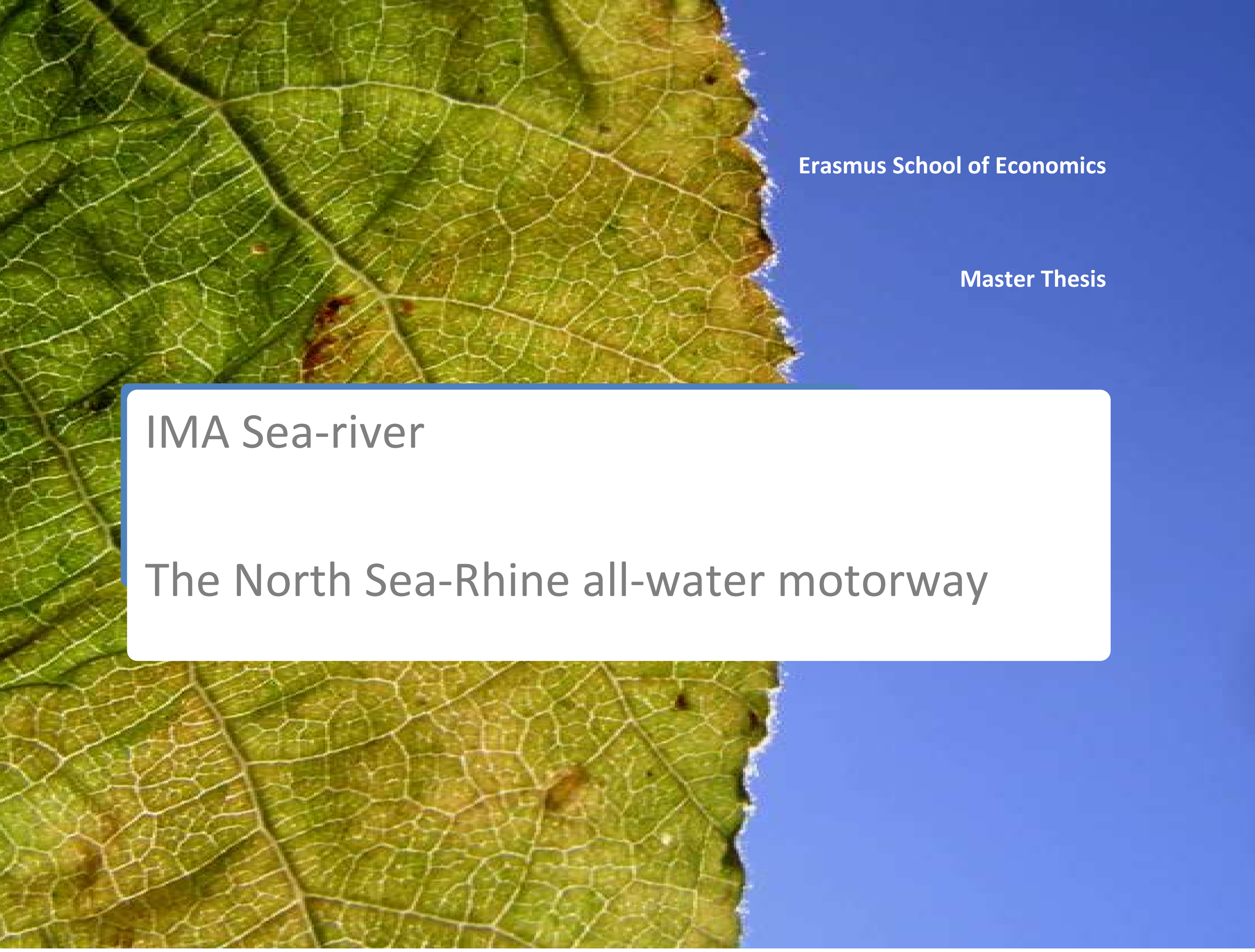


Erasmus School of Economics

Master Thesis

IMA Sea-river

The North Sea-Rhine all-water motorway

The impact of a Sea-river RoCon innovation on the carbon footprint of the Germany-United Kingdom transport corridor.

Gerrit-Jan Fidder

February 2012

Erasmus School of Economics

IMA Sea-river, The North Sea-Rhine all-water motorway

The impact of a Sea-river RoCon innovation on the carbon footprint of the Germany-United Kingdom transport corridor.

Utrecht, February 2012

Thesis in favor of: Independent Maritime Adviser (IMA) Sea-river project team

Willem Dirkzwager, Jos Helmer & Gordon Braun

Thesis written by: Erasmus School of Economics,

Economics & Business: Master Urban,- Port,- and Transport Economics

Gerrit-Jan Fidder, exam number: 323525

Thesis supervised by: Erasmus University Rotterdam, Urban,- Port,- and Transport Economics

Dr. Bart Kuipers

Second reader: Erasmus University Rotterdam, Urban,- Port,- and Transport Economics

Dr. Michiel Nijdam

Table of content

Foreword

This master thesis forms the completion of the master Urban-, Port-, and Transport economics and would not have succeeded without the help of a number of people.

In the first place my supervisor Bart Kuipers is to be thanked for his coordination between the Erasmus University and the IMA Sea-river project team. Also his advice about the research approach and his guidance in the academic part of the project was very helpful.

Secondly I would very much like to thank the Independent Maritime Adviser, in the persons of Willem Dirkzwager, Gordon Braun and Jos Helmer. Their time, effort, contacts and knowledge were indispensible while working on the project. Thanks to their help and information the thesis could become what it is now. It was great to be working on a real project and to hopefully contribute to the success of it. I want to thank them for providing this research project.

Peter Blanken, project engineer at Damen Shipbuilders deserves thanks for his help in determining the emission figures from the Sea-river RoCon ships. At last I want to thank Eelco den Boer from CE Delft, author of STREAM, for providing necessary information concerning emissions from transport through e-mail contact and for his feedback on the concept version of this report.

My family and friends not to forget, their patience and care were indispensible during the process!

Gerrit-Jan Fidder

Utrecht, February, 2012.

Summary

The densely populated area around the port region of Rotterdam in the Netherlands and the western industrial estates of Germany have to deal with large volumes of trade and transport due to the large hinterland areas of the coastal ports and intensive industrial activity. Also large freight volumes are transported between these regions and the industrial regions of the United Kingdom. Problems on this busy trading corridor arise as a result of negative externalities from transport activities in combination with the high degree of urbanization. Especially transport by truck over the crowded road network causes congestion, air pollution, noise nuisance, delays and extra costs in transport chains due to downtime and uncertainty over travel times.

One possible solution for this problem could be the combination of inland and short-sea shipping: sea-river shipping. The effect could be considerable and these type of ships should be able to get a considerable amount of cargo from the road. Thereby potentially making a significant contribution to the reduction of the carbon footprint of the transported goods. In this research this supposed effect is further examined using a concrete innovation from Independent Maritime Adviser Rotterdam. The Sea-river RoCon project team from this company proposes the financing, building and operating of four Sea-river Container Ro-Ro vessels that will provide daily short-sea services for containers and unaccompanied trailers between the German inland port of Neuss, in the Ruhr area, and the United Kingdom (UK) port of Immingham.

It was found that transport has a large share in the greenhouse story, through emissions and other negative externalities that result from it. We have seen that the emission of CO2 defines the so-called carbon footprint and that in order to deal with climate change the way we transport goods and people needs to be changed or adapted. European policymakers pointed out that maritime transport was to be the solution for the transport problems relating to congestion and environmental impacts.

The first important result from literature regarding sea-river shipping is the advantage it has over traditional inland and sea shipping due to the fact that the transshipment of cargo in a seaport can be avoided. Also the positive influence of this kind of transport on road- and rail congestion was mentioned in the majority of researches. It was found that multimodal transport could be able to lower the amount of CO2 emissions on the Quebec City-Windsor corridor in Canada, a result that provides a good starting point for the research performed on the Sea-river RoCon innovation.

To calculate the effect of this modern Sea-river RoCon innovation on the carbon footprint of transport on the Germany-UK corridor, the main question in this research is:

To what extent does a modern Sea-river RoCon innovation reduce the carbon footprint of container and ro-ro transport on the Germany-UK corridor?

To transport cargo from Neuss to Manchester a number of modalities can be used. The possible selection of modalities has determined six scenarios, which present the most common possibilities for unitized transport on this corridor and specific route. Each of these scenarios involves another modal split and provides a different view on the influence of modality choice on the carbon footprint of the transport chain. Two of the six scenarios involve the Sea-river RoCon innovation, whereas the other four scenarios feature ‘traditional’ modalities. To quantify the results, emissions were calculated during every step of each scenario, including transshipment operations.

To measure the effect of the Sea-river RoCon project, three types of emissions are taken into account in this thesis; CO2, NOx and PM10. That means that this study is elaborating the emission of 1) a Greenhouse Gas(GHG), 2) an emission influencing the forming of smog, and 3) an emission that negatively affects human health.

Main results.

CO2 emissions are the lowest when transporting a container (FEU) between Neuss and Manchester in scenarios in which the electric train plays a relatively large role. Scenario 4 is the best example, generating a total CO2 emission of 465 kilograms. The highest CO2 emission results from scenario 1, in which the truck plays a dominant role, generating a total CO2 emission of 1122 kilograms. Scenario 5, in which the Sea-river RoCon ship is used in combination with a truck generates a total of 1030 kilograms of CO2. Scenario 6, in which the Sea-river ship is used in combination with a train, generates a total CO2 emission of 833 kilograms.

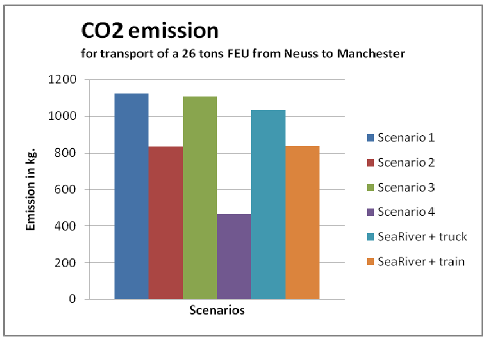


Figure 1, CO2 emissions
Source: author calculations.

NOx emissions are the lowest in scenarios in which a train is used. This is best visible in scenario 4, in which the container is transported almost entirely by train. In this scenario the total NOx emissions are limited to only 2.6 kilograms. In scenario 3, in which a barge and truck are used, the total figure adds up to 16.5 kilograms. Scenario 5, which includes the Sea-river RoCon ship generates a total NOx emission of 11.3 kilograms, Scenario 6, in which the Sea-river RoCon ship is combined with a train, the total emission is lowered to 9.4 kilograms.

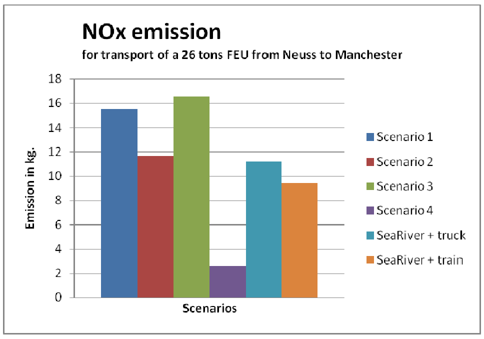


Figure 2, NOx emissions
Source: author calculations.

PM10 emissions are the lowest in a scenario in which a train plays the dominant role. Scenario 4 illustrates this. In this scenario the train transports the container from Duisburg all the way to Manchester, generating only 0.09 kilograms of PM10. The highest PM10 emission is generated by scenario 3, in which the truck and barge are dominant. Scenario 3 generates a total of 0.74 kilograms of PM10. The scenarios in which the Sea-river RoCon ship is included show remarkable results with regard to PM10 emissions. Scenario 5, in which the ship is combined with a truck generates a total of 0.24 kilograms. Scenario 6, in which the ship is combined with a train generates only 0.17 kilograms.

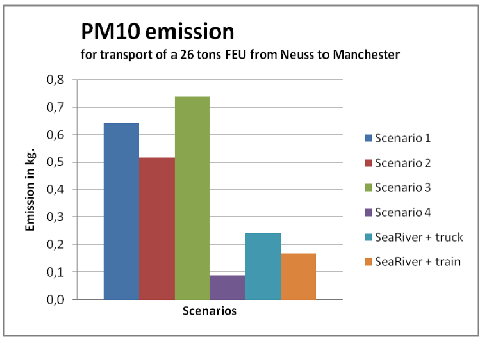


Figure 3, PM10 emissions
Source: author calculations.

Conclusion.

The emission calculations have clearly shown that the electric train is the cleanest way of transporting unitized cargo. It is unbeatable in terms of CO2, NOx and PM10 emissions. The choice for a transport mode is not dependent on emission figures only however. As it was found in the literature review a sea-river ship will predominantly compete for cargo coming from the road and other inland shipping lines. Considering the capacity of these different modes the relatively small reductions in emission figures can have considerable effects. In this respect the results from the calculations lead to the conclusion that a sea-river innovation like the IMA project is able to lower the carbon footprint of transport on the Germany-UK corridor.

1. Introduction

1.1 Background of the problem

The densely populated area around the port region of Rotterdam in the Netherlands and the western industrial estates of Germany have to deal with large volumes of trade and transport due to the large hinterland areas of the coastal ports and intensive industrial activity. Also large freight volumes are transported between these regions and the industrial areas of the United Kingdom. Problems on this busy trading corridor arise as a result of negative externalities from transport activities in combination with the high degree of urbanization. Especially transport by truck over the crowded road network causes congestion, air pollution, noise nuisance, delays and extra costs in transport chains due to downtime and uncertainty over travel times.

Not only in the aforementioned regions these problems arise, on a European and global level solutions are sought and policies made to minimize the negative externalities from transport. External costs of transport are most visible in traffic in and around cities or urban areas. One finds problems in the field of congestion (time loss/ pollution), infrastructure (wear), environmental costs (pollution, noise, etc.) and accidents (imposed on others). The strong growth of populations and an increasing trend of urbanization, together with increased volumes of traffic and freight transport have increased the importance of a new view on transport, mostly with respect to emissions and sustainability. What is important to notice in this respect is that negative externalities, and mainly the emissions and pollution from transport are linked directly to a global phenomenon: climate change, as a result of the so-called greenhouse effect.

Transport is not created for itself, but by the spatial separation of two places. The demand for transport therefore is a derived demand, which implies that the amount of transport cannot be limited without considering the competitiveness of an economy or economic system. A very important policy note that confirms this idea is the White Paper, European Transport Policy for 2010. To quote the White Paper: “Transport is crucial for our economic competitiveness and commercial, economic and cultural exchanges. This sector of the economy accounts for some €1000 billion, or over 10 % of the EU’s gross domestic product, and employs 10 million people. Transport also helps to bring Europe’s citizens closer together, and the Common Transport Policy is one of the cornerstones of the building of Europe. However, the warning signs are clear. Congestion, resulting in environmental nuisance and accidents, is getting worse day by day, and penalizing both users and the economy. If nothing is done, the cost of congestion will, on its own, account for 1 % of the EU’s gross domestic product in 2010.”

Not only from a policy-determining angle actions are undertaken. Because of a strong growing awareness and pressure from society, but even more because of rising costs as a result from an overcrowded transport system, also businesses must increasingly find alternatives for innovative and sustainable ways of transport. In the meantime policy makers try to take more measures to reduce the carbon footprint of transport activities. Something that often involves large monetary factors in the industry. Concluding, one finds that through the need for more sustainable ways of transport and the reduction of the carbon footprint from transport movements new innovative ways of transport have emerged and are coming into existences more and more. A good example of such a development is the growing focus on maritime transport. To quote S. Newton et. al (2010): “For many years, the European Commission’s Directorate General for Mobility and Transport (DG-MOVE) has recognized the importance of the maritime sector within the development of the trans-European transport network (TEN-T), as a contributor to economic growth, trade development, EU economic cohesion and to the alleviation of inland congestion.”

One of the distinctions that can be made in maritime transport in the context of the European transport network and European transport policies is between short-sea and deep-sea transport. Historically a greater emphasis has been towards the short-sea sector since this directly influenced the intra-European relations. From literature we have learned that in the deep-sea freight transport only very limited competition with other modes of transport arises. Since the transport of containers overseas can, in most cases, only be performed by deep-sea vessels. In short-sea transport this is different. Since short-sea trips could, most of the time, also be performed by other modes of transport competition between sea- and land transport does arise (S.Newton, et. al. 2010).

Several policies have been designed in the field of more intelligent transport systems, simplified administrative procedures and potentially even funding via a program called “Motorways of the Sea”. The purpose of these policies has been to address negative externalities from the crowded (road) transport network. At present a lot of the capacity of waterways transport can still be explored, while at the same time road networks are overloaded. As stated in the Motorways of the sea report (2006): “Traffic congestion in bottlenecks of the road network is at an unaffordable level and could be a barrier to sustainable socioeconomic development. ‘Motorways of the sea’ is a new concept, building on successful short sea shipping experiences, initiated by the Commission as well as EU of the Member States, to shift cargo traffic from the heavily loaded road network to environmentally-friendly waterways. Through the establishment of frequent and high quality maritime-based logistics services between Member States, Motorways of the sea will become veritable alternatives to congested roads.”

To get cargo of the road and on to the water a solid inland shipping option must be presented. While short-sea shipping seems to work on medium distance routes across Europe, the role of inland waterways and inland shipping seems to be often limited to feeding short-sea shipping routes. Cargo for these routes is transshipped in ports from inland barges to short-sea ships, an activity that leads to multiple problems. These transshipments are activities that cost time and money. They also cause delays and have a burden on local air quality. This is due to their pressure on already very busy port areas and terminals, but mainly on the surrounding infrastructure and urban areas. Moreover the reduction of the carbon footprint of the transport sector, one of the reasons to shift cargo from the road to water is at stake here.

One possible solution for this problem could be the combination of inland and short-sea shipping: sea-river shipping. With this type of transport a sea worthy ship with inland shipping characteristics is used to sail through inland waterways and sea routes. In this way it eliminates the need to transship goods at busy and overcrowded seaports, making use of remote inland ports instead. The effect from these types of ships could be considerable and additionally this type of transport should be able to get a considerable amount of cargo from the road. Thereby potentially making a significant contribution to the reduction of the carbon footprint of the transported goods. In this research this supposed effect is further examined using a concrete innovation from Independent Maritime Adviser Rotterdam. The Sea-river RoCon project team from this company proposes the financing, building and operating of four Sea-river Container Ro-Ro vessels that will provide daily short-sea services for containers and unaccompanied trailers between the German inland port of Neuss, in the Ruhr area, and the United Kingdom (UK) port of Immingham. One of the five main goals of the Sea-river RoCon project is to contribute to the environmentally friendly distribution of goods and help the reduction of the carbon footprint of the transported goods on the Germany-UK corridor.

1.2 Research question

To calculate the effect of this modern Sea-river RoCon innovation on the carbon footprint of transport on the Germany-UK corridor, and thereby the potential of sea-river shipping for comparable transport corridors worldwide, the main question in this research is the following:

To what extent does a modern Sea-river RoCon innovation reduce the carbon footprint of container and ro-ro transport on the Germany-United Kingdom (UK) corridor?

Sub-questions

A number of sub-questions arise in this respect:

1. What is a carbon footprint?
2. How is the Germany-UK corridor characterized?
3. Which factors are important on this corridor?
4. What are the main characteristics of this new Sea-River RoCon innovation?
5. Is this the right solution for this market and the demands of society for a clean environment?

Sub-questions 1, 2 and 3 are answered through a literature review, which also forms the basis for the answer to sub-question number 5. The fourth sub-question is answered throughout the report using the Sea-river RoCon business plan.

Hypotheses

To find the answer to these question the following hypotheses are formulated that form the basis of the research, calculations and conclusion:

H0: *"A modern sea-river ship has no effect on the carbon footprint of transport on a crowded transport route."*

H1: *"A modern sea-river ship has a relative positive effect on the carbon footprint of transport on a crowded transport route. "*

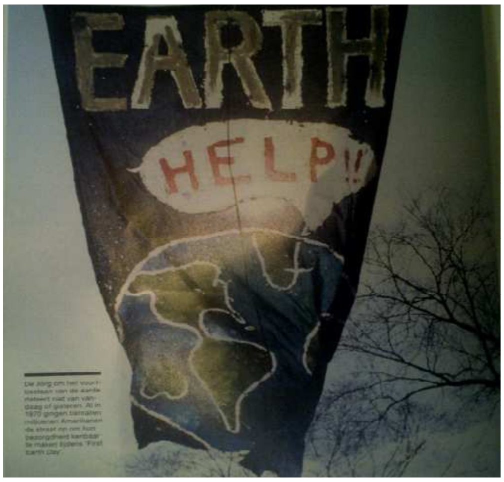
2. Literature review

In order to find an answer to the main research question and sub-questions of this thesis a literature review is elaborated to provide the necessary background information and framework for the specific analysis of the IMA initiative. According to literature, external transport costs do not end with emissions. Although the focus of this research is on the emission aspects of a Sea-river RoCon innovation, other aspects are taken into consideration as well. An overview of the current developments, researches and ideas in the field of the greenhouse effect, carbon footprint, external costs, maritime transport and sea-river shipping is provided in this chapter. An answer to the question why such a project is important is found and also the literature review provides an oversight of other research in this field and on this specific transport corridor.

First the terminology of external costs and the carbon footprint from transport is considered, together with current developments in this respect. Secondly we take a closer look at short-sea shipping and policies made in this respect. The Germany-UK corridor and its characteristics in terms of geography and transport issues are analyzed further in the third section of this literature review. A fourth part is formed by an analysis of current theories and comparable research to similar innovations and issues. At last the market for such a project is investigated to place the initiative of IMA and the results of this research into perspective.

2.1 Global warming, the 'Carbon footprint' and external costs of transport

Figure 4, Earth help!



Source: Delta Lloyd Q magazine.

Worldwide, there is increasing attention for sustainable economic development. Over the past 10/20 years, the attention for environmental protection has increased under the influence of aggravating pollution and a phenomenon referred to as "Global Warming". As the picture shows already for decades the attention for a sustainable world is on the agenda. Already in 1970 millions of Americans went out on the streets during "First Earth Day" to ventilate their concern about our planet and the impact people have on its environment. Other examples are the Club of Rome, which warned about the boundaries for economic growth in 1972, the Norwegian Prime minister Gro Harlem Brundtland who in 1987 in her report 'Our Common Future' called on the world for a sustainable way of development. Not to forget about the film from 2006; 'An inconvenient truth', about the campaign of Al Gore to educate citizens about global warming (Delta Lloyd, Q magazine, June 2011). Especially the transport and energy industry have negative environmental impacts. Therefore, international, national and local governments are promoting sustainable transport modes, like rail transport, inland shipping and multimodal transport. (de Langen et al., 2010).

This has all to do with global warming, as the result of the so-called "greenhouse effect". This greenhouse effect is caused for a large part by the emissions of carbon dioxide, CO2. Therefore the term "carbon footprint" if often used in this respect to determine the influence of a certain project, activity, company or person on the total CO2 emission. On different governance levels policies are made to manage and control these negative externalities and to minimize the consequences for our environment and climate. The transport sector accounts for about 24% of global CO2 emissions (Rothengatter, 2009). Besides this, Rothengatter (2009) states that the external environmental and safety costs amount to about 7% of the GDP of the economies of the main EU member states. Therefore it is tried to minimize the carbon footprint of our activities and transport movements. A number of important policies are made that deal with this phenomenon, we will analyze these later on in the second section of this literature review. For now a closer look is taken at the (possible) effects of global warming and the link it has with transport.

As an article in the New Scientist from June 2011 shows, the emissions from transport and power stations rose to 30.6 giga tons in 2010, an increase of 1.6 giga tons in comparison with the year before. This increase in emissions represents a serious setback, so the article says, to the target of limiting the global rise in temperature to no more than 2°C. According to this publication a rise of global temperature beyond this limit has a worrying effect on sea-water levels due to melting polar ice and can cause low-lying countries such as Bangladesh to flood. As Clare Goodess of the University of East Anglia’s Climate Research Unit in the United Kingdom states: “The further you go beyond 2°C, the harder it is to adapt, emission control will be the key to limiting the amount of damage.” Hamzelou, J. (2011).

The focus on emissions directly explains the link with transport and an article in the OECD Observer from May-June 2008 writes about this clearly: “Any serious attempt to deal with climate change must involve transport.” More specifically, the article shows that about 75% of all global transport emissions come from road transport, aviation accounts for roughly 12% and maritime transport for 10%. Since the transport sector accounts for such a large part of the problem, it should also be a large part of the solution. It is expected that the amount of transport will rise further in the coming years, due to growth in international trade and consumption. Since, despite technological innovations, transport is still almost entirely dependent on oil a “business as usual” approach cannot be sustained (Short, 2008).

The hinter lying principle discussed in this respect is that of the external costs. External costs are defined as costs that are not included in the market price of a good because they are not included in the supply price *(Economic Glossary, 2008).* More easily put, the external costs are costs the transport user causes to a third party, but for which he does not pay. External costs of transport are most visible in traffic in and around cities or urban areas. One finds problems in the field of congestion, pollution and accidents for example. The importance of these external costs of transport has increased largely over the past decades (Rothengatter, 2009). The strong growth of populations and an increasing trend of urbanization, together with increased volumes of traffic and freight transport have increased the importance of a new view on transport with respect to emissions and sustainability (Piecyck & McKinnon, 2009). As a report of INFRAS (2004) shows, the total external costs amounted to €650 billion for the year 2000 in the EU17 countries, which was 7.3% of the total GDP. Climate change was the most important cost category in 2000, which accounted for 30% of these total costs. What is interesting to find in this report is that two thirds of these external costs were caused by passenger transport and one third by freight transport. The main reasons the research presents for the increase in external costs are the increasing traffic volumes that lead to higher greenhouse gas (GHG) emissions and increasing climate change risks. The research points out that particularly road freight traffic has a large share in air pollution costs, despite developments in engine technology.

