results can be seen in Figure 14 and Figure 15.

Figure 14: TEU.km (left) and tonne.km (right) (10^6) on NRW territory RALP corridors (Mod Road scenario)

[26] In the BAU scenario the increase was 5.2. So the scenario impact is an 1.7 factor increase in train veh.kms

[27] It has to be mentioned that in the calculation no capacity restrictions are taken into account.

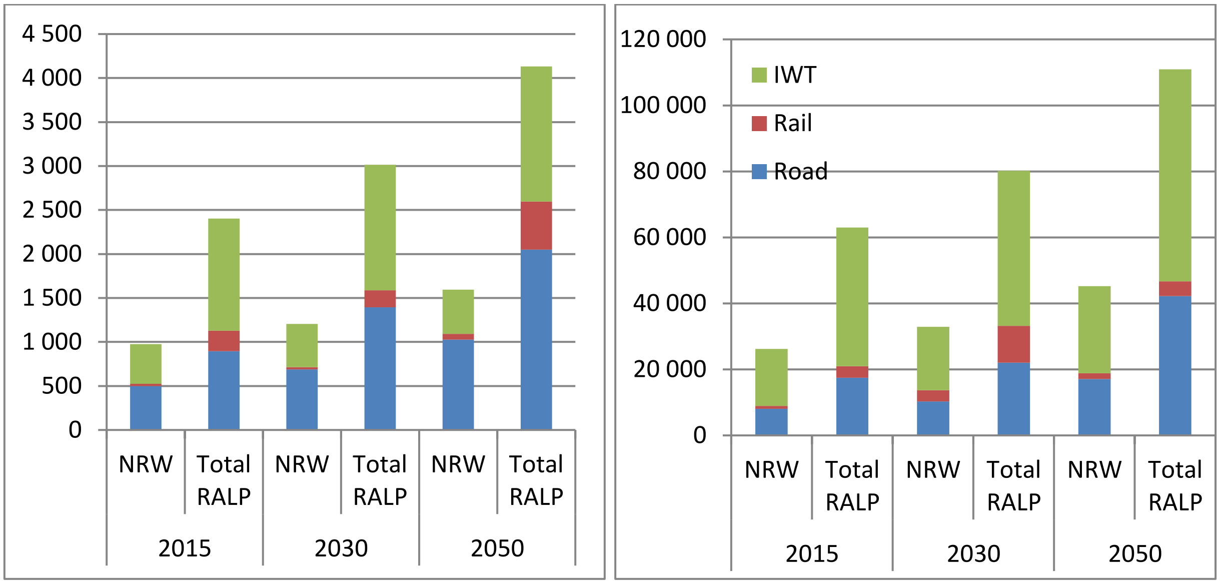
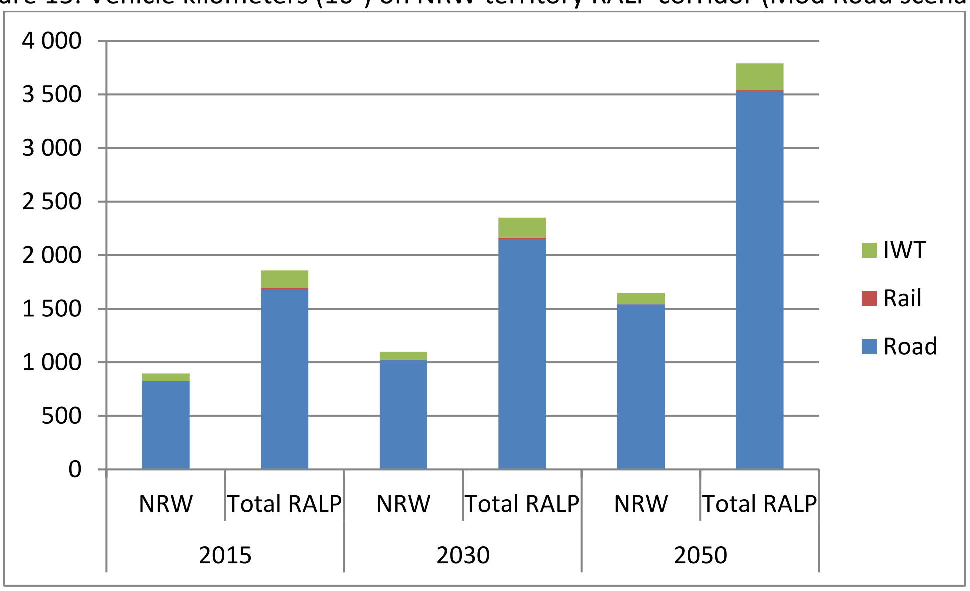


Figure 15: Vehicle kilometers (10^6) on NRW territory RALP corridor (Mod Road scenario)



From the scenario analysis can be concluded that there is decrease in rail share for container transport in 2030 from 3% to 2%, while the modal share increases to 4% in 2050. IWT still has the highest modal share for dry bulk, liquid bulk and general cargo, while for container transport for road transport the modal share will increase from 49% in 2015 to 64% in 2050 for cargo flows on the territory of NRW. With respect to the vehicle kilometres, this will increase from 0.9 billion in 2015 to 1.64 billion in 2050, on the territory of NRW, which is increase in 64.3%. The increase in train veh.km in this scenario is 1.38 for 2050. This increase still comes from the growth in freight transport.

6.2.5 Pro Road

With respect to the Pro Road scenario, the results can be seen in Figure 16 and Figure 17.

Figure 16: TEU.km (left) and tonne.km (right) (10^6) on NRW territory RALP corridors (Pro Road scenario)

