Modal Shift in Reverse?: An examination of the modal shift on the Rotterdam – Duisburg Freight Route

ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics

Master Thesis Urban Port and Transport Economics

Title: *Modal Shift in Reverse?: An examination of the modal shift on the Rotterdam – Duisburg Freight Route*

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Date final version: 21-4-2022

Abstract

The need for hinterland transportation to decarbonize has been a longstanding goal of European and Dutch policymakers. The aim has been to promote a modal shift from road to more sustainable forms of transportation such as rail and inland waterway. More recently, the European Commission has opted to include the road and shipping industry into the Emission Trading System. The question arises how the introduction of a carbon price will affect the competitive position of truck, train and barge in hinterland transportation. This thesis aims to examine this between Europe's largest seaside port and inland port, the Rotterdam – Duisburg container freight route. It is found that the effect of carbon pricing is dependent on multiple factors such as the current emission per mode; innovation rate in terms of efficiency and decarbonization and logistical cost assumptions. At current mode emission levels, a carbon price of 60-80 EUR/Ton CO_2 is effective in reducing total carbon emissions. However, the expected relatively lower emission levels in 2030 improve the competitive position of road transport and necessitate more extreme carbon price ranges in order to be effective. This calls upon policy makers to reconsider whether investments towards intermodal infrastructure are the most efficient way in reducing emissions in hinterland transportation. Lastly, the extent to which the carbon price would be absorbed by either shipper or forwarder, due to market structure and power dynamics, is not addressed and presents as a promising topic for further research.

Keywords: *Modal shift, emission pricing, sustainable transport, hinterland transportation*

Preface

The writing of this MSc thesis has been an interesting process, and to be able to dive into future fuel technologies and several interdependencies with regards to introducing sustainable freight transportation was very rewarding. I would like to thank Mr. Holstein from the Port of Duisburg and Mr. van Schuylenburg of the Port of Rotterdam for providing data and expert insights. Lastly, I would like to thank my supervisor Dr. Bart Kuipers for his crystal-clear feedback and enthusiasm in guiding my writing process.

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List of Abbreviations

3PL	Third Party Logistics Provider
BET	Battery Electric Truck
CO_2	Carbon dioxide (emissions)
FCET	Fuel Cell Electric Truck (Often considered hydrogen)
GRT	Gross register tonnage
TEU	Twenty Foot Equivalent Unit
EGD	European Commission Green Deal
ETS	Emission Trading System
EU	European Union
EUA	EU Carbon Permit
GHG	Greenhouse Gas (emissions)
MSR	Market Stability Reserve
NO_x	Nitrogen (emissions)
PM_{10}	Particulate matter (emissions)
TLC	Total Logistic Costs
TTW	Tank-To-Wheel (Emissions during usage of vehicle/vessel)
WTT	Well-To-Tank (Emissions during production of fuel)
WTW	Well-To-Wheel (Emissions of fuel usage of overall supply chain)

Introduction

With the intention of limiting the rise of global temperatures to a maximum 2°C, rapid decarbonization is essential (Rockström, et al., 2017). The transportation sector, both passenger and freight, accounted for 29% of global emissions in 2019 (IEA, 2021). Within this sector, road freight vehicles accounted for 2.4 Gigatons of CO_2 which easily exceeds the emissions of aviation and shipping combined (IEA, 2022). In order to reduce the climate impact of road freight transportation, but also negative externalities such as congestion, noise pollution and accidents (Ambra, Caris, & Macharis, 2019) a modal shift from road to rail and inland waterway is essential.

In order to support this shift, the European Commission Green Deal (EGD) has set ambitious goals for several industries within the European Union (EU). As a part of their EGD the European Commission has announced its 'Fit for 55 Package' which aims to reduce greenhouse gas emissions by a minimum of 55 percent in 2030, compared to levels of 1990 (PwC, 2021). In this mission, the European Commission is striving to become the first climate-neutral continent of the world by 2050.

One of the most prominent market based measures that is utilized by the European Commission to reduce emissions, is the Emission Trading System (ETS). In short, the system aims to set a limit on the amount of emissions that can be emitted by an industry, while allowing the participants to trade emission rights with one another. The system has been in place since 2005, first including energy-intensive industries while over time the scope of included gases and industries is expanded (IETA, 2018).

The ETS-System will keep expanding its scope, with the road and maritime transport industry being mentioned in the near future (European Commission, 2021a). This carbon pricing mechanism will affect the competitive position of barge, rail and truck in hinterland transportation. But will this lead to the desired modal shift from road to rail and inland waterway transportation?

In recent research, the possibility of a reverse modal shift is mentioned, where trucks will be able to be decarbonize at a faster rate compared to ships due to faster innovation rate, available infrastructure and shorter average technical lifespan (TNO, 2020). If this reverse modal shift occurs, the goal of decreasing emissions would be achieved by increasing truck transport, which is contradictive to current modal shift policy. In order to examine the trade-off between the ETS carbon pricing mechanism and the reverse modal shift a specific hinterland transportation route will be examined.

The inland Port of Duisburg is the largest European inland terminal measured in container volume and is at a distance of 250km from the Port of Rotterdam (CCNR, 2020). On this particular distance, trucks are relatively competitive in terms of costs with barge and, to a lesser extent, with rail transport (Jonkeren, 2017). Thus, a reverse modal shift would be feasible and the impact on the European hinterland supply chain in terms of volume would be considerable. The above leads to the following research question:

How will the implementation of an Emission Trading System affect the modal split on the Rotterdam – Duisburg freight route?

The environmental benefits of a modal shift from transportation by road to rail and inland waterways are clearly of societal importance (Kaack et al., 2018). The European Commission has a long standing tradition of supporting this modal shift, starting with with the Whitebook in 2011 (EU Commission, 2011). However, it is observed that the modal share between road/rail has remained relatively constant in the past decades (EEA, 2011). It is therefore essential for the future of the transportation industry to keep evaluating new market based measures to enable economic growth in a sustainable manner (Saidi & Hammammi, 2017; Geerlings, Kuipers, & Zuidwijk, 2017)

The mechanics on how to influence a modal shift has been a popular topic of research with extensive organizational and economic aspects (Blauwens et al., 2006; Kaack et al., 2018). How can shippers be incentivized to switch and what are the largest bottlenecks with regards to logistical infrastructure or supply chain transparency (Woodburn, 2003)? Research has for example focused on synchromodality, where all transport modes are aligned with regards to logistic parameters and real-time information allowing to purely select a transport mode based on quality and cost-aspects (Behdani et al., 2016). A carbon pricing mechanism such as the EU-ETS will in its simplest form increase the costs of less environmentally friendly transport modes, incentivizing shippers to change their decision process (de Vries, 2019). But how does this compare to other mode-dependent preferences such as lead time, reliability and service level (Bask & Rajahonka, 2017)? This paper seeks to add to existing literature in several ways.

Zhang et al. (2014) show that the most efficient way to implement carbon pricing for containerized transport in The Netherlands would be the mandatory usage of biofuels, which is essentially a fuel tax. However, there it is unlikely that there is sufficient supply of biofuel for all transport by road. Meanwhile, a carbon price as a result of the EU-ETS would not require immediate physical infrastructure and is therefore more achievable in the near future. Additionally, de Vries (2019) examined a carbon pricing mechanism on Dutch scale for containerized and non-containerized cargo. A limited effect was found on the modal split. However, on this macro-economic scale the type of freight that is easily interchangeable, is limited and not all routes can be served by non-road transport. Moreover, in the long term due to the energy transition the amount of petrochemical, dry and liquid bulk cargo is expected to decline, possibly diminishing future relevancy of non-containerized cargo (CCNR, 2020). Therefore, we aim to examine a specific container transport route so the availability of intermodal transport is guaranteed throughout the analysis and specific trade-offs between required service level, lead time and height of carbon price can be examined.

In order to answer the main research question several sub-questions have been formulated. Firstly, the relevant literature with regards to current modal choice decision, modal shift policy in the past decades and sustainable freight policy measures will be discussed through the following literature questions:

1. *Who decides which mode of transport is used and which recent developments have influenced this decision process?*
2. *How has the modal shift policy developed itself in the past decades on European and Dutch level?*
3. *How can the modal shift policy be designed to promote sustainable freight transport?*

Subsequently, the potential of the reverse modal shift with regards to emission reduction will be explored through expert interviews and examining policy reports. Then, the baseline scenario of the Rotterdam-Duisburg freight route with regards to current container modal split and annual container flow will be assessed. And lastly, the implementation of carbon pricing and the effect on hinterland market share will be assessed through several simulations. This leads to the following methodology questions:

4. *How much CO_2 emissions does each transport mode emit currently and how will this develop towards 2030?*
5. *How has the modal split of Duisburg developed itself from 2006-2019?*
6. *How will the implementation of a carbon pricing affect the competitive position of transport by barge rail and road on the Rotterdam – Duisburg container route?*

In order to answer the main research question, the answers to all the above questions will be summarized and potential for further research and limitations of this thesis will be discussed.

Literature Review

The literature review will consist of three chapters with a dedicated main question as stated earlier. The research area in scope for the literature review is the hinterland transportation of containerized goods. The cargo type is limited to containerized goods as they are more suited for direct transfer between different modes, enabling competition between these modes (Blauwens et al., 2006). With regards to the considered modes, three modes will be evaluated which are transportation by road, rail or inland waterway. Which are also referred to as transportation by truck, train or barge, respectively. In evaluating Dutch modal shift policy the transportation mode of pipeline is also reported by Jonkeren et al. (2017), however this mode will not be considered as it does not compete with the transport of containerized goods and already has a high efficiency (Otten, et al., 2020).

Chapter 1 Modal Choice Criteria

Chapter Main Question: *Who decides which mode of transport is used and which recent developments have influenced this decision process?*

1.1 Actors involved and decision making process

In order to assess which choice criteria are of most importance when a certain transport mode is chosen, it is necessary to establish which actors are involved in this process and who possesses the power to make decisions. Van der Horst and de Langen (2017) introduce a framework for actors in the inland shipping hinterland chain, which can be seen in Figure 1.

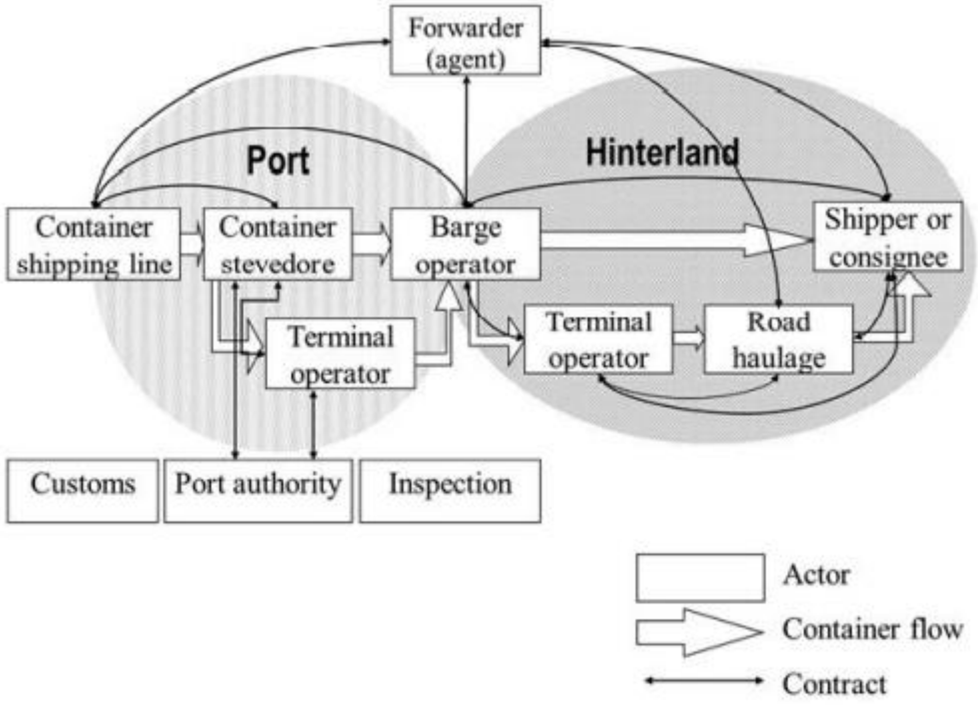

Figure 1: Overview of actors in the hinterland shipping chain

Source: (van der Horst and de Langen, 2017, p.164)

Roughly, these actors can be divided into maritime transport, port handling activities and inland transportation. Van der Horst and de Langen (2017) mainly focus on the coordination between these actors and existing contractual relationships. With regards to modal choice this diagram has two configurations, the hinterland transport is either carried out entirely by the barge operator or the barge operator delivers it to a terminal where the container is delivered through road haulage. Transportation by train is not shown directly in the model, but is mentioned by the authors so it is not overlooked.

It can be observed that both the *forwarder* and *shipper/consignee* have existing contractual relationships related to modal choice, which are the *barge operator* and *road haulage*. The figure also shows that a multitude of parties are involved when transporting a single container from point A to B. Looking at hinterland transport mode decision making in practice, three types of relationships can be distinguished. These are the merchant haulage, carrier haulage and terminal haulage, where the latter is relatively new (Veenstra, Zuidwijk, & Van Asperen, 2012).

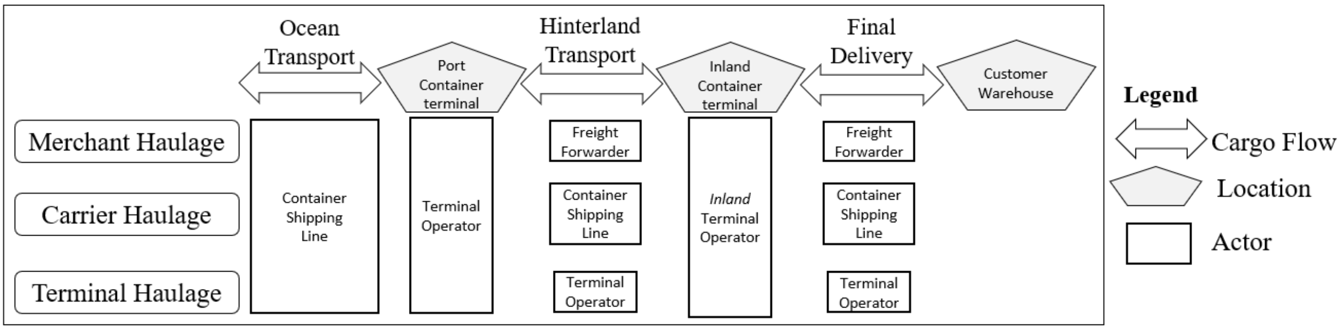

Figure 2: Overview of responsibilities in hinterland transportation.

Source: Created by Author

In Figure 2, a schematic overview of the several type of relationships can be seen. Merchant haulage is when the shipper or consignee, often through a forwarder, arranges the container transport on its way to the port of embarkment and after it has arrived at the destination port, through the hinterland (Veenstra, Zuidwijk, & Van Asperen, 2012). A freight forwarder or third party logistics provider (3PL) is specialized in freight transport and utilized when a shipper wants to outsource the transportation of their cargo. Alagheband (2011) shows that the decision for a company to outsource their transportation needs depends on multiple factors such as fluctuations in demand, availability of inhouse expertise and equipment.

For carrier haulage, the container shipping line is responsible for the inland transport as well as the transport by sea. Franc and van der Horst (2010) provide several explanations for this vertical integration. It can be seen as an opportunity for shipping lines to increase their revenue and provide additional logistic services to cargo-owners with whom they already have a strong relationship. For the cargo-owner it lessens the amount of third parties they need to be engaged with. An interesting recent development is highlighted by Notteboom, Pallis and Rodrigue (2021) with regards to the impact of the COVID-19 pandemic. They state that container lines might utilize their record financial profits from this period to further the vertical integration with increased involvement in inland logistics. With this development the traditional carrier such as Maersk is assuming the role of merchant as well (Maersk, 2021).

Rodrigue and Notteboom (2009) build upon this by discussing the different share of merchant and carrier haulage contracts in certain markets. They point out that for the barge market between the ports of Rotterdam and Antwerp, carrier haulage (deep-sea shipping lines) is the dominant form. On contrary, for the inland market merchant haulage by large shippers is most common.

A more recent development is terminal haulage. Whereas carriers might opt to develop hinterland transportation services to adjust for the unreliable services of an inland terminal, deep sea terminal operators are establishing ways to deal with the space scarcity on site and insufficient coordination with hinterland transport providers (Fremont & Franc, 2010). Deep sea terminals are opting for a more horizontal integration by aligning with inland terminals. In this way the deep sea terminal is able to ‘push’ freight to the hinterland terminal, decreasing the scarcity of space in the port. This horizontal integration is also referred to as the Extended Gate concept. Veenstra et al. (2012) argue that this extended gate concept might offer substantial benefits with regards to logistical performance, modal shift and regional development.

As can be seen in Figure 2, the main difference between the relationships arises from the responsibility of the cargo after it has been handled by the terminal operator at the port. As stated above, for merchant haulage the freight forwarder is responsible for choosing the mode of hinterland transportation, while when it comes to carrier haulage the container shipping line is responsible. Lastly, Rodrigue and Notteboom (2009) point out that merchant haulage is the most dominant form for hinterland transportation.