As Medda and Trujillo (2010) point out, congestion costs in particular are external costs to be concerned about, since they differ from other external costs. Congestion puts a multiplier effect on other external costs. Pollution, noise, accident rates and infrastructure wear for example are all variables whose level grows with an increasing level of congestion. Emissions into the air are largely dependent on freight speed and higher air emissions are measured at very low speeds. Congestion costs account for more than 50% of the total external costs of freight transport in 2010 and the importance of maritime transport in this respect becomes more and more apparent (Klein, 2007). This is also stated by Baird (2007) in his article: “The economics of Motorways of the sea”. The author says: “It seems logical then that sea transport is to become an effective ‘alternative’ to long-distance land transport. Maritime transport these days is widely regarded as a sustainable alternative to road transportation, specifically in Europe where short-sea and inland waterway navigation is well developed due to the large amounts of inland waterways for example.”

A problem in this respect arises however, and it is one that is maybe quite obvious: ship emissions. Ship emissions become relatively more important since land based transport and emissions are decreasing. The Marine Environmental Protection Committee (MEPC) agreed on a work plan to develop mechanisms that are needed to reduce the CO2 emissions from ships. As Burgel (2007) states: “Noting that although shipping is regarded as an environmentally friendly and fuel-efficient mode of transport it needs to take care of its production of GHG’s.” In order for ships to function they need a port to be loaded and unloaded, which directly puts a pressure on local air quality, as is also stated by Schrooten et.al. (2009). One of the reasons for this is that ships, when in a port for loading or unloading, need to be handled at a certain terminal. This process often takes up a lot of time, not only for loading and unloading, but increasingly often for waiting an maneuvering as well, due to an increasing number of ships in the port area (van der Beek, 2009). Besides this the terminals that handle the cargo, directly generate emissions on a local scale, something analyzed by Geerlings and van Duin (2010) for example. In this thesis the direct emissions from transshipment operations on terminals is taken into account therefore as well.

Transportation of freight and people is essential for our economy to function, so policy makers try to find ways to lower the external costs from transport without hurting the economies. This process is referred to as decoupling, and it is basically “…the prospect of growing economic prosperity without a corresponding increase in freight-related externalities”(McKinnon, 2007). As McKinnon points out however, the externalities are not simply a function of the demand for freight movements, he shows that they are affected by three other factors as well: the modal split, the vehicle utilization and the emission level. “It is possible”, he says, “to cut freight related externalities by reducing one or more of these ratios even when the total amount of transport (measured in ton/kilometers) continues to rise.”

Concluding remarks.

Concluding, we have found that transport has a large share in the greenhouse problem, through emissions and other external costs that result from it. We have seen that the emission of CO2 defines the so-called carbon footprint and that in order to deal with climate change the way we transport goods and people needs to be changed or adapted. It was found that among external costs congestion is one of the most important, due to its multiplier effect on other externalities, and that maritime transport is regarded as a sustainable and fuel-efficient alternative. We found that maritime transport, however environmentally friendly had an important impact on local air quality in and around ports due to waiting, maneuvering and handling at terminals. In the next section of this literature review we find out what policies are made to deal with these issues.

2.2 Short-Sea shipping, from a policy perspective

In this part of the literature review we take a closer look at four of the most important policies made by the EC to establish their targets in the field of transport and we will find out what the effects of these policies have been in the past years.

During the 1990's Europe began to suffer from congestion in certain areas and on certain routes, which gradually started to threaten the economic competitiveness of the entire European Union. In order to reduce the congestion on the European road network, to improve access of remote and island regions and to encourage more environmentally-friendly modes of transport the European Commission (EC) has come up with a number of important policies in the past decades. As Baird (2007) points out, the EU transport policies increasingly focus on the development of new and improved logistics solutions and the role that maritime transport can play in this. If nothing is done it is forecasted that the total freight transport by road in Europe will grow with roughly 60% by 2013, which would have a big effect on the negative externalities as we have seen in the previous section. To temper the effects the EC proposes policies to come to a modal shift, in favor of maritime transport. Actually a modal shift in this respect means the movement of freight from road to more environmentally friendly modes of transport (Casaca & Marlow, 2007).

According to Baird (2007) the advantages of sea transport compared to land transport are for example that the sea is virtually free, it already exists and does not require as much maintenance as land infrastructure does. In ports however, dredging is a an important issue, on open sea however this doesn't apply. Baird (2007) also mentions that the seas are very large open spaces that are not affected for most of the times by traffic congestion. Besides this the capacity of the sea transport system can be increased relatively easy by increasing the number of ships or the capacity of these ships. Which is different from land transport, where an increase in capacity requires very expensive adjustments to infrastructure or legislation. An important side note here is that although capacity of the sea transport system can be increased relatively easy, the capacity of ports can form a bottle neck.

The EC has made short-sea shipping one of the major priorities for European transport and maritime industries and they have made it one of their most important areas of development since 1992. Short-sea shipping is defined by the EC as "the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports situated in non-European countries having a coastline on the enclosed seas bordering Europe'' (Motorways of the sea, 2006).

It would be incredibly time consuming to analyze all policies made over time on this subject, therefore we take a look at the four most important ones: TEN-T, the 2001 and 2011 White paper on transport and the 2006 Motorways of the sea report.

TENT-T.

The EU has a lot of paved roads, railway lines and navigable waterways, but most of these transport infrastructures have been developed under national policy. To establish a single network that combines land, sea and air transport networks throughout the EU, European policymakers established the "Trans-European Transport Network, allowing goods and people to circulate quickly and easily between Member States and assuring international connections" (EC, 2011). The Trans-European Transport Network (TEN-T) policy was developed during the 1990's. It originated from the need to shift freight from land based transport to underused, but more environmentally friendly, transport modes, as was proposed in the 1992 White paper on the common transport policy. The EC proposed the use of multimodal/ intermodal transport solutions, implying that road transport should be used in the pre- and end carriage of the transport chain.

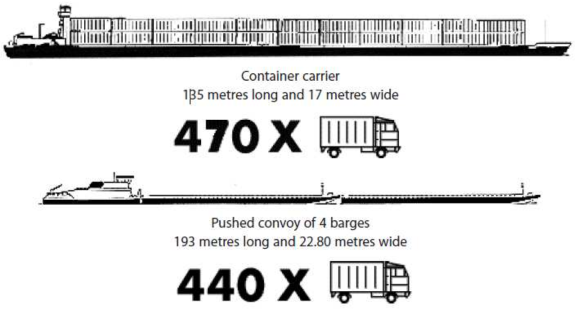
When the White paper on transport in 2001 considered that one of the main purposes of the TEN-T was to relieve congestion the TEN-T was supplemented with sea and inland ports and so short-sea and inland shipping became part of the network as well. Today, the TEN-T consists of 89,511km of roads, 93,741 km of railways, a large fraction of high-speed lines, 330 airports, 270 international seaports, 210 inland ports, traffic management systems, navigation, and user information systems (Casaca & Marlow, 2007).

2001 White paper on transport.

The 2001 White paper on transport summarized the current state of the European transport system and set out an action plan of around 60 actions that were to carried out between 2001 and 2010. The paper focused on the transport system as a whole, proposing measures for every aspect of it, concerning the road-, aviation-, maritime- and railway sector.

The policy reviews the fact that road freight transport makes up for 44% of all freight transport, in terms of ton/kilometer, and that congestion of the main road and rail routes leads to problems in towns and urban areas. Also the negative externalities for public health and the environment are important aspects. The increasing use of the road for freight transportation led to a situation in which congestion, particularly on the main European corridors, threatened the competitiveness of the European economy. Therefore the paper proposed policies in two directions: first the competition between modes would be regulated, and secondly the linking of modes, which should lead to a more successful intermodal transport system. Since the dense network of inland waterways that is present in the European Union, the White paper proposed to make certain shipping links and ports part of the TEN-T. The EC mentioned the fact that inland waterway transport complements sea transport and that major North Sea ports use inland waterways extensively for their inward and outward container traffic. The White paper states: “Intra-Community maritime transport and inland waterway transport are two key components of intermodality which must provide a means of coping with the growing congestion of road and rail infrastructure and of tackling air pollution” (EC, White paper, 2001). This resulted in the proposal of the ‘Motorways of the sea’ development.

Figure 5, Potential of inland maritime transportation



Source: EC, White paper on transport (2001).

Furthermore the White paper mentioned the fact that inland waterway’s capacity was considerably underused in terms of infrastructure and ships because of the tendency of infrastructure policy to prior investments in other modes of transport. It showed clearly the possibilities and potential of inland maritime transportation with figure 5.

Motorways of the sea

Since the Trans European Transport Networks were developed in Europe to relieve congestion and safeguard economic prosperity, and the 2001 White paper on transport specifically asked for the development of maritime transport, the ‘Motorways of the sea’ concept was included in TEN-T in 2003. (EC, Motorways of the sea, 2006).

The European Commission indicates that Motorways of the sea constitute a special mode within short-sea shipping and can be defined as “existing or new sea-based transport services that are integrated in door-to-door logistical chains and concentrate flows of freight on viable, regular, frequent, high-quality and reliable SSS links." (Lopez-Navarro, 2011). Motorways of the sea is in short a list of four important sea corridors that were developed to successfully contribute to the enlargement of the European Union, to reduce road congestion, to improve maritime links and improve the cohesion between member states and to improve multi modality in order to support sustainable development. The program consists of the following corridors (EC, Motorways of the sea, 2006):

- Motorway of the Baltic Sea (linking Baltic Sea states with Member States in Central and Western Europe, including the route through the North Sea/Baltic Sea Canal) (2010);
- Motorway of the sea of western Europe (leading from Portugal and Spain via the Atlantic Arc to the North Sea and the Irish Sea) (2010);
- Motorway of the sea of south-east Europe (connecting the Adriatic Sea to the Ionian Sea and the Eastern Mediterranean to include Cyprus) (2010);
- Motorway of the sea of south-west Europe (western Mediterranean), connecting Spain, France, Italy and including Malta, and linking with the Motorway of the Sea of south-east Europe (2010).

2011 White paper on transport.

The 2011 White paper forms a vision on a competitive and sustainable European transport network in the year 2050. The basis of this vision is a strong increase in the amount of transport, together with a reduction of transport emission with 60% in 2050 and a growing independence of Europe from imported oil. To realize these goals the main focus of the paper is on the bundling of cargo (and passengers) to increase efficiency together with a combination of the most efficient modes of transport. To reach the emission reduction goal ten objectives were elaborated. A number of these objectives directly focused on short-sea shipping, through the stimulation of large scale, relatively environmental friendly and energy-efficient modes of transport, which are strengths of short-sea shipping, and through strong modal-split policies. One notable measure is the introduction of a so-called "Blue belt" in the seas of Europe. In this belt the formalities concerning taxes and administration for ships sailing between European ports are simplified with the purpose to increase the market access to ports. The white paper also mentions the fact that the short-sea shipping sector needs to internalize its external costs in terms of local (air) pollution en noise nuisance in port areas and on open sea. The White paper on transport, with a vision for 2050 remains rather unclear about concrete measures and steps to be taken to achieve the ambitious emission goals however. According to Kuipers (2011): "Summarizing, the White paper outlines an ambitious vision on 2050, the steps necessary for the achievement of these goals remain unclear however."

Concluding remarks.

European policymakers have a strong emphasis regarding short-sea and inland shipping as a solution to congestion problems in the transportation network. The development of a Europe-wide network including rail, air and road lines showed the way in which the policymakers tried to overcome transport problems that were increasingly threatening the economic development of the region. And with the inclusion of maritime transport in this network the focus went more and more to short-sea and inland shipping. This was stated very clearly in the 2001 and 2011 White papers that were discussed. In the 2001 White paper the policy makers strongly asked for the implementation of the Motorways of the sea, and pointed out that maritime transport was to be the solution for the transport problems relating to congestion and environmental impacts. The 2011 White paper sets ambitious emission goals, and emphasizes the role of short-sea shipping in the achievement of these goals. The Motorways of the sea concept that was effectuated in 2006 was a result of this focus and helps developing and improving maritime transport in Europe, something that is very important to take into consideration when reviewing a project such as the IMA Sea-river RoCon innovation.

2.3 Germany-UK corridor

The inclusion of sea- and inland ports in the TENs shows the importance of these transport nodes in the overall transport system. In this respect we take a closer look at the way these ports work. We will find out about the hinterland of ports and the way this is organized for the specific situation of the IMA Sea-river RoCon project, this means a closer look is taken at the Germany-UK transport corridor. First we take a closer look at the term hinterland and what it actually means with a focus on this specific corridor, secondly the current situation in the region of Rotterdam is discussed and we see why it can be very interesting to avoid the port on a trip from the Ruhr area to Immingham. Thirdly we take a closer look at the Rhine-Scheldt data, the Ruhr area and the port and region of Immingham. A description is made of developments in these regions and the effect they can have on a Sea-river project, which is important when analyzing the results of this research.

Hinterland

When considering the transport overseas through inland waterways the term hinterland is a very important one to consider. The term hinterland refers to the area behind a seaport in which a port has a substantial competitive advantage because of lower generalized transport costs (De Langen et.al., 2010). In order to transport goods to and from this hinterland area different transport modes are used. Since the IMA project is intended to transport unitized cargo (containers and unaccompanied trailers), pipelines are kept out of this review and the focus will be on road- and rail transport and inland shipping. Every transport mode has its own characteristics and market position. Inland shipping is strong for large volumes of non time critical cargo, with average speeds around 15-20 km/h and capacities up to about 400TEU (Twenty-feet Equivalent Unit, the standard measure for a container). Trucks have a very strong position in door-to-door distribution on relatively short distances, with average speeds around 60-70 km/h and capacities of about 2TEU. Rail transport has a strong position on long distance transportation, with average speeds around 25-40 km/h and capacities up to 100TEU.

The Germany-UK corridor is a very busy transport route, one of the busiest of Europe, which leads to a number of problems, specifically in the port area of Rotterdam. As Beek (2009) explains, a linkage such as the river Rhine connects important and large residential and industrial centres such as the Ruhr area in Germany, to the port. With such a good connection to the global transport network “the Ruhr area had a growth advantage over other regions and was therefore able to grow faster. With the development of the Ruhr area came more transport through the port of Rotterdam as well. The growth the port experienced, placed it at the preferred location for more users needing a gateway. This again ensured further growth in the hinterland, leading again to enlargement of the port.”

The port of Rotterdam

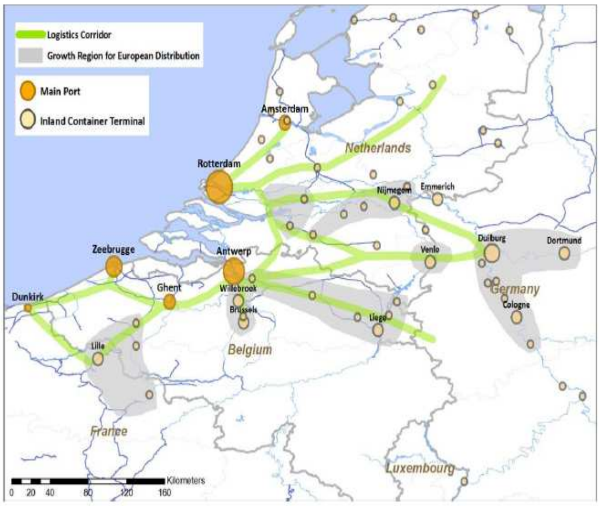
As pointed out by van der Beek (2009), the port of Rotterdam has had great help from the river Rhine that connects it to a large and industrial active hinterland. Because of this prosperity, the port of Rotterdam copes with a number of problems though. Located at the North Sea and surrounded by the city of Rotterdam it is, besides its waterway connection, largely dependent on the A15 motorway, which deals with a vast amount of congestion. In port cities this congestion is caused not only by commuters but also by the haulage of cargo. This has put an increasing pressure on the industry to come up with solutions and in the Netherlands the emphasis is on a shift to barge and rail transport. Both are considered cleaner per ton/kilometer than trucking and they put no further pressure on the road infrastructure. Railway requires expensive infrastructure that is often built with public money, barging however requires little investments in infrastructure as natural waterways and already dug canals can be used.

Gateway seaports such as Rotterdam have to deal with more and more calls from barges, having a huge influence on turnaround times, which have increased dramatically. This situation currently leads to a long stay of barges in the port since call patterns have not been adapted to this situation. "Time in port is seen as unproductive as barges only make money when sailing. From a port point of view the numerous ships that lie waiting take up precious place, and the sheer number of movements in the ports between the different load and discharge points is seen as challenge in itself. From a point of view of the entire transport chain, the number of calls in the port and the prolonged turnaround time are seen as inefficiencies and cost factors to take into account.", says van der Beek (2009).

Besides this the city and region of Rotterdam deal with environmental issues related to the intense port activities and due to the emissions coming from the large amount of (waiting) ships and road traffic. This is important because "container ports have become a link in larger logistics chains. For them to succeed, such chains need to achieve a high degree of coordination and cooperation" (Lun, 2010), in which delays pose a huge problem to the overall performance of a chain. This is also supported by Rodrigue & Notteboom (2011), who point out that "the evolution of inland freight distribution can be seen as an ongoing development of containerization and intermodal transportation. Modal availability, capacity and reliability of regional inland access have an important role to play in shaping this development. As maritime shipping networks and port terminal activities become better integrated, the focus shifted on inland transportation and the inland terminal as a fundamental component of this strategy."

The Rhine-Scheldt delta.

Figure 6, The Rhine-Scheldt delta

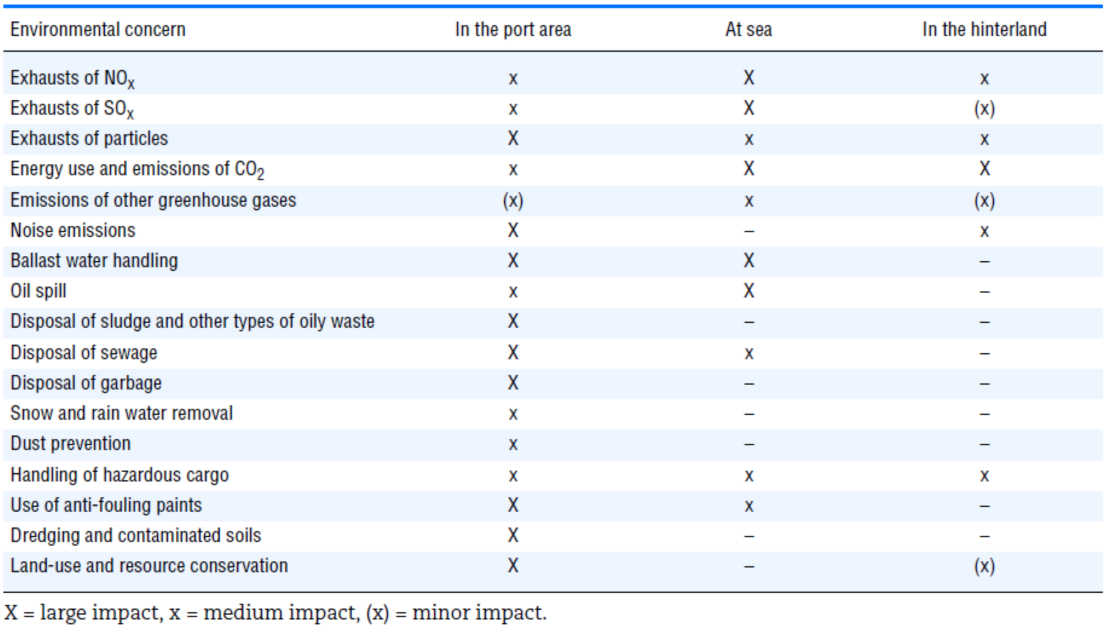


Source: Rodrigue & Notteboom, 2011.

The increasing focus on inland transportation and remote terminals has led to a growing number of remote ports, or so-called 'dry-ports' (Rodrigue & Notteboom, 2011) of which a large concentration is found in the Rhine-Scheldt delta. Dry ports are intermediary locations between a sea-port and further hinterland connections. In the Rhine-Scheldt delta a total container throughput of over 22 million TEU was established in 2010, which makes it Europe's most important gateway region. In northwest Europe, barge transport gets a more and more important role in the transportation of containers and gateway traffic. Barge container transport was, historically, done between the large port of Antwerp and Rotterdam. In part due to the fact that a number of container lines only called at one of the two ports. Later on this kind of transport expanded towards other waterways in the delta, and the Rhine became increasingly (very) important. Antwerp and Rotterdam together handled nearly 5 million TEU of inland barge traffic in 2010 or about 95% of total European container transport by barge (Rodrigue & Notteboom, 2011).

Due to the large amount of transport activity in this region environmental problems are present and increasingly demand adaptations from the industry in order to remain competitive. As the OECD (2011) shows the environmental impact caused by port activities can be related to specific types of ships and cargo but the overall environmental impact of ports depends also on the type of location. The environmental impact of a port and port activities may therefore be divided in three categories: *1)* problems caused by port activity itself; 2*)* problems caused at sea by ships calling at the port; and 3*)* emissions from inter-modal transport networks serving the port. The following table presents the main environmental concerns and the places it concerns.

Table 1. Environmental concerns and the places it concerns



Environmental concern	In the port area	At sea	In the hinterland
Exhausts of NO_x	x	X	x
Exhausts of SO_x	x	X	(x)
Exhausts of particles	X	x	x
Energy use and emissions of CO_2	x	X	X
Emissions of other greenhouse gases	(x)	x	(x)
Noise emissions	X	–	x
Ballast water handling	X	X	–
Oil spill	x	X	–
Disposal of sludge and other types of oily waste	X	–	–
Disposal of sewage	X	x	–
Disposal of garbage	X	–	–
Snow and rain water removal	x	–	–
Dust prevention	x	–	–
Handling of hazardous cargo	x	x	x
Use of anti-fouling paints	X	x	–
Dredging and contaminated soils	X	–	–
Land-use and resource conservation	X	–	(x)

X = large impact, x = medium impact, (x) = minor impact.

Source: OECD (2011)

The port and region of Immingham

Not only the port region of Rotterdam and the Rhine-Scheldt delta deal with problems as a result of congestion and a sharp increase of transport movements over the past decades. Also in the United Kingdom (UK), as Wright (2007) puts it: “a country that is very much dependent on maritime transport for its link with international transport chains because it is an island.” Wright (2007) mentions the fact businesses facing higher transport costs and longer transit times after a number of leading consortia of container shipping lines did cut back direct calls at some of the main UK ports to avoid severe congestion. Which was an interesting development since now goods were instead shipped to continental ports such as Rotterdam and then brought on smaller feeder ships to often minor ports, such as Immingham. These detours made the goods more expensive of course since UK businesses had to pay for extra handling and the smaller ship’s higher costs.

As Allistair Darling said in his speech on the ‘Transport 2010 and beyond conference’ in 2004: “The UK Government ‘invests’ considerable public sector resources in railways and roadways, yet the notion of any public expenditure directed towards sea transport is regarded (by the government) as ‘subsidy’, and considered not to be a good idea on the basis that this leads ‘to market distortions, and inefficiencies”.

The expenditure of public money on sea transport became an important part of transport policy, since the UK government has now set itself the goal to reduce the total CO2 production with 80% by 2050. Hereby it followed the advice from its Climate Change Committee in 2008 (Piecyck, 2009). The committee advised a continuing modal shift towards rail and water transport. (Mc Kinnon 2007).

Concluding remarks.

We found a number of developments in the Germany-UK transport corridor, of which the high (and increasing) amount of transport is the most important. Due to the gateway function of the port of Rotterdam and the Rhine-Scheldt delta this region deals with vast amounts of barge transport, road freight and negative externalities resulting from this transport. Not only in this delta however such problems arise, also in the UK policies were made in this respect due to a sharp increase in road freight transport and the congestion and environmental issues resulting from this. Not only with respect to external costs but also in relation to internal effects on transit times, overall costs and the reliability of transport chains. Regarding this specific transport corridor it is therefore very interesting to review a specific innovation in the field of maritime transportation; sea-river shipping. In the next section a closer look is taken at this phenomenon.

2.4 Sea-river innovations and comparable research

So far we have found that due to global warming and the relation this phenomenon has with transport, the European (amongst other) policy makers have put their emphasis on rail-, and maritime transport. We have also found that due to an increase in waterborne transport in the Rhine-Scheldt delta and on the Germany-UK corridor, congestion and the environmental effects of the heavy transport have become a very important aspect in the planning and organization of (inland) transport chains. This has put a pressure on businesses to come up with solutions dealing with both these problems. In this section we will take a closer look at a development in maritime transport: sea-river shipping. We will analyze this type of transport first to find out its main reasons for existence. Secondly a closer look is provided into research performed to this type of transport, the implementation of it on transport corridors around the world and the environmental results that were analyzed. This will put this specific research in perspective and provide guidance to the calculations and the discussion of their results.

Sea-river shipping refers to the transportation by ship over both inland waterways and the sea and is organized in several forms. A first distinction can be made according to the modality or used technology: sea-river transport with cargo transshipment between sea and inland waterways transport, and sea-river transport without this transshipment. This second category is the sort of sea-river transport that applies to this research and this category could be further divided into a group concerning sea-river vessels and a group concerning a new technological system called the sea-river push barge.

Sea-river transportation without transshipment is possible when a ship can sail through both inland waterways and over sea routes. The advantage of such a mode of transport lies specifically in the transshipment costs, in terms of money and time, that are not incurred. And as we have seen in previous sections, the related external effects this can have in busy port areas and the surrounding regions in terms of congestion and environmental effects. The use of sea-river vessels is limited however due to navigational conditions at sea and the length, beam and draught of these ships are limited due to restrictions of the inland waterways (Radmilovic, 2011).