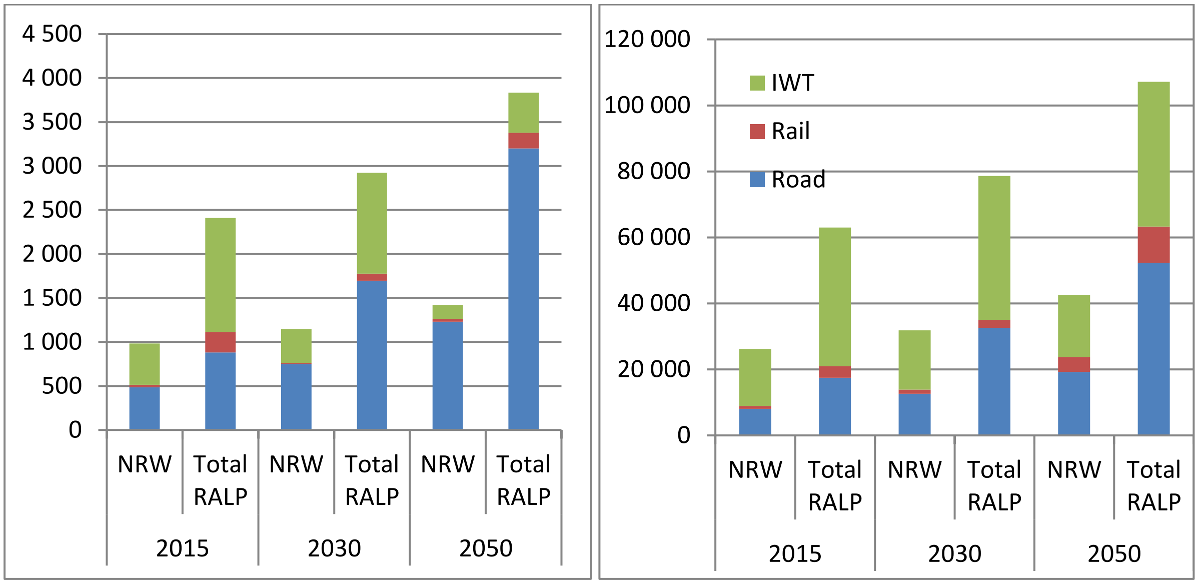
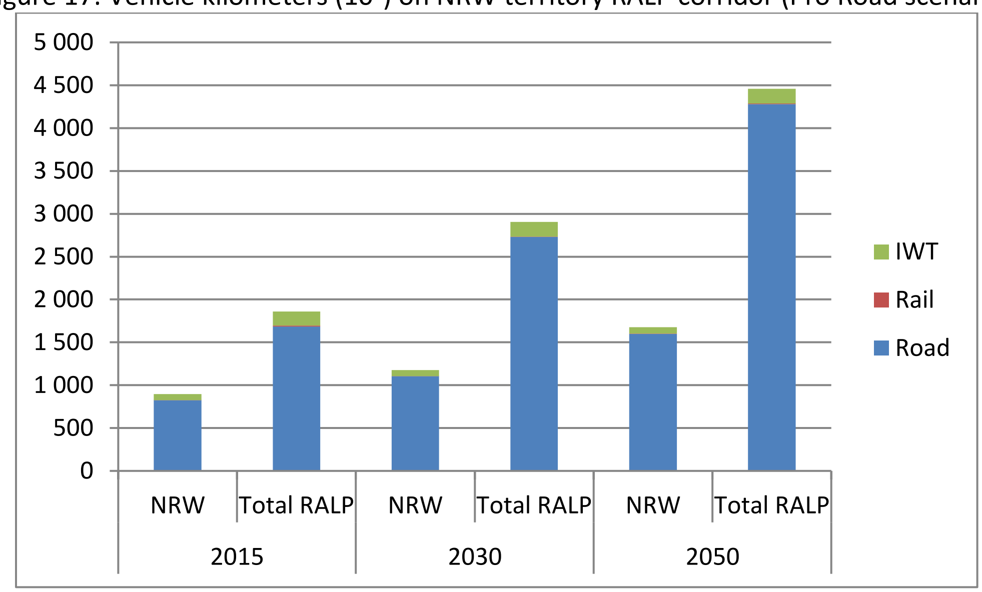


Figure 17: Vehicle kilometers (10^6) on NRW territory RALP corridor (Pro Road scenario)

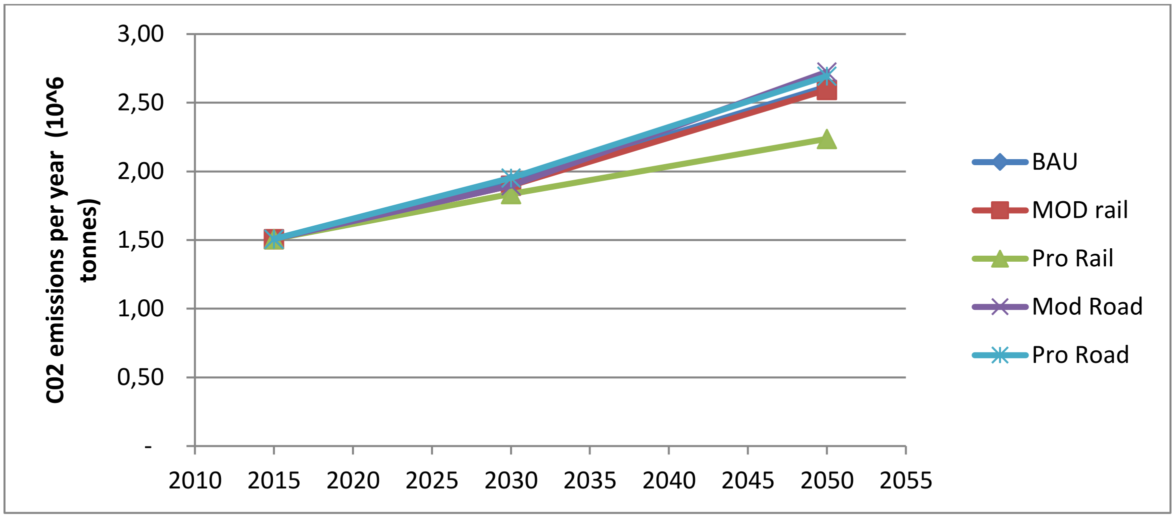


The Pro Road scenario a very strong growth in road transport is observed. There is increase in total vehicle.km for the cargo flows on the NRW territory (+87%) and a 140% increase for the whole corridor. In this scenario, the modal shares of both road and rail increase a bit but a very strong decline of IWT is observed (from 53% to 12% for container transport and from 67% to 41% for the other cargo types).

6.2.6 GHG emissions

For each scenario, also the fixed rate GHG emissions are calculated. As we use constant GHG emission factors per mode, this theoretical value isolates the mode shift effect from all other impacts on GHG emissions. In Figure 18, the results of the calculations can be found for the CO_2 emissions per year on the NRW territory for cargo flows on the RALP corridor.

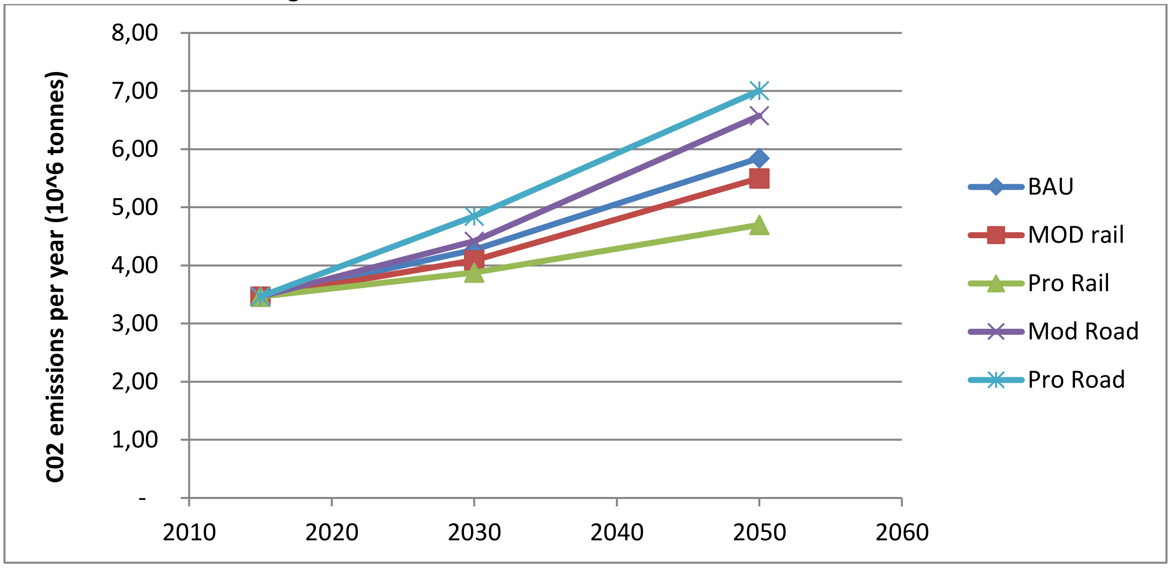
Figure 18: GHG emissions NRW for the RALP corridor



From Figure 18, it can be concluded that there is an increase in fixed rate GHG emissions over time in all scenarios. In the BAU scenario the fixed rate GHG emissions grown from 1.51 10^6 tonnes/ year in 2015 to 2.62 10^6 tonnes/year in 2050. This is an increase by 73%. For the Pro rail scenario, the increase is the smallest (+48% in 2050 compared to 2015). The difference in CO_2 equivalent emissions between the different scenarios is relatively small . This is due to the fact that the travelled distance, on the NRW territory, is small.