An important aspect to take into account when comparing the different modes of transportation is switching costs. Gharehgozli, de Vries and Decrauw (2019) discuss the role of standardization in European intermodal transportation. Whether a shipper is able to switch from mode will depend on the degree of standardization and the specific type of loading unit, available infrastructure and method of information exchange. Riessen (2018) adds to this that within organizations several different processes also need to be aligned in order to be able to switch between different modes. Such as exchange of information with supply chain partners, IT developments and a behavioral change for operational departments involved from planning, sales and communication .

But what underlying criteria do these forwarders and carriers look at when switching from mode of transportation? There are several criteria which a shipper might take into account such as reliability, flexibility, costs and environmental impact (Bask & Rajahonka, 2017; Kaack et al. 2018.; Kopytov & Abromov, 2012). In the following section we will discuss the competitive position of inland waterway, road and rail transportation and any recent developments which might influence the modal choice process.

1.1.1 Definitions

Before we dive into the competitive position and recent developments, we will discuss several definitions with regards to the utilization of different transport modes that have been used in the industry and literature. First of all, *Multimodal* transportation can be considered as the least restricting definition. It refers to the usage of at least two different modes of transportation in a sequence. It can be applied to different units of transportation such as boxes, containers or swap bodies (Crainic & Kim, 2007).

Secondly, *Intermodal* transportation can be considered as a certain type of multimodal transportation and refers to the process of transporting the same unit from origin to destination without handling the goods within this unit, e.g. a TEU container (Crainic & Kim, 2007). The usage of the same unit provides the clients of intermodal terminals with the flexibility of being able to use multiple transport modes.

Thirdly, *Co-modal* is aimed at the efficiency of different modes, individually and combined. The United Nations Economic Commission for Europe defines two main differences from multimodality: It is utilized in the chain by a grouping of shippers and the transportation modes are utilized with aim to maximize the respective benefits, especially with regards to sustainability (Verweij, 2011;UNECE,2009).

Lastly, *Synchromodal* transportation is envisioned as form of intermodal transportation, which is also horizontally integrated. For example, by integrating train, truck and barge on a route and consider these combined modalities as a single transport service on this route (Behdani et al. 2016). In this way, carriers or customers can independently select the desired mode purely based on a trade-off between quality and cost aspects.

1.2 Competitive position inland waterway transportation

As the infrastructure for transportation by barge is determined by the availability of waterways, it historically has a smaller serviced land area focused around major rivers flowing through The Netherlands, Belgium, France and Germany. From the mid-1990s barge operators have become more involved by offering complete logistical solutions such as warehousing and integrating with road transport companies to offer fully intermodal transport routes (Tavasszy et al., 2017). Currently, the line service network where a vessels visits multiple terminals in the hinterland is the most dominant form. Pilots are also being performed with hub-and-spoke configuration which improves frequency even further.

With regards to freight segments, the barges have been performing well in handling large volumes in the liquid and dry bulk sector and providing economies of scale for container transport. Main strengths are a strong cost competitiveness, integration with inland terminals and the large capacity of inland waterways (Konings, van der Horst, Hutson, & Kruse, 2010).

Considering these advantages, the overall market share of inland waterway transportation has remained constant or decreased throughout the EU (Table A1, Appendix A). Is this the case because of other developments such as the influence of low water levels or terminal congestion?

1.2.1 Influence of lower water levels on the choice for barge as a modal transport mode

When assessing the competitive position of inland waterway transportation, the effect of future climate change on the natural waterways in Europe needs to be taken into account. As the main factors of climate change such as global temperature and atmospheric circulation are quite uncertain Jonkeren et al. (2011) have developed several scenarios. In the most pessimistic scenario, it is estimated that the annual quantity of freight transported by barge in Northwest Europe would decrease with 5.4%, which is considered rather limited. Beuthe et al. (2014) also do not find any significant change in modal split in several climate scenarios, the authors do point out that dry scenarios would justify the usage of smaller vessels.

With regards to elasticity, the model of Jonkeren et al. (2011), based on simulated freight flows, finds the demand for inland waterway transport to be rather inelastic. This corresponds with the findings of Jonkeren et al. (2007) which were based on actual freight flows. It should be noted that this assumption is most likely to hold in the short term, as barge transport often concerns large volumes such as dry and liquid bulk which cannot easily be taken over by other modes.

Jonkeren et al. (2014) add upon this by stating that the barge operators are often able to distribute the economic burden of low-water periods among their clients by increasing their prices according to the cost increases. The temporary reduction in capacity could even benefit some barge operators due to the upward pressure on prices.

Overall, the effect of lower water levels on the modal choice seems limited in the short term, due to the inelastic demand and large volumes of cargo in the inland waterway transportation market.

1.2.2 Key factors contributing to congestion on deep sea terminals for barges

Rodrigue and Notteboom (2009) state that within supply chains, transport terminals regulate freight flows and influence the capacity and reliability of the entire network. The terminal stacking area functions as a temporary storage and buffer zone between deep-sea transportation and inland transportation modes. A rise in container demand would lead to an increase of this buffer zone.

Subsequently, both seaside and inland terminals are seizing a more active role in supply chains and confront market parties with operational aspects such as time and capacity restrictions: e.g. berthing windows, assigning truck slots or additional charges for dwell time. Terminals step away from their traditional transshipment function and increasing vertical integration enlarges pressure on port capacity (Rodrigue & Notteboom, 2009).

Another development with regards to the role of inland terminals is that the amount of inland logistic service centers has substantially increased in the past decades, which provide a wide range of functions ranging from consolidation of cargo to value-adding logistical services. This increase of functions for the inland terminals has led to more competition with the deep sea terminals for European distribution facilities (Rodrigue & Notteboom, 2009). Reliable and efficient intermodal connections is one of the most important factors for further development of an inland terminal. Likewise, seaports rely on inland terminals to maintain their attractiveness. Thus, quality of hinterland transportation and accessibility has become of increasing importance for the competitive position of ports as well. Especially ports in Northwest Europe, where the distance to cargo demanding inland areas does not differ substantially, are competing more and more to serve the same areas (Konings, 2007).

This is process is referred to by Rodrigue and Notteboom (2009) as ‘regionalization’, where the deep sea and inland terminals compete as a combined ecosystem with their logistical capabilities. Congestion on marine terminals, which causes severe delays, is therefore a substantial influence on the competitive position of transportation by barge. In this section, the key factors that contribute to the congestion for barges in deep sea terminals will be explored.

Caris, Macharis and Janssens (2011) state three main factors that contribute to congestion for barges. Firstly, inland barges visit multiple terminals, which can be time-consuming. During peak-periods the queue of barges can be considerable. This is mostly due to capacity restrictions of a terminal such as available labor force and amount of cranes at the quay side.

Secondly, the construction and layout of deep sea terminals is designed towards handling large container carriers, while barges utilize the same infrastructure. This is illustrated by the fact that deep sea carriers are given priority in handling, as the costs of delay are much higher compared to inland barges. The existing delay can cause a domino-effect for the inland barge, not being able to visit successive port terminals on time as well.

Thirdly, deep sea terminals only have a contractual obligation with shipping companies. The absence of legal ties between the inland terminal and barge operator leads to a diminished negotiation position for the latter with regards to service levels, operation modes and charges for handling.

An increase of container volume would further increase this problem of congestion. A solution that is proposed by Konings (2007) is uncoupling the distribution and collection services in the port area. A dedicated barge hub would be established so that barges only have to visit one terminal.

Konings (2007) states that recent solutions towards reducing the waiting times of barges have been: improving the quality of information exchange between involved actors, fixed berthing time windows and improved route planning. However, the moves of inland barges between multiple terminals in itself still consumes time. Konings (2007) and Caris et al. (2011) both find in their simulations for the ports of Rotterdam and Antwerp, respectively, that a centralized barge hub would increase efficiency significantly.

However, Konings (2007) points out that the feasibility for a centralized barge hub, also depends on the distance of inland terminals. The farther away an inland terminal, the willingness to pay an additional fee for decreased delay, increases. Thus, the benefits for relatively nearby terminals such as Duisburg are ambiguous. Konings views most benefits for cargo transportation towards the Middle Rhine region.

Another barrier to this solution is the alignment of stakeholders, carriers strive for a high utilization rate at their own deep sea terminals, decreasing possible interest for adding additional feeders (Konings, 2007). Furthermore, logistical and organizational complexity would be increased in forms of additional administration and communication. Lastly, barge operators would have to decrease their operational scope, which they could view as a threat to their position in the supply chain.

In conclusion, congestion on barge terminals is a problem with several interdependencies between actors in the port area, solutions are available but in order to align all these stakeholders an integrated approach would be required. With regards to the influence on modal choice decision, it would be wise to include large reliability margins for the transit time of transportation by barge, as waiting times can increase to more than 24 hours (Konings, 2007). This increases the total cost of barge services and negatively affects their competitive position.

1.3 Competitive position road transportation

Transport by road is considered as the most reliable and dominant form of transportation in most regions worldwide (Kaack et al., 2018). This reliability stems from the ability to switch to alternative routes, avoid congestion and live data sharing. However, when looking from a purely cost-based perspective it is not necessarily the cheapest and as shall be discussed in section 1.5 there sometimes is a potential for modal shift without increasing the total costs. The largest setback of truck transportation is the environmental emissions and other negative externalities such as noise pollution and traffic congestion. An important development that impacts these negative characteristics is the so-called ‘reverse modal shift’, which will be discussed in the next section.

1.3.1 Reverse modal shift

In the report ‘Outlook Hinterland & Continental Freight’ the risk of a reverse modal shift is mentioned (Topsector Logistiek, 2018). In a reverse modal shift the market share of road transport increases at the expense of other modes such as inland waterways and rail. The increase of road transport can be driven by technological innovations, which lead to a reduction of relative costs. For example, Meers et al. (2018) state that allowing lengthier and weightier automobiles could cause a reverse modal change where operators shift from railways and inland waterways to road transport. Such is the case within European countries such as Belgium, where the spatial effects of permitting the lengthier and heavier vehicles are evident. The need for longer vehicles is to increase the loading capacity and thus cut the transport costs per unit. Most European countries, including Netherlands and Spain, have adopted the longer and heavier vehicles in various parts of their roads to tap on the benefits of reduced transport costs (Meers et al., 2018). In order to elaborate upon what drives the reverse modal shift, TNO (2020) distinguishes three main drivers: automatization, environmental and digital platforms.

Automatization

Trucks

For the automation of transport by road, several different levels are distinguished by Society of Automotive Engineers (SAE, 2018). Currently in the Netherlands, there is a high focus on ‘Partial Automation’ which is also referred to as truck platooning. Truck platooning comprises of several trucks driving automatically in close distance from each other. This reduces transport costs by decreasing fuel usage due to enhanced aerodynamics, only requiring a driver in the front of the column and optimization of transport times (Janssen, 2015).

Several experiments are currently being conducted with regards to truck platooning on European level (Reuters, 2019). An important goal is to assess the necessary data and infrastructural/legal requirements in order for platooning to be accepted by both users and stakeholders. The European ENSEMBLE project is set out to create a technology standard, through which trucks of different brands can be connected (ENSEMBLE, 2020).

The speed of this development remains to be seen, where currently there are singular examples of autonomous trucks such as in Sweden. Kässer (2018) has forecasted that trucks could be completely driverless from 2027, leading to a 45% reduction in total-cost-of-ownership (TCO) which would greatly affect the competitive position of transport by road.

Barge

TNO, Marin and TU Delft (2018) have assessed the advantages of automatization within the inland waterway transportation sector and found that high levels of automation could lead to a 50% reduction of operational costs by sailing without a crew. However, current legislation obligates a minimum amount of crew per type of vessel, which is set to be changed in 2024. The authors predict that tasks such as maintenance will only be carried out when the vessel is berthed and the steering and maneuvering can be done from a remote control center. Currently, there are few initiatives as they are capital-intensive and largely dependent on EU-grants/subsidies. Additionally, the vessel ownership-structure; often family-owned and a long technical lifespan are an important obstacle to fleet renewal.

Rail

There are very recent experiments with regards to ‘Automatic Train Operation (ATO). This system supports or completely takes over the operation of a train (de Leeuw van Weenen et al., 2019). Besides decreasing the need of a driver it also offers opportunities to optimize speed, energy-usage, safety and punctuality. The rate of automation for rail transport is unclear, moreover other factors such as safety and punctuality seem more important and the costs of personnel are relatively less substantial compared to transport by road or barge (Poulus, van Kempen, & van Meijeren, 2018).

Environmental

The environmental impact of freight vehicles is rapidly changing, due to availability of electric vehicles for city logistics and longer distances. Also other forms of cleaner fuel such as RCCI-technology, green hydrogen and seaweed fuel. The ultimate victor of these technologies remains to be seen, but that transport by road will be just as clean or even cleaner than rail and barge is important for its competitive position (TNO, 2020).

Digital Platforms

De Kok (2016) signals an increase of digital matching platforms able to align supply and demand. This increases efficiency if parties are properly incentivized. An intrinsic advantage of trucking, relative to other modes, is the flexibility with regards to switching routes, dealing with route disruptions and the high availability of data considering capacity and disruptions.

1.3.2 Modal Shift Policy Implications

TNO (2020) argues that the combination of these three drivers leads to a underestimation of the future potential of transport by road. The road as a modal choice might become more cost-effective and environmentally friendly compared to barge and rail. The latter two modes will require substantial infrastructural investments in order to remain competitive and accommodate the formulated modal shift policy. TNO (2020) advises a re-evaluation of the current modal shift policy, taking all the new developments for each modality into account. Instead of investing all resources towards non-road infrastructure, a reverse modal shift might lead to an overall more robust and efficient hinterland transport system. Possible road-infrastructure investments could be tax incentives for transporting by night or new business models and technology wherein parties can exchange information.

1.4 Competitive position rail transportation

Originally, the rail transportation network has been aimed at continental transport of swap bodies or truck trailers. Currently, the division between continental and hinterland freight is estimated to be 50/50. With the volume of containers increasing, standardization for the exchanging and transshipment of containers at so-called shunt yards developed rapidly. However, the process of bundling wagon groups at the shunting yards struggled to become competitive with road transport in terms of costs and transit time (Tavasszy et al., 2017). Since the early 1990s direct shuttle services were introduced where the train can run in a fixed formation of wagons, improving reliability and transit time. The shuttle concept has remained the dominant form, but is difficult to compete when volumes of cargo are low in establishing new routes. In order to service more destinations ‘gateway networks’ are being developed, connecting already established rail networks.

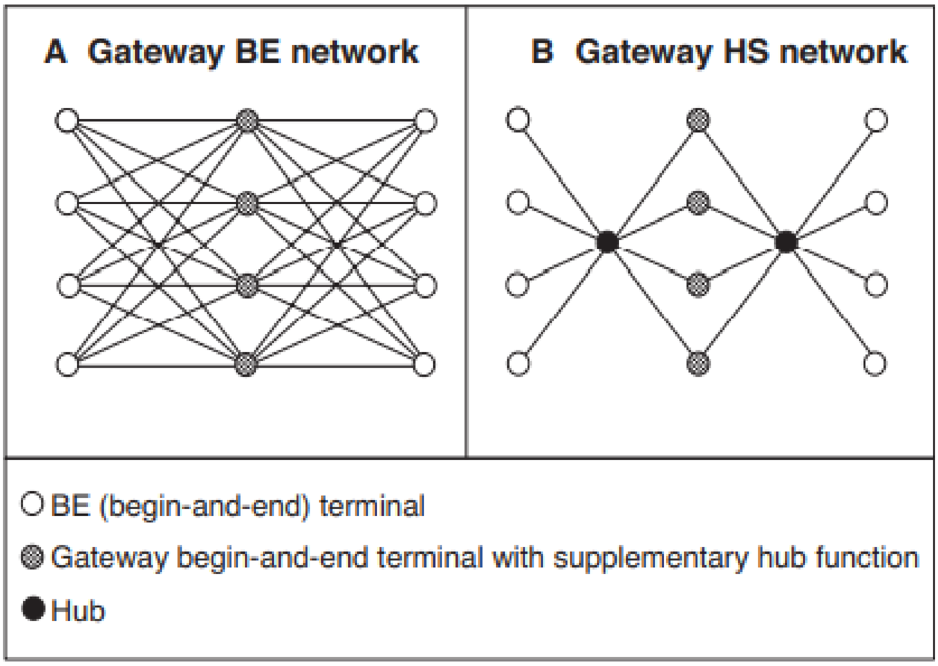

Figure 3: Overview of gateway networks in rail transportation

Source: (Kreutzberger, 2008)

Transporting freight by rail becomes most cost-competitive at long distances defined as more than 500 miles in the US according to Kaack et al., (2018) or 300 kilometres by EU Commission (2011). This has caused it to be the dominant form of long-haul freight transportation in large countries such as the US, Canada and Russia (Kaack et al., 2018). Moreover, as electricity is the main power source for rail transportation, it has the least environmental impact compared to barge and road, which will be discussed further in section 3.1.

Rail Infrastructure

As transportation by rail is not dependent on the presence of waterways, the share of road vs. rail is often discussed in a European policymaking context. The largest challenge for transport by rail is to overcome the infrastructural demands in comparison to road. Especially the alignment of information sharing and standardizing of rail networks on a European level, as rail networks are often maintained on national level, would allow the flexibility of rail transport to increase (Gharehgozli et al., 2019). An interesting development in modal choice selection, transcending the available modes and only looking at logistic requirements, is synchromodality which will be discussed in the next section.