The following scheme illustrates the way in which sea-river ships can bypass seaports and sail directly from one inland port to another, which saves time and thereby money (Rodrigue et. al., 2006):

Figure 7, Sea-river shipping bypasses seaport

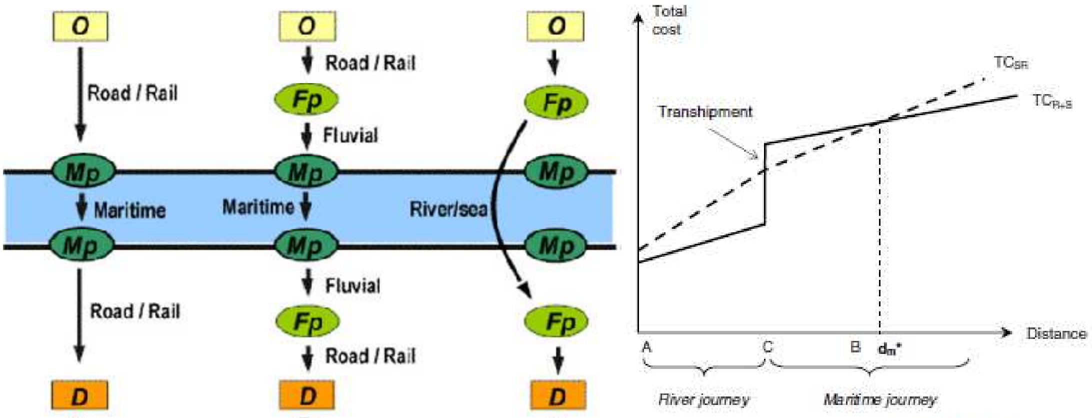


Fig. 9. Transport costs, distance and modal choice.

Source: Rodrigue et. al. (2006)

Sea-river navigation in Europe.

In 1994 Rissoan discussed the fact that the increase in intra-European trade had benefitted all modes of transport, particularly short-sea shipping but most of all sea-river shipping. Rissoan (1994) refers to the main advantage of sea-river as shipping as being the fact that the transshipment operations at coastal ports are skipped, providing the sea-river ships with a competitive advantage over 'traditional' roll-on/roll-off and container ships. Furthermore he states in his paper that this type of transport has important consequences for land locked areas with navigable waterways and that sea-river transport pollutes less and can be a solution for congested roads and railways. In his paper he further investigates the possibilities this kind of transport can have for Europe and it is interesting to read his conclusion. In this he mentions that sea-river transportation seems destined for future growth since it is able to link Western Europe with the countries in the former Socialist bloc via the Black sea for example. Furthermore he mentions the possibilities for trade between Western Europe and the countries around the Mediterranean and the Black Sea, which should contribute to a dynamic European economy. At last he concludes with the environmental aspects of this type of transport and shows that sea-river shipping can be able to transfer great amounts of cargo from rail or road to rivers and the sea, thereby helping to combat environmental problems specifically caused by the overuse of trucks. These aspects were all put together later in the "Motorways of the sea" concept.

The competitiveness of the sea-river transport system.

In 2000 Konings and Ludema presented their paper on the opportunities for sea-river shipping on the Germany-UK corridor. The authors mention the positive attributes of the sea-river concept but also that the concept has not yet been widely developed in Europe. As Radmilovic (2011) also taught, specifically restrictions from inland waterways seemed to be the reason for this and the concept seems economical viable for only a very limited number of transport corridors for this reason. The paper of Konings and Ludema evaluates a special kind of push-barge design, its service on the UK-Germany corridor and the ways in which this service competes with alternative transport modes. The approach was to develop a model to determine the best port to serve with this new sea-river push barge concept. The authors compared the concept with the most important existing transport options, being road/ferry transport and the barge/short-sea shipping chain. The analysis focused on containers, since this is the freight most suitable for intermodal transport. Of the analyzed alternatives the road/ferry alternative is labeled as the fast alternative. Reasons for this are found in the fact that speeds are relatively high, on the road as well as on the water, and transshipment times relatively low due to the roll-on/roll-off by trucks onto the ferries. The barge/short-sea alternative on the other hand was labeled as the slow alternative, since goods have to be transshipped in three ports. This is also the cheaper alternative however. As Konings and Ludema (2000) conclude, an important finding is that "the shorter the overall transport time, the greater the comparative time savings achieved by avoiding an intermediate transshipment at a seaport."

Sea–river shipping competitiveness and its geographical market area.

The limitations of sea-river shipping are placed along its main advantage by Lopez (2007); the absence of transshipment at a seaport. In his analysis Lopez (2007) puts a sea-river alternative up against a traditional transport chain in which a separate barge and short-sea vessel are used and he determines the threshold in terms of tonnage for which sea-river vessels are more efficient for a number of ports on the Rhône-Saône corridor. Furthermore he calculates the area for which a sea-river shipping alternative can have a competitive advantage based on different inland ports in this corridor. Among the advantages of less transshipments, also the smaller risk of damage due to less handling, and the reliability of the transport chain are put forward in his research. These seem to be the most important considerations for shippers in their choice of transport. The environmental aspects related to a modal shift towards sea-river transport are not analyzed in this research, but Lopez (2001) mentions the fact that his study could be completed by including these external costs in the model.

The potential for premium-intermodal services to reduce CO2 emissions.

In his research to the Quebec City-Windsor corridor, Patterson (2008) took external costs in account. The Quebec City-Windsor corridor is the busiest transport corridor in Canada and in his research the potential CO2 emission reductions in the freight transportation were estimated based on a switch by shippers to more intermodal services. The research did not specifically focus on sea-river shipping but it is interesting to see that the emission and environmental aspect on such a busy corridor is analyzed in relation to the inter modality of transport. Patterson (2008) places the intermodal alternative against a truck-only alternative, since he notes that intermodal services struggle to compete with this truck-only alternative at present. He determines a number of scenarios for a number of ports in the corridor and his findings are that adding intermodal services to this corridor can reduce CO2 emissions. He finds however that the reduction in CO2 emissions is highly dependent on assumptions made in the different scenarios. The possibility exists of a CO2 reduction of 50% compared to the most common truck-only alternatives in this corridor however. This idea is supported by Schilperoord (2004) who states that the environmental performance of different modes of transport are dependent on a large number of parameters, making a comparison in general terms is therefore almost impossible (Royal Haskoning, Schilperoord, 2004).

In 2010 Medda and Trujillo showed that an increasing role of short-sea shipping could reduce the environmental damage on the Genoa (Italy)-Preston (UK) corridor. The authors have found that the marginal external costs of transport by ship is about €0.14 per kilometer, whereas these costs amount up to €0.24 per kilometer for all road transport. Although this advantage can be positively valued from a societal perspective, Medda and Trujillo (2010) state: "it seems highly unlikely that significant use of any alternative shipping facility will occur unless a clear benefit is offered, e.g. of either cost or time saving for the carrier." What is interesting to find from this research is that short-sea shipping would be an alternative to road transport if it were able to provide a door-to-door service, or if the external costs for road transport were to be internalized within the total trucking costs. The conclusion of the authors is that inclusion of both private and public costs could provide a reduction of total transportation costs in the range of 30-45%.

The carbon footprint if maritime freight transport.

The Carbon footprint, in terms of CO2 emission, of maritime transport has been analyzed by Leonardi and Browne in 2010. In their paper the authors propose a method to calculate the carbon footprint in international supply chains with a focus on the maritime sector and with a comparison of 25 companies in the UK, France and Belgium. The research was performed through the analysis of data relating to the energy use and GHG emissions in a number of global logistics activities in two product supply chains, that of furniture and that of apples. With this approach a very practical analysis was made, albeit with an emphasis on deep sea container carriers that used heavy fuel oil (HFO, with an emissions factor of 3153grams of CO2 per kilogram). The methodology of this research used the emissions of GHG's during the physical transport and not during storage, production, logistics, service or trade activities. A stepwise approach was taken that described the different sub-activities needed for the transportation of the two products, and the emissions from these activities were added to compare the different scenarios and alternatives. To determine the energy consumption and therewith the emissions from the vessels the following indicators were collected and used:

- identification of the vessel;
- main and auxiliary engine fuel use;
- nominal capacity in TEU or in tons;
- maritime line and port calls;
- mean load factor in % of the nominal capacity.

In the research the analysis of the apple supply chain considered the region of Nelson in New Zealand as the origin location, and the destinations were Felixstowe or Antwerp for the container vessels, and Sheerness for the bulk carrier vessel. The production location for the furniture was in Brazil. The ship sailed between Itajai and Le Havre, Felixstowe or Antwerp. "Two routes were used; the first with a stop at the hub in Algeciras and a transshipment to another vessel; the second involving a direct trip using one vessel going to Le Havre after nine port calls." (Leonardi and Browne, 2010). The main conclusions from the research were that there seems to be a relatively weak relationship between the size of a ship and the GHG emissions per load unit. An important uncertainty coming from this research was the net load of the analyzed TEU. The load weight of one 40foot container in this research was 20 tons for apples as well as furniture, which is the weight of the container load, excluding the weight of the container itself. To quote Leonardi and Browne (2010), the conclusion of the research showed that: "the longest trip observed (>25,700 km) was leading to an amount of about 880g. of CO2 equivalent per kilogram of product. The least efficient container ship was showing transport CO2 efficiency values of about 100g. of CO2 equivalent per ton/kilometer. The most efficient vessel observed recorded a value of 27g. CO2 e/tkm."

Concluding remarks.

The analysis of research performed to the potential of short-sea and sea-river shipping in Europe with regard to negative externalities, the carbon footprint and the economic viability of such a concept has provided a number of insights and a framework for further analysis. The first important result from sea-river research is the advantage it has over traditional inland and sea shipping due to the fact that the transshipment of cargo in a seaport is avoided. Also the positive influence of this kind of transport on road- and rail congestion was mentioned in the research. The effect of not having to transship goods in a seaport is larger when the overall trip is shorter, an important conclusion from Konings and Ludema (2000). It was found that multimodal transport could lower the amount of CO2 emissions on the Quebec City-Windsor corridor in Canada, a result that provides a good starting point for the research performed to the IMA Sea-river RoCon innovation. Disadvantages of the sea-river concept were found in relation to restrictions from inland waterways and the influence these have on the capacity of vessels and the economic potential, which is limited therefore to only a small number of corridors (in Europe). From Patterson (2008) it was learned that sea-river shipping would need to be able to provide a door-to-door service in order to compete with road freight transport. Although this may be the case in Canada, on the Germany-UK route it can be a whole different story. In this research we will not look at the competitive position of the IMA Sea-river RoCon vessels however, but only at the carbon footprint, supplemented with other emissions besides CO2.

2.5 The market for a sea-river innovation

In this last part of the literature review a closer look is taken into the market for a sea-river innovation. A number of important developments in this respect are discussed to analyze the rationale of an innovation such as the IMA one.

Figure 8, EC aims to implement "green transport corridors"

EC aims to implement 'green transport corridors'

The European Commission (EC) wants to see the creation of 'green transport corridors', incorporating multi-modal systems (including rail, shipping and road) to carry freight between and across EU countries.

The corridors are detailed in an action plan promoting environment-friendly freight movements in Europe, published by the EC. Officials would organise "co-operation between authorities and freight transport logistics operators...to identify improvements" in these routes "to ensure adequate infrastructure for sustainable transport".

The action plan says these corridors should receive funding under the EU's trans-European networks (TENs) and Marco Polo combined transport schemes.

Source: Motor Transport; oct 25, 2007, p. 1

First we will analyze trends in supply chain management and logistics, for example with respect to cleaner transportation and sustainability. Secondly an overview is provided of research concerning the way in which short-sea shipping and other maritime transport is adapted, or has to adapt to these trends and developments. This will provide the necessary background for an analysis of the potential of the IMA Sea-river RoCon innovation and should help to answer the question of whether this is the right solution for this market and the demands of society for a clean environment.

Global trends in logistics and supply chain management.

Costs for warehousing are increasing and the demand from consumers becomes more and more differentiated. This has a strong influence on the way transport is organized (Panayides, 2002). Just in time delivery increases the need for a stable mode of transport, but it is important to notice that an increase in speed yields an increase in energy consumption and thus emissions. The slower you go, the less you emit, which is perfectly visible in the (super) slow steaming policies applied in deep-sea transport for example (Cariou, 2010). However, reductions in speed because of congestion have the opposite effect and increase fuel consumption and emissions, but mainly transit times become longer and more difficult to predict. Today, increasingly faster ships are in a position to compete with trucks. The greater power demand and consumption rate of ships however, result in higher emission levels which results in a loss of the environmental advantage over road transport (Martinez, 2009).

As Panayides (2002) and Medda & Trujillo (2010) note, trends in production such as global sourcing, just in time delivery and door-to-door service, have a clear influence on the way transport demand has developed. Something that can also be concluded from the increasing number of transport forwarding companies and third party logistic service providers. Companies that basically only manage the different transporting parties and organize the coordination for their clients (Nordmann, 2007). By lowering the number of different modalities in a supply chain the coordination between them can be facilitated more easily, which is demonstrated by the economic theory of transaction costs, which teaches that uncertainty about the quality of service will increase the costs from the different transactions. Since transaction costs are greater when the frequency of exchange and complexity of transport chains increase, the role of the IMA project should be reviewed in this perspective. Additionally the fact that multiple parties have to work together increases the uncertainty about reliability of contracted parties, thereby increasing costs for negotiations (Panayides, 2002). As Panayides (2002) also states: "these costs are incurred when firms or organizations interact both in the initial stage of contracting and in the stage of enforcement of the contract. In the transaction cost concept vertical integration might lead to lowering of the transaction costs since a larger part of the chain is under own scrutiny."

Notteboom and Rodrigue (2011) found that through widely available information shippers are increasingly able to determine the activities in supply chains that generate costs, which puts a pressure on the entire chain. The authors state that the largest part of the total costs are made in the last part of the journey and therefore inland transportation has become increasingly important for the competition between distribution chains. With the enlargement of the hinterlands more inland terminals have been set up, and specifically in Europe a complex network of terminals exists. The emergence of more inland terminals have helped to lower the share of road transport in the advantage of rail and barge transport.

As a result of increasing demand for cleaner transport alternative fuel types emerge and find their way to current operators and transport companies (Western Governors Association, 2008). Bio-fuels such as ethanol and ethanol blends, biodiesels and renewable diesel types. But also a more extensive use of electricity, certain diesels produced through coal-to-liquid processes and hydrogen fuel. Compressed natural gas (CNG) and liquefied natural gas (LNG) are already in development and have found their use in transport. Because these developments are relatively new and alternative fuels currently evolve at various rates of development the data collection from operations is still limited. However it would be very interesting to produce similar calculations like the ones in this research using data, or projections and estimates, for the use of alternative fuels.

The challenges for short-sea shipping and maritime transport

The short-sea shipping market is characterized by three main technologies:

- Roll-on–Roll-off (RO–RO) cargoes compete on near sea and short-sea distances with local transport;
- Lift-on–Lift-off (LO–LO) competes over longer distances with rail, road and air transport;
- Float-on–Float-off (FLO–FLO)

As Casaca and Marlow (2007) show, specifically the Ro-Ro and Lo-Lo categories are important in the dry cargo market. The Ro-Ro market mainly competes on near sea and short-sea distances with local transport, whereas Lo-Lo competes mainly over longer distances with rail, road and air transport

The volume of international trade has grown dramatically, resulting in a different demand from shippers. Shippers increasingly expect their transport and logistics providers to supply more rapid and reliable delivery services to minimize their overall transport costs. With these chaning demands, carriers increasingly provide a variety of, and more sophisticated options in, their transport logistics services (Lun, 2002). As Baird (2007) concludes: "…if SSS is to penetrate this market, the challenge (for maritime transport) will be to offer the same overall service package as road transport, which is precisely what the Commission has suggested Motorways of the sea must achieve." Baird (2007) also refers to the ongoing development of new type of ships and fast-conventional RoRo/Ropax ferries. These types of vessels offer high payloads and thus scale economies, higher speeds, shorter transit times and excellent reliability. This is a positive development for the further competitiveness of short-sea shipping in the future.

"Short-sea shipping is competitive for a certain type of distance, product and with certain types of ships in relation to the time taken to travel from door-to-door", says Medda (2010). A project conducted on the effective distance in relation to short-sea shipping operations showed that it is convenient to select stretches of sea between 650–800 km, which thereby places short-sea shipping in direct competition with road freight (Medda, 2010).

For transshipment operations a terminal is needed and Rodrigue (1999) identifies the terminal as the main spill for improving a transport system. He comes up with a description of the 'space-time collapse' caused by globalization. This 'space-time collapse' is the result of large improvements in transportation and extensive infrastructural investments. The importance of time and space has to a large extent disappeared, since information is available every single moment, and cheap, reliable and fast transport widely available. Rodrigue (1999) concludes that only in terminals real time saving can occur, and terminals should therefore be the focus of improvements, he says.

Concluding remarks.

The market for short-sea shipping is thriving since the focus of society and the European Union is directed towards environmental friendly ways of transport, getting freight of the road and on to the water. Sea-river shipping as a relatively new concept has the potential to develop a stable mode of transport since transshipment at (congested) ports can be avoided. It is to be kept in mind however that the success of a sea-river innovation, according to literature, is dependent on its ability to offer a competitive alternative for road freight possibilities. In the Germany-UK corridor this potential seems rather likely.

3. Methodology

This third chapter focuses on the methodology used to find an answer on the main research question of this thesis. First the possible ways of dealing with such a question are provided and it is explained why a certain approach is chosen. The transport corridor is elaborated and explained and scenarios are sketched that are used as the basis for comparison. The second section of this methodology chapter is formed by the elaboration of the different modalities present in the scenarios and the indicators used to calculate their emissions, including the calculations and there assumptions.

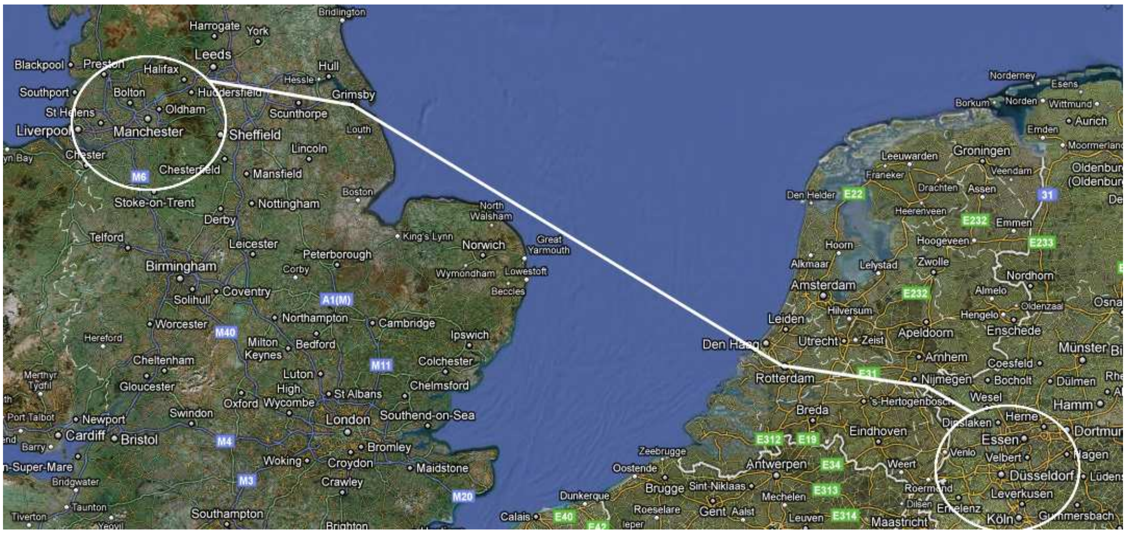
3.1 Research lay-out

The previously elaborated literature review showed that a number of researchers have also analyzed the way in which multimodality, short-sea shipping or sea-river shipping influences the emissions on a number of transport corridors. The approach these researchers chose was sometimes very different and depended largely on the focus of their research. In order to analyze the effect of the IMA sea-river innovation in terms of GHG emissions, a combination is made of the ways three researchers performed their research. Medda and Trujillo (2010) analyzed the marginal external costs of short-sea shipping on the Genoa-Preston corridor. Patterson (2008) provided an analysis of the Quebec City-Windsor corridor and looked at the CO2 reduction of a multimodal transport option. The author elaborated a number of scenarios of which one was a truck-only scenario. Leonardi and Brown (2010) made a very practical analysis of an apple and furniture supply chain and calculated the total energy use and GHG emissions for a number of scenarios. Different steps in these scenarios were elaborated and per step the energy use of the used modality (in this case mostly deep-sea ships) was calculated to result in a total emission figure per scenario. In this research a number of indicators were used, of which the ‘Fuel use’, ‘Capacity in TEU’ and ‘Load factor in %’ were the most important.

To determine the influence of a sea-river innovation on the reduction of the carbon footprint of container and ro-ro transport on the Germany-UK corridor, a combination is made from the approaches taken in the before mentioned researches. What is eminent from these researches is that they were focused on busy trading/transport corridors and elaborated a number of scenarios that provided the basis for comparison.

The corridor and transport route. To be able to analyze the potential effect of a sea-river innovation on the carbon footprint of a transport corridor it was important to take into account a number of characteristics. The first being that the corridor needed to be busy and coping with a number of problems concerning external costs such as congestion and transport emissions. Secondly the selected corridor had to be able to provide a solid potential for a sea-river innovation. After consideration of these aspects the Germany-UK corridor was selected. More specifically the transport route between the very busy German Ruhr area and the large industrial area of Greater Manchester, which generate a vast amount of cargo and trade. These large industrial areas causes a number of problems concerning transport, besides this the corridor has a good network of navigable waterways and therefore a strong potential for a sea-river innovation. The route that was chosen to analyze in this corridor was that between the city of Neuss in the Ruhr area to Manchester, via the port of Rotterdam and Immingham. The route is presented graphically below in figure 9:

Figure 9, The Neuss-Manchester route as a basis for analysis



Source: Google Maps (2011)

Six scenarios. To transport cargo from Neuss to Manchester a number of modalities can be used. The selection of modalities have determined six scenarios, which present the most common possibilities for unitized transport on this corridor and specific route. Each of these scenarios involves another modal split and provides a different view on the influence of modality choice on the carbon footprint of the transport chain as a whole. Two of the six scenarios involve the IMA Sea-river project, whereas the other four scenarios feature 'traditional' modalities. To quantify the results, emissions are calculated during every step of each scenario. In these steps a number of determinants are taken into account, which are identical for every scenario, providing a solid basis for comparison, these determinants are elaborated in paragraph 3.2.

The load. Since the IMA Sea-river project will be capable of transporting unitized cargo, containers as well as unaccompanied trailers, the load in this research is defined as a so-called Fourty-feet Equivalent Unit (FEU), because such a unit has about the same size and measurements as a truck trailer. The FEU in this research has a total weight of 26 tons. This weight includes the weight of the load and the container itself (CE Delft, 2008).

Modalities. In this research the emissions of the following modalities are taken into account:

Table 2. Used modalities in scenarios

Modality	Fuel type	Used in scenario
Truck (EURO 4-5)	Diesel	1, 2, 3, 4, 5, 6
Train	Electricity	2, 4, 6
Train	Diesel	4, 6
Barge	Fuel oil (Marine diesel oil)	3
Short-sea ship	Fuel oil (Marine diesel oil)	1, 2, 3
Sea-river RoCon	Fuel oil (Marine diesel oil)	5, 6

The selection of modalities included in this thesis is based on that from the STREAM report. The data from this report is based on fleet averages in the Netherlands in 2008 (CE Delft, 2008).

3.2 Emission calculation, definitions and base data

To measure the effect of the IMA Sea-river project, three types of emissions are taken into account in this thesis: CO2, NOx and PM10. That means that this study is elaborating the emission of 1) a GHG, 2) an emission influencing the forming of smog, and 3) an emission that negatively affects human health. In this part a description is made of what these types of emissions exactly are and what role they play in this analysis.

CO2. CO2 is the abbreviation of Carbon Dioxide. A gas that is naturally present in the Earth's atmosphere and is released in large quantities through the burning of fossil fuels such as diesel. Carbon Dioxide is commonly known for its effect on global warming. Due to its ability to absorb infrared radiation it lowers the reflection of heat from the sun and thereby it causes a greenhouse effect.

NOx. NOx is a general term for Nitric Oxide and Nitrogen Oxide (NO and NO2). These oxides are produced during combustion due to a reaction of Nitrogen and Oxygen gases in the air. NOx is an important factor in the formation of smog and acid rain and also key in the formation of ozone. It can form photochemical smog, a significant form of air pollution, especially during summer periods (Jacobson et. Al., 2004). The most important source of NOx production lies in nitrogen-bearing fuels such as coals and oil.

PM10. In the abbreviation PM10, PM stands for particulate matter and 10 describes the aerodynamic diameter, which in this case is maximum 10 micrometer. In this research we look at the so-called primary particulate matter, which arises during combustion of fossil fuels. But also through friction and evaporation. When looking at the sources of particulate matter for this research the emissions from traffic, through combustion in engines in trucks, ships and trains are most important. PM10 is taken into account in this research because high levels, especially in dense urban areas, can have considerable effects on human health (Vardoulakis & Kassomenos, 2006).

Emissions during transhipment and handling. In the analysis of transport emissions and for the sake of a fair comparison between different modalities and transport chains the direct emissions from transporting goods as well as indirect emissions from transhipment and handling activities have to be accounted for (Nellen, 2011). This is also stated by Geerlings & van Duin (2010) in their article on terminal emissions. The equipment used and the lay-out of the terminal are important factors determining the overall emission performance of a terminal. A distinction is made between diesel powered equipment and equipment running on electricity, for the production of which emissions are generated. By adding these different emissions a total CO2 emission per terminal can be calculated, based on the combinations of various equipment per container move and the different distances this equipment is driven.

Two steps. The emissions of trucks, barges, short-sea ships and trains are calculated in two steps. The basis of these calculations forms the approach taken in the STREAM report (CE Delft, 2008) in which the emissions for different modalities are calculated using a three step method. First the energy consumption of the vehicle is determined, secondly the emissions from this consumption and thirdly the emissions during the refining process of the needed fuel or energy. In this research only the energy consumption of the vehicle and the emissions resulting from this consumption are taken into account. Emissions during the refining process of the fuel are not taken into account because it was beyond the scope of this research to analyze the total fuel supply chain for every modality. Therefore the focus is on the direct effects of the transport only.