For the entire corridor, the results can be observed in Figure 19.

Figure 19: GHG emissions for the entire RALP corridor



Also for the entire corridor, an increase in the fixed rate GHG emissions is observed. Here, the difference between the different scenarios is larger due to the fact that the travelled distances are larger. The highest increase in fixed rate GHG emissions/year are expected for the Pro Road scenario (+102%) while for the Pro Rail scenario "only" an increase of 35% is expected. This is a difference of 2,300,000 tonnes of CO_2-equivalents per year in the year 2050. The total reduction in GHG emissions between 2015 and 2050 between the BAU scenario and the Pro Rail scenario is 10,511,000 tonnes of CO_2. For the Pro road scenario, an increase of 10.200.000 tonnes of CO_2-equivalents is expected compared to the BAU scenario.

6.3 North Sea Baltic Corridor

For the North Sea Baltic Corridor, no specific yearly growth factor for transport demand was found. Therefore, the same growth factor as for the Rhine Alpine corridor was used (1.7% in transport demand per year). Also the NSB corridor the output is presented in terms of TEU.km, tonne.km and vehicle.km along with the GHG emissions for each scenario. The overview of the modal split data can be seen in Appendix B.

6.3.1 Business As Usual

In Figure 20 and Figure 21 the results of the BAU scenario can be observed for the NSB corridor.

Figure 20: TEU.km (left) and tonne.km (right) (10^6) on NRW territory on the NSB corridor (BAU scenario)

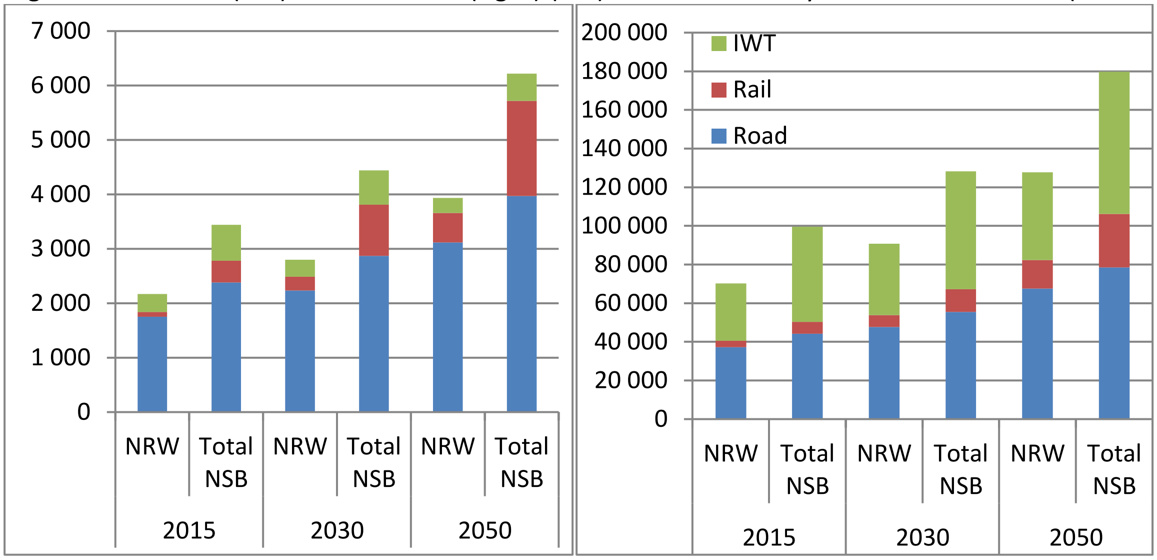
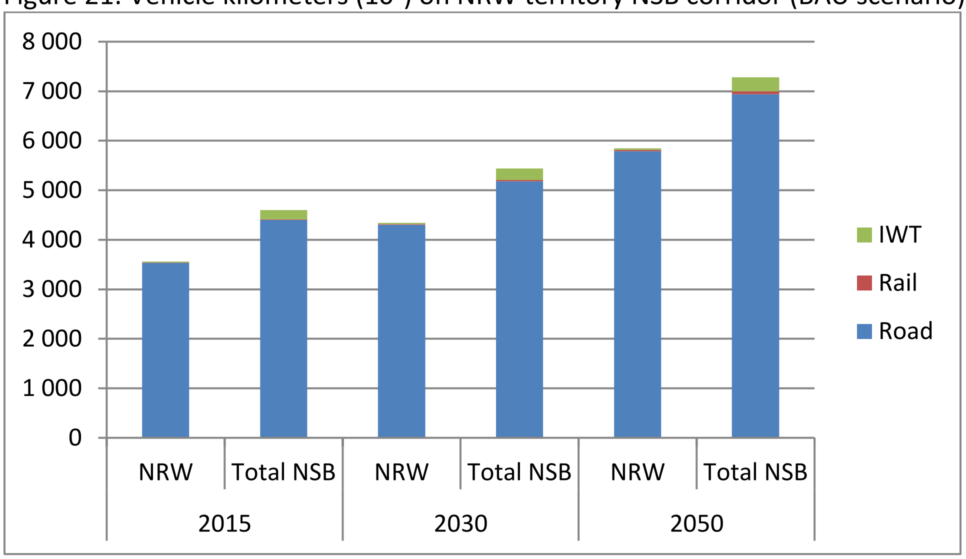


Figure 21: Vehicle kilometers (10^6) on NRW territory NSB corridor (BAU scenario)



From the above tables, it can be concluded that the amount of freight transport grows very much. The amount of vehicle.km on the territory of NRW is growing from 3.5 billion veh.km in 2015 to 5.8 billion in 2050 (+63%). The biggest part of this growth is caused by a strong growth in road veh.km. The share of rail transport is growing from 4% to a share of 14% for container transport and 5 to 12% for bulk transport. In terms of veh.kms road transport is very dominant on this corridor. The reason for this is that the NRW, for this corridor, has five different NUTS-2 regions. The inter-regional traffic is mostly road transport (short distance transport), which makes that road transport has such a high modal share.

6.3.2 Modest Rail

In Figure 22 and Figure 23, the output of the modest Rail scenario for the NSB corridor can be found.