1.5 Influence of synchromodality on modal choice decision process

Tavasszy, Behdani and Konings (2017) describe synchromodality as the next step in logistics, providing a ‘one stop shop’ for shippers. As stated in the section 1.1.1, a main aspect of synchromodality is the horizontal integration which is virtually displayed in Figure 3. In a synchronized intermodal network, the service level is no longer dependent on type of modality, instead a range of customized services for different products and logistic requirements can be designed. Additionally, depending on these requirements and the real-time availability of modes, an appropriate transport method can be selected (Tavasszy, Behdani, & Konings, 2017).

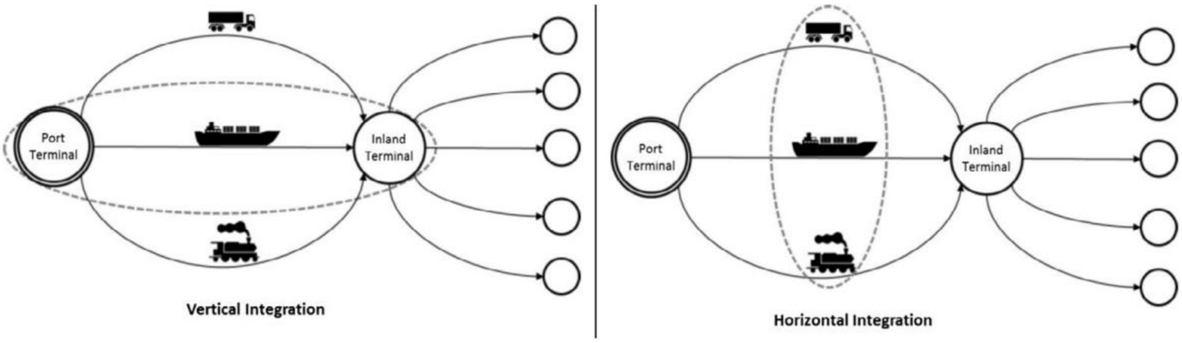

Figure 4: Horizontal and vertical integration in freight transportation

Source: (Dong et al., 2018)

Riessen (2018) notes that synchromodality can be achieved through a unified network design, actual network planning, and a balance between customer value and flexibility. Synchromodality offers a framework for shippers to manage their supply chains flexibly and efficiently (Riessen, 2018). Riessen et al. (2015) add that the idea of optimizing transportation purely on costs is long gone. Apart from the low tariffs, customers want high-quality service. Quality of service comprises delivery speed, on-time delivery, and consistency.

Dong et al. (2018) add that most businesses still depend on road transport for their small and recurrent cargo transportation, and the adoption of railways and waterways has been slow. Among the prominent reasons that the modal split has been hard to adjust, is that many participants have not examined the impact of multimodal transportation on the supply chain. While trains and barges are less expensive, they lack elasticity in frequency and planning. Therefore, a straightforward move from trucks to trains is considered to affect the supply chain negatively (Dong et al., 2018). Vannieuwenhuyse et al. (2003) support this after interviewing 500 shippers and logistic service providers, they found that flexibility is one of the most important criteria in the transport decision making process.

Dong et al. (2018) simulated a synchromodal transportation model for a large shipper of 45ft containers in Western Europe with access to intermodal rail and trucking. The authors found that it is possible to achieve a reduction in environmental emissions and total costs simultaneously. It is noted that this does depend on the stability of freight demand, where a more stable demand forecast allows for a larger adaptation by rail. The environmental benefits of synchromodal transportation are supported by Lemmens et al. (2019), who examined a theoretical implementation of synchromodal transport process. By allowing parallel usage of modes and real-time switching, inventory costs increase slightly, however total costs and emissions are reduced on average. Considering the cost and environmental advantage of intermodal transport compared to unimodal road transport, synchromodality seems a beneficial development towards promoting a modal shift. However, Tavasszy et al. (2017) formulate some barriers with regards to the adaptation of synchromodal transportation:

On a logistical level, the resources in the transportation network need to be aligned continuously with demands and needs of customers, in order to provide clear insight into frequency, service levels and real-time availability (Riessen, 2018). Furthermore, from a transaction-based perspective a certain paradigm shift is required from the viewpoint of the customer, since the mode of transportation is no longer selected but only service requirements and costs are indicated. Transportation modes need to be viewed as complementary instead of competitors (Tavasszy et al., 2017). Additionally, from an organizational perspective, the level of collaboration between service providers and shippers needs to increase. This is necessary to compare service levels instead of only price levels as is done currently. Subsequently, current legal barriers to sharing information need to be examined and Klievink et al. (2012) point out that there also is a lack of incentives to share information in global trade lanes. The method of information sharing needs to be decentralized in order for a holistic view of the supply chain (Klievink, et al., 2012).

In conclusion we can establish that synchromodality can indeed be seen as the next step in logistics in accordance with Tavasszy et al. (2017). Lemmens et al. (2019) and Dong et al. (2018) show clear environmental and costs benefits. However, there are several barriers with regards to the organization, availability of information and shift of customer perspective towards mode preference (Tavasszy et al., 2017). Lastly, it should be noted that the environmental gains in literature are under the assumption that barges and rail have lower emissions than transport by road. While this is true currently, the development of a ‘reverse modal shift’ challenges this assumption and will be discussed in the next section.

Conclusion Chapter 1

In hinterland transportation, merchant haulage is the most dominant form, thus the freight forwarder makes the decision with regards to the utilized mode of transport. While costs play an important part in logistic decision making, other aspects as service level, quality and environmental standards are the most important recent criteria. This is especially noticeable in the concept of synchromodality, where clear environmental benefits can be seen. On another hand, the development of a reverse modal shift could counteract the currently assumed environmental benefits of transportation by road vs. barge/rail.

Chapter 2: Modal Shift Policy Development on European and Dutch level

Chapter Main Question: *How has the modal shift policy developed itself in the past decades on European and Dutch Level?*

2.1 Development of modal shift policy on European level

Overview current situation

A modal shift has been one of the key strategies for the European Union to promote decarbonizing in freight transportation for the past two decades (OECD, 2001). In Figure 4, we can see that the development of the modal split has remained relatively stable for the past decades, where the share of road has increased with 2% in 2019 compared to 2005. The share of railways and inland waterway have both decreased by 1%.

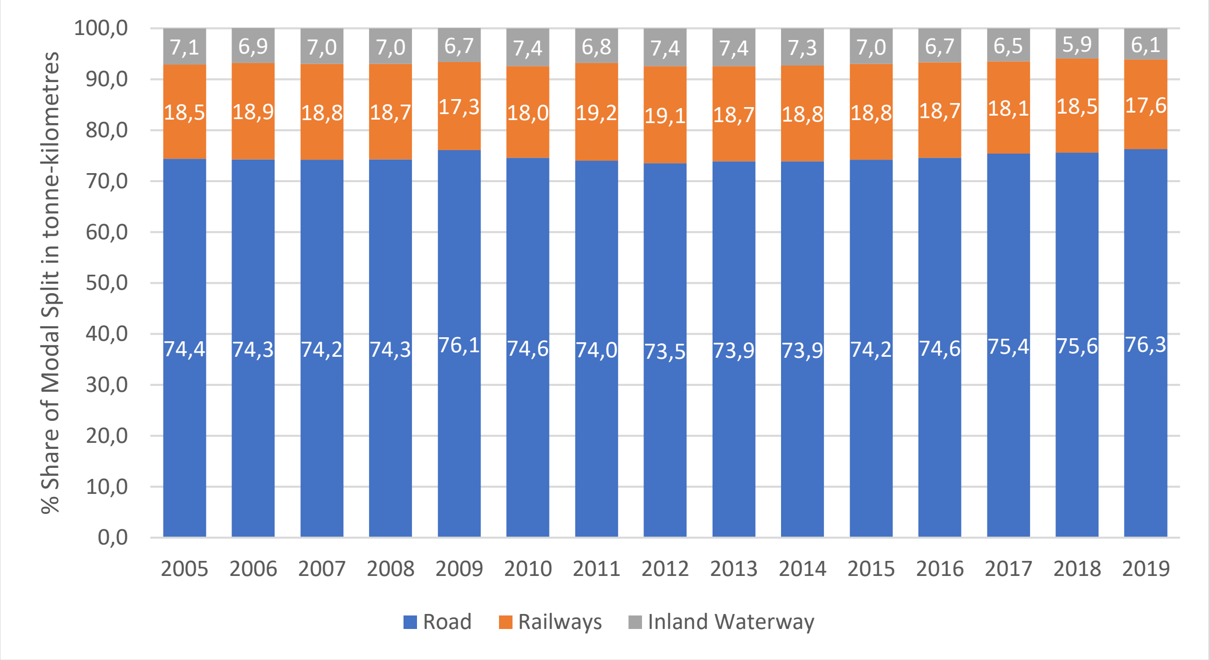

Figure 5: Modal split development for inland freight transport 2005-2019 for EU-27*

Source: Eurostat (2022) and edited by Author

* EU-27 excludes the United Kingdom.

Blauwens et al. (2006) argued that a modal shift in European Union countries would be uncertain. The alternate transportation modes can compete with road transportation when they fulfill shippers' logistics demands and optimize the supply chains. The choice of transport modes is not just based on costs. Rail- and waterway transportation would be the leading choices if this were the situation. Kaack et al. (2018) note that most European states still depend heavily on road transport. . In most European countries, the model split for road and rail is 82:18. The share of railway transport has even decreased in parts of Eastern Europe, benefitting road transport. Fioretti (2017) argues that the increase of transportation by road in Eastern Europe could be driven by low truck driver wages, which are lower than the minimum wage in most Western European countries. Kaack et al. (2018) point out that a barrier to the adoption of rail is speed and predictability. In order to stimulate intermodal transport, investments in capacity, efficiency and connectivity are required.

Policy Instruments

In the 2011 White Paper regarding transportation, the European Union committed to moving 30% of road freight above 300km to water or rail by 2030 and 50% by 2050 (Kaack et al., 2018). The formulated targets were to be achieved by increasing the rail infrastructure, enhancing service levels, and improving intermodal connectivity. Takman & Gonzalez-Aregall (2021) identified 93 policy instruments adopted in Europe. These policies revolve around grants and subsidies and focus on the modal shift from road transport to rail. They claim that even though the 2011 White Paper set guidelines for a modal shift, the switch from the road to waterways and rail has not reached the intended levels. Road transport has remained dominant in the years after the 2011 White Paper. Islam, Ricci and Nelldal (2016) further add that in order for the modal shift objectives established by the EU White Paper 2011 to be fulfilled, the railway network must be doubled from the current 18% by 2050. Subsequently, the rail volume has to handle more than three times its current volume.

Another initiative of the EU has been the Marco Polo program, which ran from 2003 to 2013 and offered subsidies to several modal shift projects (EU Commission, 2013). With regards to efficiency, only 46% of the targeted modal shift in billion tonne-kilometres was achieved. However, with regards to environmental benefits the European Commission (2013) estimated these at 434 million EUR, with a total investment of only 32.6 million EUR. With regards to road transportation, The European Union has been proactive in internalizing freight transportation costs by increasing diesel taxes. Standard in most European nations, these charges are guided by the Directive 1999/62/EC. Moreover, as of 2017, most European countries have some form of surcharge for heavy vehicles (Broaddus & Gertz, 2008)**.**

On the field of promoting transport by rail, the EU's Horizon Project 2020 funds research and innovation programs of which *Shift2Rail* is an undertaking that aims to promote the development of modal shift strategies and rail technology (Shift2Rail, 2020). From cross-mode perspective, in the form of standardizing data systems and promoting missing collaboration between modes, the EU has set up the COMCIS project. This also touches upon priorly discussed concepts such as synchromodality and the adaptation of dry ports, (COMCIS, sd). Additionally on a regional level, van den Berg and de Langen (2014) note that numerous European ports only allow sustainable port development and have sometimes mandated modal share targets when assigning terminal concessions and planning port infrastructure.

More recently, the European Commission (2019**)** postulates in their Green Deal that greenhouse gas emissions (GHG) need to be reduced by at least 55% in 2030, compared to 1990 levels, and by 90% in 2050. One of the major instruments will be the incorporation of the transportation industry into the

Emission Trading System (ETS), which will be discussed further in Chapter 3. Other specific measures of the European Commission (2021**)** are to opt for more rail transshipment terminals, improving handling capacity and reducing waiting times. This will also create nine main transport corridors which integrate transport between barge, rail and truck.

Conclusion

The European Union has promoted modal shift extensively for the past two decades in a wide range of initiatives. However, the earlier stated target of 30% transportation by non-road modes in the 2011 white paper has not been reached yet. It is unclear whether the EU policy has been ineffective or has prevented an even larger reverse modal shift, as the counterfactual situation without policy intervention cannot be observed. The EU Commission recently proposed further measures such as the European Green Deal, of which the effects should be monitored closely.

2.2 Development of modal shift policy on Dutch level

Policy Intervention

Jonkeren (2020) states that policy instruments with regards to modal shift are mostly implemented at the micro-economic level, stimulating individual freight forwarders or logistic service providers to switch from road to barge or rail. From a market-economic perspective, government intervention in order to facilitate a modal shift can be justified from an environmental perspective as the CO_2 emissions per tonkm of trucks are higher than rail and barge. Furthermore, trucks contribute to congestion which can be considered a negative externality. This justifies government intervention, in order to prevent market failure. Thus, following the definition of Wortelboer-van Donselaar en Lijesen (2008), the goal of the policy is to reduce CO_2 emissions and road congestion.

Modal Shift Policy

In 1990, the ‘Structuurschema Verkeer en Vervoer II’ stipulates not only the enhancement/improvement of mobility but also its need to be reduced (Tweede Kamer, 1990). This implied efficiency-improving measures to increase barge, rail and intermodal transport and until 2010 the goal was to shift 65 million tons of cargo from road to other modes of freight transport. In order to achieve this reduction, several benchmarks were formulated to decrease inland road transport. This reduction/shift was to be reached through efficiency-measures and improved inner city logistics. Additionally, on an environmental level, through technical innovation, emissions also needed to decrease and specifically NO_x with 60% in 2010 compared to 1994.

Later, the modal shift target of 50 million tons was allocated to rail (20 million tons) via the Betuweroute in 2015; barges (20 million tons) and short sea transport (11 million tons). As a response to the European Whitebook targets of 2011, the Dutch government emphasized the importance of environmentally friendly freight transport. A market-based approach is preferred through more efficient vehicles; higher load factors; improving cooperation in the logistical chain and promoting synchromodality. The government does not favor quantitative targets (Tweede Kamer, 2011).

Subsequently, in policy reports of 2001-2012, these explicit targets were let go off. The new policy view was to assist the functioning of the entire logistical system. The Dutch Ministry of Infrastructure and Water Management (2019) incorporated the modal shift as an important goal of freight transport and agenda-specific programs were implemented to stimulate barge and rail such as: ‘Topsector Logistiek’, ‘Beter Benutten’ and ‘Meer Bereiken’ (Tweede Kamer, 2016). TNO (2020) notes that on a regional level, with the construction of the ‘Tweede Maasvlakte’ the share of road transport in the modal split should be a maximum of 35% in 2033, while the past years that share has remained stable at 48-50% (Geerlings, Van Meijeren, Vonk-Noordegraaf, & Soeterbroek, 2009; Huizen, 2020).

Jonkeren (2020) compared several of these improvement programs of the Dutch government and formulated points of improvement for policy makers. Two important takebacks regardless of the used policy instrument is (1) the usage of quantifiable indicators to monitor and evaluate modal shift project and (2) formulate specific targets for modal shift. It is not possible to measure the effectivity and efficiency of policy measures without quantifiable indicators or specific policy goals. Although these might seems straight forward, not all modal shift projects met these demands.

The most often used policy instrument for modal shift is subsidies, education, intent agreements and ambassadors. Intent agreements came forward as too open-ended for participating companies, not able to substantiate investments in transshipments facilities. It was advised in ‘Quick Wins Binnenvaart’ and ‘Stimuleren Efficiente Goederenstromen’ to make agreements more enforceable by using covenants. The instrument of education/informing aims to make consignees aware of the opportunities of rail and barge and to bundle their cargo. This instrument can be more effective by using advisors or logistical ambassadors (Jonkeren, 2020). The Dutch government supports the green deal to aid the implementation of sustainable projects while accelerating the transition to a sustainable economy (Korteweg, 2017). The deal proposes an active modal shift policy from road to water.

Conclusion

Jonkeren (2020) concludes that the usage of Dutch policy instruments has mostly been aimed at reducing the relative costs of non-road transport modes, incentivizing freight forwarders to switch. This can have a direct effect through investments in infrastructure such as quays and transshipment facilities but also indirect by bundling cargo which leads to economies of scale that decrease costs. Subsidies are often used, and are deemed an appropriate policy instrument, as they do not directly intervene with the modal choice but incentivize parties towards modes with less external negativities. The questions remains if this instrument should be the only tool in the toolbox and a cost-benefit analysis is essential for each subsidy scheme. An additional policy instrument could be pricing mechanisms such as a tax for trucks in 2023 (Visser & Kansen, 2018).