Energy consumption of the vehicle. At first the energy consumption of the modality in Mega Joules[1] (MJ) per ton/kilometer (t/km)[2] is calculated. To do so the following formula is used in which the energy consumption of the vehicle in MJ per t/km is a function of the energy consumption in MJ per kilometer, divided by the average load, times the percentage of productive kilometers.

$$Evhl = evhl/(L^{*}p)$$

Where: Evhl = vehicle's energy consumption in MJ (fuel) per t/km
evhl = energy consumption in MJ/km
L = load
p = productive kilometers

Vehicle emissions. Based on the energy consumption of the modality the resulting emissions are calculated. To do so the following formula is used in which the vehicle emission in grams per t/km is a function of the emissions per MJ of fuel times the vehicle's energy consumption.

$$EMvhl = emmj{-}fuel^{*}Evhl$$

Where: EMvhl = the vehicle emission in grams/ton km
emmj-fuel = the emission per MJ/fuel
Evhl = vehicle's energy consumption

3.2.1 Truck emissions

Road type. A distinction is made between three road types; city, secondary and highway. The road type has an important influence on the emissions of a truck, since the energy consumption on city roads is higher than on highways due to more braking and acceleration movements. In the calculations therefore the share of every road type in the total trip is estimated. These shares determine the average energy consumption during the trip in MJ/km. This energy consumption is the term *evhl* in the formula.

Load. The load in this analysis is the 26 tons FEU. However, when the truck has delivered this container it hypothetically takes back another container on its return trip. It is stated that in this case the return load is a 13 tons TEU, this means that the average load is 19.5 tons, the term *L* in the formula (CE Delft, 2008).

Productive kilometers. The productive kilometers of a truck are determined by the load it takes on its journey and the one it takes on the return trip. The capacity of the truck in this research is set to 27 tons. This means that the productive kilometers of this specific truck result to be 72%. The term *P* in the formula (CE Delft, 2008).

Vehicle emissions. Combining the three previous variables with emission figures from fuel the total vehicle emissions are calculated. To come to a figure for the emission of fuel on a specific trip, the emission data is combined with the road type distribution and the corresponding energy consumption of the truck. This results in an average energy consumption in MJ/km, which is then used to determine the average emission of CO2, NOx and PM10, the term *EMvhl* in the formula. Since the energy consumption of the truck already includes the load and since the emissions from fuel are dependent on the energy consumption, the resulting figure is the emission of the vehicle in grams per t/km.

---

[1] The joule is a derived unit of energy or work in the International System of Units.

[2] A ton kilometer (t/km) stands for the transport of 1 ton over 1 kilometer, or 10 kg. over a distance of 100 kilometers, and so on.

Base data. The above is summarized in the following table in which the base data for truck emission calculations is provided. In this table the energy consumption for each road type is combined with the load factor and productive kilometers, yielding the emission factors of CO2, NOx and PM10 in gram per kilometer.

Table 3. Base data truck emission calculations

	Energy consumption	Emission factors			Utilization degree based on capacity in tons
	DIESEL	CO2	NOx	PM10	
	MJ/Km	g/km	g/km	g/km	%
Total	12,1	883	10,0	0,33	52
City	18,1	1326	15,2	0,50	52
Secondary	12,6	923	10,7	0,35	52
Highway	10,8	790	8,8	0,29	52
Calculations are based on the following load factor and productive kilometers, yielding the utilization degree					
Load factor:	**72%**	Productive km.	**72%**		
Capacity:	27	Loaded on A-B trip	96%		
Load on A-B trip	26	Loaded on B-A trip	48%		
Load on B-A trip	13				

Source: Author calculations based on STREAM table 7, p.30 (2008)

3.2.2 Train emissions

Determinants. The emission of a train is dependent on a number of factors, of which the locomotive type, the number of locomotives pulling the train and the load are the most important. By combining the energy consumption of every additional locomotive with the additional energy needed to pull an extra ton of load the energy consumption figure can be calculated for every specific train.

Energy consumption. To calculate the energy consumption of a loaded train the following formula is used in which the before mentioned determinants are taken into account:

$$Etrainfull = n * Eloc + Mfull * Em$$

Where:
Etrainfull = energy consumption of a fully loaded train
n = the number of locomotives
Eloc = energy consumption of every locomotive
Mfull = gross mass of the fully loaded train
Em = energy consumption per ton gross weight

Vehicle emissions. This total energy consumption is transformed into emission figures using the emission figures per MJ from diesel and per Kwh[3]. of electricity production. The emissions of NOx and PM10 during this process are not taken into account due to a lack of data.

Base data. The above is summarized in the following table in which the base data for train emission calculations is provided. In this table the energy consumption for each locomotive type is provided combined with the additional energy consumption per extra ton of load.

---

[3] The kilowatt hour (Kwh) is a unit of energy equal to 1000 watt hours or 3.6 megajoules.

Table 4. Base data locomotives emission calculations

Train	Energy consumption locomotive	Energy consumption Gross weight wagons
	MJ/km	**MJ/tkm**
Electric	3	0,05
Diesel	25	0,11

Source: STREAM table 11, p.33 (2008)

Table 5. Base data train emission calculations

Container transport	No. of locs	No. of wagons	Capacity in TEU	gross weight locomotive	Weight empty wagon	
					Including 3 empty containers	Excluding 3 empty containers
Electric	1	22	66	88	27,5	25,3
Diesel	1	22	66	110	27,5	25,3

Load factor	Loaded no. Of TEU	Weight per TEU in total (load + container weight)	Total train load in tons	Gross mass of full train Load + wagons in tons
75%	50	13	643,5	1200,1
75%	50	13	643,5	1200,1

Source: Author calculations based on STREAM table 12, p.33 (2008)

3.2.3 Barge emissions

Two steps. The calculation of emissions from barges is performed according to the same methodology as discussed earlier in this paragraph. Based on the energy consumption and the emission from this consumption the total emissions are calculated.

Generators. Not only the main propulsion engines of the ship generate emissions, also the generator aboard, generating the needed electricity for machinery and facilities. In the calculations these emissions are also taken into account. Using this method also the emissions during quay time are accounted for thereby. Generator emissions can have an important influence on the overall emissions from ships (*P. Blanken, 2011) (CE Delft, 2008).*

Round-trip. The emissions of barges are calculated based on a round-trip model. This means that the emission figures are based on a trip from A to B and back. This is important because in this way the current directions of the rivers are taken into account, which have a large influence on the needed engine power and thereby the energy consumption and so the emission figures.

Load Factor. The load factor of the ship is set to 75% (CE Delft, Jens, J., 2005). In the scenario in which a barge is used the assumption is made that only a 200TEU Rhine container ship is used. This seems fair since the TEU capacity (excluding trailers) of the Sea-river ship, with which it competes on this part of the journey, is 210. (Sea-river business plan, 2011)

Base data. The above is summarized in the following table in which the base data for barge emission calculations is provided.

Table 6. Base data barge emission calculations

	Capacity TEU	Capacity Tons	Load factor	Productive kilometers	Energy consumption on Rhine river in MJ/km	Change in energy consumption per % load factor in MJ/km
Container ship (Rhine)	200	2600	75%	78%	535,2	3,8
Container ship (JOWI class)	470	6110	75%	78%	768,6	7,4

	CO2 g/MJ	NOx g/MJ	PM10 g/MJ
Emission factors inland shipping	73	1,07	0,049

Source: Author calculations based on STREAM table 15 + 16, p.36,table 17, p. 37 and table 49, p. 117 (2008)

3.2.4 Short-sea ship emissions

Damen 800 Container Feeder. In this analysis the short sea ferry is visualized as a DAMEN 800 class ship. With a capacity of 7987tons. The ship consumes traditional fuel oil. And its capacity is approximately 800TEU. For more information on this vessel one can consult appendix 7 of this report. In this analysis wind and current directions are not taken into account. The Damen feeder is a modern ship, which makes a comparison with the IMA Sea-river RoCon innovation more equal.

GT-class. Using the data from the STREAM (2008) report it is found that the DAMEN 800 ship is part of the GT class ranging from 1599 – 9999GT. The average in this class is 5800GT. (Table 50, STREAM (2008). In order to provide a reliable figure, the energy consumption figure is calculated using this average, to come to an estimated energy consumption level for the ship in this analysis.

Energy consumption. The energy consumption of the vessel is the product of its consumption in MJ per kilometer divided by the average load, times the percentage of productive kilometers the ship sails. In this case the load is defined as 6000 tons on this specific trip. On the return trip the ships takes on a new load, defined in this case as 6000 tons. These figures determine the productive kilometers.

Base data. The above is summarized in the following table in which the base data for barge emission calculations is provided.

Table 7. Base data barge emission calculations

	Energy consumption	Emission factor		
	MJ/km	CO2 g/km	NOx g/km	PM10 g/km
5800GT	754	116000	2300	100
7987GT	**866**	**130189**	**2855**	**142**
20000GT	1484	208000	5900	370
Loadfactor:			**75%**	
Productive kilometers			**75%**	

Source: Author calculations based on STREAM table 18, p.37 (2008)

3.2.5 Sea-river RoCon emissions

PON Caterpillar. Due to a lack of actual emission data of the ship due to the fact that the ship has not yet been built, the emissions of the Sea-river RoCon project are calculated using the emission data from the engine manufacturer, PON Caterpillar. The data available on the engine's fuel consumption under several conditions is a good proxy for the overall fuel consumption in different scenarios.

MCR. To measure the fuel consumption of the engines under several conditions the MCR is used, this means the Maximum Continuous Revolution of the engine. This MCR is lower than the maximum power output of the engine, but it defines the maximum power output the engine can deliver continuously, without a restriction of time. In this case the MCR of the fitted engines is defined at 1250kW each (P. Blanken, Project engineer Damen). Also for the generator set the MCR is defined. By following the MCR of the main propulsion, which is 93% of maximum power the MCR is set at 93% of 301kW = 280kW.

The emission of the ship is calculated under three different conditions.

Sailing at sea. When sailing at sea both engines have to work at 100% of their continuous power output. In this case therefore the total power output is 2 x 1250kW = 2500kW. This part of the trip concerns the route between Rotterdam and Immingham. The speed of the ship under these conditions is 12knots (P. Blanken, 2011).

Downstream sailing on the river Rhine. When the ship sails downstream on the river Rhine it only has to make use of 75% of the power output of one engine. That means that the total power output is 75% of 1350 = 1000kW. This part of the trip concerns the route between Neuss and Rotterdam. The maximum permitted speed at the Rhine is 11knots. The current in this respect is defined at 3 knots, which means that the ship has to achieve a speed of only 8 knots (P. Blanken, 2011).

Up-Stream sailing on the river Rhine. When the ship has to sail upstream on the river Rhine it fully needs the power of both engines. The power output in this case therefore is 2 x 1250kW = 2500kW. This part of the trip concerns the route between Rotterdam and Neuss. The maximum permitted speed at the Rhine is 11knots. Since the ship has to sail against the current, it can only achieve a speed of 7 knots though (P. Blanken, 2011).

Fuel consumption. The fuel consumption of the engines is based on the output they have to deliver. In the following table the fuel consumption is shown for the situation in which one engine is used (downstream) and for the situation in which both engines are used (upstream and at sea). Besides the fuel consumption of the main propulsion engines, also the generator aboard uses fuel, this is taken into account in the calculations as well. The generator not only runs when the ship is sailing but also when it is being loaded/unloaded etc. Therefore the generator emission is calculated over the total trip time in hours, including sailing, loading and discharging. A round trip using the Sea-river RoCon ship takes 4 days, so 96 hours (Sea-river business plan, 2011).

Table 8. Fuel consumption Sea River RoCon

Number of engines	**kW** in total	**Fuel consumption** liter per hour
1	1000	280
2	2500	333
Generator set	301	100

Source: information obtained from P. Blanken, project engineer at Damen Shipbuilders, 2011

The fuel consumption of the ship is calculated according to the number of hours the engines have to run on a specific trip under a specific condition. By averaging the figures a general fuel consumption figure is calculated. Based on this figure the emission of CO2 can be found using the emission figures per MJ from diesel. This data is reviewed alongside the data provided by the engine builder PON Caterpillar as a check. The test data provided by the engine builder is also used to calculate NOx and PM10 emissions. For the calculation of emissions the following data is used:

Table 9. Emission factors Sea River RoCon

	MCR %	CO2 kg./hr.	NOx gr./hr.	PM10 gr./hr.
Main propulsion	100 75	786 640	8697 5893	65 62
Generator set	100 75	200 188	1765 1318	37 27

Source: information obtained from P. Blanken, project engineer at Damen, 2011

Capacity. The load factor of the Sea River RoCon vessel in this analysis is defined at 75%. The capacity of each ship is 163 units, which, just for the sake of analysis have been converted to FEU, the results are found in the table below. To calculate emissions per t/km the capacity and load factor of the ship are taken into account. Since the capacity is 3510 tons, and the load factor over the first three years is about 75% the load of the ship is defined at 2633 tons.

Table 10. FEU capacity Sea River RoCon

Load	Units	FEU
Unaccompanied trailers (2 decks)	61	61
20’ containers/tanks	10	5
30’,40’ containers/tanks	12	10
45’ containers	80	90
Total Units	163	166

Source: Sea-river business plan, 2011

3.2.6 Terminal emissions

Short-sea terminals. In the analyzed scenarios only two short-sea terminals are considered. The Rotterdam Short-sea Terminal (RST) in the port of Rotterdam and the ABP terminal in the port of Immingham (ABP). It is important to take the emissions during transshipments of the container into account because these have an influence on the overall performance of the transport chain (Geerlings, Van Duin 2010). During transshipment a number of vehicles and machines are used of which some are diesel- whilst some others are electrically powered. The direct and indirect emissions are taken into account, the emissions during the electricity production are accounted for as well. Every terminal has another layout, resulting in different sub-processes to handle containers and therefore different emission levels. For both short-sea terminals only the emission of CO2 is taken into account, due to a lack of data. The emissions of NOx and PM10 are estimated based on the analysis of Nellen (2011). Since the emissions of NOx and PM10 are relatively small compared to the entire transport chain they are estimated to have the same proportion as the inland terminals analyzed in that research.

For the transshipment of a container from a truck to a ship the following sub-processes occur at both short-sea terminals:

TRUCK >>>> STACK >>>> STACK >>>> SEA SHIP

Each terminal handles its containers differently and with a wide variety of equipment. The terminals in this research make use of the following equipment:

1	Quay Crane	(QC)
2	Rail -mounted Stacking Crane	(RSC)
3	Terminal Truck	(TT)
4	Reach Stacker	(RS)

Base data. Each of these types of equipment uses energy in the form of electricity or diesel. In the scenarios these details are analyzed in depth, combining the equipment types' energy consumption per kilometer (in Kwh. or liter) with the number of kilometers the equipment is driven per container move. The calculations are based on the following data:

Table 11. Base data short-sea terminal emission calculations

Type of equipment	Energy	Fixed cons. per containermove kw/h	Variable cons l/km
BC RC, ASC, P QC RSC	Electric Electric Electric Electric	4,00 5,00 6,00 7,25	
AGV	Diesel	1,1 liter	1,80
SC	Diesel	0,80 liter	3,50
TT	Diesel		4,00
MTS	Diesel		4,20
RS	Diesel		5,00

Source: Geerlings en Van Duin table 1, p. 5 (2010)

Inland- and Rail terminals. In the analyzed scenario in which a barge, train or the Sea-river RoCon ship is used the transshipment of the container is performed on an inland terminal. Due to a lack of data and since the emissions of these terminals have a rather limited effect on the overall emissions of the transport chain, emission figures are estimated based on the analysis of Nellen (2011). In this study the emissions of a number of different inland terminals in the Netherlands are analyzed:

Nijmegen (Container Terminal Nijmegen, CTN),	old terminal
Den Bosch (Bossche Container Terminal, BCT),	large terminal
Veghel (Inland Terminal Veghel, ITV),	small terminal
Alphen aan de Rijn (Alpherium),	new terminal

Base data. Since the analysis of Nellen (2011) is based on the equipment distinctions made by Geerlings and Van Duin (2010) the equipment data forming the basis of calculations here is identical to the ones used for analyzing short-sea terminal emissions. The estimations for the inland terminals in the different scenarios consider the type of terminal in relation to the following data:

Table 12. Base data inland terminal emissions

Terminal	CO2 In kg. per container move	NOx In kg. per container move	PM10 In kg. per container move
CTN	4.27-6.65 (5.46 on avg.)	0.048	0.004
BCT	5.37-7.29 (6.33 on avg.)	0.056	0.004
ITV	3.28-3.95 (3.62 on avg.)	0.053	0.004
Alpherium	3.50 (average, est.)	0.051 (est.)	0.004 (est.)

Source: Nellen, tables 5 + 7 + 9 (2010) and author estimations

4. Scenarios

In this chapter the scenarios as introduced in the methodology section of this report are further elaborated. For every scenario a detailed description is made from the different steps that are needed to transport the load from Neuss to Manchester and the emissions resulting from these steps are calculated. At the start of each scenario description the characteristics of the scenario are provided in terms of total distance, used modalities and number of transshipments. Secondly an overview is given for each scenario in the form of a map, consisting of the route and the projection on that map of the different activities in the specific scenario. At the end of each scenario a summary is provided in which the emissions from all the steps are added together to form a total emission figure per scenario, which is briefly discussed at last.

In every scenario a large number of calculations were made in order to come to the presented emission figures, these detailed calculations are to be found in the appendix section of this report. A reference to these calculations is made in the scenarios when necessary.

4.1 Scenario 1 “truck_sss_truck”

Main characteristics. The first scenario describes the transport of the container per truck, short-sea ferry and truck. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 1.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*880 kilometers*
Used modalities:	*truck: 505 kilometers, short-sea ferry: 375 kilometers*
Transshipments:	*2, Rotterdam and Immingham*

Overview. An overview of the first scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 5, is elaborated afterwards.

Figure 10, Overview scenario 1

Source: Google Maps (2011)

Activity 1. Driving from Neuss to Rotterdam. The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the Short sea Terminal in Rotterdam via the city of Neuss. This trip has a total distance of approximately 280 kilometers, distributed between city roads, secondary roads and highways, table 12 shows the distribution of the different road types for this specific trip.

Table 13. Distribution of road types for route Neuss - Rotterdam

			% of total	Kilometers
Route total kilometers	280	City	5%	14
		Secondary	10%	28
		Highway	85%	238

Source: author estimates based on Google Maps (2011)

To calculate the emissions of the truck on this trip the energy consumption of the truck and the emissions related to this consumption are taken into account. Combining the emissions from the vehicle with the total number of ton kilometers, 26*280 = 7280, yields the total emissions:

Table 14. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	429.33	4.82	0.16

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the Rotterdam Short-sea Terminal (RST). When the container arrives at the RST it is transshipped from the truck to a short-sea ferry that takes it to the port of Immingham. For the performance of this transshipment the following machines are used (Oonk, 2006):

- **Quay Crane (QC):** used to (un) load different types of ships. Electrically driven cranes that can pick up a container directly from a tractor or automatic guided vehicle.
- **Platform (P):** electrically driven type of equipment
- **Rail -mounted Stacking Crane (RSC):** gantry cranes placed on rails, electrically driven
- **Reach Stacker (RS):** transport containers on short distances, diesel powered.

According to Geerlings and Van Duin (2010) the RST has two alternative ways for the transshipment of a container from a truck to a ship, one completely electric and one diesel/electric alternative. To come to a figure for the emissions during the transshipment at the RST the average of these figures is calculated, based on the idea that on average the diesel/ electric and fully electric alternative are used aside each other. This results in the following emissions:

Table 15. Total emissions during activity 2

	CO2	NOx	PM10
Total emission in kg.	27.55	0.28	0.02

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 3. Sailing from Rotterdam to Immingham. During the third stage of the trip the container is transported on a short-sea ferry from the port of Rotterdam to the port of Immingham. The distance between the two ports is roughly 375 kilometers. To calculate the emissions of the vessel on this trip the energy consumption and the emissions related to this consumption are taken into account . Combining the emissions from the vessel with the total number of ton/kilometers, 26*375 = 9750 yields the total emissions during this trip:

Table 16. Total emissions during activity 3

	CO2	NOx	PM10
Total emission in kg.	281.62	6.18	0.31

Source: author calculations based on STREAM table 18, p.37 (2008)

Activity 4. Transshipment at the ABP Terminal Immingham (ABPT). When the container arrives at the ABP Terminal it is transshipped from the short-sea ferry to a truck that takes it to the greater region of Manchester. For the performance of this transshipment the following machines are used (Oonk, 2006):

- **Quay Crane (QC):** used to (un) load different types of ships. Electrically driven cranes can pick up a container directly from a tractor or automatic guided vehicle.
- **Terminal Truck (TT):** diesel powered type of truck transporting trailers or containers
- **Rail -mounted Stacking Crane (RSC):** gantry crane placed on rails, electrically driven
- **Reach Stacker (RS):** transports containers on short distances, diesel powered.

This results in the following emissions:

Table 17. Total emissions during activity 4

movement	Used equipment	Fuel type	Energy consumption	kwh l/km	Distance driven on average	Emissions		
						CO2	NOx	PM10
Ship to Terminal Truck	QC	Electric	6,00	kwh	0	2,17		
To stack	TT	Diesel	4,00	l/km	1,5	15,90		
Stack to stack	RSC	Electric	7,25	kwh	0	2,63		
	RSC	Electric	7,25	kwh	0	2,63		
Stack to truck	RS	Diesel	5,00	l/km	0,3	3,98		
TOTAL emissions per container move in kg.						27,30	0,27	0,021

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 5. Driving from Immingham to Manchester. The last activity in the transport chain is the transportation by truck from the port of Immingham to the greater area of Manchester. This trip has a total distance of 225 kilometers, distributed between city roads, secondary roads and highways. Table 18 shows the distribution of the different road types for this specific trip.

Table 18. Distribution of road types for route Immingham-Manchester

			% of total	Kilometers
Route total kilometers	225	City	10%	22,5
		Secondary	10%	22,5
		Highway	80%	180

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*225 = 5850, yields the total emissions:

Table 19. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	356.13	4.00	0.13

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 1.

Table 20 provides the summary of emissions from scenario 1

Table 20. Summary of emissions scenario 1

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	429.33	4.82	0.16
2	27.55	0.28	0.02
3	281.62	6.18	0.31
4	27.30	0.27	0.02
5	356.13	4.00	0.13
Chain total	**1121.93**	**15.55**	**0.64**

Source: authors calculations based on Geerlings et. al. (2010), STREAM(2008) and Nellen (2011)

From scenario 1 we can conclude a number of things. The first thing is that the trucking part of the scenario is responsible for the largest part of emissions, from CO2 as well as NOx and PM10. The second thing is that the short-sea shipping part of only 375 kilometers emits roughly 281 kg. of CO2, which seems quite a high figure. When compared to road freight however it is found that the short-sea shipping part of the trip emits less than half that of the truck. (Short-sea shipping about 0.75 kg. CO2 per kilometer, trucking around 1.6 kg. per kilometer).

4.2 Scenario 2 “truck_train_sss_truck”

Main characteristics. The second scenario describes the transport of the container per truck, train, short-sea ferry and truck. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 2.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*858 kilometers*
Used modalities:	*truck: 275 kilometers, train: 208 kilometers, short-sea ferry: 375 kilometers*
Transshipments:	*3, Neuss, Rotterdam and Immingham*

Overview. An overview of the second scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 7, is elaborated afterwards.

Figure 11, Overview scenario 2

Source: Google Maps (2011)

Activity 1. Driving from greater Neuss to the Neuss Intermodal Terminal (NIT). The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the Neuss Intermodal Terminal in the port of Neuss. This trip has a total distance of approximately 50 kilometers, table 21 shows the distribution of the different road types for this specific trip.

Table 21. Distribution of road types for route Greater Neuss - NIT

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

To calculate the emissions of the truck on this trip the energy consumption and the emissions related to this consumption are taken into account. Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions:

Table 22. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the NIT. When the container arrives at the NIT it is transshipped from the truck to a train that takes it to the port of Rotterdam. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the NIT is compared to inland terminals analyzed by Nellen to form a realistic estimation, the results of this analysis are provided below:

Table 23. Emissions during transshipment at NIT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6,33		
Alpherium	3,50		
Neus Intermodal Terminal	4,92		
TOTAL emissions per container move in kg.	4,92	0,05	0,004

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 3. Train from the NIT to Rotterdam. From the NIT the container is transported to Rotterdam by train. This trip, of roughly 208 kilometers, is performed by electric train, a very clean type of transport with low emissions. The emissions in this respect come from the production of electricity. The particulate matter produced by the movements of the train are not taken into account. Table 24 provides the emissions during this part of the trip:

Table 24. Total emissions during activity 3

	CO2	NOx	PM10
Total emission in kg.	53.27	0.00	0.00

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 4. Transshipment at the RST. When the container arrives at the RST it is transshipped from the train to a short-sea ferry that takes it to the port of Immingham. According to Geerlings & van Duin (2010) the RST has two alternative ways for the transshipment of a container from a train to a ship, one completely electric and one diesel/electric alternative. The average of these figures is calculated based on the idea that on average the diesel/ electric and fully electric alternative are used aside each other. The transshipment operations produce the following emissions:

Table 25. Total emissions during activity 4

	CO2	NOx	PM10
Total emission in kg.	27.55	0.28	0.02

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 5. Sailing from Rotterdam to Immingham. During the fifth stage of the trip the container is transported on a short-sea ferry from the port of Rotterdam to the port of Immingham. The distance between the two ports is roughly 375 kilometers. To calculate the emissions of the vessel on this trip the energy consumption of the vessel and the emissions related to this consumption are taken into account . Combining the emissions from the vessel with the total number of ton/kilometers, 26*375 = 9750 yields the total emissions during this trip:

Table 26. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	281.62	6.18	0.31

Source: author calculations based on STREAM table 18, p.37 (2008)

Activity 6. Transshipment at the ABPT. When the container arrives at the ABP Terminal it is transshipped from the short-sea ferry to a truck that takes it to the greater region of Manchester. This results in the following emissions:

Table 27. Total emissions during activity 6

movement	Used equipment	Fuel type	Energy consumption	kwh l/km	Distance driven on average	Emissions		
						CO2	NOx	PM10
Ship to Terminal Truck	QC	Electric	6,00	kwh	0	2,17		
To stack	TT	Diesel	4,00	l/km	1,5	15,90		
Stack to stack	RSC	Electric	7,25	kwh	0	2,63		
	RSC	Electric	7,25	kwh	0	2,63		
Stack to truck	RS	Diesel	5,00	l/km	0,3	3,98		
					TOTAL emissions per container move in kg.	27,30	0,27	0,021

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 7. Driving from Immingham to Manchester. The last activity in the transport chain is the transportation by truck from the port of Immingham to the greater area of Manchester. Table 28 shows the distribution of the different road types for this specific trip:

Table 28. Distribution of road types for route Immingham-Manchester

			% of total	Kilometers
Route total kilometers	225	City	10%	22,5
		Secondary	10%	22,5
		Highway	80%	180

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*225 = 5850, yields the total emissions during this trip:

Table 29. Total emissions during activity 7

	CO2	NOx	PM10
Total emission in kg.	356.13	4.00	0.13

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 2.