Figure 22: TEU.km (left) and tonne.km (right) (10^6) on NRW territory on the NSB corridor (Mod Rail scenario)

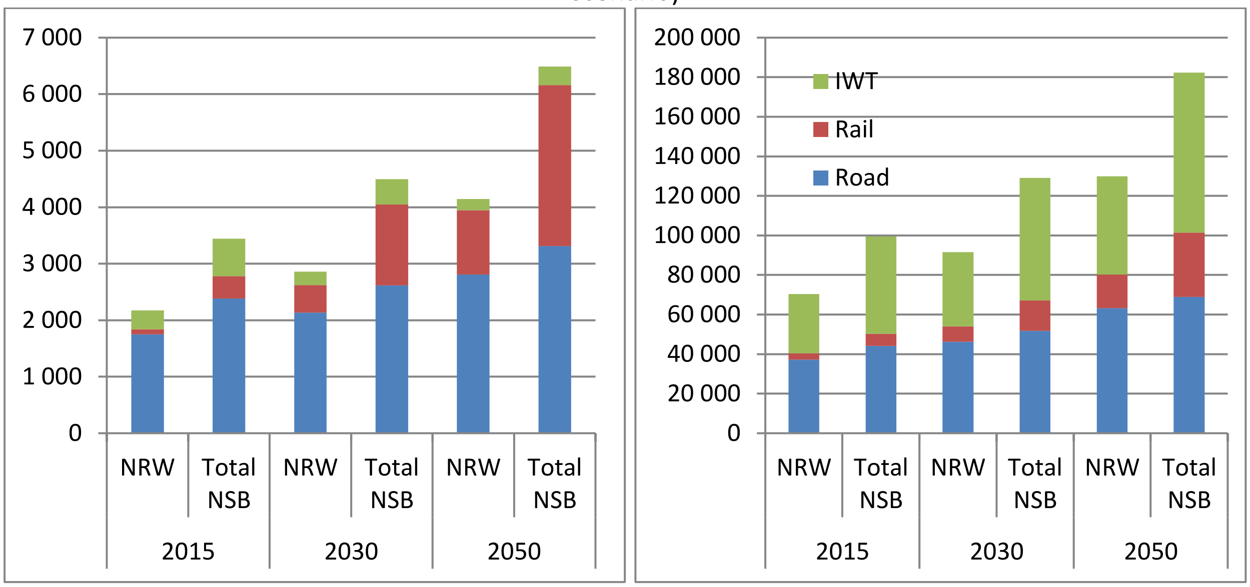
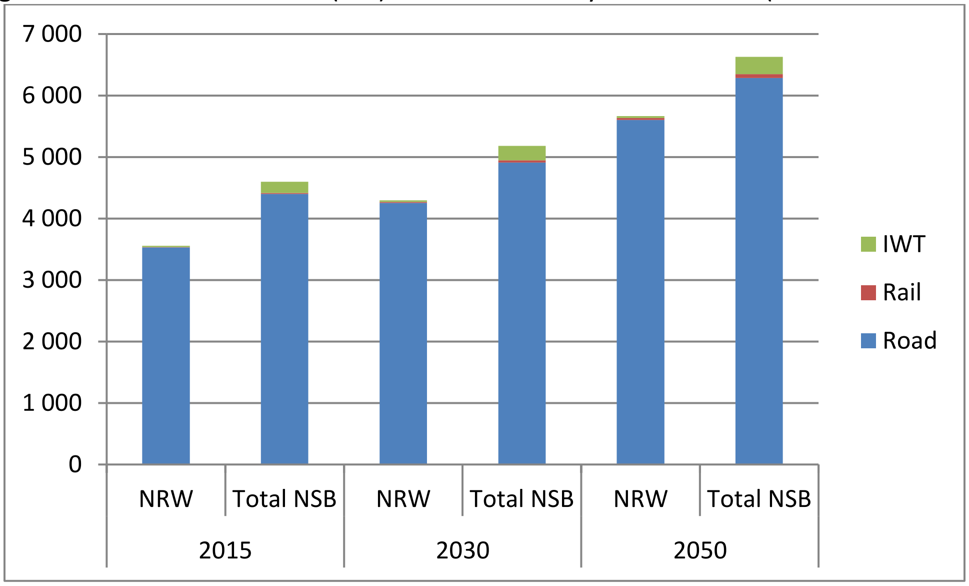


Figure 23: Vehicle kilometers (10^6) on NRW territory NSB corridor (Mod Rail scenario)



From the above figures, it can be concluded that the amount of freight transport grows very much. The amount of vehicle.km on the territory of NRW is growing from 3.5 billion veh.km in 2015 to 5.6 billion in 2050 (+58%). The biggest part of this growth is caused by a strong growth in road veh.km. The share of rail transport is growing from 4% to a share of 28% for container transport and 5 to 13% for bulk transport. In this scenario the modal share for IWT container transport is decreasing. This means that in this scenario the growth of the container rail share comes from the IWT sector.

6.3.3 Pro Rail

In Figure 24 and Figure 25 the output of the Pro Rail scenario for the NSB corridor can be found.

Figure 24: TEU.km (left) and tonne.km (right) (10^6) on NRW territory on the NSB corridor (Pro Rail scenario)

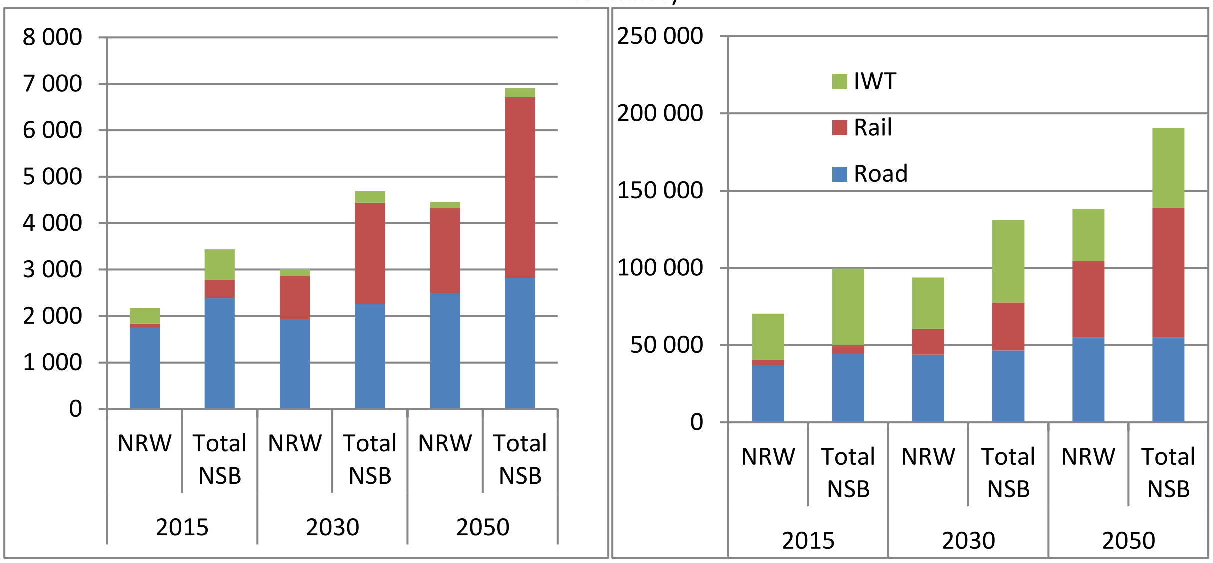
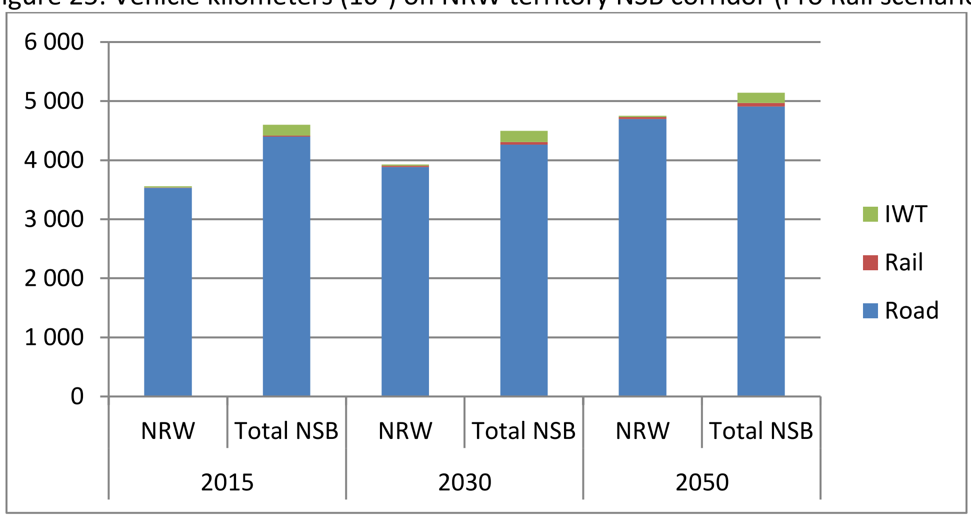