Chapter 3: Available policy measures for influencing modal shift

Main Question to be answered in chapter 3: *How can the modal shift policy be designed to promote sustainable freight transport?*

3.1 Emissions per modality

In order to determine how sustainable freight transportation modes can be promoted, we first need to determine which mode of transportation is the most sustainable. Thus, the environmental impact of each mode will first be assessed and compared. Kaack et al. (2018) mapped out confidence ranges for the emissions of CO_2/tonkm for heavy road, medium road, rail and inland vessels for China, North America, Europe, India and other regions. These estimates depend on multiple factors, such as age, fuel type, payload, terrain, driving patterns etc. In general it is found that rail and inland waterway transportation emit considerably less than road for all regions. Furthermore, transport by inland waterway is more carbon intense than rail. Lastly, inland shipping is more intensive than ocean shipping (Sims, 2014).

On another hand, Zhang et al. (2014) pose that barges emit the least per TEUkm (vs. tonkm), and rail emits relatively more. However, this is countered CE Delft (2017), who state that electric-powered rail emits the least CO_2/tonkm, followed by barge and road in agreeance with Kaack et al. (2018). We can conclude that when determining the emission per mode several factors such as cargo type (bulk vs. container), vessel size and unit of measurement (tons vs. TEUs) need to be taken into account (de Vries, 2019).

Each transport mode has a certain capacity to improve efficiency or switch to other propulsion methods, decreasing the environmental footprint. The (possibility to improve) energy efficiency for each mode will be discussed in the following paragraphs.

Road

With regards to transport by road, IEA (2017) finds that truck energy usage could be decreased with 34% in 2050. Besides improving efficiency, electrification of trucks is also an option through usage of batteries, hydrogen fuel cells or electrified roads. However, with current technology this is only economically viable for relative short distances, within a range of 150km (IEA, 2017).

Barriers to adoption of these new technologies is users requiring a payback within two years, insufficient funds for high capital investments and hesitance regarding the reliability/safety of new technologies (Bynum et al., 2018). This especially goes for companies with a fleet of less than 20 trucks. Furthermore, Farrel, Keith and Corbett (2003) state that hydrogen-powered vehicles are mostly suited for point-to-point routes with a small geographic scope. An example of this would be in the ports of Long Beach and Los Angeles, where hydrogen-powered trucks are used for drayage in the port area.

Rail

The potential of decarbonization of rail transport is closely tied to the decarbonization of the energy providers, as most rail systems in the world are electric. The US is an exception to this with diesel-electric trucks being quite dominant. There is some experimenting in Norway towards (hybrid) hydrogen powered propulsion of rails, being able to work without installing overhead catenaries, which would provide a cost reduction of 50% (Zenith, Møller-Holst, & Thomassen, 2016).

Barge

A large determinant for the emissions of barge transport is the vessel size (van Essen et al., 2003). Van Essen et al. (2003) state that small vessels carrying less than 250 tons of non-bulk cargo have a similar or higher GHG-intensity compared to trucks. This is not supported by CE Delft (2017), small vessels (96 TEU) do emit almost twice as much as large vessels (208 TEU), however the 96 TEU vessel still has 50% less CO_2 emission than transport by road (Geertsma, Negenborn, Visser, & Hopman, 2017). Several studies into reducing fuel usage by electric hybrid propulsion technologies, show a possible reduction of 10-35%. Vessels that operate on a route with a limited range are most suitable for the installment of electric batteries (Van Biert et al., 2016; Boffey, 2018). An example of this is the brewery of Heineken in Zoeterwoude, which installed interchangeable battery containers on their barge vessels while navigating a 60km trip from Alphen aan den Rijn to the Port of Moerdijk (Port of Rotterdam, 2020).

Other Emissions

Lastly, with regards to the emissions of different modes, most policies are focused on the reduction of CO_2 while Jonkeren et al. (2017) also offer an overview of two other types of emission which are relevant for trucks, barges and diesel-powered trains. These are nitrogen (NO_x) and particulate matter (PM_{10}), Jonkeren et al. (2017) show that the amount of nitrogen/tonkm has declined substantially for road transport, while the nitrogen-emission for other modes started at a lower level and declined to a lesser extent. For particulate matter, the decline has been steep for all modes due to stricter environmental regulations and technical innovation (NT, 2021).

3.2 Market based environmental measures

3.2.1 Fuel Levies

On the field of measures that specifically target environmental standards such as CO_2 emission reduction, several market-based measures are available. A prominently discussed measure is a bunker or fuel levy. Gu et al. (2019) argue that it is a cost-effective way of reducing emissions without direct intervention of the government. It is a relatively easy measure to implement and allows operators to be able to adjust to a known increase in fuel cost. This is supported by Chai, Lee and Gaudin (2019), noting that it would be especially suitable for shipping to incentivize the development and adoption towards more efficient fuel technologies.

A question that comes to mind is how this tax is enforced between asset-owners and operators. Whether the owner or user of the asset should be contributing to these taxes. Kosmas and Acciaro (2017) found that especially the freight rates, market conditions and level of capacity utilization affect this. The authors conclude that if there are positive market conditions such as a high freight rate, cargo recipients will contribute to a higher percentage of the tax costs.

While the fuel levy seems an adequate measure, it is not without requirements. Lagouvardou, Psaraftis and Zis (2020) postulate some challenges which need to be addressed. Firstly, the type of ships that are included needs to be considered, where ships of a very small size (below 400 GRT) are possibly excluded. Furthermore, to increase the environmental incentive, fuels with a low carbon footprint should also be, partially, excluded from the levy. Lastly, the amount of tax and corresponding effect are also estimated by Lagouvardou et al. (2020). It is stated that a moderate effect is expected with a medium levy between of 5-75 USD per ton of CO_2. A levy above 75 USD/ton CO_2 is expected to have significant effect, improving the cost-efficiency of alternative fuels. With regards to a level-playing field for each mode it should be noted that a fuel levy would predominantly affect transportation by road and barge as most freight trains are powered electrically.

Low Carbon Fuels

The utilization of low-carbon fuels contributes to decarbonization while mostly avoiding the construction and investment in new fuel storage and infrastructure. Brynolf et al. (2018) pose that these pathways to low-carbon fuels do however face barriers with regards to costs and availability. With regards to fuels produced from biomass, for a sustainable product lifecycle the land usage needs to be minimized, which limits the total availability.

Zhang et al. (2014) explore the topic of low-carbon fuels further by comparing the implementation of carbon pricing scheme of 50-200 EUR/ton CO_2 to the mandatory usage of biodiesel for the container transport network in the Netherlands. They find that carbon pricing is only effective at relatively high levels (80-200 EUR). Zhang et al. (2014) state that implementing biodiesel would be more efficient as the reduction of emissions is higher and the total system cost increase is lower, compared to carbon pricing. However Zhang et al. do note that the price of biodiesel is assumed to be constant and in sufficient supply for entire road transport, which are strong assumptions.

3.2.2 Emission Trading Systems

Another available policy measure to reduce emissions is the usage of an Emission Trading System (ETS). On a global scale two basic types of trading systems can be distinguished, which are a so called ‘baseline-and-credit’ and ‘cap-and-trade’ system (OECD, 2020). In a baseline-and-credit system there is no upper limit to the total amount of emissions, participants who stay below their baseline of emissions gains credits, which they can trade with polluters that emit more than the baseline. In a cap-and-trade system a limit is placed on total amount of emission and emission rights are distributed through a combination of auctions and ‘free’ allocation (Mellin et al., 2020). The free distribution is based upon certain criteria such as for example historical production levels. Thus, operators and other actors such as investment banks or financial institutions are able to trade emission rights. Parties gain the choice to either ‘consume’ their own emission rights or decrease their emissions, enabling them to sell their rights to parties who are seeking to emit more than the freely granted emission rights (Mellin et al., 2020).

The EU-ETS is a cap-and-trade system which has been in place since 2005. At the start it has placed a maximum on GHG emissions for about 12,000 industrial installations ranging from chemical refineries to power plants. From 2012, intra-EU aviation has also been included. It is interesting to note that the ETS compassed around 40% of total GHG emissions in 2018 compared to 45% in 2008. The share has a downward trend since sectors that are part of the ETS are required to decrease their emissions at a faster rate compared to non-included sectors (IETA, 2018).

A large ongoing debate is whether the emissions of the shipping sector can best be handled through measures on a global or regional scale. Streng et al. (2020) point out that this is mainly due to the footloose nature of the shipping industry where strict regional measures could increase the risk of ‘carbon leakage’, where vessels will simply readjust their operations towards regions with more lenient environmental regulations (Kuik & Hofkes, 2010). In order to remain concise, our scope will be limited to the Regional/European level.

On a European level, the question remains if the ETS for the freight transportation industry will be ‘open’ or ‘closed’. In an open system it would be possible for the sector to trade with other industries. Where in a ‘closed ETS’, also referred to as a METS, freight transport companies can only exchange emissions rights with one another. According to Wang, Corbett and Firestone (2007), the larger scale of an open ETS improves transparency and efficiency of allocation of emission rights in theory. Kågeson (2007) adds to this that it would be more difficult to set an appropriate cap for the METS since the (potential) growth of the industry itself has to be gauged. If the cap is too restrictive it might cause excessive pressure, harming the development of the sector.

However, the METS also comes with its advantages. Schmidt, Lawson and Lee (2004) point out that from an institutional and economic view the METS may be more practical to implement. Targeting an established sector and organizing data collection at sectorial level for example through organizations as the IMO might be more manageable. However, the difficulties that come with implementing a METS should not be underestimated.

More recently, it became clear that the current EU-ETS will be extended to the maritime sector and thus becoming part of the ‘open’ ETS. With regards to road transportation a separate EU-ETS trading scheme will be developed including road transportation and the built environment. The ETS for the road transportation sector will in essence be designed as a fuel tax, administered by fueling stations (EU Commission, 2021).

EU Carbon Price Development

While the cap-and-trade system has been proven to be successful in reducing the total amount of emissions over the past decades, the EU Carbon Permit (EUA) price level is essential for the effect on participating companies. As carbon price levels dropped below an effective level of 15 EUR during 2011-2015, the EU introduced a Market Stability Reserve (MSR) which absorbs excess, unused or unauctioned carbon certificates to decrease supply and keep the price stable (Bel & Joseph, 2015). More recently, the EUA has reached record levels of 90 EUR due to uncertainty in the power generation markets (Osorio et al., 2021).

Inland Waterway Considerations

Another aspect that needs to be fleshed out further is which vessels will be included in the ETS schemes. The heterogenous nature of vessels with different cargo types, corresponding operational costs and energy efficiency. Zheng et al. (2013) propose to utilize the Energy Efficiency Design Index (EEDI) for new vessels. This tool takes a multitude of criteria into account in order to calculate the baseline for different types and size of vessels.

Furthermore, market structure characteristics and competitive conducts in each shipping sector will also affect the results of an ETS. For example, inland barge vessels designed for bulk cargo are generally perceived as less expensive and energy inefficient in comparison to container vessels. Luo (2013) illustrates this as well by the fact that the low value of bulk cargo causes these vessels to sail slower due to decreased holding and inventory costs, compared to container vessels. Lam and Van de Voorde (2011) argue that the high market concentration and therefore less competitive nature of the container shipping market needs to be taken into account as well.

In order to reduce the complexity for the European shipping sector Ricardo et al. (2013) discuss the topic of which ships should be included/excluded from emission schemes. The authors illustrate an increased effectiveness by excluding certain vessel types and sizes. More specifically, Ricardo et al. argue the excluding of two main groups: Firstly, special ship-types such as offshore, service vessels, fishing vessels and yachts. Secondly, excluding vessels smaller than 5.000 GT to lessen the administrative burden. Excluding both these groups results in 90% of the CO_2 emissions to be covered while only 56% of the vessels need to participate. More recently, CE Delft (xx) assessed that for maritime shipping vessels below 5.000 GT will indeed be excluded and traffic between ports as well. Moreover, for inland navigation LNG is not seen as a long term solution, while it is very suitable for shipping (CE Delft, 2022).

Road Transport Considerations

Heinrichs, Jochem and Fichtner (2014) assessed the effect of including road freight transport in the EU-ETS for the German market. It is found that the inclusion of road transport would be an efficient solution, promoting the development of technological innovation in non-emission vehicles. This incentivization of innovation had a stronger effect on emissions than the price-increase of CO_2-pricing. Although, it should be noted that the authors did not apply very high levels of CO_2-pricing, the maximum was 60 EUR/ton.

De Vries (2019) did simulate a wider range of carbon-pricing, ranging up to 500 EUR/ton CO_2. For a small distance range of 100-150km battery-electric road vehicles became more economical with a carbon price of 200 EUR. While looking at the modal shift to rail and barge, this mostly occurred at distances larger than 250km with a carbon price of 200 EUR/ton. This partly overlaps with the modal shift found by Zhang et al. (2014) at a price level of 80-200 EUR. De Vries (2019) does note that for some part of the evaluated network, only unimodal transport was available.

More specifically, CE Delft (2021) examined the effect of a emission trading system for the road transportation industry in the Netherlands. It was found that very high allowance prices were necessary ranging from 220-690 EUR/ Ton CO_2. They assess that an ETS would result in significant fuel price increases stimulating freight companies to improve fuel-efficiency and load factors. But also, partial price-increase could be passed on to customers.

3.3 Conclusion

The main difference between the two environmental measures is the price level. The price level of a fuel levy will be fixed and can be anticipated by transporting parties, while the price of carbon certificates in an ETS is affected by multiple factors such as supply, demand, energy market conditions and EU-policy considerations. Multiple researches have been conducted with regards to which type of vessels should be included in an ETS and to what extent a modal shift will take place. The effect on the modal shift is mostly determined by the distance, ETS-price level and availability/accessibility of other transport modes.

Chapter 4: Methodology

4.1 Research Design

In the previous chapters the background with regards to modal choice process, European/Dutch modal shift policy and sustainable freight policy measures has been established. The main conclusions of the established framework shall be incorporated into the further analysis, if applicable. In order to formulate an answer to the main research question '*How will the implementation of an Emission Trading System affect the modal split on the Rotterdam – Duisburg freight route'* it will be divided in several subsections which are the following:

1. *How much CO_2 emissions does each transport mode emit currently and how will this develop towards 2030?*

As the EU-ETS is a pricing scheme with a tariff for each ton of CO_2 that is emitted, the amount of emission will have to be estimated for each mode. As we have seen in Section 3.1 this depends on several factors such as cargo type, transport capacity and unit of measurement. As previously stated, the cargo type will be containerized transport as this standard transport unit is suited for switching between various modes. Logically, the aim will thus be to find and compare current and future emission rates that are measured for containerized cargo. These will be retrieved from various sources such as: recent literature, public research reports and European/Dutch guidelines.

2. *How has the modal split of Duisburg developed itself from 2006-2019?*

In order to assess the impact of an additional policy measure, the current situation and recent history of the inland port of Duisburg will be discussed. The past development of the modal split can give insight into the progress the port has to make with regards to promoting sustainable transport. Data of the modal split will be retrieved from annual port reports; expert-interview with the Port of Rotterdam; data-request from the Port of Duisburg and market reports of the Central Commission for the Navigation of the Rhine (CCNR, 2021). Moreover, Duisburg is the largest inland port of Europe and thus has a substantial influence and impact on the entire hinterland supply chain. In order to simulate the market as close to practice as possible, parameters as annual container flow from Rotterdam-Duisburg and container content/value will be assessed. Lastly, the influence of low-water levels will be examined and compared with the literature findings.

3. *How will the implementation of a carbon pricing affect the competitive position of transport by barge rail and road on the Rotterdam – Duisburg container route?*

As illustrated in section 3.2, the exact requirements and characteristics of the ETS are important when determining its eventual effect on hinterland transportation. Since these exact conditions such as which types of vessels will be included and whether it will be an open or closed ETS are currently unknown, the implementation of the ETS will be examined in a specific hinterland route. The maritime mobility and ‘footloose’ nature of the shipping industry is not as present (Streng et al., 2020). This leads to a suitable case study where the implementation of an ETS (carbon pricing scheme) for transport by road and inland waterways can be studied.

4.2 Scenario Calculation

In order to estimate the market shares of truck, train and barge on the Rotterdam – Duisburg route, the Total Logistics Costs (TLC) method of Blauwens et al. (2006) will be utilized and slightly adjusted.

While Danielis, Marcucci and Rotaris (2005) point out that service quality attributes are more important than shipping costs with regards to modal choice decision making, Arenciba et al. (2015) argue that including, especially inventory-related, costs and financial risks is in fact decisive. Moreover, the above mentioned factors are often interdependent, the height of inventory costs is dependent on frequency and reliability. The TLC-method takes the shipping costs, inventory costs and a margin for the reliability of the associated transportation method. This enables to study specific trade-offs, such as which transportation method is chosen for low-value goods and which is chosen for shippers that require high service levels. The TLC-method is chosen as it enables to study the above-mentioned specific trade-offs and also allows for the introduction of policy measures with regards to sustainability, such as carbon pricing. In this way we add upon the work of Blauwens et al. (2006) where sustainability was not in scope.