Table 30 provides the summary of emissions for this transport chain

Table 30. Summary of emissions scenario 2

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	80.37	0.91	0.03
2	4.92	0.05	0.004
3	53.27	0.00	0.00
4	27.55	0.28	0.02
5	281.62	6.18	0.31
6	27.30	0.27	0.02
7	356.13	4.00	0.13
Chain total	**831.16**	**11.68**	**0.52**

Source: authors calculations based on Geerlings et. al. (2010), STREAM (2008) and Nellen (2011)

From scenario 2 we can conclude that the use of a train instead of a truck, as was the case in scenario 1, substantially reduces the overall emissions from the total transport chain. Although an extra transshipment needs to be made the overall emission figure remains relatively low with respect to scenario 1 although the distance of 208 kilometers driven by train is fairly short, only a fourth part of the total trip.

4.3 Scenario 3 "truck_barge_sss_truck"

Main characteristics. The third scenario describes the transport of the container per truck, barge, short-sea ferry and truck. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 3.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*915 kilometers*
Used modalities:	*truck: 275 kilometers, barge: 265 kilometers, short-sea ferry: 375 kilometers*
Transshipments:	*3, Neuss, Rotterdam and Immingham*

Overview. An overview of the third scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 7, is elaborated afterwards.

Figure 12, Overview scenario 3

Source: Google Maps (2011)

Activity 1. Driving from greater Neuss to the Neuss Intermodal Terminal (NIT). The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the Neuss Intermodal Terminal in the port of Neuss. This trip has a total distance of approximately 50 kilometers, with a distribution as shown in table 32:

Table 31. Distribution of road types for route Greater Neuss - NIT

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 32. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the NIT. When the container arrives at the NIT it is transshipped from the truck to a barge that takes it to the port of Rotterdam. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the NIT is compared to inland terminals analyzed by Nellen to form a realistic estimation. The results of this analysis are provided in table 33:

Table 33. Emissions during transshipment at NIT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6,33		
Alpherium	3,50		
Neus Intermodal Terminal	4,92		
TOTAL emissions per container move in kg.	4,92	0,05	0,004

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 3. Barge from the NIT to Rotterdam. From the NIT the container is transported to Rotterdam via inland waterways. This trip, of roughly 265 kilometers, is performed by barge. Table 34 provides the emissions during this part of the trip:

Table 34. Total emissions during activity 3

	CO2	NOx	PM10
Total emission in kg.	330.68	4.85	0.22

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 4. Transshipment at the RST. When the container arrives at the RST it is transshipped from the train to a short-sea ferry that takes it to the port of Immingham. This transshipment results in the following emissions:

Table 35. Total emissions during activity 4

	CO2	NOx	PM10
Total emission in kg.	27.55	0.28	0.02

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 5. Sailing from Rotterdam to Immingham. During the fifth stage of the trip the container is transported on a short-sea ferry from the port of Rotterdam to the port of Immingham. The distance between the two ports is roughly 375 kilometers. Combining the emissions from the vessel with the total number of ton/kilometers, 26*375 = 9750 yields the total emissions during this trip:

Table 36. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	281.62	6.18	0.31

Source: author calculations based on STREAM table 18, p.37 (2008)

Activity 6. Transshipment at the ABPT. When the container arrives at the ABP Terminal it is transshipped from the short-sea ferry to a truck that takes it to the greater region of Manchester. This results in the following emissions:

Table 37. Total emissions during activity 6

movement	Used equipment	Fuel type	Energy consumption	kwh l/km	Distance driven on average	Emissions		
						CO2	NOx	PM10
Ship to Terminal Truck	QC	Electric	6,00	kwh	0	2,17		
To stack	TT	Diesel	4,00	l/km	1,5	15,90		
Stack to stack	RSC	Electric	7,25	kwh	0	2,63		
	RSC	Electric	7,25	kwh	0	2,63		
Stack to truck	RS	Diesel	5,00	l/km	0,3	3,98		
					TOTAL emissions per container move in kg.	27,30	0,27	0,021

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 7. Driving from Immingham to Manchester. The last activity in the transport chain is the transportation by truck from the port of Immingham to the greater area of Manchester. Table 38 shows the distribution of the different road types.

Table 38. Distribution of road types for route Immingham-Manchester

			% of total	Kilometers
Route total kilometers	225	City	10%	22,5
		Secondary	10%	22,5
		Highway	80%	180

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*225 = 5850, yields the total emissions during this trip:

Table 39. Total emissions during activity 7

	CO2	NOx	PM10
Total emission in kg.	356.13	4.00	0.13

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 3.

Table 40 provides the summary of emissions for this transport chain as a whole.

Table 40. Summary of emissions scenario 3

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	80.37	0.91	0.03
2	4.92	0.05	0.004
3	330.68	4.85	0.22
4	27.55	0.28	0.02
5	281.62	6.18	0.31
6	27.30	0.27	0.02
7	356.13	4.00	0.13
Chain total	**1108.57**	**16.53**	**0.74**

Source: authors calculations based on Geerlings et. al. (2010), STREAM(2008) and Nellen (2011)

Scenario 3 show that the transport over the river Rhine by barge generates about the same emissions as by truck. Additionally an extra transshipment is made which causes emissions, albeit a fairly small influence on the overall figure from the scenario. The emissions of NOx and PM10 are even higher than those of the first scenario, in which a truck was used instead of a barge.

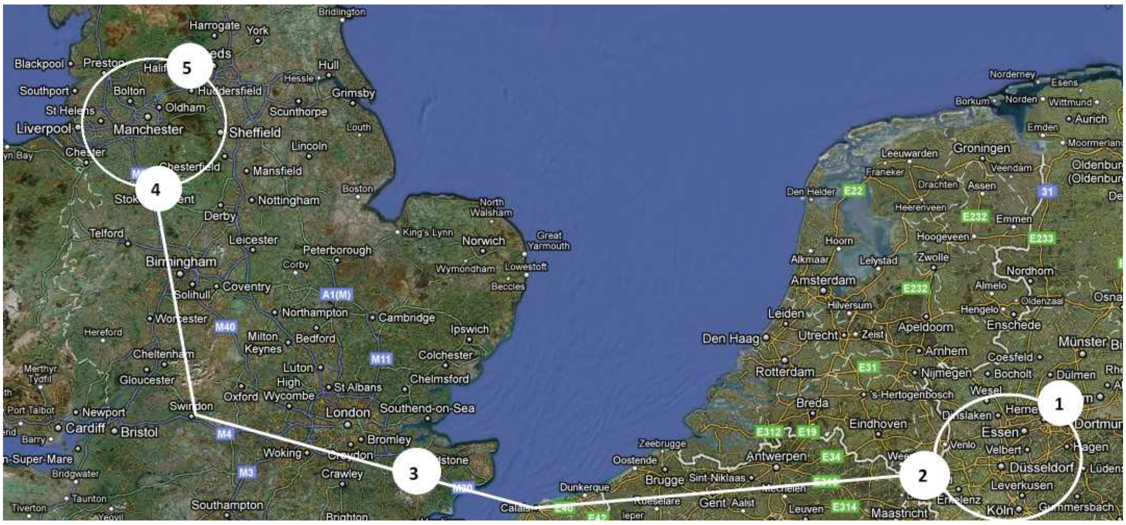
4.4 Scenario 4 "truck_tunnel-train_truck"

Main characteristics. The fourth scenario describes the transport of the container per truck and train. The train in this respect travels through the canal tunnel, directly to Manchester. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 4.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*1060 kilometers*
Used modalities:	*truck: 135 kilometers, train: 925 kilometers*
Transshipments:	*2, Duisburg and Manchester*

Overview. An overview of the fourth scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 5, is elaborated afterwards.

Figure 13, Overview scenario 4



Source: Google Maps (2011)

Activity 1. Driving from greater Neuss to the DUSS Terminal Duisburg (DTD). The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the DTD in the city of Duisburg. This trip has a total distance of approximately 85 kilometers. Table 41 shows the distribution of the different road types for this specific trip.

Table 41. Distribution of road types for route Greater Neuss - Duisburg

			% of total	Kilometers
Route total kilometers	85	City	10%	8.5
		Secondary	20%	17
		Highway	70%	59.5

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 42. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	136,63	1,54	0,05

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the DTD. When the container arrives at the DTD it is transshipped from the truck to a train. An estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the DTD is compared to inland terminals analyzed by Nellen to form a realistic estimation. The results of this analysis are provided in table 43:

Table 43. Emissions during transshipment at DTD

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6,33		
Alpherium	3,50		
Neus Intermodal Terminal	4,92		
TOTAL emissions per container move in kg.	4,92	0,05	0,004

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 3. Train from the DTD to Manchester. From the DTD the container is transported to Manchester by train, through the canal tunnel. This trip, of roughly 925 kilometers, is performed by electric train and diesel train. For 921 kilometers an electric train is used and for 4 kilometers a diesel powered one (Ecotransit, 2011). Table 44 provides the emissions during this part of the trip:

Table 44. Total emissions during activity 3

	CO2	NOx	PM10
Electric train	235.89	0.00	0.00
Diesel powered train	1.85	0.04	0.00
Total emission in kg.	237.74	0.04	0.001

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 4. Transshipment at the Manchester Rail Terminal (Roadways MCT). When the container arrives at the MCT it is transshipped from the train to a truck that takes it to the greater area of Manchester. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the MCT is compared to inland terminals analyzed by Nellen to form a realistic estimation. The results are provided in table 45:

Table 45. Emissions during transshipment at MCT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6.33		
CTN	5.46		
Roadways MCT	5.90		
TOTAL emissions per container move in kg.	5.90	0.06	0.005

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 5. Driving from the MCT to the greater area of Manchester. The last activity in the transport chain is the transportation by truck to the greater area of Manchester. This trip has a total distance of 50 kilometers, distributed in the following way:

Table 46. Distribution of road types for route MCT-Manchester

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

To calculate the emissions of the truck on this trip the energy consumption of the truck during this trip and the emissions related to this consumption are taken into account. Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 47. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 4.

Table 48 provides the summary of emissions for this transport chain.

Table 48. Summary of emissions scenario 4

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	136,63	1,54	0,05
2	4,92	0,05	0,004
3	237.74	0.04	0.001
4	5.90	0.06	0.005
5	80.37	0.91	0.03
Chain total	**465.54**	**2.59**	**0.09**

Source: authors calculations based on Geerlings et. al. (2010), STREAM(2008) and Nellen (2011)

Scenario 4, although the longest trip, shows what literature already told; an electric train is a very environmental friendly mode of transport. In this scenario the electric train through the channel tunnel is used for the majority of the trip and the result is remarkable, an overall emission figure that is less than half that of scenario in which the majority of the kilometers is performed by barge or truck. NOx/PM10 emissions being very low as well, mainly due to the fact that the train in this respect is an electric one.

4.5 Scenario 5 “truck_Sea-river RoCon_truck”

Main characteristics. The fifth scenario describes the transport of the container per truck and the Sea-river RoCon ship. The Sea-river ship sails from Neuss to Immingham directly. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 5.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*914 kilometers*
Used modalities:	*truck: 275 kilometers, Sea-river ship: 639 kilometers*
Transshipments:	*2, Neuss and Immingham*

Overview. An overview of the fourth scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 5, is elaborated afterwards.

Figure 14, Overview scenario 5

Source: Google Maps (2011)

Activity 1. Driving from greater Neuss to the Neuss Intermodal Terminal (NIT). The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the Neuss Intermodal Terminal in the port of Neuss. This trip has a total distance of approximately 50 kilometers, table 49 shows the distribution of the different road types for this specific trip.

Table 49. Distribution of road types for route Greater Neuss - NIT

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 50. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the NIT. When the container arrives at the NIT it is transshipped from the truck to the Sea-river ship that takes it directly to Immingham. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the NIT is compared to inland terminals analyzed by Nellen to form a realistic estimation.

Table 51. Emissions during transshipment at NIT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6,33		
Alpherium	3,50		
Neus Intermodal Terminal	4,92		
TOTAL emissions per container move in kg.	4,92	0,05	0,004

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 3. Sailing from Neuss to Immingham. During the third stage of the trip the container is transported with the Sea-river RoRo ferry from the NIT in Neuss to the port of Immingham. The distance between these two places is 639 kilometers. The emissions of the ship on this trip are calculated using the approach described in the methodology section of this report. Combining the emissions from the vessel with the total number of ton/kilometers, 26*639 = 16614, yields the total emissions during this trip:

Table 52. Total emissions during step 3

	CO2	NOx	PM10
Total emission in kg.	561.77	6.02	0.06

Source: author calculations based on P. Blanken, project engineer at Damen (2011)

Activity 4. Transshipment at the ABPT. When the container arrives at the ABP Terminal it is transshipped from the Sea-river RoCon vessel to a truck that takes it to the greater region of Manchester. This results in the following emissions:

Table 53. Total emissions during activity 4

movement	Used equipment	Fuel type	Energy consumption	kwh l/km	Distance driven on average	Emissions		
						CO2	NOx	PM10
Ship to Terminal Truck	QC	Electric	6,00	kwh	0	2,17		
To stack	TT	Diesel	4,00	l/km	1,5	15,90		
Stack to stack	RSC	Electric	7,25	kwh	0	2,63		
	RSC	Electric	7,25	kwh	0	2,63		
Stack to truck	RS	Diesel	5,00	l/km	0,3	3,98		
					TOTAL emissions per container move in kg.	27,30	0,27	0,021

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 5. Driving from Immingham to Manchester. The last activity in the transport chain is the transportation by truck from the port of Immingham to the greater area of Manchester. This trip has a total distance of 225 kilometers. Table 54 shows the distribution of the different road types.

Table 54. Distribution of road types for route Immingham-Manchester

			% of total	Kilometers
Route total kilometers	225	City	10%	22,5
		Secondary	10%	22,5
		Highway	80%	180

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*225 = 5850, yields the total emissions during this trip:

Table 55. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	356.13	4.00	0.13

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 5.

Table 56 provides the summary of emissions for this transport chain.

Table 56. Summary of emissions scenario 5

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	80.37	0.91	0.03
S 2	4,92	0,05	0,004
o 3	561.77	6.02	0.06
u 4	27,30	0,27	0,021
r 5	356.13	4.00	0.13
c **Chain total**	**1030.49**	**11.25**	**0.24**

Source: authors calculations based on expert interview (2011), Geerlings et al. (2010), STREAM(2008) and Nellen (2011)

The results from scenario 5 in which the IMA Sea-river project is included are maybe less positive than expected. In terms of CO2 emissions the scenario is able though to lower the amount of emissions with roughly 80kg. on this, relatively short, trip when compared to a traditional trucking (scenario 1) and barge alternative (scenario 3). The total NOx and PM10 emission levels however are clearly lower than those of the trucking and barge scenarios.

4.6 Scenario 6 “truck_Sea-river RoCon_train_truck”

Main characteristics. The last scenario describes the transport of the container by Sea-river RoCon ship in combination with trucks and a train. First the main characteristics of this scenario are provided, detailed calculations are to be found in Appendix 6.

Pick-up:	*greater Neuss in Germany*
Delivery:	*greater Manchester in the United Kingdom*
Total distance:	*914 kilometers*
Used modalities:	*truck: 100 kilometers, train: 175 kilometers, Sea-river ship: 639 kilometers*
Transshipments:	*3, Neuss, Immingham and Manchester*

Overview. An overview of the fourth scenario is provided below. It shows the route and the different activities that are performed. Each of these activities, 1 to 7, is elaborated afterwards.

Figure 15, Overview scenario 6

Source: Google Maps (2011)

Activity 1. Driving from greater Neuss to the Neuss Intermodal Terminal (NIT). The first activity in the transport chain is the transportation by truck from the area of greater Neuss to the Neuss Intermodal Terminal in the port of Neuss. This trip has a total distance of approximately 50 kilometers, table 57 shows the distribution of the different road types for this specific trip.

Table 57. Distribution of road types for route Greater Neuss - NIT

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 58. Total emissions during activity 1

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the NIT. When the container arrives at the NIT it is transshipped from the truck to the Sea-river ship that takes it directly to Immingham. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the NIT is compared to inland terminals analyzed by Nellen to form a realistic estimation. The results of this analysis are provided in table 59:

Table 59. Emissions during transshipment at NIT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6,33		
Alpherium	3,50		
Neus Intermodal Terminal	4,92		
TOTAL emissions per container move in kg.	4,92	0,05	0,004

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 3. Sailing from Neuss to Immingham. During the third stage of the trip the container is transported with the Sea-river RoRo ferry from the NIT in Neuss to the port of Immingham. The distance between these two places is 639 kilometers. Combining the emissions from the vessel with the total number of ton/kilometers, 26*639 = 16614, yields the total emissions during this trip:

Table 60. Total emissions during step 3

	CO2	NOx	PM10
Total emission in kg.	561.77	6.02	0.06

Source: author calculations based on P. Blanken, project engineer at Damen (2011)

Activity 4. Transshipment at the ABPT. When the container arrives at the ABP Terminal it is transshipped from the Sea-river RoCon vessel to a train that takes it to Manchester. This results in the following emissions:

Table 61. Total emissions during activity 4

movement	Used equipment	Fuel type	Energy consumption	kwh l/km	Distance driven on average	Emissions		
						CO2	NOx	PM10
Ship to Terminal Truck	QC	Electric	6,00	kwh	0	2,17		
To stack	TT	Diesel	4,00	l/km	1,5	15,90		
Stack to stack	RSC	Electric	7,25	kwh	0	2,63		
	RSC	Electric	7,25	kwh	0	2,63		
Stack to truck	RS	Diesel	5,00	l/km	0,3	3,98		
TOTAL emissions per container move in kg.						27,30	0,27	0,021

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 5. Rail transport from Immingham to Manchester. The fifth activity in the transport chain is the transportation by train from the port of Immingham to the Roadways MCT in Manchester. This trip has a total distance of 175 kilometers, and a diesel and electric train are used according to the following distribution:

Table 62. Use of train types Immingham to Manchester

			% of total	Kilometers
Route total kilometers	175	Diesel	77%	135
		Electric	23%	40

Source: eco-calculator on www.ecotransit.org (2011)

To calculate the emissions of the train on this trip the energy consumption of the different types of trains and the emissions related to this consumption are taken into account. Combining the emissions with the total number of ton/kilometers yields the total emissions during this trip:

Table 63. Total emissions during step 5

	CO2	NOx	PM10
Diesel	62,52	1,21	0,02
Electric	10,24	0,00	0,00
Total emission in kg.	72,76	1,21	0,02

Source: author calculations based on STREAM table 11 + 12, p.33/34 (2008)

Activity 6. Transshipment at the Manchester Rail Terminal (Roadways MCT). When the container arrives at the MCT it is transshipped from the train to a truck that takes it to its final destination in the greater area of Manchester. For the calculation of emissions during this transshipment an estimation is made based on the analysis of Nellen (2011). In this estimation the size and age of the MCT is compared to inland terminals analyzed by Nellen to form a realistic estimation.

Table 64. Emissions during transshipment at MCT

Compared inland terminal	Emissions		
	CO2	NOx	PM10
BCT	6.33		
CTN	5.46		
Roadways MCT	5.90		
TOTAL emissions per container move in kg.	5.90	0.06	0.005

Source: Nellen, tables 5 + 7 + 9 (2011) and author calculations

Activity 7. Driving from MCT to the greater area of Manchester. The last activity in the transport chain is the transportation by truck to the greater area of Manchester. This trip has a total distance of 50 kilometers, distributed in the following way:

Table 65. Distribution of road types for route MCT-Manchester

			% of total	Kilometers
Route total kilometers	50	City	10%	5
		Secondary	20%	10
		Highway	70%	35

Source: author estimates based on Google Maps (2011)

Combining the emissions from the vehicle with the total number of ton/kilometers, 26*50 = 1300, yields the total emissions during this trip:

Table 66. Total emissions during activity 5

	CO2	NOx	PM10
Total emission in kg.	80.37	0.91	0.03

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Summary of scenario 6.

Table 67 provides the summary of emissions for this transport chain.

Table 67. Summary of emissions scenario 6

Activity	CO2 (kg.)	NOx (kg.)	PM10 (kg.)
1	80.37	0.91	0.03
S 2	4,92	0,05	0,004
o 3	561.77	6.02	0.06
u 4	27,30	0,27	0,021
r 5	72,76	1,21	0,02
c 6	5.90	0.06	0.005
e 7	80.37	0.91	0.03
: **Chain total**	**833.38**	**9.42**	**0.17**

Source: authors calculations based on expert interview (2011), Geerlings et al. (2010), STREAM(2008) and Nellen (2011)

The combination of the IMA Sea-river vessel with a train service between Immingham and Manchester makes up for an interesting emission figure. The overall emissions from this scenario are roughly identical to the ones in a scenario in which a train is used to transport containers from the Ruhr area to the Port of Rotterdam, scenario 2. However, the figures for NOx and PM10 emissions are clearly lower, the reduction in NOx is about 20% and for PM10 a figure of 67% is found.

5. Main findings and conclusion

In this concluding chapter a summary is made of the results from the scenario analysis and literature review. First the results from the literature review are mentioned, secondly the main findings from the scenario calculations are provided. This research is performed to find an answer to the research question:

To what extent does a modern Sea-river RoCon innovation reduce the carbon footprint of container and ro-ro transport on the Germany-United Kingdom (UK) corridor?

Six scenarios were elaborated for the transport of a 26 tons container (FEU), from the German city of Neuss to the city of Manchester in the UK. For every step in these scenarios the emissions generated by the different modalities and transshipments were calculated and added, to form an overall emission figure per scenario. Four scenarios involved only 'traditional' modalities, in two scenarios the IMA Sea-river RoCon innovation was also included. The calculations not only focused on CO2 emissions, also NOx and PM10 emissions were taken into account. The results of the calculations, together with the results from the literature review provide an answer to our research question.

5.1 Main findings

General results

What is a carbon footprint? (sub question 1)
A literature review was made to provide a starting point for the analysis and a framework for the evaluation of the results. It was found that transport has a large share in the greenhouse problem, through emissions and other external costs that result from it. We have seen that the emission of CO2 defines the so-called carbon footprint and that in order to deal with climate change the way we transport goods and people needs to be changed or adapted. European policymakers pointed out that maritime transport was to be the solution for the transport problems relating to congestion and environmental impacts.

How is the Germany-UK corridor characterized, and which factors are important on this corridor?
(Sub questions 2 and 3)
A number of developments were found in the Ruhr-Immingham transport corridor, of which the high amount of transport is the most important. Due to the gateway function of the port of Rotterdam and the Rhine-Scheldt data this region deals with vast amounts of barge transport, road freight and external costs coming from this transport. Not only in this delta however such problems arise, also in the UK policies were made in this respect due to a sharp increase in road freight transport and the congestion and environmental issues resulting from this.

Is this the right solution for this market and the demands of society for a clean environment?
(Sub question 5)
The Sea-river RoCon project team proposes the financing, building and operating of four Sea-river Container Ro-Ro vessels that will provide daily short-sea services for containers and unaccompanied trailers between the German inland port of Neuss, in the Ruhr area, and the United Kingdom port of Immingham. One of the five main goals of the Sea-river RoCon project is to contribute to the environmentally friendly distribution of goods and help the reduction of the carbon footprint of the transported goods on the Germany-UK corridor.

The first important result from sea-river research is the advantage it has over traditional inland and sea shipping due to the fact that the transshipment of cargo in a seaport is avoided. Also the positive influence of this kind of transport on road- and rail congestion was mentioned in the majority of researches. The effect of not having to transship goods in a seaport is larger when the overall trip is shorter, an important conclusion from Konings and Ludema (2000). It was found that multimodal transport could be able to lower the amount of CO2 emissions on the Quebec City-Windsor corridor in Canada, a result that provides a good starting point for the research performed to the IMA Sea-River RoCon innovation.

Results from scenario calculations.

CO2 emissions are the lowest when transporting a container between Neuss and Manchester in scenarios in which the electric train plays a relatively large role, scenarios 2 and 4. Scenario 4 is the best example. In this scenario the container is transported by train between Duisburg and Manchester through the channel tunnel, generating a total CO2 emission of 465 kilograms. In scenario 2 the container is transported by train from Neuss to Rotterdam, a distance of 208 kilometers only, generating a total CO2 emission of 831 kilograms.

Both scenarios draw attention because of their low CO2 emissions in relation to scenario 1 and 3 in which the truck and barge play a larger role. The highest CO2 emission results from scenario 1, in which the truck plays a dominant role, generating a total CO2 emission of 1122 kilograms. Scenario 3, in which a barge is included generates a total of 1109 kilograms.

Scenario 5, in which the Sea-river RoCon ship is used in combination with a truck, shows that CO2 emissions are lower than in the other scenarios in which a truck is used, scenario 1 and 3. Scenario 5 generates a total of 1030 kilograms of CO2. Scenario 6, in which the Sea-river ship is used in combination with a train, generates a total CO2 emission of 833 kilograms.

Table 68. Comparison of CO2 emissions.

Comparison of CO2 emissions						
	t.o.v. scenario 1	t.o.v. scenario 2	t.o.v. scenario 3	t.o.v. scenario 4	t.o.v. scenario 5	t.o.v. scenario 6
scenario 1	0%	+35%	1%	+141%	+9%	+35%
scenario 2	-26%	0%	-25%	+79%	-19%	0%
scenario 3	-1%	+33%	0%	+138%	+8%	+33%
scenario 4	-59%	-44%	-58%	0%	-55%	-44%
scenario 5	-8%	+24%	-7%	+121%	0%	+24%
scenario 6	-26%	0%	-25%	+79%	-19%	0%

Source: authors calculations

NOx emissions are the lowest in scenarios in which a train is used. This is best visible in scenario 4, in which the container is transported nearly entirely by train. In this scenario the total NOx emissions are limited to only 2.6 kilograms. In scenario 2, in which the train plays a smaller role and only transports the container from Neuss to Rotterdam, the total NOx emission amounts to 11.7 kilograms.