Figure 25: Vehicle kilometers (10^6) on NRW territory NSB corridor (Pro Rail scenario)

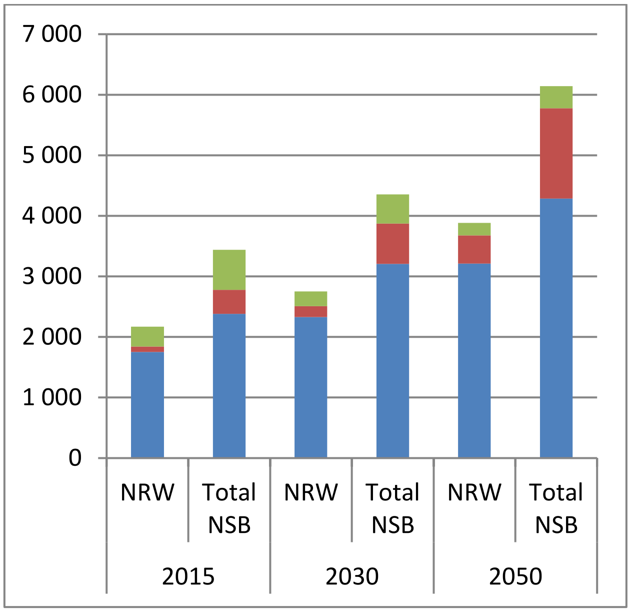


For the Pro Rail scenario, the growth in veh.km on the territory in NRW is not growing as fast as in the BUA scenario (33%). In this Pro Rail scenario, the rail freight output (TEU.km and tonne.km) is growing quite a lot (2000% for container transport and 900% for the other cargo types). Also here, the capacity restrictions of the railway infrastructure is not taken into account. So this strong growth can only be achieved if the rail infrastructure is able to deal with this strong increase. In this scenario, a large decrease in IWT share is observed, for container transport, from 13% to 3% and for the other cargoes from 43% to 24%. So also for the NSB corridor, it can be concluded that the biggest increase in modal share of rail transport comes from the IWT.

6.3.4 Modest Road

In Figure 26 and Figure 27 the output of the modest rail scenario for the NSB corridor can be found.

Figure 26: TEU.km (left) and tonne.km (right) (10^6) on NRW territory on the NSB corridor (Mod Road scenario)



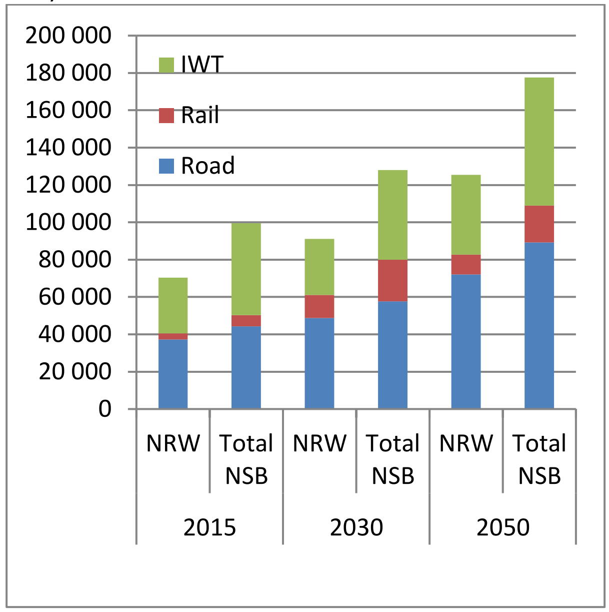
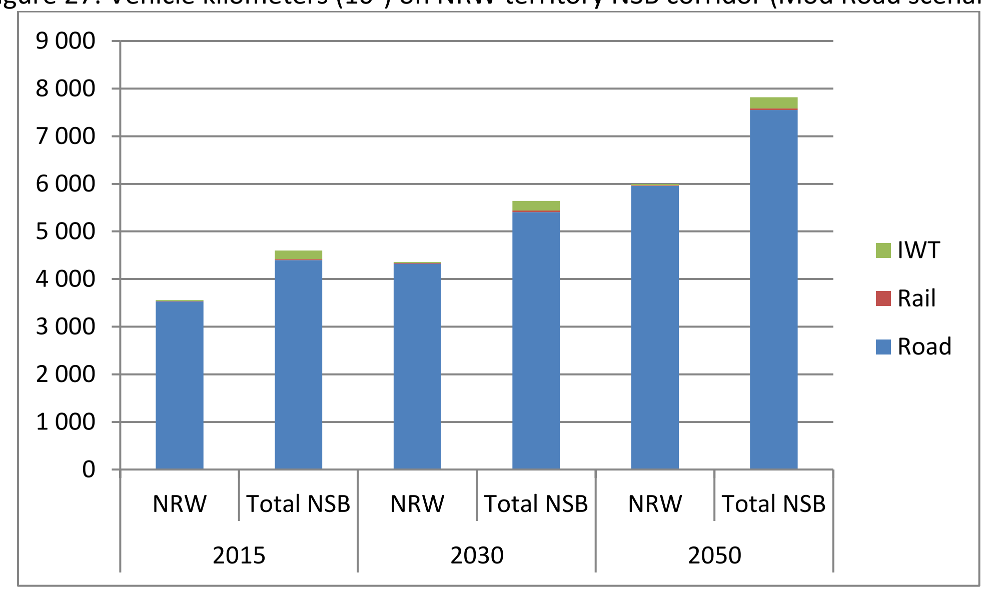


Figure 27: Vehicle kilometers (10^6) on NRW territory NSB corridor (Mod Road scenario)



In the modest road scenario, there is a strong increase in vehicle kilometers. These grow from 3.6 billion to 6.0 billon vehicle kilometers on the territory of NRW. For container transport the highest modal share is for road transport (83% in 2050). For bulk transport, the highest modal share is also for road transport (57% in 2050).

6.3.5 Pro Road

In Figure 28 and Figure 29 the output of the Pro Rail scenario for the NSB corridor can be found.