The TLC method consists of four logistical characteristics: transportation costs, loading capacity, average lead-time, and variance of the lead-time (Blauwens et al., 2006). Furthermore, the goods flow consists of six parameters: annual volume, average daily demand, variance in daily demand, goods value, holding costs and required service level by freight recipient. The original TLC is represented by Formula 1.

$$(1)\ TLC = TC + \left(\frac{1}{R} * \frac{Q}{2} * v * h\right) + \left(L * v * \frac{h}{365}\right) + (\frac{1}{R} * v * h * K * \sqrt{(L * d) + (D^2 * l)}$$

The first term ‘TC’ represents the transportation costs, which are also referred to as the ‘out of pocket costs’ for the shipper. The second term accounts for the cycle stock, which is on average half of the shipment size (Q/2) multiplied by the value of goods (v) and certain holding costs (h). The cycle stock costs per unit are given by dividing by the annual volume (1/R) (Blauwens et al., 2006).

As each mode has a different lead time (L), dependent on the speed of the mode, the third term represents inventory transit costs. Finally, the fourth term is the safety stock costs. Parameter ‘K’ is the safety factor which is the requested service level of the shipper, while the square rooted formula forms the standard deviation of demand which is the operationalization of the reliability of the cargo flow.

In order to represent different cargo demands that a certain shipper could have, the parameters will have different values such as high or low-value cargo (v) or different levels of holding costs (h). Subsequently, the TLC is calculated for each of the three transport modes: truck, barge and rail for each ‘shipper’. In order to determine the market share, it is assumed that the transport mode that yields the lowest amount of TLC for each possible combination of parameters is chosen by the shipper. Thus, complete symmetry in information availability and rational decision making is assumed (Blauwens et al., 2006).

Table 1: Overview of logistical parameters in TLC-Method

Goods flow parameters		**Transport mode parameters**	
Annual volume (units)	R	Transportation costs (/unit)	TC
Average daily demand (units/day)	D	Loading capacity (units)	Q
Variance of daily demand (units^2/day)	d	Average lead-time (days)	L
Value of the goods (€/unit)	v	Variance of lead-time (days^2)	l
Holding cost (% per year)	h	Amount of CO_2 (kg/container/km)	E
Safety factor	K	Carbon Price (EUR/ ton CO_2)	C

In order to assess the effect of the ETS, the costs and amount of emissions, represented by E and C, will be added for the fuel-based transportation methods which are barge and road. This is represented in Formula 2.

$$(2)\ TLC = TC + \left(\frac{1}{R} * \frac{Q}{2} * v * h\right) + \left(L * v * \frac{h}{365}\right) + (\frac{1}{R} * v * h * K * \sqrt{(L * d) + (D^2 * l)} + (E * C)$$

4.3 Data

Transport Costs (TC) will be estimated by utilizing the Cost Freight Figure Index of KiM (2020). This index has been actualized in 2018 and accounts for cargo type, commodity group and specific vehicle type. As the lead time is an important determinant, several comparison tools were evaluated. The Ecorys Intermodal Links (2022) generated an overview for all available operators for transport by rail and inland waterway. According to the overview in Ecorys, there are 7 operators active on the Rotterdam – Duisburg Freight route (Appendix B, Table B1). Ecorys did provide the weekly frequency but not the lead time, amount of transfers or kilometers travelled. Furthermore, it was only possible to select routing on port-level. Subsequently, the websites of each respective operator were examined. They provided information with regards to weekly departure schedules but not in terms of lead time or amount of kilometers. European Gateway Services (EGS) also provides an intermodal route finder, but this is not publicly available. The Navigate tool (2021) of the Port of Rotterdam does provide an overview of available operators, lead time in hours and distance in km. Therefore, in order to estimate the lead times an average of all available operators in Navigate who provide a direct route will be taken for train an barge.

In Navigate, the Hutchison ECT Delta Terminal was chosen as point of departure in the Port of Rotterdam and the Hutchison Port DeCeTe as point of arrival in the Port of Duisburg. Both terminals were chosen as they are located in the major container handling areas of the ports, provide intermodal connections and handle considerable volume. Furthermore, the final destination of the customer warehouse is assumed to be at 30km from the DeCeTe Duisburg Terminal. This 30km is added directly to the transportation by road, while for rail and barge an additional handling time and handling fee by the inland terminal will be retrieved from the website or directly requested (ECT, 2022).

It should be noted that by looking at a container level of goods instead of the individual goods themselves such as Hoen et al. (2014), the price of CO_2 per good is quite a rough estimate and does not account for any emission related to the actual goods inside the container. Likewise, since only the monetary value of the container is incorporated, the difference between emission of reefer and non-reefer containers is also disregarded. While reefer containers do have a higher amount of emission (Castelein, Geerlings & Van Duin, 2020). Furthermore, with regards to the pricing of emission, several interdependencies can be noted. De Vrijer and Akkerman (2019) note that as the carbon price increases it could prompt energy producer to switch to cleaner forms of energy. This effect will not be taken into account, as energy production market dynamics is beyond the scope of this thesis.

Furthermore, as discussed elaborately in section 1.4, the so called reverse modal shift might be further incentivized by a rise in carbon pricing. This is also a realistic assumption as the road transport sector has a large contribution to GHG-emissions and is most likely of the three transport modes to be incorporated into the EU-ETS.

With regards to the price of emission, if we assume that there will be an open ETS system, the effect of the transportation industry on the entire market will probably not be significant and therefore the current market price of 50 EUR/Ton CO_2 would be exogenous (Wang, Fu & Luo, 2015). However, since it is uncertain whether it will be an open ETS, the price level for emission will be varied between 20-500 to provide several benchmarks (Mellin et al., 2020).

Moreover, Bektas and Crainic (2007) point out that inland terminals often are one of the most critical links in the transition between certain modal choices. The available infrastructure with regards to crane capacity, transshipment and customs handling is assumed to be sufficient in Duisburg. First of all because it is the largest inland port of Europe. Secondly, it is one of the few Rhine terminals with sufficiently large volumes for a direct rail service with ECT Maasvlakte and Waalhaven in Rotterdam (Kreutzberger & Konings, 2013). With regards to the congestion of barges on deep sea terminals as discussed in section 1.2, it will be monitored. If the market share of barge increases substantially (>5%), lead times will be increased with tranches of 0.5 days substantially. Lastly, it should be mentioned that this is a static model, where the effect of trading emissions between parties and the allocation of 'free emission rights' can unfortunately not be taken into account.

Chapter 5: Results

5.1 Emissions per transport mode

Main Question: *How much CO_2 emissions does each transport mode emit currently and how will this develop towards 2030?*

Estimating emissions per transport mode depends on several factors such as the specific type of vehicle used, route length, cargo type and pre- and post- haulage in case of intermodal transport. As this paper is examining a specific freight route for containers, the route length and cargo type have been accounted for. Another important distinction when looking at the development of sustainable transport methods is that between WTT (Well-To-Tank) and TTW (Tank-To-Wheel) emissions. TTW-emissions are the direct emissions generated while operating the vehicle, thus for electrically powered vehicles this is often considered to be zero. However, the WTT-emission is generated by the preceding part of the energy supply chain, which also needs to be taken into account and for electrically powered vehicles the emission thus depends, among other factors, on the power generation mix of a country. Combining both these emissions to arrive at the total of the supply chain is referred to as the WTW (Well-To-Wheel) or (Well-To-Wake) emission for vehicles/vessels. This benchmark, if fully available, will be utilized in this paper. In Table 2 an overview of the current emission levels can be seen for container transport. The TTW-emissions of particulate matter and nitrogen are more harmful for the direct environment and thus considered more relevant for policy making decisions.

Table 2: Emissions figures per modality for container transport

Modality	**Vehicle/Vessel Type**	**CO_2 (g/tkm) (WTW)**	**PM_v (g/tkm) (TTW)**	**NO_x (g/tkm) (TTW)**
Road	Truck + Trailer (2 TEU)	121	0,003	0,30
Rail	Train (90 TEU)	18	0,002	0,08
Barge	R.H.K. (Rhine-Herne-Kanaal) (96 TEU)	52	0,019	0,55
	Large Rhine-vessel (208 TEU)	32	0,013	0,34

Source: (CE Delft, 2021b)

It should be noted that it is of importance to look at the figures for containerized transport, as the emissions for bulk and break cargo per tonkm are generally lower, as the weight of the break/bulk cargo is on average higher compared to containers. With regards to the selected vehicle/vessel types, the truck/trailer combination is responsible for 75% of transported tonkm for heavy freight and assumed to be representative for truck traffic (CBS, 2019). For transportation by barge, the Rhine-Herne and Large Rhine vessel are responsible for 50% of the cargo transportation in the Netherlands and are assumed to be used in a 50/50 split on the Rotterdam-Duisburg freight route (CE Delft, 2021b). In order to estimate the emissions of each mode in 2030, the available technologies; barriers with regards to economic viability and available infrastructure will be discussed for each mode in the following section.

5.1.1 Road Transportation

The decarbonization of transport by road has been facing increased attention for the past decades, also because of the other negative externalities such as noise and air quality in urban areas. TRAN (2021) looks at future fuel infrastructure for heavy duty freight vehicles. In the short term, bio-fuel seems most promising as a transitionary fuel, while a combination of hydrogen (FCET) and battery-electric (BET) is seen as a long term solution. Methods that are in pilot are overhead catenary systems and e-fuels, the latter is produced through a mixture of green hydrogen and CO_2.

A large barrier for electrified heavy vehicles is the infrastructure. Fast-charging and low-power overnight charging will be required at resting stops along the TEN-T corridors to accommodate long range heavy freight transport. Subsequently, the power grid capacity on EU-level also needs to be extended and adjusted.

The usage of biofuels can mostly utilize existing infrastructure, as a limited percentage of biofuels is already being blended in with current fuels. Also, on a technological level, most currently used EURO-VI diesel engines are able to utilize biofuels (Topsector Logistiek, 2018). Interesting to note is that EU Commission is not investing as much in LNG/CNG. It will be no further incentivized by policy incentives and instead the focus will be on bio-LNG/ advanced biofuels or renewable energy. The opinion towards the rate of adaptation of LNG-trucks towards 2030 differ, on the one hand it offers a relatively limited potential for CO_2 reduction (Table 3). While on the other hand, it is already a mature solution for long distance trucking in terms of technology and infrastructure. The EU Commission aims to provide necessary infrastructure for (bio)LNG but considers that this stimulus should not be at the expense of BET and FCET vehicles (TRAN, 2021). In Table 3 an overview of available technology and economical and environmental benchmarks for trucking can be seen.

Table 3: Overview of characteristics of available fuel technologies for road trucking in 2030.

Technology/Fuel	**Cost Level** (TCO over 5-year-period) (€)		**Estimated share of EU fleet in 2030** (Low vs. High Scenario)	**Estimated Emissions 2030** (WTW CO_2 g/km)
	2025	2030		
Diesel	420.000	410.000	74% – 90%	1.051
LNG	360.000	350.000	6% - 9%	783
Biodiesel (FAME/HVO)	480.000	-	-	149
Bio-LNG	-	-	-	307

Battery-Electric (BEV) 800km	450.000	400.000	0,5% - 5%	162
Hydrogen-Electric (FCEV)	550.000	480.000	0,01% – 0,5%	376

Sources: Topsector Logistiek (2018) ; (TRAN, 2021); CE Delft (2021b); (Öko Institute, 2020)

It is important to note that the costs in Table 3 do not include infrastructure costs, which are quite impactful. For example an overhead catenary system for battery-electric trucks decreases the need for charging stations and thus has a high initial investment cost but relatively low operating costs.

Conclusion

Until 2030, the blending of biodiesel and BET-trucks for ranges until 400km seem most feasible. The BET-vehicles will facilitate short haulage routes but not long range heavy transport. Infrastructure for hydrogen and electricity faces large challenges, it is uncertain at which pace this will develop. On the one hand, the increased electrification of passenger vehicles could push for more overall availability of electric charging, compared to hydrogen which will mostly be shared with heavy industry and aviation/maritime shipping. On the other hand, the congestion on electrical power grid will increase even more. A large barrier for renewable hydrogen will continue to be the availability, as it requires considerable amounts of renewable energy which are only expected to be available in the long term after 2030 (PBL, 2020). Lastly, BET-vehicles have an energy efficiency of 73%, while for FCET-trucks this is currently only 31% as energy is lost in conversion from electricity to hydrogen (Öko Institute, 2020).

5.1.2 Inland Waterway Transportation

(Royal Haskoning, 2019) interviewed 25 forwarders who stated that decarbonizing is not seen as a pressing issue. Transportation by inland waterways is already seen as a relatively environmentally friendly transportation mode with low costs of transport per tonkm and a relatively low fuel usage/emissions. However, with emission reduction targets of 2030 and 2050 coming up, this sentiment is changing. The Dutch Green Deal has a target of 150 zero emission vessels in 2030, of which 100 will be battery-powered and 50 hydrogen-powered (TNO, 2020b).

Furthermore, prominent shippers in the nutritional industry have stated they would prefer to use zero-emission vessels instead of combustions engines (Royal Haskoning, 2019). The first pilots for hydrogen and battery-electric vessels are being performed for short distances. These pilots by ZES and Nobian require collaboration across the supply chain as long term delivery contracts with the shipper on a specific point-to-point route are in place. With regards to decarbonizing inland transportation on the short, medium and long term several technologies are available.

In the short term, there are several ways to (prepare to) decarbonize inland shipping which are not mutually exclusive. Firstly, the current diesel engines need to be replaced with diesel-electric engines. Although diesel-electric engines are less efficient in terms of energy conversion, they are more suitable to be propelled by other energy carriers such as batteries or hydrogen. According to Panteia (2019) this is feasible for 40% of the current fleet in the Netherlands. Diesel-electric engines require a higher initial investment but can achieve higher fuel efficiency, depending on the navigation profile. For the vessels where diesel-electric propulsion is not economically feasible due to high-energy usage or having a very young engine, additional blending of biofuel is an option (Panteia, 2019).

Biofuels

From a technical perspective, the engines that are currently mostly used by inland vessels and installed between 2002-2020 (CCRI & CCRII), biofuels FAME and HVO can be mixed in up to a maximum percentage of 37%. For Stage V Engines, which are mostly installed after 2020, FAME can be blended until 8% and HVO for 100% (TNO, 2020b). The synthetic biodiesel HVO is seen as more superior compared to FAME as it has less technical complications when being blended in engines, however HVO is more expensive. Both fuels are made from the same resource which is Used Cooking Oil (UCO) and both can be referred to as biodiesel (TNO, 2020b).

Panteia (2019) shows that a blending of 15% of biofuel would enable achieving the intermediate climate goal of 20% reduction in 2030. A concern with the usage of bio-fuel is the overall availability. While biofuels will not only be used by inland vessels but also by road, deepsea shipping and aviation. However, as the inland navigation would only require a maximum blend-in of 30%, TNO (2020b) estimates this to be only 5% of the total demand for biofuel and is not expected to diminish supply for other sectors. Biodiesel is estimated to be 17-24% more expensive compared to current fuels.

Electrification and hydrogen

For a specific segment in inland waterway transportation, container freight, the usage of battery-containers seems suitable. This segment is characterized by a predictable sailing route between port and inland terminals, high frequency and relatively low energy demand (Panteia, 2019). This would however require the alignment of infrastructure across the inland TEN-T corridors. The question does arise if shippers are willing to pay a premium in the competitive inland container market for sustainable transportation.

On the long term, battery-electric and hydrogen-electric also seem to be shared technologies with road transportation. Battery-electric is most suitable for specific segments wit predictable routing patterns. The energy demand of a route needs to be small enough to be able to last on batteries. While on the other hand vessels with a very low energy usage are also not able to recoup the high investments costs for batteries. On the long term, a large part of inland navigation will most likely be hydrogen fueled

(Panteia, 2019). The energy density is much higher compared to batteries, allowing for more cargo space on small inland vessels. The unknown factor is which carrier of hydrogen will be used, hydrogen can be liquified, pressurized or bound to methanol/formic acid/ammonia. Economically, the price of hydrogen needs to drop below 2,50-2,00 EUR/kg while the current price 5 EUR/kg. The price is expected to drop somewhere after 2030 (Panteia, 2019).

LNG

Lastly, with regards to LNG it has been promised a large future and has been available during the past decade, but the decrease of diesel prices in 2014-2017 diminished the attractiveness (Panteia, 2019). Moreover, an expert of TKI Dinalog (2022) points out an LNG-engine is a substantial investment, leading to less container places as the tanks are larger in size. Environmental gains are dependent on your initial fuel, but based on diesel as prior fuel there will only be a 20% emission reduction (Table 3**)**. This makes the barrier for an investment dedicated towards LNG for inland barge operator substantial, also considering the long technical lifespan. Moreover, the EU Commission (2021) states that it does not view LNG as long term solution for inland navigation transport but more suitable as transitionary fuel for maritime shipping.

Conclusion

In conclusion, the inland waterway transportation sector seems to suffer from a first mover dilemma, as there are several technologies available but high investments costs need to be made. Thus for the short term, solutions for which the infrastructure are in place such as biofuel or efficiency-improving innovations to reduce emissions seem most likely. While electrification is feasible for specific routes and container segments or by establishing long term collaboration with a shipper. However, as the future infrastructure still needs to be realized, considering the large lifespan of vessel engines, the hesitance to make definite decisions is very high, as there will likely be a multitude of solutions. With the current knowledge in 2030, additional blending of biofuels and partly electrifying seems to be most likely to occur.