The scenarios in which trucks play a larger role show similar results. Scenario 1, in which the truck is the dominant transport mode, the total NOx emission is 15.5 kilograms. Scenario 3, in which also a barge is included, the total figure even adds up to 16.5 kilograms.

Scenario 5, which includes the Sea-river ship generates a total NOx emission of 11.3 kilograms, Scenario 6, in which the Sea-river ship is combined with a train, the total emission is lowered to 9.4 kilograms.

Table 69. Comparison of CO2 emissions.

Comparison of NOx emissions						
	t.o.v. scenario 1	t.o.v. scenario 2	t.o.v. scenario 3	t.o.v. scenario 4	t.o.v. scenario 5	t.o.v. scenario 6
scenario 1	0%	+33%	-6%	+499%	+38%	+65%
scenario 2	-25%	0%	-29%	+350%	+4%	+24%
scenario 3	+6%	+41%	0%	+537%	+47%	+75%
scenario 4	-83%	-78%	-84%	0%	-77%	-72%
scenario 5	-28%	-4%	-32%	+334%	0%	+19%
scenario 6	-39%	-19%	-43%	+263%	-16%	0%

Source: authors calculations

PM10 emissions are the lowest in a scenario in which a train plays the dominant role. Scenario 4 illustrates this, in this scenario the train transports the container from Duisburg all the way to Manchester, generating only 0.09 kilograms of PM10. The positive effect of the train is eliminated in scenario 2, in which the train only plays a minor role, this scenario generates 0.52 kilograms of PM10.

The highest PM10 emission is generated by scenario 3, in which the truck and barge are dominant. Scenario 3 generates a total of 0.74 kilograms of PM10. Scenario 1, in which the truck is dominant generates a total of 0.64 kilograms PM10.

The scenarios in which the Sea-river ship is included show a remarkable result with regard to PM10 emissions. Scenario 5, in which the ship is combined with a truck generates a total of 0.24 kilograms. Scenario 6, in which the sip is combined with a train generates 0.17 kilograms.

Table 70. Comparison of CO2 emissions.

Comparison of PM10 emissions						
	t.o.v. scenario 1	t.o.v. scenario 2	t.o.v. scenario 3	t.o.v. scenario 4	t.o.v. scenario 5	t.o.v. scenario 6
scenario 1	0%	+24%	-13%	+611%	+164%	+282%
scenario 2	-20%	0%	-30%	+471%	+112%	+207%
scenario 3	+15%	+43%	0%	+716%	+203%	+338%
scenario 4	-86%	-82%	-88%	0%	-63%	-46%
scenario 5	-62%	-53%	-67%	+169%	0%	+45%
scenario 6	-74%	-67%	-77%	+86%	-31%	0%

Source: authors calculations

5.2 Conclusion

From the literature review and calculations the following conclusion can be drawn with regard to the main research question.

The market for short-sea shipping is thriving since the focus of society and the European Union is directed towards environmental friendly ways of transport, getting freight of the road and on to the water. Sea-river shipping as a relatively new concept has the potential to develop a stable mode of transport since transshipment at (congested) ports can be avoided. It is to be kept in mind however that the success of a sea-river innovation, according to literature, is dependent of its ability to offer a competitive alternative for road freight possibilities. In the Germany-UK corridor this potential seems rather likely. The market of today demands a fast door-to-door total transport and logistics service. Sea-river shipping can positively contribute to this because of its logistical advantages. In terms of costs, through less transshipments and scale economies, and through its decrease in complexity as a result of the smaller number of transshipments. The competitiveness of a new initiative however is very dependent on its environmental performance, a new business can simply not succeed when this aspect is overlooked or underestimated.

The emission calculations have clearly shown that the electric train is the cleanest way of transporting unitized cargo. It is unbeatable in terms of CO2, NOx and PM10 emissions. As it was found in the literature review a sea-river ship will predominantly compete for cargo coming from the road and other inland shipping lines. Considering the capacity of these different modes the relatively small reductions in emission figures can have considerable effects. In this respect the results from the calculations lead to the conclusion that, although the effect is smaller than expected, a sea-river innovation like the IMA project is able to lower the carbon footprint of transport on the Germany-UK corridor.

It seems therefore that the IMA Sea-river RoCon innovation scores on all areas. Its reliable, relatively cheap, simple and also in environmental perspective favorable service, makes it a commercially attractive transport option.

5.3 Overview of main research results.

Figure 16, CO2 emissions from six scenarios

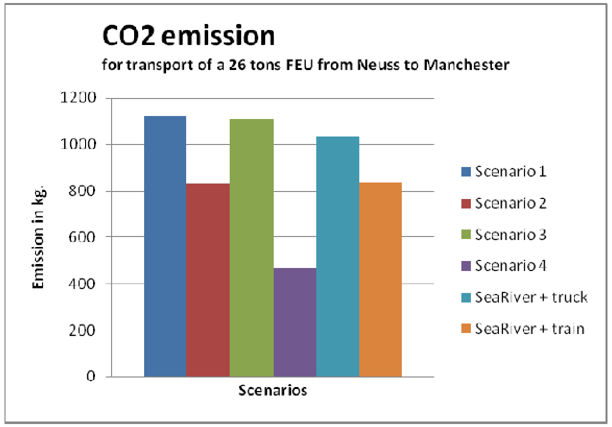


Figure 17, NOx emissions from six scenarios

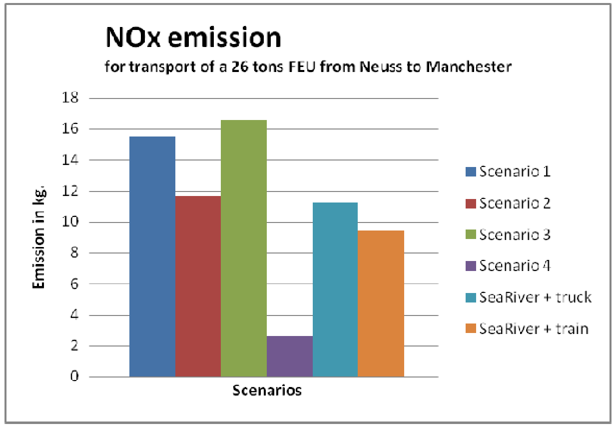
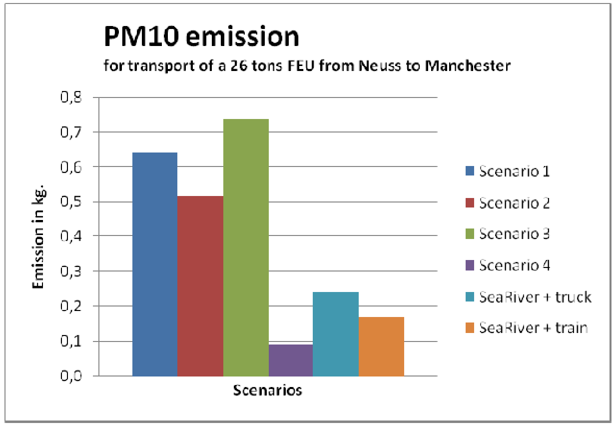


Figure 18, PM10 emissions from six scenarios



Source: author calculations

Table 71. Summary total emissions from six scenarios for the transport of a 26 tons FEU

Scenario		Transshipments	**Kilometers per modality**					**Emissions in kg. per 26 tons FEU**		
			Truck	Train	Barge	Short-sea ferry	Sea-river ship	CO2	NOx	PM10
Scenario 1	Truck + short sea ferry + truck	2	505			375		1122	15,5	0,64
Scenario 2	Truck + train + short sea ferry + truck	3	275	208		375		831	11,7	0,52
Scenario 3	Truck + barge + short sea ferry + truck	3	275		265	375		1109	16,5	0,74
Scenario 4	Truck + tunnel train + truck	2	135	925				466	2,6	0,09
Scenario 5	Truck + Sea-river + truck	2	275				639	1030	11,3	0,24
Scenario 6	Truck + Sea-river + train + truck	3	100	175			639	833	9,4	0,17

Source: author calculations

6. Discussion and recommendations for further research

6.1 Discussion

The results of this research have been roughly what was expected up front. From literature it was found that the electric train is a very clean mode of transport, whereas the truck is not. This research shows that as well and therefore the conclusion is not surprising. This does not mean the results are not interesting though. The effect of a sea-river ship in this research is rather small in terms of emissions, however, these emissions are calculated based on t/km. In practice the capacity of the different modes determines the total t/kms they are able to generate. A relatively small improvement can therefore become very important. The sea-river ship from IMA has a capacity of 166 FEU, this means that when fully loaded, the ship is able to lower the number of trucks on the road by a minimum of 166.

6.2 Recommendation for further research

Common practice. The results of this analysis could form a basis for further research to the composition of transport chain emissions. A first recommendation would be to research the practical feasibility of the different scenarios more closely. Determining a common practice and quantify the number of transport movements per modality or container on an annual basis could be a way in which certain emission figures can be put in perspective. The results of such an analysis could be used to determine the effect the ship has on the market per year for example.

Competition. Determining the market position of this project in relation to existing players should help to determine the indirect effects of the project. The effect of switching cargo from one modality to another is larger when the traditional modality is faced with relatively high emissions per t/km (trucks) and the new modality is not (Sea-river RoCon).

Transshipments. Additionally the calculations of terminal emissions should be examined further. Especially the indirect effects of transshipments on transit times and indirect emissions from traffic in and close to port areas is not taken into account in current literature and this research.

Transit times. It would be very interesting to determine the effect of the Sea-river RoCon project in terms of emissions per amount of time. Based on the theory that slower transport yields less emissions due to a lower energy consumption, it would be interesting to research the effect of the project in terms of transit times. For such a research a possible starting point would be to determine the transit times of the different scenarios and the findings of Martinez & Castells (2009). In their work on the relation between external costs and speed they point out the importance of the different economic, geographic and environmental conditions to which transport modalities have to adapt.

By calculating the emissions per amount of time period the “cleanest” scenario would be the one with the lowest emissions per round trip of “x” days for example. In this research a scenario with a total emission of 1200kg. of CO2 and a transit time of 3 days, would be cleaner than one with a total emission of 900kg. and a transit time of 4 days. One necessary component of this research would be the valuation of transit time.

Overall transport costs. The same kind of reasoning applies to transport costs. Lowering the overall costs of transport demands lower speed and thereby causes increased transit times, resulting in lower emissions due to a lower energy consumption. This implies that a certain equilibrium could be determined between transportation costs, transit times and emissions. By putting a weight on each of these three aspects one could for every specific case determine a certain optimal figure. A relation that would be very interesting to analyze in future research. In this respect developments in road pricing for example and other policy measures taken to internalize external costs from transport (King et. al., 2007) (Doll et. al., 2007) can be taken into account as well.

Fuel types. As a result from increasing demand for cleaner transport, alternative fuel types emerge and find their way to current operators and transport companies (Western Governors Association, 2008). Biofuels such as ethanol and ethanol blends, biodiesels and renewable diesel types. But also a more extensive use of electricity, certain diesels produced through coal-to-liquid processes and hydrogen fuel. Compressed natural gas (CNG) and liquefied natural gas (LNG) are already in development and have found their use in transport. Because these developments are relatively new and alternative fuels currently evolve at various rates of development the data collection from operations is fairly limited. However it would be very interesting to produce similar calculations like the ones in this research using data, or projections and estimates, for the use of alternative fuels.

7. References

Baird, A.J. (2007). ***The economics of motorways of the sea***. Maritime Research Group, Napier University Transport Research Institute, Edinburgh, United Kingdom. Maritime Policy & Management 34, 287-310, 23 pp.

Beek, D.J., van der. (2009). ***Barging on the Rhine and the challenge for the port of Rotterdam.*** Master Thesis. Rotterdam: Rotterdam School of Economics.

Blanken, P. (2011). ***Project engineer at Damen Shipbuilders.*** Email consultation about Sea-river RoCon vessel emissions, energy consumption and round trip travel times.

Blauwens, G., De Baere, P., & Van de Voorde, E. (2008). ***Transport Economics: Third Edition.*** Antwerpen: De Boeck.

Bontekoning, Y.M., Macharis, C., & Trip, J.J. (2003). ***Is a new applied transportation research field emerging? A review of intermodal rail-truck freight transport literature.*** Elsevier: Transportation Research Part A 38 (2004) 1–34.

Braun, G., Dirkzwager, W., & Helmer, J. (2011). ***Business Plan Sea-river Container RoRo Service: UK East Coast / German Hinterland.*** Rotterdam: Sea-river.

Burgel, A.P. (2007) ***Air Pollution from Ships: Recent Developments.*** WMU Journal of Maritime Affairs, Vol. 6 (2007), No.2, 217–224.

Cariou, P. (2010). ***Is slow steaming a sustainable means of reducing CO_2 emissions from container shipping?.*** Marseille, France: Working Paper, Euromed Management.

Casaca, A.P., & Marlow, P.B. (2007). ***The Impact of the Trans-European Transport Networks on the Development of Short Sea Shipping.*** Maritime Economics & Logistics, 2007, 9, 302–323.

CE Delft, Boer, L.C. den., Brouwer, F.P.E., & van Essen, H.P. (2008). ***STREAM, Studie naar TRansport Emissies van Alle Modaliteiten.*** Publication number: 08.4482.11

CE Delft, Jens, J., & van Essen, H.P. (2005). ***Beladingsgraden - ruimte voor verbetering. Delft.*** Publication for the Rabobank, June 2005.

Commission of the European Communities. (2001). ***White Paper, European transport policy for 2010: time to decide.*** Brussels, 12.9.2001. COM(2001) 370 final.

Distri Rail. ***Nieuwe Distri Rail shuttle op Neuss (6th April 2011) .*** Press release, retrieved, 17th September 2011, from *http://www.portofrotterdam.com/nl/actueel/pers-en-nieuwsberichten/Pages/nieuwe-distri-rail-shuttle-neuss.aspx/*

Doll, C., & Schaffer, A. (2007). ***Economic impact of the introduction of the German HGV toll system***. Transport Policy 14, 49-58, 9 pp.

Duurzame Logistiek connect. ***Emission calculations: transport emissions in general.*** Retrieved, 15th October 2011, from *http://www.emissieberekenen. nl/stap6/vervoersemissies-in-het-algemeen/*

EC, Directorate-General for Energy and Transport. (2006). ***Motorways of the Sea, Modernizing European short sea shipping links.*** Manuscript, Zhaomin Zhang, Neptune, May 2006.

ECMT, European Conference of Ministers of Transport. (2007). ***Cutting transport CO_2 emissions: What progress?*** Paris, France: OECD publishing.

EcoTransIT. ***Ecological Transport Information Tool***, retrieved throughout the research, from *http://www.ecotransit.org/ecotransit.en.phtml/*

EICB, Expertise- en InnovatieCentrum Binnenvaart. ***Introduction to inland container shipping.*** Retrieved, 20th September 2011, from *http://www.informatie.binnenvaart.nl /vervoer/containervaart.html/*

European Commission. (2006). ***Motorways of the Sea, Modernizing European short seashipping links.*** Manuscript completed by Zhaomin Zhang, Neptune, in May 2006.

Geerlings, H., & van Duin, R. (2010). ***A New Method for Assessing CO_2 emissions from container terminals: A promising approach applied in Rotterdam.*** Elsevier: Journal of Cleaner Production xxx (2010), doi:10.1016/j.jclepro.2010.10.012.

Hamzelou, J. (2011). ***Record carbon emissions mean 2 °C rise ever closer.*** New Scientist: magazine issue 2815, published 31st may 2011, edited on 2nd June 2011.

Jacobson, M.Z., Seinfeld, J.H., Carmichael, G.R., & Streets, D.G. (2004). ***The effect on photochemical smog of converting the U.S. fleet of gasoline vehicles to modern diesel vehicles.*** American Geophysical Union: Geophysical Research Letters, Vol. 31, L02116, doi:10.1029/2003GL018448.

KennisConsult. ***Benuttingsgraad, betekenis van het begrip “benuttingsgraad”***. Retrieved, 2nd October 2011, from *http://www.kennisconsult.nl/begrippen/4021/*

King, D., Manville, M. & Shoup, D. (2007). ***The political calculus of congestion pricing.*** Department of Urban Planning, University of California, Los Angeles. Transport Policy 14, 111-123, 12 pp.

Klein, H.J. (2007). ***Shipbuilding Trends in Response to Environmental Issues.*** Germanischer Loyd. WMU Journal of Maritime Affairs, Vol. 6 (2007), No.2, 167–175.

Klink, A.H., van der & Berg, C., van den. (1998). ***Gateways and intermodalism.*** Journal of Transport Geography, Vol. 6, No. 1, pp. 1-9.

Konings, R., & Ludema, M. (2000). ***The competitiveness of the River-sea transport system: market perspectives on the United Kingdom – Germany corridor.*** Journal of Transport Geography 8 (2000), 221-228.

Kuipers, B. (2011). ***EU Witboek Transportbeleid: eerste stappen op weg naar 2050?*** ShortSea journaal, no. 2, 2011, pp.5.

Langen, P.W. de, Nijdam, M.H., & van der Lugt, L.M. (2010). ***Port economics, policy and management.*** Rotterdam: Erasmus Universtiy Rotterdam.

Leonardi, J., Browne, M. (2010). ***A method for assessing the carbon footprint of maritime freight transport: European case study and results.*** International Journal of Logistics Research and Applications, 13:5, 349-358.

Link, H., (2005). ***Transport accounts: Methodological concepts and empirical results.*** Elsevier: Journal of Transport Geography 13, 41-57, 16 pp.

Lopez, C. (2007). ***Sea-river shipping competitiveness and its geographical market area for the Rhone --Saone corridor.*** Journal of Transport Geography, No. 16, 2008, pp. 100-116.

López-Navarro, M.A., Moliner, M.A., Rodriguez, R.M., & Sanchez, J. (2011). ***Accompanied versus unaccompanied transport in short-sea shipping between Spain and Italy: an analysis from transport road firms perspective.*** Transport Reviews: A Transnational Transdisciplinary Journal, 31:4, 425-444.

Lun, Y.H.V., Lai, K.-H., & Cheng, T.C.E. (2010). ***Shipping and Logistics Managements. Chapter 10: Intermodal Transport System.*** Springer, 2010, 135-149 pp.

Malcolm, A.C. (2002). ***Multimodal Transport in the New Millennium.*** St. John's College, Cambridge University. WMU Journal of Maritime Affairs, 2002, No.1, 71-84.

Martínez, de Osés. X., Castells, M. (2009). ***The External Cost of Speed at Sea:An Analysis Based on Selected Short Sea Shipping Routes.*** Universitat Politècnica de Catalunya. WMU Journal of Maritime Affairs, Vol. 8 (2009), No.1, 27–45.

McKinnon, A. (2007). ***Decoupling of road freight transport and economic growth trends in the UK: An exploratory analysis***. Transport Reviews 27, 37-64, 27 pp.

Medda, F., & Trujillo, L. (2010). ***Short-sea shipping: An analysis of its determinant.*** Maritime Policy & Management, 37:3, 285-30.

Motor Transport. (2007). ***EC aims to implement 'green transport corridors'.*** Motor Transport, October 25, 2007, p. 1.

Mulligan, R.F., & Lombardo, G.a. (2006). ***Short Sea Shipping: Alleviating the Environmental Impact if Economic Growth.*** WMU Journal of Maritime Affairs, 2006, Vol. 5, No.2, 181–194.

Nellen, J. (2011). ***The Environmental Performance of Inland Shipping: Development and Application of a Framework to Compute Emissions in the Inland Shipping Transport Chain.*** Master Thesis. Rotterdam: Rotterdam School of Economics, published May 2011.

Neuss Intermodal Terminal. ***General information.*** Retrieved, throughout the research, from *http://www.nitneuss.de/index.php?page=Home/*

Newton, S., Kawabata, Y., Maurer, H., Pearman, A., van Meijeren, J., de Jong, G., (2010). ***Ports and their connections within the TEN-T.*** European Commission, Directorate-General Mobility and Transport, Final report for project: TREN/R1/350-2008 lot 2, Vigie fiche 394-1, B1.

Nordmann, M. (2007). ***Global Freight Forwarding 2007. An analysis of the global freight forwarding industry, trends, trade flows and the key market players.*** Wiltshire: Transport Intelligence Ltd. April 2007 TIGFF0704.

OECD, (2011). ***Environmental Impacts of International Shipping: The Role of Ports***, OECD Publishing. *http://dx.doi.org/10.1787/9789264097339-en*

Oonk, H., (2006). ***Emissions to Air Due to Activities on Container Terminals and Future Developments as a Result of Autonomous Developments and Additional Measures.*** TNO Built Environment and Geosciences TNO, Apeldoorn, Netherlands.

Panayides, P.M., (2002). ***Economic organization of intermodal transport.*** Hong Kong: Hong Kong Polytechnic University, Department of Shipping and Transport Logistics. Transport Reviews, 2002, Vol. 22, No. 4, 401-414.

Patterson, Z., Gordon, E.O., & Haider, M. (2008). ***The potential for premium-intermodal services to reduce freight CO_2 emissions in the Quebec city – Windsor corridor.*** Transportation Research Part D 13 (2008) 1–9.

Piecyck, M.I., & McKinnon, A.C. (2009). ***Forecasting the carbon footprint of road freight transport in 2020.*** Logistics Research Centre, School of Management and Languages, Heriot-Watt University, Edinburgh. Elsevier: Int. J. Production Economics 128 (2010) 31–42.

Radmilovic, Z., Zobenica, R., & Maras, V. (2011). ***River-sea shipping – competitiveness of various transport technologies.*** Journal of Trnasport Geography 19 (2011), 1509-1516.

Rissoan, J.P., (1994). ***River-sea navigation in Europe.*** Journal of Transport Geography, 1994, No. 2, pp. 131-142.

Rodrigue, J.P., Notteboom, T. (2011). ***Dry Ports and the Maritime Hinterland: Gaining Momentum.*** Port Technology International, No.50.

Rothengatter, W. (2009). ***Quantifying the environmental impact of freight transport.*** London: Railway Gazette International 165. Â10 (Oct 2009): 39-40,43-45.

Royal Haskoning, Schilperoord, H.A. (2004). ***Binnenvaart Voortdurend Duurzaam: Environmental Performace of Inland Shipping***. Amsterdam: Royal Haskoning.

Ruiter, W. de. (2006). ***International Maritime Legislation: The EU and Enforcing Resolutions Editorial.*** WMU Journal of Maritime Affairs, 2006, Vol. 5, No.1, 1–3.

Schrooten, L., Vlieger, I. de, Panis, L.I., Cosima, C., & Pastori, E. (2009). ***Emissions from maritime transport: A European reference system.*** Science of the Total Environment 408 (2009) 318–323.

Short, J.P. (2008). ***Solving transport's CO_2 problem.*** OECD Observer, 2008, No. 267, May-June, P.45.

Short, J.P., & Notteboom, T. (2011). ***Dry ports and the Maritime Hinterland: Gaining Momentum.*** New York: Hofstra University, Antwerp: University of Antwerp.

Short Sea Shipping Voorlichtingsbureau, (2011) ***Short Sea Shipping Factsheet Verenigd Koninkrijk.*** Retrieved from: http://www.shortsea.nl/main/attachements/DEF_fctsht_Verenigd_Koninkrijk2010_nl_01f.pdf.

U.N. Intergovernmental Panel on Climate Change, (1998). ***Kyoto protocol to the United Nations framework convention on climate change.*** From United Nations framework convention on climate change website.

Vardoulakis, S., & Kassomenos, P. (2008). ***Sources and factors affecting PM10 levels in two European cities: Implications for local air quality management.*** Elsevier: Atmospheric Environment 42 (2008), 3949-3963.

Western Governors Association, (2008). ***Transportation Fuels for the Future.*** Denver February, 2008.

Wikipedia. (2011). ***European Emission Standards.*** Retrieved, 24th September 2011, from *http://en.wikipedia.org/wiki/European_emission_standards/*

Wright, R., (2007). ***Container lines cut services over congestion.*** Financial Times, December 9th 2007.

8. Appendices

Appendix 1, additional calculations scenario 1

Activity 1. Driving from Neuss to Rotterdam Short sea Terminal (RST).

The energy consumption of the vehicle.