Figure 28: TEU.km (left) and tonne.km (right) (10^6) on NRW territory on the NSB corridor (Pro Road scenario)

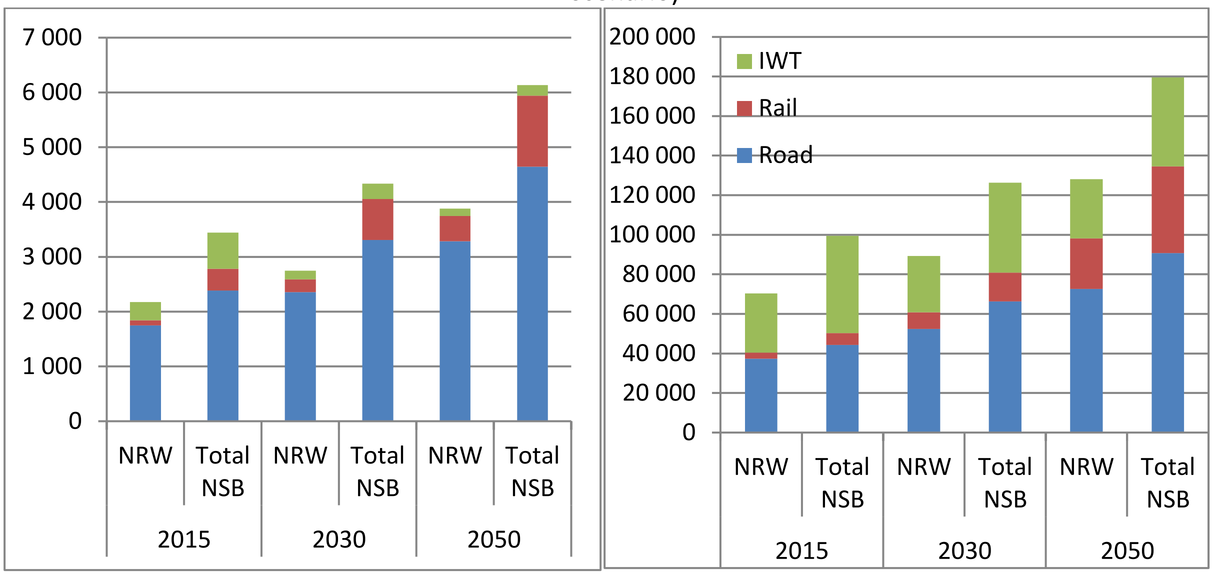
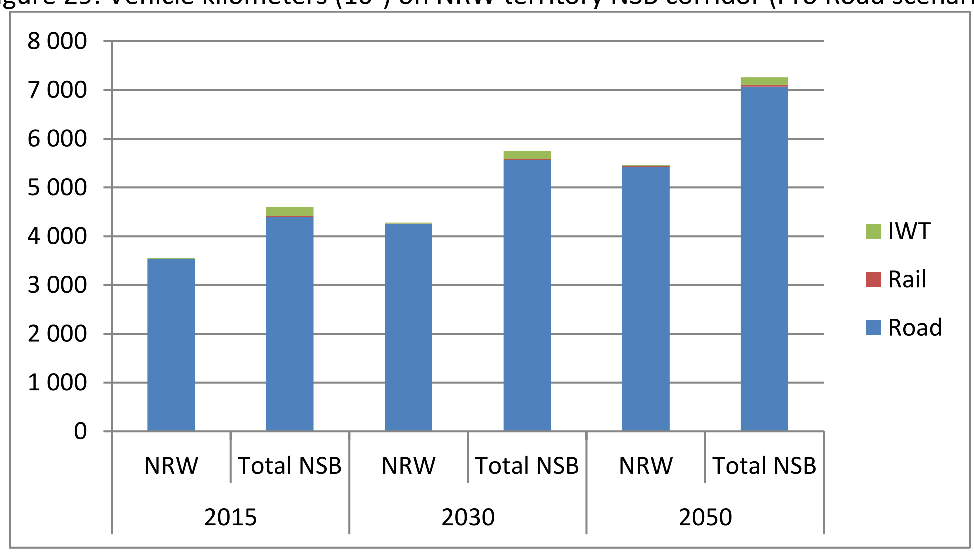


Figure 29: Vehicle kilometers (10^6) on NRW territory NSB corridor (Pro Road scenario)

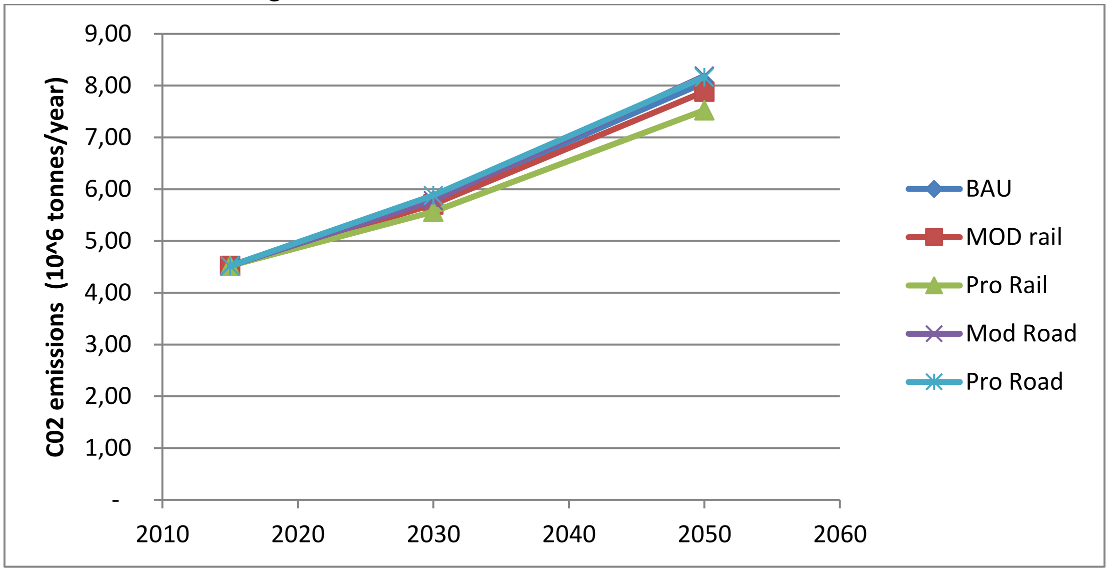


For the Pro Road scenario, a smaller increase in veh.km is expected on the territory of NRW compared to the BAU scenario (+53%). The share of road transport is higher but in this scenario the load capacity is also increased, which leads to lesser veh.km. The share of rail transport in this scenario is between 12% in 2050 for container transport and 20% for bulk transport. But also here, a strong growth in absolute terms is observed for the rail TEU.km and tonne.km (growth factor of 4.2 for container transport and 8 for bulk transport).

6.3.6 GHG emissions

The fixed rate GHG emissions for each scenario are also calculated for the NSB corridor. In Figure 30, the results of the calculations can be found for the CO_2 emissions per year on the NRW territory for cargo flows on the NSB corridor.