5.1.3 Rail Transportation

Currently, rail is the form of transportation with the least amount of emissions. Train is dominated by the usage of electricity, only on specific routes and in rearranging hangars without an available catenary are diesel-powered locomotives being utilized (CE Delft, 2021b**)**. Looking at the electricity-production mix of the Netherlands in 2019, it emits 420g CO_2/kWh with 19% of energy being produced renewable through solar, wind and nuclear (PBL, 2020). For 2030, the share of renewable power generation in the Dutch electricity mix is estimated to be 62% mainly due to a large increase in wind and solar production. This would decrease the emission of electricity generation to 120g CO_2/kWh which would decrease the WTW-emission of rail transport with 70%.

5.2 Modal Split Development Duisburg

Main Question: *How has the modal split of Duisburg developed itself from 2006-2019?*

Duisburg is the largest inland port in Europe when looking at the amount of tons transshipped to inland vessels and container volume (Table A2, Appendix A). As of 1998 it has grown to the leading trimodal terminal for Middle-Europe. The success of Duisburg can be explained by the formation of multiple strategic connections with logistic service providers and more recently, an alignment with China's Belt Road Initiative (Raimbault, Jacobs, & van Dongen, 2015). The Port of Duisburg is profiling itself as the 'Gateway to Europe' and is competing on this level with the Port of Rotterdam (Port of Duisburg, 2019).

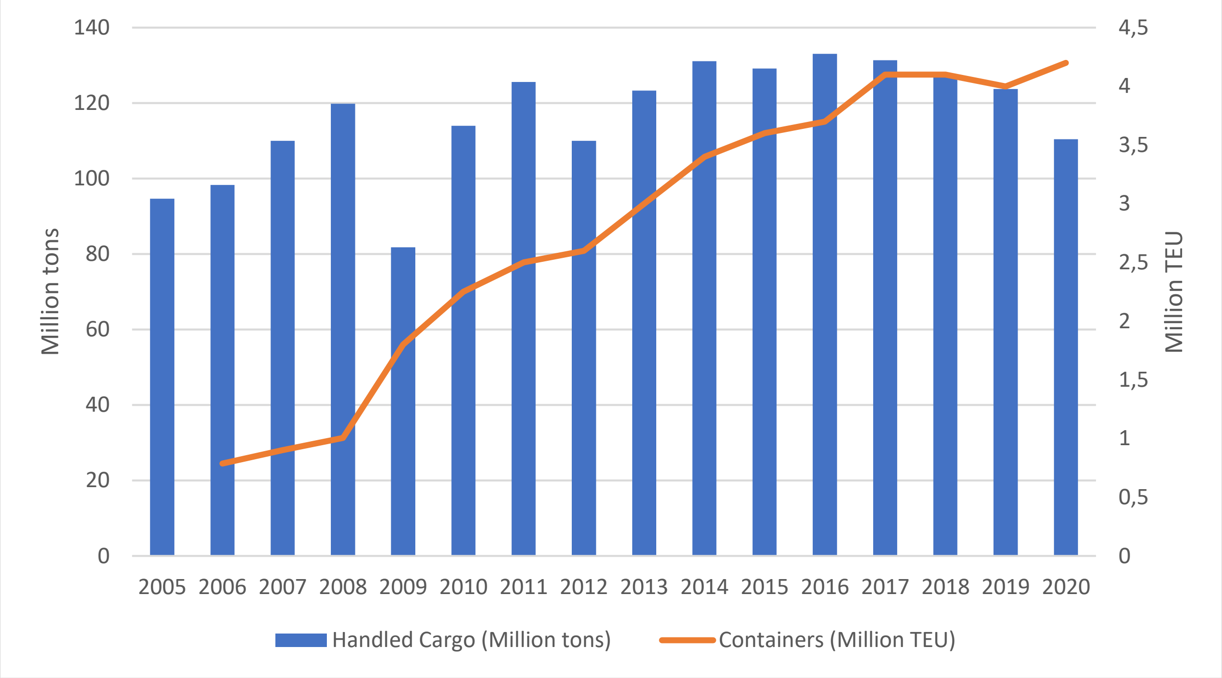

Figure 6: Amount of handled cargo and containers in all Duisburg Ports* in 2005-2020

*Private Ports have been estimated

Source: Duisburg Group Annual Reports 2005-2020

In Figure 6 the performance for all Duisburg ports is mapped out in terms of handled cargo in million tons and amount of containers. It can be seen that the amount of containers handled has grown consecutively amounting to an average annual growth rate of 14% for 2006-2020. The amount of tons handled has been declining since 2016 due to the phasing out of coal and industrial production.

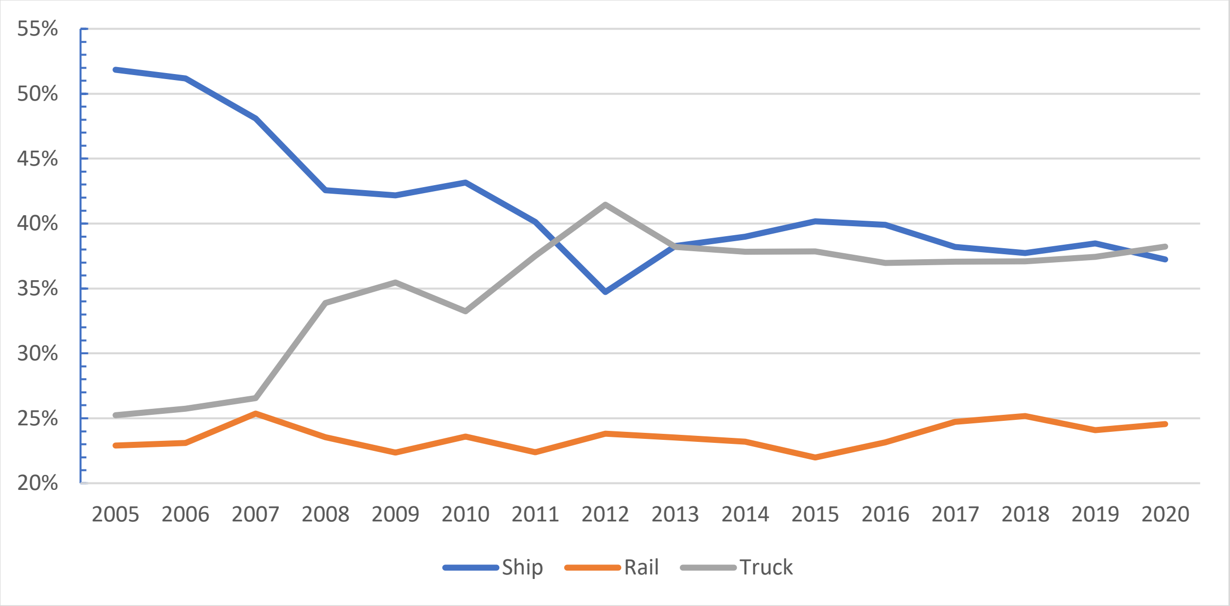

Figure 7: Modal Split handled cargo in all Duisburg Ports 2005-2020 in million tons

In order to explore the amount of cargo handled, the modal split for all types of cargo in million tons can be seen in Figure 7. While the share of rail has remained relatively constant, the share of transport by road has clearly increased, while ship has decreased. This could be an indicator that transport by ship/truck are in more competition with each other, while rail is unaffected. The modal share of ship decreased in 2011 and 2015 and these two years did experience lower water levels which decreased the loading degree of inland barges (CCNR, 2017). Subsequently, during 2012 there was a catch-up of the share of barge transport, indicating the potential of modal shift. Conversely, for the year of 2018 which also experienced low water levels, no substantial decrease can be seen while a steel factory in Duisburg had to reduce its production because insufficient resources could be transported via barge (Streng, van Saase, & Kuipers, 2020). While the market share of the of waterway/road transport seems relatively stable for the past decade, it should be taken into account that we are looking at all types of handled cargo in million tons, of which only a part is containerized. The large share of waterway transport could be driven by high-volume/low-value dry bulk cargo such as iron ore.

Container flow Rotterdam – Duisburg

No direct figures for the modal split of container transport from the Port of Rotterdam to the Port of Duisburg could be retrieved from the Rotterdam Port Authority. However, several estimates and benchmarks have been collected and summarized in Table 4.

Table 4: Estimates of container model split on Rotterdam – Duisburg freight route

Description	**Modal Split (%)**			**Source**
	Road	Inland Waterway	Rail	
Port of Rotterdam All Terminals to Hinterland	56,9	32,5	10,5	Interview Port of Rotterdam (2022)
Port of Rotterdam to Germany	22,6	54,1	23,3	Interview Port of Rotterdam (2022)
Container Import and Export in Netherlands 100-300km*	50 - 60	35 - 40	5 - 10	Jonkeren (2017)
Container Import and Export in Netherlands 300-500km*	40 - 55	20 -50	10 - 20	Jonkeren (2017)
Empirical Synchromodal Simulation Rotterdam - Duisburg	5 - 10	60 - 70	20 - 35	Zhang and Pel (2016)

*Estimates are respective market share of 2005 and 2014

With regards to the hinterland of Port of Rotterdam we can see that the majority is transported by road, however if we compare this to the container flow of Port of Rotterdam to Germany, the modal share of road diminishes and inland waterway transport becomes dominant. This indicates that most container road transport is destined within the Netherlands, which is confirmed in an expert interview with Port of Rotterdam. Comparing this observation to the market shares of Jonkeren (2017) on different route lengths *within* the Netherlands, it can be seen that the share of road diminishes as we move from 100-300km to 300-500km, while barge and rail increase. The simulation of Zhang and Pel (2016) seems a bit extreme, as the market share of road is very low, compared to the other estimates. It does confirm the majority of transport by barge, as is the case for all containers from Port of Rotterdam to Germany. Overall, with regards to the Rotterdam – Duisburg container modal split, we expect the share of inland waterway to be dominant, around 40-50%, while road will come second and freight by rail to be the smallest around 10-20%.

Container flow Duisburg – Rotterdam

With regards to the Port of Duisburg, some figures with regards to the container flow of rail and ship were available. The amount of containers transported via road is not registered by Duisburg. It should be noted that in Table 5 'Export' suggests the flow of Duisburg to Rotterdam and 'Import' vice versa.

Table 5: Annual Container flow Rotterdam - Duisburg 2016-2021 (TEU x 1000)

Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Ship - Import	142	161	167	157	167	170
Ship - Export	79	82	85	85	118	127
Ship - Total	**220**	**244**	**252**	**242**	**285**	**297**
Rail - Import	87	81	66	61	59	64
Rail - Export	80	77	64	59	60	65
Rail - Total	**168**	**158**	**130**	**120**	**118**	**129**
Total Rail and Ship	**388**	**401**	**382**	**362**	**404**	**426**
Proportion Ship: Rail	1,3	1,5	1,9	2,0	2,4	2,3

Source: Requested from Port of Duisburg

In Table 5 we can see that the total amount of container flow by rail has remained relatively constant and decreased with ca. 30.000 TEU in the past years. While the total amount of flow by ship has increased consequently each year. Especially the fact that the total ship container flow has increased in 2018 compared to 2017 while 2018 faced low water levels is striking. For the entirety of the Netherlands a slight (5%) decrease in hinterland container transport by barge is observed in 2018 by Streng and van Saase (2020), followed by an increase of 5% in 2019, which is the opposite of Table 5. Perhaps by looking more specifically at the Port of Rotterdam, this can be explained by the fact that the amount of containers transport through the hinterland from the Port of Rotterdam remained stable in 2018, compared to 2017 (Table A3, Appendix A). Streng and van Saase (2020) also point out that trimodal terminals are better suited towards dealing with low water levels as all modes are available and bulk cargo such as ores or steel are more vulnerable to low water levels as they cannot easily be transferred between modes. Furthermore, the proportion between shipping and rail transported containers has increased steadily, and around twice as much containers are transported by ship, compared to rail. This corresponds to the earlier stated market shares, if rail would be 20% of total then ship would be around 40%. The remaining 40% for road transport would somewhat conflict with the fact that most road transport from the Port of Rotterdam is destined within the Netherlands, however it would confirm that the distance of 250km is quite a competitive distance for truck transportation as shown by Jonkeren (2017).

Cargo Flow Properties

From the expert interview with Port of Rotterdam it was assessed that most exported cargo from Duisburg to the Port of Rotterdam is high value machinery. On the other hand, low and medium value cargo is most likely to be transported to the Port of Rotterdam in containers, as these goods are less time-sensitive. Thus, in our simulation we will assume low, medium and high value cargo to be transported on the route.

Furthermore, with regards to the total amount of containers transported on the Rotterdam – Duisburg freight route, no exact total estimates could be retrieved. Van Vuure (2015) states that 800.000 TEU are transported on an annual basis. However the amount of containers handled by port of Duisburg has increased with 17% in 2015-2020 (Figure 6). With regards to the figures from the Port of Duisburg the combined amount for rail and ship is 430.000 (Table 5), if we assume road has a market share of 30-40%, the total would be a minimum of 620.000 TEU. Combining these two estimates we estimate the annual container flow between the Port of Rotterdam and the Port of Duisburg to be between 600.00 - 800.000 TEU per annum.

5.3 Simulation

Main Question: *How will the implementation of a carbon pricing affect the competitive position of transport by barge rail and road on the Rotterdam – Duisburg container route?*

In order to construct a realistic simulation for the Rotterdam-Duisburg container freight route, several parameters from the TLC-formula as explained in section 4.2 need to be calculated or estimated. An overview of these parameters can be seen in Table 6.

Table 6: Container Flow Parameters

Parameter / Value	Low	Middle	High
Annual volume of container per shipper *(R)*	4325	8650	12975
Value of goods per container (*v)*	5.000	50.000	250.000
Annual holding cost % of cargo value (*h)*	20	30	40
Safety factor *(K)*	85%	90%	95%

In order to account for the varying characteristics and logistical requirements of a shipper, for each parameter a low, medium and high value is estimated. Subsequently, each of these parameters can be combined with each other, for example a shipper with a medium annual volume, high value of goods, high holdings costs and low safety factor. Which yields 3^4= 81 different combinations, representing a market of 81 shippers with a unique set of requirements for their respective container flow. With regards to the annual volume (*R),* as previously stated in section 3.2, the annual flow of containers is estimated to be 600.000-800.000 TEU. With 81 shippers in this market and estimating the total annual TEU in the middle at 700.000, this would yield an average of roughly 8.650 TEU per shipper. 8.650 will thus be the middle value for 27 shippers, where the remainder of annual cargo is assumed to be normally distributed between 'low' and 'high' volume. This yields a total annual container volume of 700.650 TEU (Appendix B Table B1.1).

With regards to the estimated value of cargo per container (*v)* these are retrieved from a case study for hinterland transportation through from the Port of Antwerp to Germany (Blauwens et al., 2006). As the ports of Antwerp and Rotterdam are in a similar competitive range and both have direct intermodal routes towards Duisburg the value segments are assumed to be representative for this case study as well.

Furthermore, the annual holding costs (*h*) are a percentage of the value of goods and account for interest, depreciation, insurance and warehousing costs during the time that goods are in transit (Blauwens et al., 2006). Robert, Larry and Patterson (2009) show that the holding costs can globally vary from 9-50% of goods value while a range of 15-25% is common in most industries. However, as we are examining containerized transport which is characterized by relatively long lead times, the higher estimates in the available range will be considered. Leading to a low, medium and high value of 20, 30 and 40%, respectively (Tran & Lam, 2021; Blauwens et al., 2006).

Lastly, the safety factor (*K*) can be interpreted as the required service level. Halim, Kwakkel and Tavasszy (2016) illustrate that these can vary from 80 to 95% for intermodal hinterland transportation within 250km of European ports. A service level of 95% implies an expected probability of not running out of stock during the lead time, thus not losing any sales (Meers et al., 2017). In Table 7 the estimated parameters for each transport mode can be seen and will be explained.

Table 7: Transport Mode Parameters

Mode / Parameter	Transport Cost *(TC)* + Inland Terminal Handling Fee	Lead Transport Time in Hours *(L)*	Variance of lead transport time in days *(l)*	Terminal Handling + Last Mile Delivery in Hours	CO_2 WTW Emissions/g/tonkm (*E)*
Road	233,8	5,2	0,022	0	120,9
Barge + Road	133,8 + 35	32,6	0,136	16 + 0,5	42,0
Rail + Road	218,8 + 35	6,3	0,026	16 + 0,5	13,0

Utilizing the transportation cost index figures of KiM (2020) the transport costs are calculated with the following formula:

$$(3)\ TC = \frac{Cost\ per\ tonkm * average\ tonnage * amount\ of\ km}{\text{Number of TEU per mode}}$$

Furthermore, for transportation by rail and barge a 35 EUR handling fee is charged (ECT, 2022) at the inland terminal and costs of last mile delivery by road for intermodal transport are incorporated into the transport costs by using the previously mentioned KiM cost index figures. The lead transport times are retrieved from all available direct route operators in Navigate (2021) and can be seen in Table B2 (Appendix B). The variance of the lead time is estimated to be 10%. It is stated by ECT (2022) that the handling time for an intermodal transport container to be available to be trucked to the customer warehouse can be around 24 hours as the container needs to be retrieved from train/barge, stacked and corresponding truck needs to arrive. As this is a competitive case study we will take a optimistic estimate of 16 hours. The delivery time for the 30km trip to the customer warehouse from the inland terminal is estimated at 30 minutes, driving an average speed of 90 km/h and a 50% tolerance for last mile urban congestion. Lastly, emission estimates for current and future transportation methods are retrieved from CE Delft (2021b) which are published annually.