Since on the trip from Neuss to Rotterdam the truck is loaded for 96%, whilst on the return trip for only 48%, **P = 72%**. The load on average, **L = 19.5** tons. A truck consumes more energy when driving in the city than it does on a highway. Following the distribution provided in table 12, and combining this with the MJ/km consumption from STREAM (2008) we find that for this trip the average **evhl = 11.34** MJ/km. Substituting these figures in the provided formula we find:

Table 72. Energy consumption vehicle in MJ (fuel) per t/km

		CO2	NOx	PM10
Evhl = evhl/(L*p)	**evhl**	11.34	11.34	11.34
	L (Load)	19.5	19.5	19.5
	p (productive km)	72%	72%	72%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.81**	**0.81**	**0.81**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

The vehicle emissions

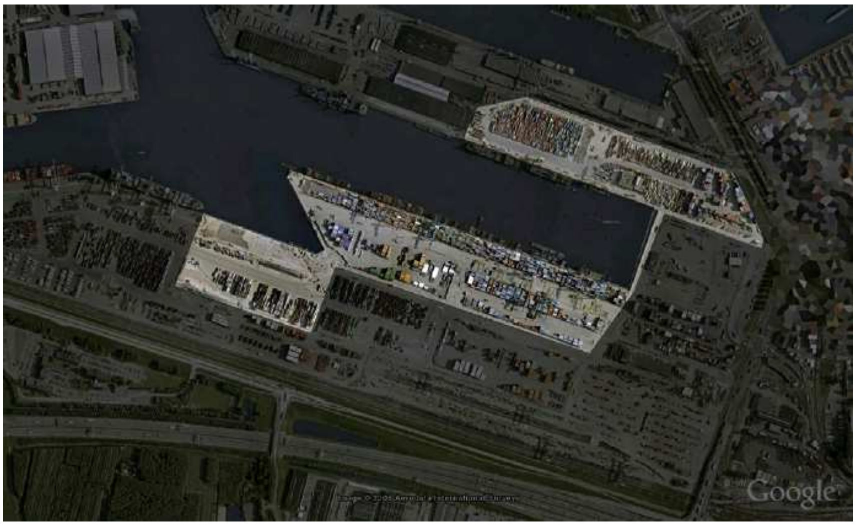
Since **Evhl = 0.81**, the emission per MJ/fuel is calculated next. For this calculations the distribution of road types from table 12 and the figures from table 2 are combined to find:

Table 73. Emission of vehicle in grams per t/km

			CO2	NOx	PM10
EMvhl = emmj-fuel * Evhl		**Evhl**	0.81	0.81	0.81
		emmj-fuel	73.22	0.82	0.03
Emission of vehicle in g/tkm		**EMvhl =**	**58.97**	**0.66**	**0.02**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the Rotterdam Short sea Terminal (RST)



Source: Google Maps (2011)

According to Geerlings and Van Duin (2010) the RST has two alternative ways for transshipment of a container from a truck to a ship, one completely electric and one diesel/electric alternative. First we take a look at the electric alternative, table 74 shows what happens:

Table 74. Emissions during transshipment at RST, electric alternative

Movement	**used equipment**	***electric diesel***	**Energy consumption**	***kwh l/km***	**Distance driven avg. (km.)**	**Emissions**		
						CO2	NOx	PM10
Truck to Stack	QC	Electric	6.00	kwh	0	2.1732		
Stack to Stack	QC	Electric	6.00	kwh	0	2.1732		
	P	Electric	5.00	kwh	0	1.811		
	RSC	Electric	7.25	kwh	0	2.62595		
Stack to Sea ship	QC	Electric	6.00	kwh	0	2.1732		
					TOTAL emissions per container move in kg.	**10.96**	**0.11**	**0.009**

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

For the diesel/electric alternative the following figures arise:

Table 75. Emissions during transshipment at RST, electric alternative

Movement	**used equipment**	***electric diesel***	**Energy consumption**	***kwh l/km***	**Distance driven avg. (km.)**	**Emissions**		
						CO2	NOx	PM10
Truck to Stack	QC	Electric	6.00	kwh	0	2.1732		
Stack to Stack	QC	Electric	6.00	kwh	0	2.1732		
	RS	Diesel	5.00	l/km	0,6	7.95		
Stack to Sea ship	QC	Electric	6.00	kwh	0	2.1732		
					TOTAL emissions per container move in kg.	**14.47**	**0.14**	**0.011**

Source: author calculations based on Geerlings and Van Duin, table 1, p.5 (2010)

Activity 3. Sailing from Rotterdam to Immingham

The energy consumption of the vessel

Since on the trip from Rotterdam to Immingham as well as on the return trip the ship is loaded for 75%, **P = 75%**. The load on average, **L = 6000** tons with a given capacity of around 8000tons. A ship of this class consumes around 866 MJ/km (STREAM, 2008), so we find that for this trip **evhl = 866** MJ/km. Substituting these figures in the formula we find:

Table 76. Energy consumption vessel in MJ (fuel) per t/km

		CO2	**NOx**	**PM10**
Evhl = evhl/(L*p)	**evhl**	866	866	866
	L (Load)	6000	6000	6000
	p (productive km)	75%	75%	75%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.19**	**0.19**	**0.19**

Source: author calculations based on STREAM table 18, p.37 (2008)

The vessel’s emissions

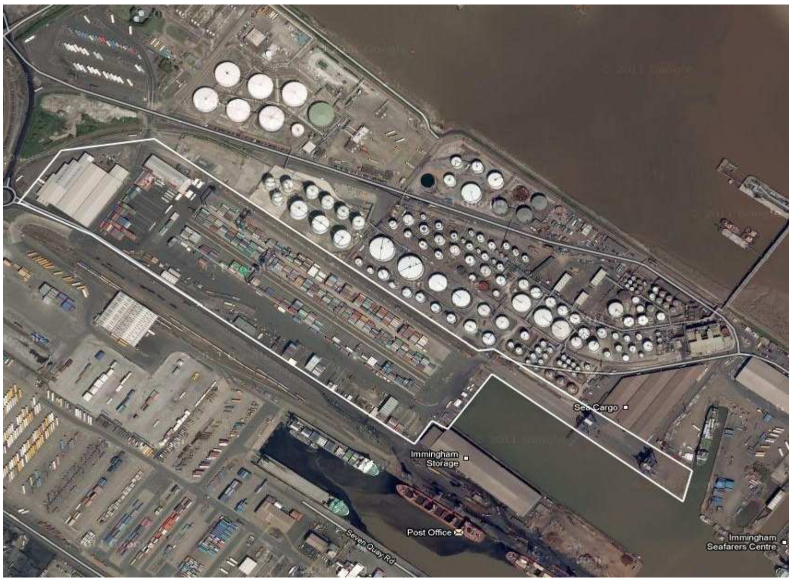
Since **Evhl = 0.19**, the emission per MJ/fuel is calculated next, we find:

Table 77. Emission of vessel in grams per t/km

			CO2	NOx	PM10
EMvhl = emmj-fuel * Evhl		**Evhl**	0.19	0.19	0.19
		emmj-fuel	150.33	3.30	0.16
Emission of vehicle in g/tkm		**EMvhl =**	**28.88**	**0.63**	**0.03**

Source: author calculations based on STREAM table 18, p.37 (2008)

Activity 4. Transshipment at the ABP terminal in the port of Immingham



Source: Google Maps (2011)

Activity 5. Driving from Immingham to Manchester

The energy consumption of the vehicle

Since on the trip from Immingham to Manchester the truck is loaded for 96%, whilst on the return trip for only 48%, **P = 72%**. The load on average, **L = 19.5** tons. A truck consumes more energy when driving in the city than it does on a highway. Following the distribution provided in table 17, and combining this with the MJ/km consumption from STREAM (2008) we find that for this trip the average **evhl = 11.71** MJ/km. Substituting these figures in the formula we find:

Table 78. Energy consumption vehicle in MJ (fuel) per t/km

Evhl = evhl/(L*p)	**evhl**	11.71	11.71	11.71
	L (Load)	19.5	19.5	19.5
	p (productive km)	72%	72%	72%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.83**	**0.83**	**0.83**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

The vehicle emissions

Since **Evhl = 0.83**, the emission per MJ/fuel is calculated next. For this calculations the distribution of road types from table 12 and the figures from table 78 are combined to find:

Table 79. Emission of vehicle in grams per t/km

EMvhl = emmj-fuel * Evhl		**Evhl**	0.83	0.83	0.83
		emmj-fuel	73.23	0.82	0.03
Emission of vehicle in g/tkm		**EMvhl =**	**60.88**	**0.68**	**0.02**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Appendix 2, additional calculations scenario 2

Activity 1. Driving from greater Neuss to the Neuss Intermodal Terminal (NIT).

The energy consumption of the vehicle.

Since on the trip from greater Neuss to the NIT the truck is loaded for 96%, whilst on the return trip for only 48%, **P = 72%**. The load on average, **L = 19.5** tons. Following the distribution provided in table 21, and combining this with the MJ/km consumption from STREAM (2008) we find that for this trip the average **evhl = 11.89** MJ/km. Substituting these figures in the provided formula we find:

Table 80. Energy consumption vehicle in MJ (fuel) per t/km

		CO2	**NOx**	**PM10**
Evhl = evhl/(L*p)	**evhl**	11.89	11.89	11.89
	L (Load)	19.5	19.5	19.5
	p (productive km)	72%	72%	72%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.84**	**0.84**	**0.84**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

The vehicle emissions

Since **Evhl = 0.84**, the emission per MJ/fuel is calculated next. For this calculations the distribution of road types from table 21 and the figures from table 79 are combined to find:

Table 81. Emission of vehicle in grams per t/km

			CO2	**NOx**	**PM10**
EMvhl = emmj-fuel * Evhl		**Evhl**	0.84	0.84	0.84
		emmj-fuel	73.24	0.83	0.03
Emission of vehicle in g/tkm		**EMvhl =**	**61.82**	**0.70**	**0.02**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the Neuss Intermodal Terminal (NIT).

Source: Google Maps (2011)

Activity 3. Train from the NIT to Rotterdam. From the NIT the container is transported to Rotterdam by train. This trip, of roughly 208 kilometers, is performed by electric train. The emissions in this respect come from the production of electricity, the particulate matter produced by the movements of the train are not taken into account. For the calculations the base data from table 3 is used, the MJ/km figures are converted to kWh/km. (1MJ = 0.278 kWh) Table 82 provides the calculation of emissions during this part of the trip:

Table 82. Total emissions during activity 3

Train		Distance	Total energy consumption in KwH	Emission in kg.		
Locomotive	1			CO2	NOx	PM10
kWh/km	0.83	208	173.33			
Mass in tons	1200.10	208	3466.96			
Load in tons	643.5					
kWh/tkm	0.01					
		TOTAL	3640.29	1318.51	0.00	0.00
		Total per load t/km		0.01	0.00	0.00
		For this trip with 26t. FEU	**5408.00**	**53.27**	**0.00**	**0.00**

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 4. Transshipment at the Rotterdam Short sea Terminal (RST). See Annex 1, activity 2.

Activity 5. Sailing from Rotterdam to Immingham. See Annex 1, activity 3.

Activity 6. Transshipment at the ABP terminal in the port of Immingham. See Annex 1, activity 4.

Activity 7. Driving from Immingham to Manchester. See Annex 1, activity 5.

Appendix 3, additional calculations scenario 3

Activity 1. Driving from greater Neuss to the NIT. See Annex 2, activity 1.

Activity 2. Transshipment at the Neuss Intermodal Terminal (NIT). See Annex 2, activity 2.

Activity 3. Barge from the NIT to Rotterdam. From the NIT the container is transported to Rotterdam via inland waterways. This trip, of roughly 265 kilometers, is performed by barge.

The energy consumption of the vessel.

Since on the productive kilometers of the barge in the STREAM (2008) report ae set to 78%, in our calculations, **P = 78%**. The load on average, **L = 1950** tons. we find that for this trip the average **evhl = 535.20** MJ/km. Substituting these figures in the formula we find:

Table 83. Energy consumption vessel in MJ (fuel) per t/km

		CO2	NOx	PM10
Evhl = evhl/(L*p)	**evhl**	535.20	535.20	535.20
	L (Load)	1950	1950	1950
	p (productive km)	78%	78%	78%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.35**	**0.35**	**0.35**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

The vehicle emissions

Since **Evhl = 0.35**, the emission per MJ/fuel is calculated next:

Table 84. Emission of vessel in grams per t/km

			CO2	NOx	PM10
EMvhl = emmj-fuel * Evhl		**Evhl**	0.35	0.35	0.35
		emmj-fuel	0.14	0.002	0.0001
Emission of vehicle in g/tkm		**EMvhl =**	**0.05**	**0.001**	**0.00**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 4. Transshipment at the Rotterdam Short sea Terminal (RST). See Annex 1, activity 2.

Activity 5. Sailing from Rotterdam to Immingham. See Annex 1, activity 3.

Activity 6. Transshipment at the ABP terminal in the port of Immingham. See Annex 1, activity 4.

Activity 7. Driving from Immingham to Manchester. See Annex 1, activity 5.

Appendix 4, additional calculations scenario 4

Activity 1. Driving from greater Neuss to the DTD.

The energy consumption of the vehicle.

Since on the trip from greater Neuss to Duisburg the truck is loaded for 96%, whilst on the return trip for only 48%, **P = 72%**. The load on average, **L = 19.5** tons. Following the distribution provided in table 41, and combining this with the MJ/km consumption from STREAM (2008) we find that for this trip the average **evhl = 11.89** MJ/km. Substituting these figures in the provided formula we find:

Table 85. Energy consumption vehicle in MJ (fuel) per t/km

		CO2	**NOx**	**PM10**
Evhl = evhl/(L*p)	**evhl**	11.89	11.89	11.89
	L (Load)	19.5	19.5	19.5
	p (productive km)	72%	72%	72%
Energyconsumption vehicle in MJ (fuel) per t/km	**Evhl =**	**0.84**	**0.84**	**0.84**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

The vehicle emissions

Since **Evhl = 0.84**, the emission per MJ/fuel is calculated next. For this calculations the distribution of road types from table 41 and the figures from table 85 are combined to find:

Table 86. Emission of vehicle in grams per t/km

			CO2	**NOx**	**PM10**
EMvhl = emmj-fuel * Evhl		**Evhl**	0.84	0.84	0.84
		emmj-fuel	73.24	0.83	0.03
Emission of vehicle in g/tkm		**EMvhl =**	**61.82**	**0.70**	**0.02**

Source: author calculations based on STREAM table 7 + 8, p.30 (2008)

Activity 2. Transshipment at the DTD.

Source: Google Maps (2011)

Activity 3. Train from the DTD to Manchester. From the DTD the container is transported to Manchester by train, through the canal tunnel. This trip, of roughly 925 kilometers, is performed by electric train and diesel train. For 921 kilometers an electric train is used and for 4 kilometers a diesel powered one (Ecotransit, 2011).

Table 87. Emission of diesel train

Train		Distance	Total energy consumption in MJ	Emission in kg.		
Locomotive	1			CO2	NOx	PM10
MJ/km	25	4	100.00			
Mass in tons	1200.1	4	528.04			
Load in tons	643.5					
MJ/tkm	0.11					
		TOTAL	628.04	45.85	0.89	0.02
		Total per load t/km		0.02	0.00	0.00
		For this trip with 26t. FEU	104.00	1.85	0.04	0.00

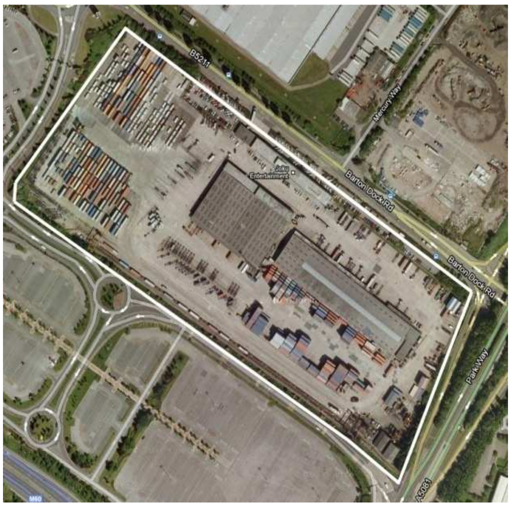
Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Table 88. Emission of electric train

Train		Distance	Total energy consumption in MJ	Emission in kg.		
Locomotive	1			CO2	NOx	PM10
MJ/km	25	921	767.50			
Mass in tons	1200.1	921	15351.28			
Load in tons	643.5					
MJ/tkm	0.01					
		TOTAL	16118.78	5838.22	0.00	0.00
		Total per load t/km		0.01	0.00	0.00
		For this trip with 26t. FEU	23946.00	235.89	0.00	0.00

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 4. Transshipment at the Roadways MCT.



Source: Google Maps (2011)

Activity 5. Driving from MCT to the greater area of Manchester. See Annex 2, activity 1.

Appendix 5, additional calculations scenario 5

Activity 1. Driving from greater Neuss to the NIT. See Annex 2, activity 1.

Activity 2. Transshipment at the Neuss Intermodal Terminal (NIT). See Annex 2, activity 2.

Activity 3. Sailing from Neuss to Immingham. During the third stage of the trip the container is transported with the Sea-river RoRo ferry from the NIT in Neuss to the port of Immingham. The distance between these two places is 639 kilometers. The emissions of the ship on this trip are calculated using the approach described in the methodology section of this report. The basis for these calculations forms the trip description in terms of sailing conditions, speed and power output. Table 89 summarizes the trip:

Table 89. Trip description, roundtrip breakdown, Sea-river RoCon project

	Km.	Needed power	No. Of engines	Engine usage	Avg. Speed (km/h)	Sailing hours
Sea	750,00	2500	2	100%	22	34,09
Down-stream	264,00	1000	1	75%	20	13,20
Up-stream	264,00	2500	2	100%	13	20,31
					Total sailing hours	67,60
					Loading/ discharging	28,40
					Total Round trip hours	96,00

Source: information obtained from P. Blanken, project engineer at Damen Shipbuilders, 2011

Based on these figures the emissions of a roundtrip are calculated, on the basis of which the emissions for every hypothetical trip could be calculated.

Table 90. Emissions for round trip with genset taken into account

	CO2 kg.	Nox kg.	PM10 kg.
Sea	53598,48	592,93	4,44
Down-stream	10376,67	114,79	0,86
Up-stream	31928,21	353,20	2,64
Generator set	17856,00	157,58	3,29
TOTAL	113759,36	1218,50	11,24

Average per kilometer	89,014	0,953	0,009
per ton/km	0,033813326	0,000362182	3,3396E-06
For 1 26tons FEU	0,87914648	0,009416743	8,68297E-05
Total for this trip	561,77	6,02	0,06

Source: author calculation based on information obtained from P. Blanken, project engineer at Damen Shipbuilders, 2011

Activity 4. Transshipment at the ABP terminal in the port of Immingham. See Annex 1, activity 4.

Activity 5. Driving from Immingham to Manchester. See Annex 1, activity 5.

Appendix 6, additional calculations scenario 6

Activity 1. Driving from greater Neuss to the NIT. See Annex 2, activity 1.

Activity 2. Transshipment at the Neuss Intermodal Terminal (NIT). See Annex 2, activity 2.

Activity 3. Sailing from Neuss to Immingham. See Annex 5, activity 3.

Activity 4. Transshipment at the ABP terminal in the port of Immingham. See Annex 1, activity 4.

Activity 5. Rail transport from Immingham to Manchester. The fifth activity in the transport chain is the transportation by train from the port of Immingham to the Roadways MCT in Manchester. This trip has a total distance of 175 kilometers, and a diesel and electric train are used according to the distribution in table 91 and 92. Based on these figures the emissions for both parts of the trip are calculated.

Table 91. Emission of diesel train

Train		Distance	Total energy consumption in MJ	Emission in kg.		
Locomotive	1			CO2	NOx	PM10
MJ/km	25	135	3375.00			
Mass in tons	1200.1	135	17821.49			
Load in tons	643.5					
MJ/tkm	0.11					
		TOTAL	21196.49	1547.34	29.89	0.57
		Total per load t/km		0.02	0.00	0.00
		For this trip with 26t. FEU	3510.00	62.52	1.21	0.02

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Table 92. Emission of electric train

Train		Distance	Total energy consumption in MJ	Emission in kg.		
Locomotive	1			CO2	NOx	PM10
MJ/km	0.83	40	33.33			
Mass in tons	1200.1	40	666.72			
Load in tons	643.5					
MJ/tkm	0.01					
		TOTAL	700.06	253.56	0.00	0.00
		Total per load t/km		0.01	0.00	0.00
		For this trip with 26t. FEU	1040.00	10.24	0.00	0.00

Source: author calculations based on STREAM table 11 + 12, p.30/31 (2008)

Activity 6. Transshipment at the Roadways MCT. See Annex 4, activity 4.

Activity 7. Driving from MCT to the greater area of Manchester. See Annex 2, activity 1.

Appendix 7, Damen Container Feeder 800.

DAMEN CONTAINER FEEDER® 800

"HENRIKE SCHEPERS"

GENERAL

YARD NUMBER	8304
DELIVERY DATE	November 2008
BASIC FUNCTIONS	Transport of containers
CLASSIFICATION	GL +100 A5 E3 GL +MC E3 AUT
REGULATIONS	Equipped for dangerous goods according to SOLAS reg. 19 II-2, excl. Class VII. Sprinklers in hold 1
FLAG	Antigua and Barbuda
OWNER	HS Schiffahrts GmbH & Co. KG MS "Henrike Schepers"

DIMENSIONS

LENGTH O.A.	140.64 m
LENGTH P.P.	130.00 m
BEAM MLD.	21.80 m
DEPTH MLD.	9.50 m
DRAUGHT	7.32 m
DEADWEIGHT	9340 ton
GROSS TONNAGE	7987 GT

TANK CAPACITIES

HFO (RMG 35)	880 m^3
MGO (DMA)	105 m^3
LUBRICATION OIL	48 m^3
DIRTY OIL	20 m^3
SLUDGE	21 m^3
SEWAGE	26 m^3
POTABLE WATER	74 m^3
BALLAST WATER	4597 m^3

CONTAINERS	TEU	TEU/FEU	30'	45'	48'/49'
IN HOLDS	206	12/97	135	97	-
ON DECK	597	69/264	376	232	40
TOTAL	803	81/361	511	329	40

PERFORMANCE

SPEED	18 kn at 7.32 m draft with 85% MCR, 200 kW PTO and 10% sea-margin

PROPULSION SYSTEM

MAIN ENGINE	MAK 9M43
POWER	8400 kW
PROPELLER	4900 mm, 4 blades, CPP
BOW THRUSTER	700 kW, 4 blades, CPP
STERN THRUSTER	500 kW, 4 blades, CPP
RUDDER	Balance type
STEERING GEAR	Rotary vane

HOLDS AND HATCH COVERS

WEATHERDECK HATCHES	Hydraulic multi folding type
HOLD 1	Dimensions 28.44 m x 18.60/ 13.20 m
HOLD 2	Dimensions 28.44 m x 18.60 m
HOLD 3	Dimensions 28.44 m x 18.60 m

AUXILIARY EQUIPMENT

SHAFT GENERATOR	1x 2000 kVA, 60 Hz
DIESEL GENERATORSETS	2x 530 kVA, 60 Hz
EMERGENCY GEN. SET	1x 124 kVA, 60 Hz
ANTI HEELING SYSTEM	1120 m^3/hr
FIRE FIGHTING	CO_2 system for engine room and cargo holds
SPRINKLERS	In hold 1

DECK LAY-OUT

ANCHOR/MOORING WINCHES	2x electric self-tensioning on forecastle deck, with a single drum and warping head
MOORING WINCHES	2x electric self-tensioning on poop deck, with a single drum and warping head
DECK CRANE	1x for free-fall boat and provisions
DECK CRANE	1x for rescue boat and life raft
CONTAINER FITTINGS	For 20', 30', 40', and 45' on tanktop and hatch covers and 48' and 49' for one layer on deck
MOVABLE CELL GUIDES	In holds for 40' and 45' containers
REEFER PLUGS	120 on main deck, 30 in hold 2, 30 in hold 3

ACCOMMODATION

For a crew of 15 persons with heating, ventilation and air-conditioning

Appendix 8, Complementing tables from Nellen (2010)

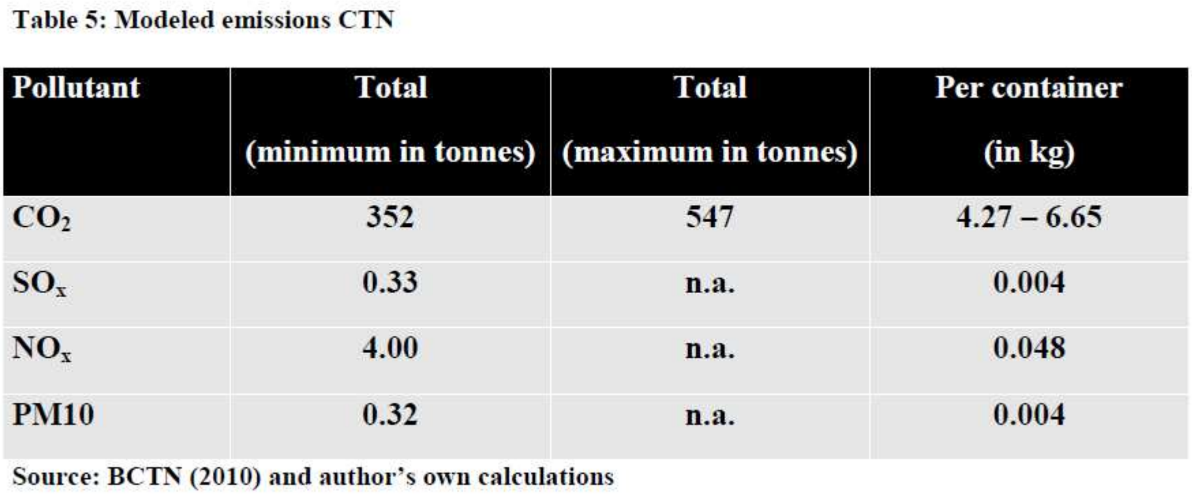


Table 5: Modeled emissions CTN

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	352	547	4.27 – 6.65
SO_x	0.33	n.a.	0.004
NO_x	4.00	n.a.	0.048
PM10	0.32	n.a.	0.004

Source: BCTN (2010) and author's own calculations

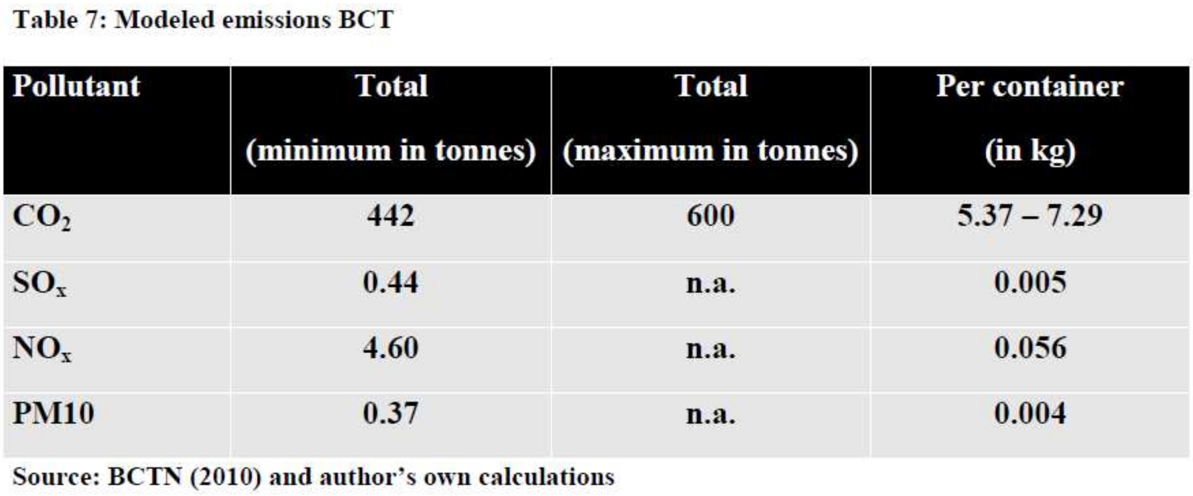


Table 7: Modeled emissions BCT

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	442	600	5.37 – 7.29
SO_x	0.44	n.a.	0.005
NO_x	4.60	n.a.	0.056
PM10	0.37	n.a.	0.004