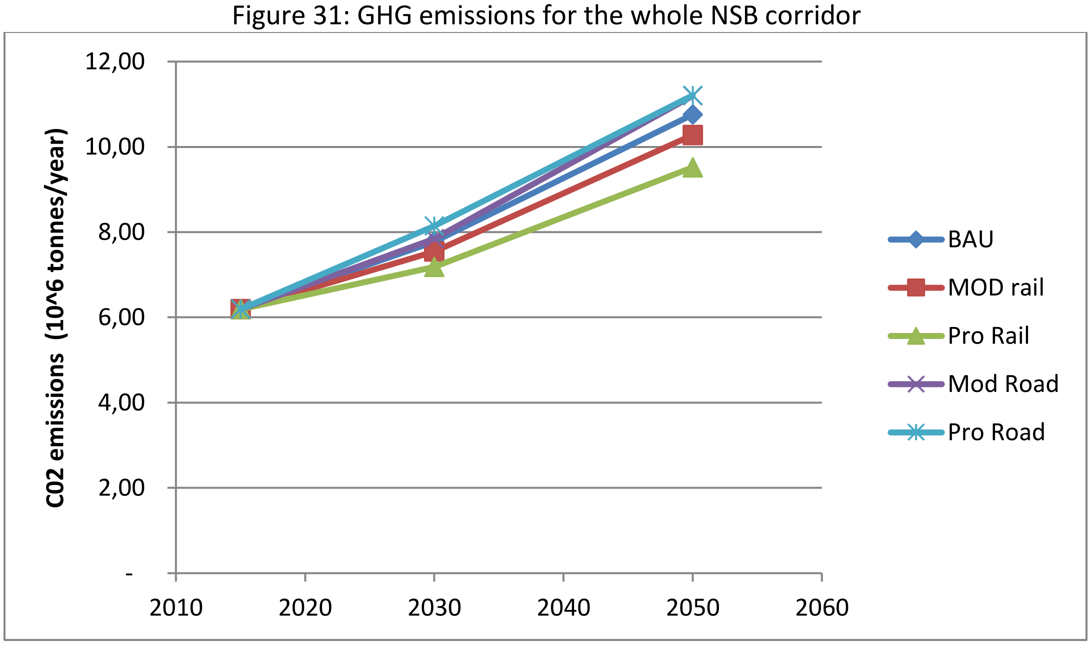
Figure 30: GHG emissions NRW for the NSB corridor



From Figure 30, it can be concluded that there is again an increase in fixed rate GHG emissions. In the BAU scenario, the CO_2 emissions grow from 4.52 10^6 tonnes/ year in 2015 to 8.06 10^6 tonnes/year in 2050. This is an increase by 73%. For the Pro rail scenario ,the increase is the smallest (+66% in 2050 compared to 2015). The difference in CO_2 emissions per year between the different scenarios is relatively small. This is due to the fact that the travelled distance on the NRW territory, is small.

For the entire corridor, the results can be observed in Figure 31.

Figure 31: GHG emissions for the whole NSB corridor



Also for the entire corridor, an increase in the fixed rate GHG emissions is observed. Here, the difference between the different scenarios is larger due to the fact that the travelled distances are larger. If the CO_2

emission lines are compared to those of the RALP corridor (Figure 19), it can be observed that the difference between the different scenarios is smaller. This is due to the fact for the NSB corridor, road transport is very dominant, especially within the NRW region.

The highest increase in CO_2 emissions/year is expected for the Pro Road scenario (+81%) while for the Pro Rail scenario "only" an increase of 53% is expected. This is a difference of 2,300,000 tonnes of CO_2 per year in the year 2050. The total reduction in CO_2 emissions between 2015 and 2050 between the BAU scenario and the Pro Rail scenario is 10,900,000 tonnes of CO_2. For the Pro Road scenario, an increase by 3,580,000 tonnes of CO_2 is expected compared to the BAU scenario.

7. Conclusions

The main research goals of this paper were to:

- Develop a method to assess different scenarios (Pro road and Pro rail).
- Determine for each scenario and freight corridor the mode shift volume and capacity needs on the infrastructure.
- Determine the total fixed rate greenhouse gas emissions per year for each scenario.

With the developed model, it is possible to fulfil these requirements.

The model is fitted on data of the ASTRA model and with the calculated spreading factors (μ), it becomes possible to calculate the modal split and TEU.km, ton.km and vehicle.km in North Rhine Westphalia. With this model, it becomes possible to change input parameters related to the cost structure and to determine the impact on the parameters mentioned above. Also the effect of changing freight flows (forecasts for 2020 and 2030) can be taken into account. The changes in the input parameters will come from the different scenarios:

- Pro Road scenario (WP 3, Doll, C., Köhler, J. (2018):)
- Pro Rail scenario (WP 5, Mader, S. and W. Schade (2018))

If the difference between the BAU scenario compared to the Pro Rail and Pro Road scenario are analysed, the following can be observed:

- The outcome of the calculations differs quite a lot in terms of modal split. These differences are caused by the inputs from the different scenarios. So, a Pro Rail scenario will lead to a high market share of rail transport which goes mostly at the expense of IWT and only to a lesser amount of road transport. The Pro Road scenario has the same effect.
- For bulk transport, the biggest part of the increase in market share of rail transport in the Pro rail scenarios come from both road transport and IWT. The modal share of IWT is impacted on the most, which makes that the Pro rails scenarios will have a strong impact on the IWT sector.
- Road transport has in absolute terms still a high market, especially on the NRW territory. This mainly due to the fact that most of the transport volumes take places at short distance (in the region of NRW) and as a result road transport is a very dominant mode of transport.
- In all scenarios, there is a very large increase in TEU.km, tonne.km and veh.km both on the territory of NRW and on the corridor as a whole. This is caused by the increase in demand for freight transport (1.7% growth). Only in the Pro Rail scenario, the amount of veh.km is the smallest, however also the capacity of the railway infrastructure needs to be taken into account. Therefore, the outcome of this scenario is only possible if the rail infrastructure can accommodate this strong increase in train veh.km.
- With respect to the CO_2 emissions, there is an increase in the absolute volume for all calculated scenarios. The smallest increases are observed for the Pro Rail scenario for both freight corridors (+ 35% per year in 2015 for the RALP corridor and + 53% for the NSB corridor).

In the course of the LowCarb-RFC project the results are to be interpreted as follows:

- Mode shift found by the transport model constitutes a theoretical maximum of market reactions. In reality we observe that modal shares are rigid and change only slowly over time. Most constraining factors are network capacity and the inoperability of certain cargo types on rail. Capacity constraints are not considered by the model. But with the full scale scenarios Pro Rail and Pro Road and their modest variants, two options for preparing the transport systems are on the table. Feeding back these results into the scenario assessments provides the opportunity to define respective investment strategies for these cases.
- Scenarios need time to unfold. As investments were not considered in the model, the respective long planning and construction periods are omitted, too. That implies that even if we provide sufficient infrastructure, the realisation of the theoretical shift potentials may lag behind current figures by 20 years or more.
- Cost reduction scenarios need to be supported by policy and entrepreneurial strategies. The assumed cost reductions can only be realised if they are partly covered by the public sector and if the railways develop sufficient and partly radical the innovation power. Change management and institutional reforms are thus integral elements in particular of the Pro Rail scenario. These issues are covered in detail by other reports of the LowCarb-RFC project.
- Concepts for inland waterway transport are crucial. The assessment of fixed rate GHG emission scenarios clearly shows, that even through unrealistically high market shares of the railways are computed, the reduction in GHG emissions only through mode shift remains rather modest. Besides the fact that the fixed rate GHG emission concept deliberately excludes decarbonisation strategies of the railways and the power sector, demand shift from IWT to rail is mainly responsible for this result. In a low carbon strategy which honestly aims at cutting the sector emissions down, the balance between all climate-friendly modes needs to be maintained.
- Real GHG mitigation potentials of mode shift scenarios need to take account of a number of other crucial factors. These include the de-carbonisation of the power sector, the electrification of today's diesel powered trains or the use of low carbon combustion fuels, efficiency gains and developments in road and IWT transport. These issues will be assessed in a separated scenario evaluation process in the LowCarb-RFC study.

LowCarb-RFC Project Publications

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

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

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

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

<u>Working Papers</u>

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

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

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

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

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

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

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

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

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

Summary Reports

Petry, C., M. Maibach, C. Gandenberger, D. Horvat, C. Doll, S. Kenny (2018) Myth or Possibility – Institutional Reforms and Change Management for Mode Shift in 'Freight Transport. Summary Report 2 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Infras, Fraunhofer ISI, T&E. Karlsruhe.