In the baseline scenario, the transport parameters of each mode, as described in Table 7, the total cost, emission, loading capacity and lead time (Appendix B, Table B2) are fixed. In order to gain an understanding of what drives the interaction between ETS-pricing and mode parameters some of these parameters will be varied, which will be explained accordingly.

To summarize, there are 81 different container flows that each represent a shipper with an unique combination of logistical demands/characteristics in this hypothesized container market. For the first baseline scenario without carbon pricing, formula (1) in Section 4.2 is applied to each of the 81 cases, yielding the total container flow to the transport mode with the lowest costs.

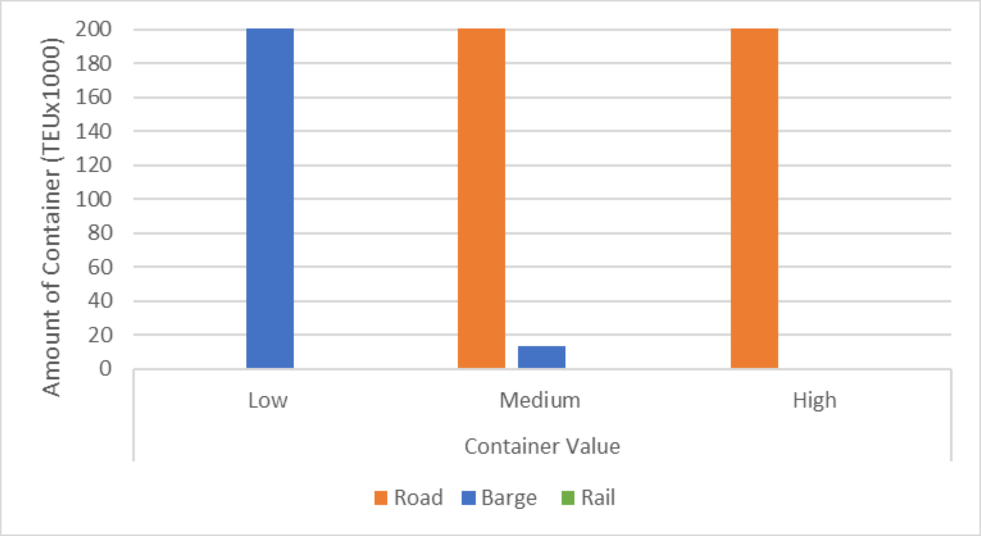

Figure 8: Overview of amount of container per mode in Baseline scenario

In Figure 8 the market shares of each mode can be seen for the baseline scenario. All containers with a low value are transported by barge. This can be explained intuitively as inventory costs are lower for goods with low value. As the value rises, inventory costs become the major component of total costs, which drives a preference towards road as the mode with the shortest lead time giving the lowest overall inventory costs. Subsequently, for high value cargo it can be seen that road dominates. For the medium value segment, only the shippers with the lowest holding cost are assigned to barge, while the rest of the cargo is allocated to road transport. As transport per rail is in the middle of barge and road in terms of lead time and transport costs it is seen as suboptimal. Apparently, the factors in which a stable market share for rail in this distance market of 250km occurs are not decisive in the TLC-model. Also, the environmental benefits of transport by rail are not yet priced in the model. Rail will not be included in the carbon pricing as it only consumes electricity and emits the least emissions and is thus unlikely to be subjected to an ETS pricing scheme (EU Commission, 2021). In Table 8 a price sensitivity analysis can be seen for implementing a carbon price for transport by road and barge on the baseline scenario of Figure 8.

Table 8: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for baseline emission levels per mode.

	Mode			
Emission Price (EUR/Ton CO_2)	**Road**	**Barge**	**Rail**	**Total Emission (Tons CO_2)**
0	65%	35%	0%	15.285
20	59%	41%	0%	14.595
40 - 80	56%	44%	0%	14.135
100	54%	46%	0%	13.982
150	46%	54%	0%	12.986
250	34%	47%	19%	10.113
300	35%	46%	19%	10.137
400	24%	37%	39%	7.334
500	23%	36%	41%	7.130

The price sensitivity analysis is performed in the following manner. For each of the 81 shipping flows, the respective emissions per mode were calculated, multiplied by the emission price and added to the total costs per mode. Subsequently, emission prices were increased with increments of 10, showing the major changes to a maximum level of 500. Finally, the market share is determined by the total amount of containers transported by a mode. Looking at Table 8, an emission price of 40-80 would result in a reduction of total CO_2 emissions with 7.5%. To put this into context, Germany has recently opted for a minimum carbon price level of 60 EUR/ton making a price range of 40-80 feasible (Reuters, 2021). A substantial reduction of more than 10% seems to start at a quite high price level of 150.

However, the level of 150 is not as extreme when taking recent EU-Carbon price developments into account where maximum price of 97 was reached in February 2022. Currently, in April 2022 the carbon price resides around 80 EUR/Ton CO_2. Before exploring the interaction between mode emission levels and ETS-pricing, the role of lead time will be addressed. As discussed below Figure 8, inventory costs are a large component of total cost, as the value of goods increases. In Table 7 it can be seen that the lead time of transport by barge is substantially higher compared to other modes. As discussed in section 1.2.2, the increased barge congestion in port terminals affects the competitive position of barge transportation negatively. This leads to think how an increase of barge efficiency, by decreasing the lead time to the minimum observed value of 12 hours (Table B2, Appendix B), affects the competitive position of barge in this simulation. In Table 9 the results can be seen if a ‘high speed’ form of barge transportation is introduced to the baseline scenario, which substantially improves the competitive position. Barge gains a majority in the medium value cargo segment (Figure C1, Appendix C). The carbon price needs to be increased to extreme levels to shift the high value cargo segment away from road transportation, which is achieved at a carbon price level of 400 EUR/ton and higher (Figure C2, Appendix C). Lastly, it is interesting to note that the shift to rail is less substantial at these levels compared to Table 8.

Table 9: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for baseline emission levels per mode and a high speed 12-hour barge transportation.

	Emission Price (EUR/Ton CO_2)	0	20	40-250	300	400	500
Market Share	**Road**	42%	36%	33%	33%	22%	22%
	Barge	58%	64%	67%	67%	76%	69%
	Rail	0%	0%	0%	0%	2%	10%
	Total Emissions (Tons CO_2)	12.450	11.683	11.377	11.300	9.849	9.214

As the weakest aspect for barge transportation is its lead time, the weakest aspect of transportation by road in this simulation are the high environmental emissions compared to rail and barge (Table 7). This leads to think as 400km BET-vehicles are becoming feasible (See Table 3). How would the sensitivity analysis (compared to baseline level) be impacted if fully electric trucks are introduced?

Table 10: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for baseline emission levels per mode and a full-electric truck transportation

	Emission Price (EUR/Ton CO_2)	0	10-30	40-70	80-500
Market Share	**Road**	65%	65%	66%	67%
	Barge*	35%	35%	34%	33%
	Rail	0%	0%	0%	0%
	Total Emissions (Tons CO_2)	5.222	5.203	5.184	5.164

*Barge leadtime is reset to the original value of Table 7

In Table 10, it can be seen that a full-electrification of trucks would lead to a very dominant position of road transport and as total emissions are on a relatively low level, the introduction of an emission price does not lead to much improvement. For all prices above 80 EUR//Ton CO_2 the market shares become stagnant, where barge remains dominant in the low value segment, but all other segments are dominated by road (Figure C3, Appendix C). The market share of rail does not become relevant as road in this scenario emits less than barge transport, and road, due to lowest lead time is in general the cheapest form of transportation. The effect of high emission pricing does not outweigh the inherent cost difference between road and train due to longer lead time of rail. In previous scenarios the emissions of road are almost 5 times higher, increasing the effect of emission prices on market shares.

However, the full introduction of only BET-Trucks in 2030 is not a very realistic scenario, as discussed in section 5.1.1. A partial implementation of biofuels and electrified transport is a more likely scenario for 2030. In this section the effect of adaptation of various new fuel technologies on the carbon pricing sensitivity analysis will be assessed. For a ‘medium’ technology adaptation scenario an adaptation level for barge will be based on 15% biofuel blend and 20% electrification. For road a blend-in of 30% biofuels and 40% electrification is assumed in 2030. Biofuel blend of 15% is chosen for barge as this will reach incremental climate goals of 2030 and 20% for electrification as the container transport segment appears to be suitable for electrification. Moreover, the long lifespans of vessels needs to be taken into consideration, resulting in the remaining 65% of barge vessels to run on diesel engines. For trucks, the biofuel blend-in is limited to 30% as the overall availability needs to be increased considerably and will be competing with aviation and maritime shipping. Furthermore, 40% electrification is assumed as 400km trucks are likely to become competitive on TCO-level (See Table 3) in 2030 and could be implemented on this relatively short distance route of 250km from Rotterdam-Duisburg. An elaboration and calculation for emission of each mode low, medium or high technology adaptation level can be found in Table B4, Appendix B. Introducing the abovementioned fuel technologies in their respective shares, referred to as ‘Medium Technology Adaptation’, into the emission calculation per mode leads to a general reduction of road-emissions with 57% and for barge with 27%. The result of combining these new emissions levels with an ETS-pricing can be seen in Table 11.

Table 11: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for ‘Medium Technology Adaptation in 2030’ emission levels per mode.

	Mode			
Emission Price (EUR/Ton CO_2)	**Road**	**Barge**	**Rail**	**Total Emission (Tons CO_2)**
0	65%	35%	0%	7.317
20	64%	36%	0%	7.277
40	62%	38%	0%	7.238
60	59%	41%	0%	7.141
80 - 100	57%	43%	0%	7.082
150 - 300	56%	44%	0%	7.024
400	45%	45%	9%	6.200
500	35%	44%	21%	5.236

In Table 11 it can be seen that the new emission levels result in a strong competitive position for road transportation. Barge transportation does remain dominant with regards to low value cargo (Figure C4, Appendix C). Road market share only loses its majority at very high price levels of 400 and higher. Comparing the total emissions to the baseline scenario of Table 8, we start at a lower total level of emissions and the incremental gains only become substantial at a high level pricing of 300-500. In the baseline scenario a total emission reduction of larger than 10% was already reached at price levels of 150. This suggests that when emission rates per mode are at a higher level, such as in the baseline scenario, the gains in terms of emission reduction can be achieved at lower price levels.

Chapter 6: Conclusion & Discussion

Conclusion

The main research question as stated in the beginning of this paper was the following:

How will the implementation of an Emission Trading System affect the modal split on the Rotterdam – Duisburg freight route?

In order to answer this, several sub-questions have been formulated in the research design. Firstly, a theoretic framework was established and explored previous research with regards to decision makers in hinterland transportation; policy development on European and Dutch level and possible pathways and available policy measures to promote sustainable transport policy. In order to further assess the effect of an implementation of ETS on the Rotterdam-Duisburg freight route, the current freight conditions and possible pathways towards a reduction of emission for each transport mode had to be mapped out. This led to the first two questions of the research design which will be answered and compared with literature results.

> *How much CO_2 emissions does each transport mode emit currently and how will this develop towards 2030?*

Looking at the possible development paths towards decarbonization of the current diesel-intensive transport modes, which are truck and barge, several insights have been found. While the long term solution for both modes seems to be in electrification and hydrogen, the intermediate pathways differ. For transport by barge it was found that a partial blending of biofuels up to 30% in the current fuel mix is feasible and will not strain the total supply of biofuel. This is in contrast to the work of Brynolf et al. (2018) who raises availability of biofuel as a major concern. For transport by road this availability, due to requiring a larger blend-in and higher annual total usage, continues to be a concern. Also, with regards to the adaptation of electrification this only seems economically feasible for specific waterway segments such as containerized transport which is in agreeance with the work of Van Biert et al. (2016) and Boffey (2018). Whereas for road transport a higher adaptation rate of electrification is expected as all transport with BET-vehicles within a 400km range is expected to be competitive with ICE-vehicles in 2030. The concern of Bynum et al. (2018) towards the high investments necessary for renewable truck engines are validated, but from a TCO-perspective appear to be offset by lower operational costs due to less maintenance and lower fuel costs (TRAN, 2021).

> *How has the modal split of Duisburg developed itself from 2006-2019?*

Looking at the past development both in terms of million tons and TEU, it can be observed that the share of rail transportation has remained relatively stable, while the amount of containers transported per barge has increased in the past decade (Port of Duisburg, 2022). The stable share of rail and increase of inland waterway transportation are in agreeance with the findings of Jonkeren (2020) for the hinterland of the

Port of Rotterdam. Moreover, looking at the modal split during low water levels the results are ambiguous. On the one hand, in 2011 a decrease in waterway transportation and increase in container transport by road can be observed, indicating the potential of modal shifting. While on the other hand in 2018, with very low water levels, the amount of containers between Rotterdam and Duisburg by ship even increased. This could be explained by the fact that the amount of containers transport through the hinterland from the Port of Rotterdam remained stable in 2018, compared to 2017 (Port of Rotterdam, 2020). Or, as Streng and Van Saase (2020) point out, that trimodal terminals such as Duisburg have an advantage in times of low water compared to inland terminals with less available modes.

> *How will the implementation of a carbon pricing affect the competitive position of transport by barge rail and road on the Rotterdam – Duisburg container route?*

The sooner an ETS carbon pricing mechanism is implemented, the larger the effect with relatively low prices of 60-80 EUR/Ton CO_2 will be, as the incentivization towards less emissions is stronger for transport parties. As modes decarbonize, price levels have to increase to keep the same level of incentive. Extreme high price levels would lead to a shift to rail as it is still the most environmentally friendly form. As we have seen for a medium level of adaptation of new fuel technologies, the effect of carbon pricing especially affects the competitive position of road. While road is able to decarbonize faster, the emissions of barge transportation start at an initial lower level. Thus, in absolute terms, transportation by barge still has lower level of emissions compared to road. The fact that a sufficient price level starts at 60-80 EUR/Ton CO_2, which is historically seen as relatively high, is in line with the work of Heinrichs, Jochen and Fichtner (2014) and Zhang et al. (2014). While in the 2030 scenario, with relatively lower emissions per mode, the extreme price ranges of more than 400 EUR/Ton CO_2 necessary are more in accordance with the work of CE Delft (2021) who also estimated ranges of 220-690 EUR to be effective.

Policy Recommendations

In line with the recommendation of TNO (2020) policy makers should reconsider investments in intermodal infrastructure to facilitate the modal shift towards rail and barge. The faster technical innovation of road due to a lower economic average lifespan of trucks, and relatively slower innovation of barge due to ownership structure and long lifespan of vessels is inherent to both modes. By pricing emissions, this incentive for road transportation to innovate and decarbonize will be further facilitated. Reducing the need for a modal shift. With regards to rail transport, pointed out during the interview with the industry expert of the Port of Rotterdam, infrastructure of rail is a long term process often involving multiple countries and permit grants on different bureaucratic levels (Gharehgozli et al., 2019). This will continue to be the main hurdle for an elaborate roll-out, also taking into account the stagnant modal share for rail in Europe and even a reverse modal shift in eastern European countries from rail to road. The question arises if rail transport is truly competing with the other modes or that there is a dedicated, stagnant, demand. As the share has remained constant despite past policy measures (Eurostat, 2022; Kaack et al, 2018).

In general, a focus on data sharing and standardization of infrastructure between transport modes, as was available through the Navigate Tool of the Port of Rotterdam (2020), can also be recommended to policy makers, enabling synchromodal choice systems that allow to optimize by taking strictly the emissions and logistical requirements into account without being affected by status-quo biases.

Limitations

With regards to the simulation of the market shares for the Port of Duisburg, several limitations need to be mentioned. The TLC-Model used in the simulation assumes the availability of unlimited infrastructure per transport mode. While Duisburg is the largest trimodal inland terminal in Europe and thus expected to have substantial capacity. Also, the amount of TEU in the simulation did not exceed the estimated total annual TEU handled by the Port of Duisburg. The scenario where 41% of containers is transported by rail would clearly lead to capacity bottlenecks in the supply chain. Furthermore, the model aims to not just take the ‘out of pocket’ costs for the shipper but also factors such as lead time, inventory costs and reliability of a certain mode into account. Nevertheless, in the baseline scenario without emission pricing, rail has a market share of 0% which is not in line with actual figures provided by the Port of Duisburg (2022). Clearly, more factors need to be taken into account, such as specific cargo types or intermarket relationships, in order to simulate a more realistic shipping market.

Moreover, with regards to the adaptation of emission pricing in the market, the effect of carbon pricing on total costs is assumed to be fully absorbed and completely transparent by/for the shipper. While this could be the case, the increasing vertical integration and market power of container carriers as pointed out by Notteboom, Pallis and Rodrigue (2021) may also lead to the forwarder absorbing some of the carbon pricing in order to remain competitive.

Lastly, while the current situation of the modal split on the Rotterdam- Duisburg freight route has been approximated through interviews and import/export figures provided by the Port of Duisburg itself, no exact data with regards to the amount of containers transported by road could be retrieved, clouding the specific competitive position of truck container transport compared to other modes.

Suggestions for further research

Multiple suggestions for further research have been distinguished. For the long term, both electric batteries and hydrogen fuel cells are mentioned as promising candidates to decarbonize both inland shipping and road transportation (TRAN, 2021; Panteia, 2019) Further research needs to look into the barriers towards developing this infrastructure on both economic and organizational level so that these sustainable fuel methods can develop as rapidly as possible. Assuming the power grid and power generation are sufficient, there is a potential of significantly decreasing the WTW-emissions of each mode (Topsector Logistiek, 2018; Meers et al. 2018).

Notteboom (2009) stipulates that the decision maker with regards to modal choice in hinterland is in majority the forwarder but an increased demand from shippers to decarbonize might create a ‘pull’ instead of ‘push’ for the selection of most sustainable transport modes. Qualitative research into which shippers and markets are likely to create this push could shape policy to aim at markets where the introduction of sustainable transport modes might need additional policy support.

Lastly, an important aspect of implementing carbon pricing is the increase of total system costs (De Vries, 2019). The consequences of this for consumer prices or a decrease of transportation demand need to be monitored closely (Beuthe et al., 2013).

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Appendix A

Table A1: Percentage of Inland Waterway Transport 2005-2019*

Country	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Belgium	13,5	13,6	13,4	13,5	12,2	14,6	14,8	16,4	15,9	15,9	15,2	14,7	15,7	12,5	11,4
Bulgaria	30,0	29,2	30,8	33,2	31,4	33,6	24,9	30,5	27,5	26,9	27,4	27,3	24,8	24,5	31,8
Germany	12,1	11,3	10,9	10,7	10,4	10,8	9,4	10,1	10,2	9,9	9,1	8,7	8,7	7,5	8,0
France	2,6	2,5	2,5	2,5	2,9	3,0	2,9	3,0	3,0	2,9	2,9	2,8	2,4	2,3	2,4
Croatia	5,1	5,0	5,6	5,7	6,1	8,2	6,4	7,3	7,3	6,9	7,8	7,4	6,3	5,2	6,5
Luxembourg	13,1	14,0	11,8	13,1	11,4	12,9	11,1	8,9	10,5	8,4	8,0	6,2	6,2	7,5	8,2
Hungary	6,3	5,3	5,8	5,7	5,8	7,4	5,7	6,4	6,1	5,5	5,4	5,4	4,8	4,1	5,2
Netherlands	43,2	42,9	44,8	44,2	41,0	45,8	45,6	47,2	46,0	46,1	45,4	44,3	44,7	43,2	42,7
Austria	3,3	3,2	4,2	3,6	3,6	4,0	3,4	3,7	3,9	3,5	2,8	3,0	2,9	2,1	2,4
Romania	23,2	23,4	25,2	25,8	24,5	33,8	27,4	29,2	29,0	29,0	30,4	29,4	27,4	27,1	28,1
Slovakia	4,2	4,0	4,4	4,8	4,6	5,6	4,5	4,7	4,6	4,0	3,2	3,7	3,6	3,0	3,6
Finland	0,2	0,2	0,3	0,2	0,2	0,2	0,3	0,4	0,4	0,4	0,4	0,3	0,3	0,4	0,3
EU-27	7,1	6,9	7,0	7,0	6,7	7,4	6,8	7,4	7,4	7,3	7,0	6,7	6,5	5,9	6,1

Source: (Eurostat, 2022)

* Excluded countries with a <0,1 percentage

Table A2: Overview of largest inland ports Europe

	2020
Inland Port	**Transported via barge (Million tons)**
Duisburg	42,4
Keulen	9,1
Mannheim	6,9
Straatsburg	6,8
Neuss	6,5
Karlsruhe	6,2
Ludwigshafen	6,8
Bazel	5,1
Mullhouse	4,2
Kehl	4,4
Mainz	3,6
Krefeld	3
Wesseling	2,5
Total	107,5

Source: (CCNR, 2021)

Table A3: Overview of containers handled in Port of Rotterdam and Hinterland 2007-2019 (TEU x 1000)

	Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
	Total Transshipment	10791	10784	9743	11148	11877	11866	11622	12305	12335	12385	13734	14513	14811
From Port of Rotterdam to Hinterland	**Road**	4749	4476	3653	4030	3951	3998	4039	4262	4605	4699	5085	5368	5279
	Barge	2445	2337	2218	2361	2393	2613	2572	2846	2933	2769	3034	3067	3109
	Rail	905	1010	744	759	818	794	790	870	889	844	939	961	1021
	Total Hinterland	8099	7823	6615	7150	7162	7405	7401	7978	8427	8312	9058	9396	9409
Hinterland Market shares %	Road	59%	57%	55%	56%	55%	54%	55%	53%	55%	57%	56%	57%	56%
	Barge	30%	30%	34%	33%	33%	35%	35%	36%	35%	33%	33%	33%	33%
	Rail	11%	13%	11%	11%	11%	11%	11%	11%	11%	10%	10%	10%	11%

Source: (Port of Rotterdam, 2020)

Appendix B

Table B1: Overview of operators on the Rotterdam – Duisburg Freight Route

Operator	**Frequency (weekly)**		**Transportation Mode**
	Rotterdam – Duisburg	Duisburg - Rotterdam	
Haeger & Schmidt Logistics	29	24	Inland Shipping
Contargo	21	26	Inland Shipping
Neska-Intermodal	15	14	Inland Shipping
European Gateway Services	13	13	Inland Shipping
Contargo	30	30	Rail
Distri Rail	24	25	Rail
Neska-Intermodal	20	22	Rail
Kombiverkehr	9	9	Rail
Haeger & Schmidt Logistics	8	7	Rail
HUPAC	6	6	Rail
European Gateway Services	6	7	Rail

Source: (Ecorys Intermodal Links, 2022)

Table B1.1: Overview of container volumes per segment*

Volume Segment Annual TEU	**Amount of Shippers**	**Volume * Shippers**	**Share of Annual Volume**
Low (4.325)	27	27*4325 = 116.775	16,6%
Medium (8.650)	27	27*8650 = 233.550	33,3%
High (12.975)	27	27*12975 = 350.325	50%
	Total TEU	700. 650	

***** The annual volume is assumed to be the average for the specific low/med/high segment, the extent to which this varies within the segment is not taken into account.

Table B2: Overview of lead times per transport mode Rotterdam – Duisburg*

Mode	**Operator**	**Lead Time (hours)**	**Transfers**
Road**	-	5,2	
Rail	IGSNL	7	0
	European Gateway Services	6	0
	Haeger & Schmidt	6	0
Barge ***	HTS Group	12	0
	Haeger & Schmidt	30	0
	Contargo	28	0

	European Gateway Services	40	0
	BCTN + Samskip	34	1
	Contargo	55	1

Source: Navigate (2020)

*Estimated on 25th April 2022

** Road distance is estimated by Google Maps at 243km, assuming a travel speed of 90 km/h gives 2,7 hours, controlling for 1 hour congestion and 1,5 hour waiting time at seaside terminal.

*** When determining average lead time for barge, the lead time of HTS Group is excluded as it is an extreme value, more than 3 times as small as other observations and therefore deemed unfeasible.

Table B3: Overview of Emissions per modal type in 2030

Mode	**Fuel**	**WTW emissions**
Road	40% Electrified/ 30% Biofuel / 30% Diesel	Electricity: 120,9 *0,7*0,5*0,40= Biofuel: 120,9*0,15* 0,30= Diesel: 120,9*0,30= **Weighted Total:** 58,6g /tonkm
Barge	20% Electrified / 15% Biofuel / 65% Diesel	Diesel: 42 *1,04*0,65 = Electrified: 42*0,10*0,20= Biofuel: 42*0,1*0,15= **Weighted Total:** 29,7g/ tonkm
Rail	Electricity	18*0,3 = 5,4 g/tonkm

Source: CE Delft (2021b)

Table B4: Overview of various adaptation levels of different fuel technologies for transportation by road and barge in 2030.

			Technology Adaptation Level		
Emission / gCO₂ per tonkm		**Fuel Vehicle/Vessel Technology**	**Low** (Road / Barge)	**Medium** (Road / Barge)	**High** (Road / Barge)
Road	**Barge**				
25,4	12,6	**Electrified***	35% / 25%	40% / 20%	45% / 25%
18,1	4,2	**Biofuel**	25% / 10%	30% / 15%	35% / 20%
120,9	42,0	**Diesel (Baseline scenario)**	40% / 75%	30% / 65%	20% / 55%

*Emission of electrified transport is assumed to be at 2030 energy production levels, which are estimated to generate 70% more renewable energy compared to 2019 levels (PBL, 2020). At 100% renewable energy production electrified transport would emit less than biofuel-based transport.

Table B5: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for 'Low Technology Adaptation in 2030' emission levels per mode.

	Mode			
Emission Price (EUR/Ton CO_2)	Road	Barge	Rail	Total Emission (Tons CO_2)
0	65%	35%	0%	8564,22
20	62%	38%	0%	8460,488
40	60%	40%	0%	8382,69
60	57%	43%	0%	8253,026
80	57%	43%	0%	8253,026
100	56%	44%	0%	8175,228
150	56%	44%	0%	8175,228
250	55%	45%	0%	8149,295
300	54%	46%	0%	8097,429
400	35%	46%	19%	6168,072
500	35%	36%	29%	5607,738

Table B6: Sensitivity analysis of the effect of emission pricing on modal market share, measured in TEU for 'High Technology Adaptation in 2030' emission levels per mode.

	Mode			
Emission Price (EUR/Ton CO_2)	**Road**	**Barge**	**Rail**	**Total Emission (Ton CO_2)**
0	65%	35%	0%	6070
20	64%	36%	0%	6044
40	62%	38%	0%	6018
60	62%	38%	0%	6018
80	59%	41%	0%	5952
100	59%	41%	0%	5952
150	57%	43%	0%	5913
250	56%	44%	0%	5874
300	56%	44%	0%	5874
400	56%	44%	0%	5874
500	45%	45%	9%	5211

Appendix C

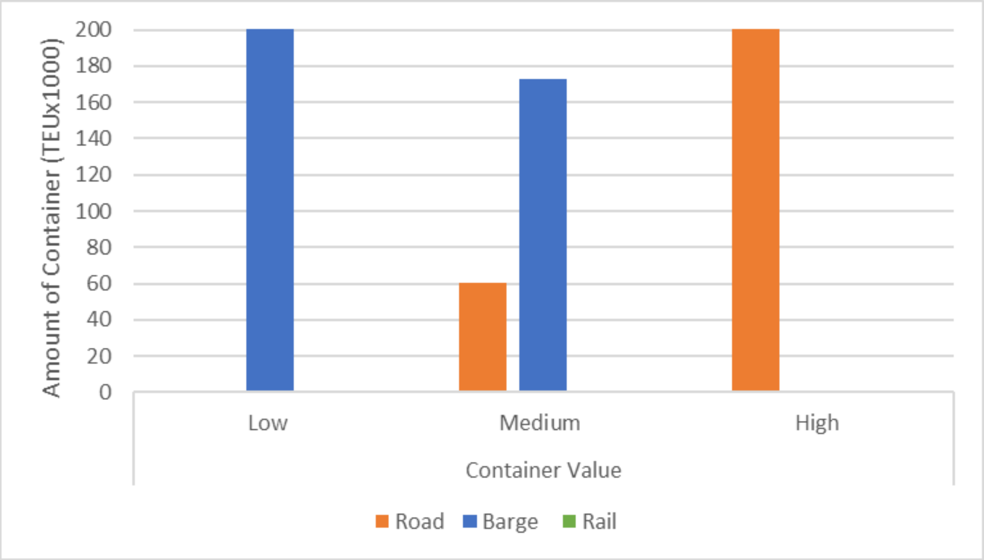

Figure C1: Overview of market shares per container cargo value segment at Emission price of 0 EUR/ Tons for the high-speed barge simulation.

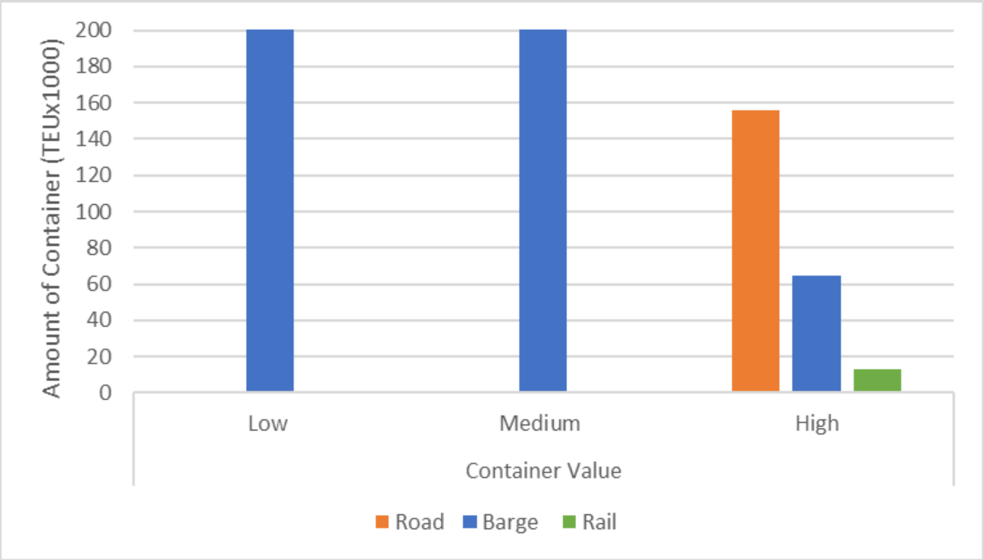

Figure C2: Overview of market shares per container cargo value segment at Emission price of 400 EUR/ Tons for the high-speed barge simulation.

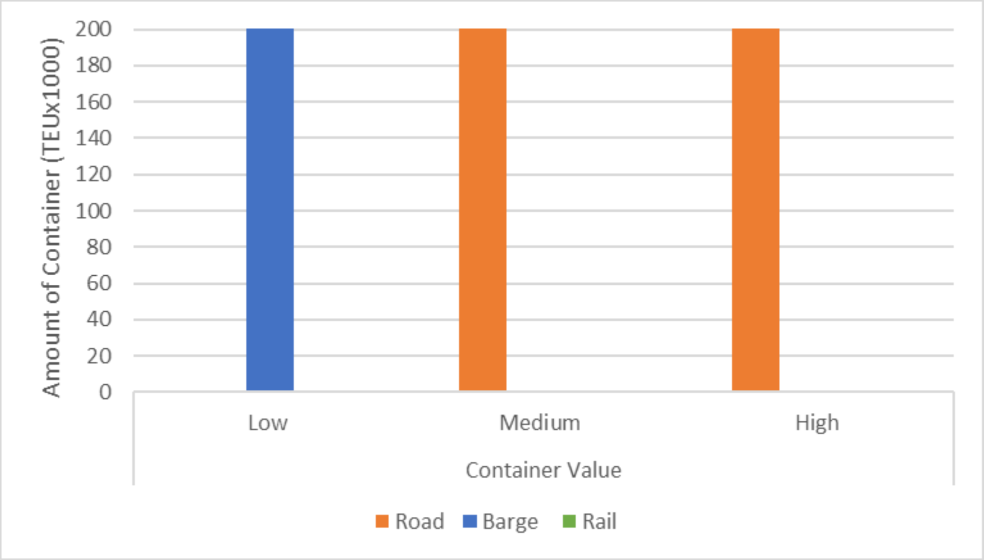

Figure C3: Overview of market shares per container cargo value segment at Emission price of 80 EUR/ Tons for the full-electric truck simulation.

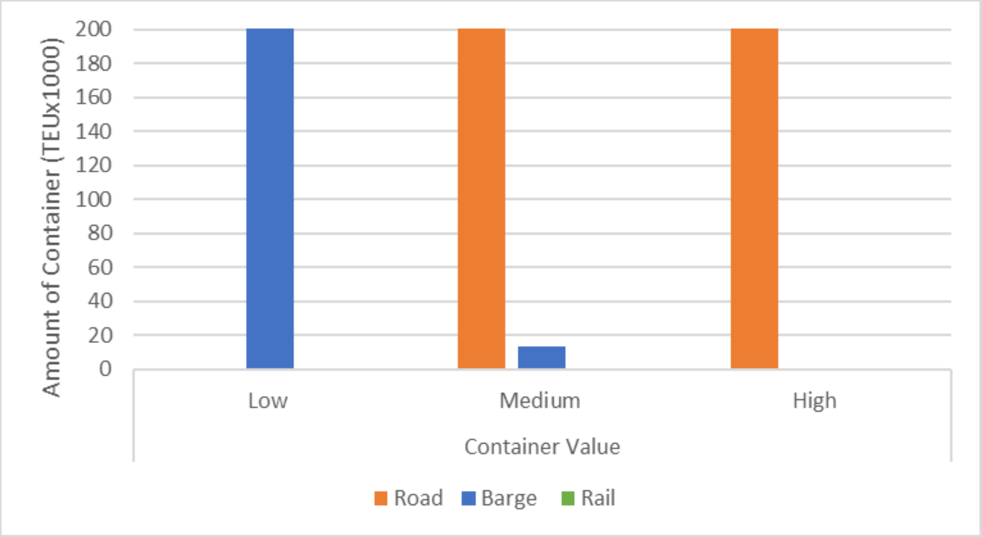

Figure C4: Overview of market shares per container cargo value segment at Emission price of 0 EUR/ Tons for the Medium Technology Adaptation simulation.