Doll, C., J. Köhler, A. Eiband, E. van Hassel, S. Mader (2018): The Contribution of Mode Shift and New Technologies to Climate Mitigation in Freight Transport. Summary Report 1 of the study LowCarb-RFC - European Rail Freight Corridors going Carbon Neutral, supported by Stiftung Mercator and the European Climate Foundation. Fraunhofer ISI, Fraunhofer IML, TPR/UNiv. of Antwerp, M-Five. Karlsruhe.

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

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Appendix A: Modal shares RALP corridor

In this appendix an overview of the modal split development is given for each scenario and forecasted year. In Table 23 the overview is given for the cargo flows on the NRW territory.

Table 23: Overview of the modal split per scenrio for the NRW region

	Scenarios	Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Road share	BAU (TEU)	51%	51%	56%	31%	29%	29%
	Mod Rail (TEU)	51%	44%	43%	31%	26%	23%
	Pro Rail (TEU)	51%	40%	34%	31%	23%	16%
	Mod Road (TEU)	51%	57%	64%	31%	26%	23%
	Pro Road (TEU)	51%	65%	87%	31%	39%	45%
		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Rail share	BAU (TEU)	3%	5%	6%	3%	6%	12%
	Mod Rail (TEU)	3%	5%	12%	3%	8%	10%
	Pro Rail (TEU)	3%	12%	41%	3%	13%	36%
	Mod Road (TEU)	3%	2%	4%	3%	8%	10%
	Pro Road (TEU)	3%	1%	2%	3%	4%	11%
		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
IWT share	BAU (TEU)	46%	44%	38%	66%	65%	59%
	Mod Rail (TEU)	46%	51%	45%	66%	66%	67%
	Pro Rail (TEU)	46%	48%	25%	66%	64%	48%
	Mod Road (TEU)	46%	41%	32%	66%	58%	58%
	Pro Road (TEU)	46%	34%	11%	66%	57%	44%

In Table 24 the modal split overview of the whole RALP corridor is given.

Table 24: Overview of the modal split per scenrio for the whole RALP corridor

	Scenarios	Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Road share	BAU (TEU)	37%	32%	37%	28%	24%	22%
	Mod Rail (TEU)	37%	26%	24%	28%	18%	14%
	Pro Rail (TEU)	37%	22%	19%	28%	14%	9%
	Mod Road (TEU)	37%	46%	50%	28%	27%	38%
	Pro Road (TEU)	37%	58%	83%	28%	41%	49%
		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Rail share	BAU (TEU)	10%	17%	19%	6%	11%	18%
	Mod Rail (TEU)	10%	17%	27%	6%	15%	19%
	Pro Rail (TEU)	10%	27%	58%	6%	21%	45%
	Mod Road (TEU)	10%	6%	13%	6%	14%	14%
	Pro Road (TEU)	10%	3%	5%	6%	3%	10%
		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
IWT share	BAU (TEU)	53%	51%	44%	67%	65%	60%
	Mod Rail (TEU)	53%	57%	49%	67%	66%	67%
	Pro Rail (TEU)	53%	52%	23%	67%	65%	46%
	Mod Road (TEU)	53%	47%	37%	67%	59%	58%
	Pro Road (TEU)	53%	39%	12%	67%	55%	41%

Appendix B: Modal shares NSB corridor

In this appendix an overview of the modal split development is given for each scenario and forecasted year. In Table 25 the overview is given for the cargo flows on the NRW territory.

Table 25: Overview of the modal split per scenrio for the NRW region

		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Road share	BAU (TEU)	83%	80%	79%	53%	53%	53%
	Mod Rail (TEU)	83%	80%	79%	53%	51%	49%
	Pro Rail (TEU)	83%	64%	56%	53%	47%	40%
	Mod Road (TEU)	83%	85%	83%	53%	53%	57%
	Pro Road (TEU)	83%	86%	85%	53%	59%	57%
		2015	2030	2050	2015	2030	2050
Rail share	BAU (TEU)	4%	9%	14%	4%	7%	12%
	Mod Rail (TEU)	4%	17%	28%	4%	8%	13%
	Pro Rail (TEU)	4%	31%	41%	4%	18%	36%
	Mod Road (TEU)	4%	7%	12%	4%	14%	9%
	Pro Road (TEU)	4%	8%	12%	4%	9%	20%
		2015	2030	2050	2015	2030	2050
IWT share	BAU (TEU)	13%	11%	7%	43%	41%	35%
	Mod Rail (TEU)	13%	8%	5%	43%	41%	38%
	Pro Rail (TEU)	13%	5%	3%	43%	35%	24%
	Mod Road (TEU)	13%	9%	5%	43%	33%	34%
	Pro Road (TEU)	13%	6%	4%	43%	32%	23%

In Table 26 the modal split overview of the whole NSB corridor is given.

Table 26: Overview of the modal split per scenrio for the whole NSB corridor

		Containers			Other types of cargo		
		2015	2030	2050	2015	2030	2050
Road share	BAU (TEU)	72%	65%	64%	45%	43%	44%
	Mod Rail (TEU)	72%	65%	64%	45%	40%	38%
	Pro Rail (TEU)	72%	48%	41%	45%	36%	29%
	Mod Road (TEU)	72%	74%	70%	45%	45%	50%
	Pro Road (TEU)	72%	76%	76%	45%	53%	51%
		2015	2030	2050	2015	2030	2050
Rail share	BAU (TEU)	11%	21%	28%	5%	9%	15%
	Mod Rail (TEU)	11%	32%	44%	5%	12%	18%
	Pro Rail (TEU)	11%	47%	56%	5%	24%	44%
	Mod Road (TEU)	11%	15%	24%	5%	17%	11%
	Pro Road (TEU)	11%	17%	21%	5%	11%	24%
		2015	2030	2050	2015	2030	2050
IWT share	BAU (TEU)	17%	14%	8%	50%	48%	41%
	Mod Rail (TEU)	17%	10%	5%	50%	48%	44%
	Pro Rail (TEU)	17%	5%	3%	50%	41%	27%
	Mod Road (TEU)	17%	11%	6%	50%	38%	39%
	Pro Road (TEU)	17%	6%	3%	50%	36%	25%

Appendix C: Abbreviations

The following short cuts are used throughout the report. The list excludes institute names and formula symbols, which are explained in the text directly.

ASTRA	Assessment of Transport Strategies (model)
BAU	Business as Usual
Benelux	Belgium, Netherlands and Luxembourg
CO_2	Carbon dioxide
EU	European Union
FP	fitting parameter
GHG	Green house gas
H	hour
IWT	Inland waterway transport
Km	kilometre
LowCarb-RFC	Low-Carbon Rail Freight Corridors for Europe
NRW	North-Rhine Westphalia
NSB	North-Sean Baltic (Corridor)
NST/R	Nomenclature uniforme des marchandises pour les statistiques de transport
NUTS-2	Nomenclature des unités territoriales statistiques
O-D	origin-destination
RALP	Rhine-Alpine (Crridor)
RFC	Rail Freight Corridor
TEU	Twenty-Foot-equivalent unit
TEU.km	TEU-kilometres
Ton.km	Ton-kilometres
Veh.km	(vehicle.km): vehicle-kilometres
VoT	value of time