Source: BCTN (2010) and author's own calculations

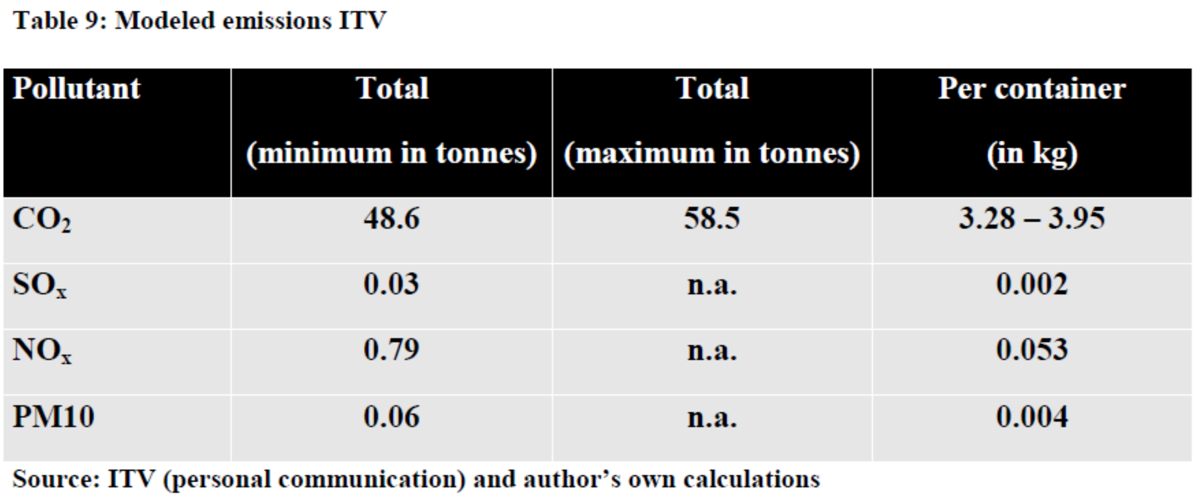


Table 9: Modeled emissions ITV

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	48.6	58.5	3.28 – 3.95
SO_x	0.03	n.a.	0.002
NO_x	0.79	n.a.	0.053
PM10	0.06	n.a.	0.004

Source: ITV (personal communication) and author's own calculations

Appendix 9, Complementing tables from Geerlings (2010)

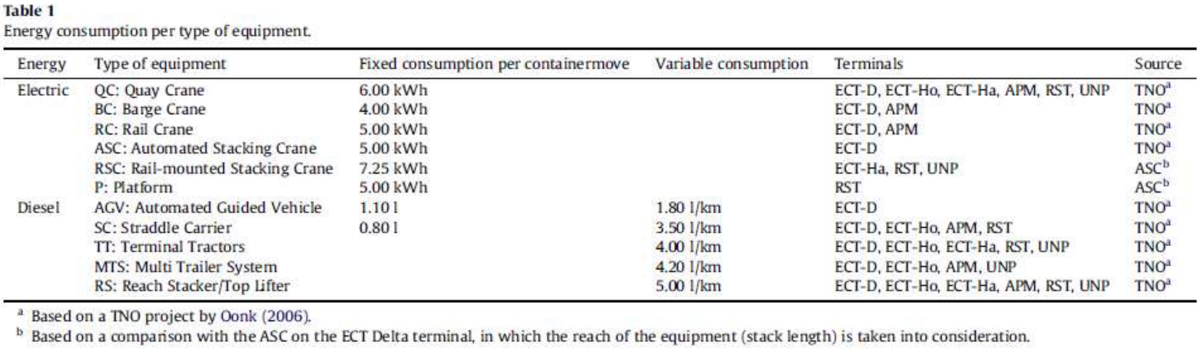


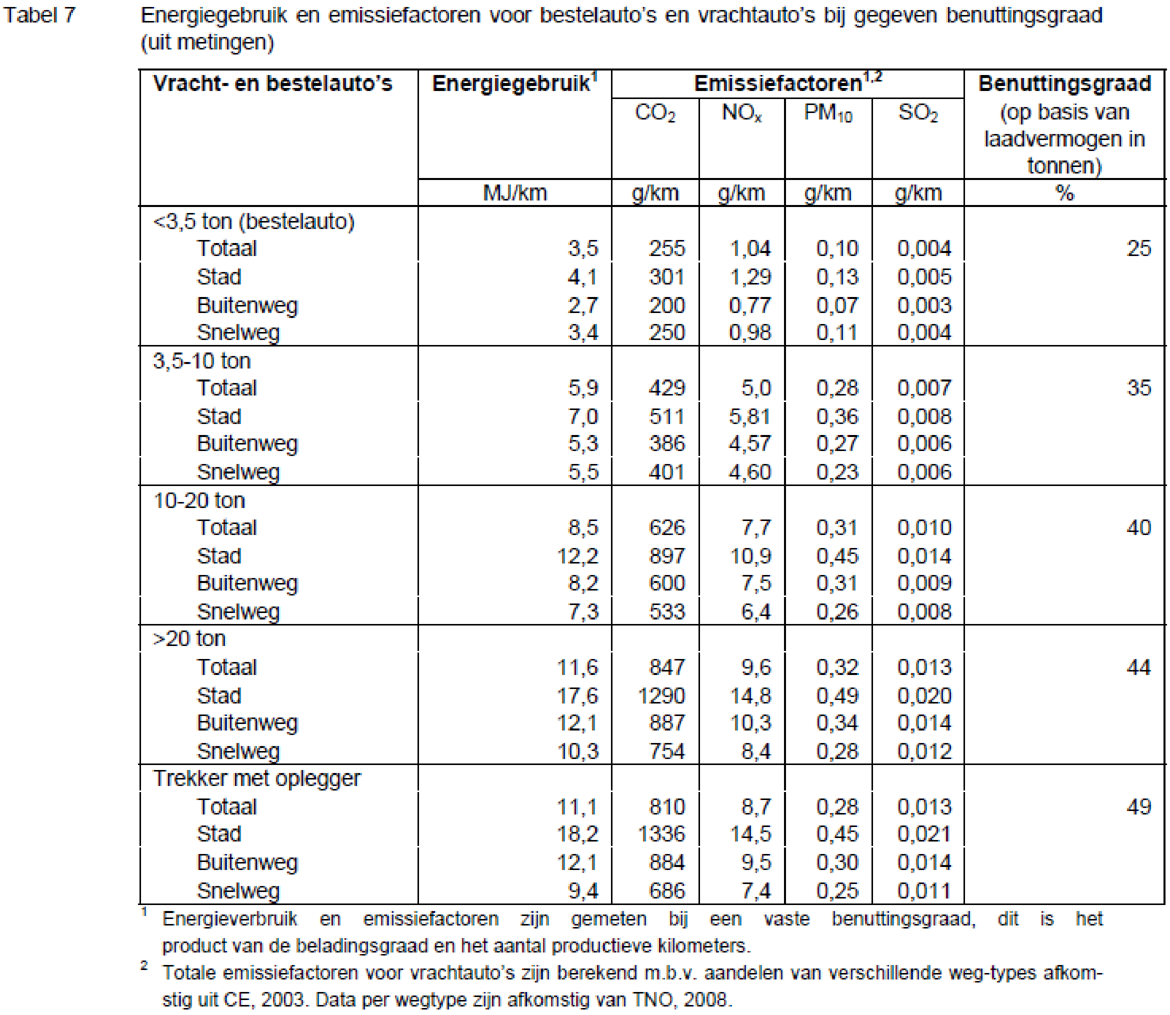
Table 1
Energy consumption per type of equipment.

Energy	Type of equipment	Fixed consumption per containermove	Variable consumption	Terminals	Source
Electric	QC: Quay Crane	6.00 kWh		ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP	TNO[a]
	BC: Barge Crane	4.00 kWh		ECT-D, APM	TNO[a]
	RC: Rail Crane	5.00 kWh		ECT-D, APM	TNO[a]
	ASC: Automated Stacking Crane	5.00 kWh		ECT-D	TNO[a]
	RSC: Rail-mounted Stacking Crane	7.25 kWh		ECT-Ha, RST, UNP	ASC[b]
	P: Platform	5.00 kWh		RST	ASC[b]
Diesel	AGV: Automated Guided Vehicle	1.10 l	1.80 l/km	ECT-D	TNO[a]
	SC: Straddle Carrier	0.80 l	3.50 l/km	ECT-D, ECT-Ho, APM, RST	TNO[a]
	TT: Terminal Tractors		4.00 l/km	ECT-D, ECT-Ho, ECT-Ha, RST, UNP	TNO[a]
	MTS: Multi Trailer System		4.20 l/km	ECT-D, ECT-Ho, APM, UNP	TNO[a]
	RS: Reach Stacker/Top Lifter		5.00 l/km	ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP	TNO[a]

[a] Based on a TNO project by Oonk (2006).

[b] Based on a comparison with the ASC on the ECT Delta terminal, in which the reach of the equipment (stack length) is taken into consideration.

Appendix 10, Complementing tables from CE Delft, STREAM (2008)

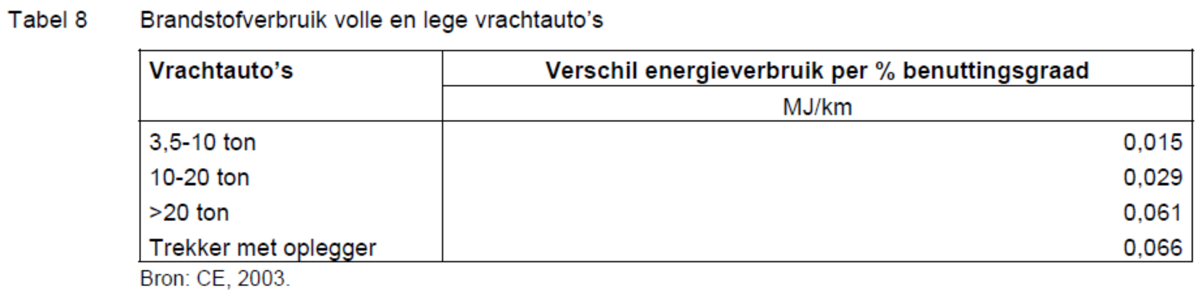


Tabel 7 Energiegebruik en emissiefactoren voor bestelauto's en vrachtauto's bij gegeven benuttingsgraad (uit metingen)

Vracht- en bestelauto's	Energiegebruik[1]	Emissiefactoren[1,2]				Benuttingsgraad (op basis van laadvermogen in tonnen)
		CO_2	NO_x	PM_{10}	SO_2	
	MJ/km	g/km	g/km	g/km	g/km	%
<3,5 ton (bestelauto)						
Totaal	3,5	255	1,04	0,10	0,004	25
Stad	4,1	301	1,29	0,13	0,005	
Buitenweg	2,7	200	0,77	0,07	0,003	
Snelweg	3,4	250	0,98	0,11	0,004	
3,5-10 ton						
Totaal	5,9	429	5,0	0,28	0,007	35
Stad	7,0	511	5,81	0,36	0,008	
Buitenweg	5,3	386	4,57	0,27	0,006	
Snelweg	5,5	401	4,60	0,23	0,006	
10-20 ton						
Totaal	8,5	626	7,7	0,31	0,010	40
Stad	12,2	897	10,9	0,45	0,014	
Buitenweg	8,2	600	7,5	0,31	0,009	
Snelweg	7,3	533	6,4	0,26	0,008	
>20 ton						
Totaal	11,6	847	9,6	0,32	0,013	44
Stad	17,6	1290	14,8	0,49	0,020	
Buitenweg	12,1	887	10,3	0,34	0,014	
Snelweg	10,3	754	8,4	0,28	0,012	
Trekker met oplegger						
Totaal	11,1	810	8,7	0,28	0,013	49
Stad	18,2	1336	14,5	0,45	0,021	
Buitenweg	12,1	884	9,5	0,30	0,014	
Snelweg	9,4	686	7,4	0,25	0,011	

[1] Energieverbruik en emissiefactoren zijn gemeten bij een vaste benuttingsgraad, dit is het product van de beladingsgraad en het aantal productieve kilometers.

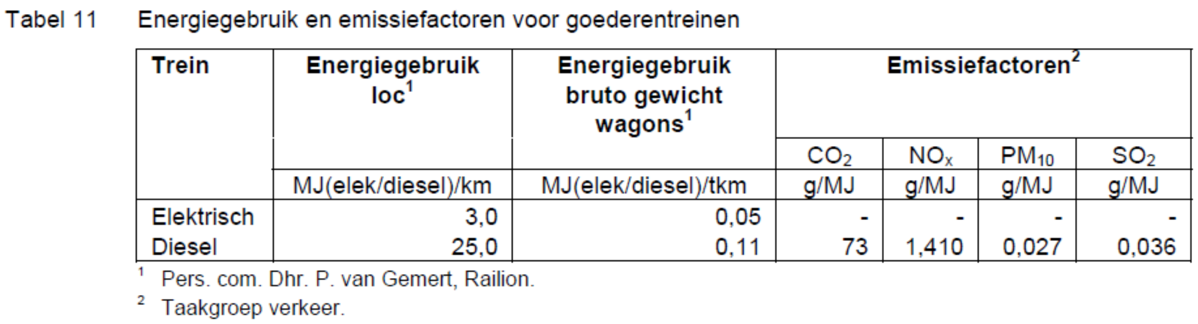
[2] Totale emissiefactoren voor vrachtauto's zijn berekend m.b.v. aandelen van verschillende weg-types afkomstig uit CE, 2003. Data per wegtype zijn afkomstig van TNO, 2008.



Tabel 8 Brandstofverbruik volle en lege vrachtauto's

Vrachtauto's	Verschil energieverbruik per % benuttingsgraad
	MJ/km
3,5-10 ton	0,015
10-20 ton	0,029
>20 ton	0,061
Trekker met oplegger	0,066

Bron: CE, 2003.

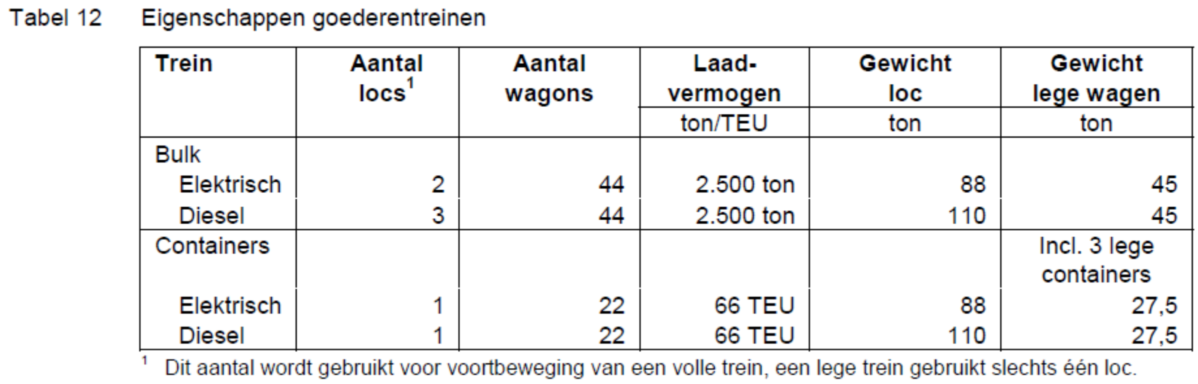


Tabel 11 Energiegebruik en emissiefactoren voor goederentreinen

Trein	Energiegebruik loc[1]	Energiegebruik bruto gewicht wagons[1]	Emissiefactoren[2]			
			CO_2	NO_x	PM_{10}	SO_2
	MJ(elek/diesel)/km	MJ(elek/diesel)/tkm	g/MJ	g/MJ	g/MJ	g/MJ
Elektrisch	3,0	0,05	-	-	-	-
Diesel	25,0	0,11	73	1,410	0,027	0,036

[1] Pers. com. Dhr. P. van Gemert, Railion.

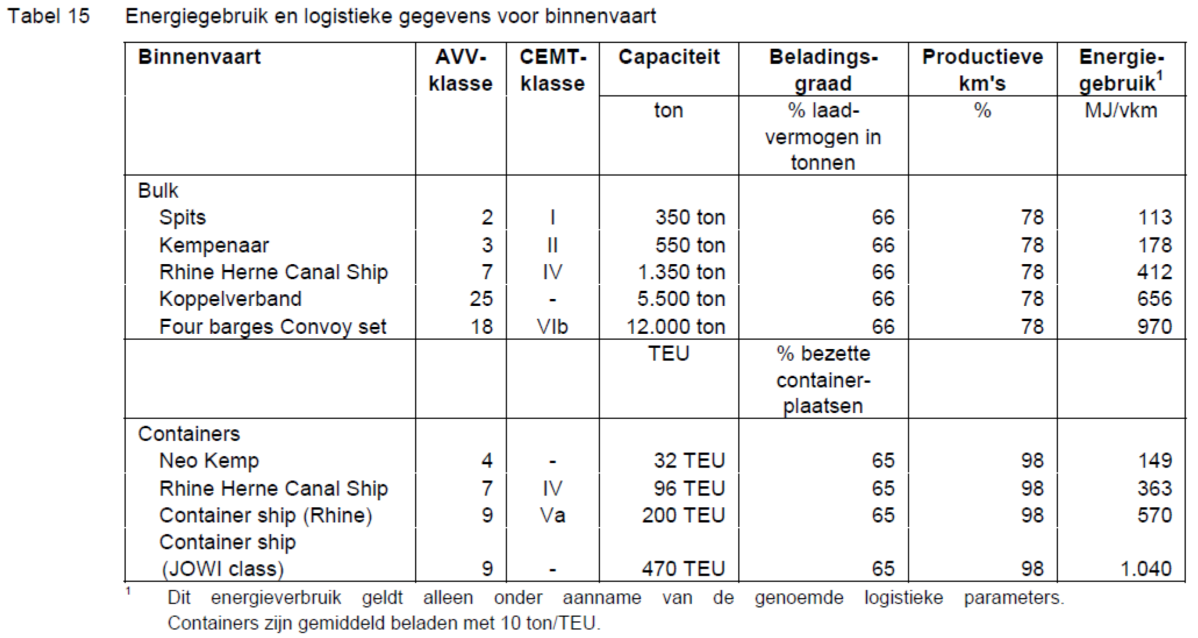
[2] Taakgroep verkeer.



Tabel 12 Eigenschappen goederentreinen

Trein	Aantal locs[1]	Aantal wagons	Laad-vermogen	Gewicht loc	Gewicht lege wagen
			ton/TEU	ton	ton
Bulk					
Elektrisch	2	44	2.500 ton	88	45
Diesel	3	44	2.500 ton	110	45
Containers					Incl. 3 lege containers
Elektrisch	1	22	66 TEU	88	27,5
Diesel	1	22	66 TEU	110	27,5

[1] Dit aantal wordt gebruikt voor voortbeweging van een volle trein, een lege trein gebruikt slechts één loc.

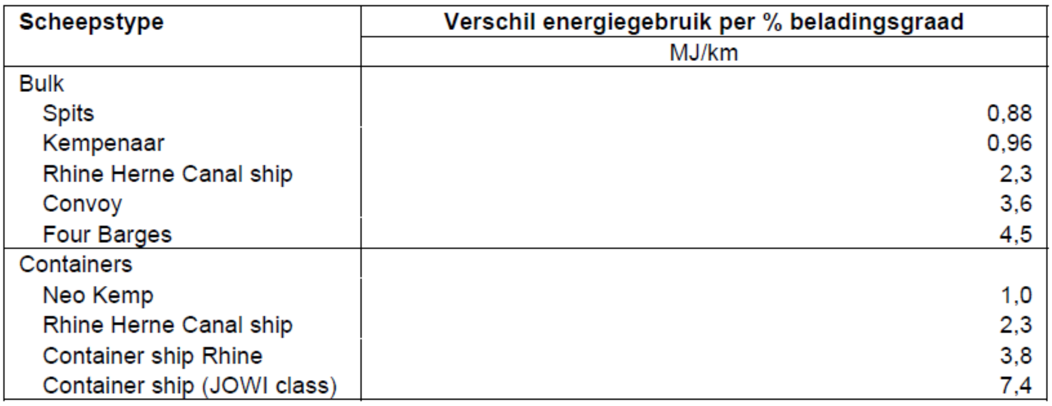


Tabel 15 Energiegebruik en logistieke gegevens voor binnenvaart

Binnenvaart	AVV-klasse	CEMT-klasse	Capaciteit	Beladings-graad	Productieve km's	Energie-gebruik[1]
			ton	% laad-vermogen in tonnen	%	MJ/vkm
Bulk						
Spits	2	I	350 ton	66	78	113
Kempenaar	3	II	550 ton	66	78	178
Rhine Herne Canal Ship	7	IV	1.350 ton	66	78	412
Koppelverband	25	-	5.500 ton	66	78	656
Four barges Convoy set	18	VIb	12.000 ton	66	78	970
			TEU	% bezette container-plaatsen		
Containers						
Neo Kemp	4	-	32 TEU	65	98	149
Rhine Herne Canal Ship	7	IV	96 TEU	65	98	363
Container ship (Rhine)	9	Va	200 TEU	65	98	570
Container ship (JOWI class)	9	-	470 TEU	65	98	1.040

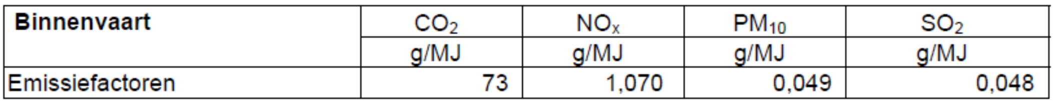
[1] Dit energieverbruik geldt alleen onder aanname van de genoemde logistieke parameters. Containers zijn gemiddeld beladen met 10 ton/TEU.

Tabel 16 Afhankelijkheid energiegebruik van de beladingsgraad voor binnenvaartschepen



Scheepstype	Verschil energiegebruik per % beladingsgraad
	MJ/km
Bulk	
Spits	0,88
Kempenaar	0,96
Rhine Herne Canal ship	2,3
Convoy	3,6
Four Barges	4,5
Containers	
Neo Kemp	1,0
Rhine Herne Canal ship	2,3
Container ship Rhine	3,8
Container ship (JOWI class)	7,4

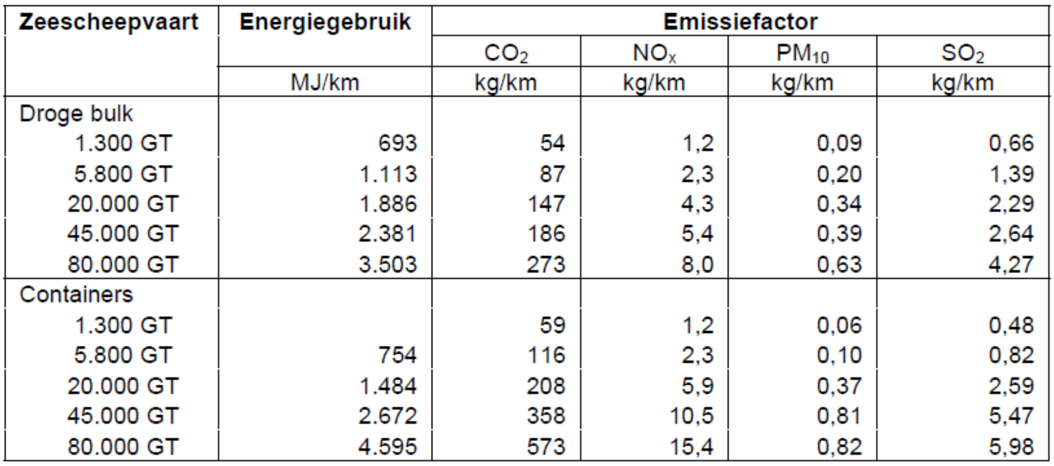
Tabel 17 Emissiefactoren binnenvaart



Binnenvaart	CO_2	NO_x	PM_{10}	SO_2
	g/MJ	g/MJ	g/MJ	g/MJ
Emissiefactoren	73	1,070	0,049	0,048

Bron: Taakgroep Verkeer en Vervoer.

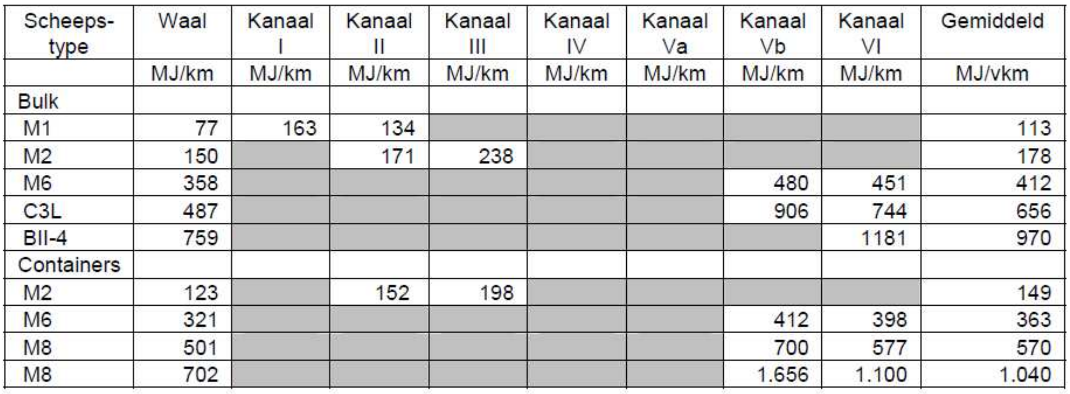
Tabel 18 Emissies en energiegebruik in de zeescheepvaart



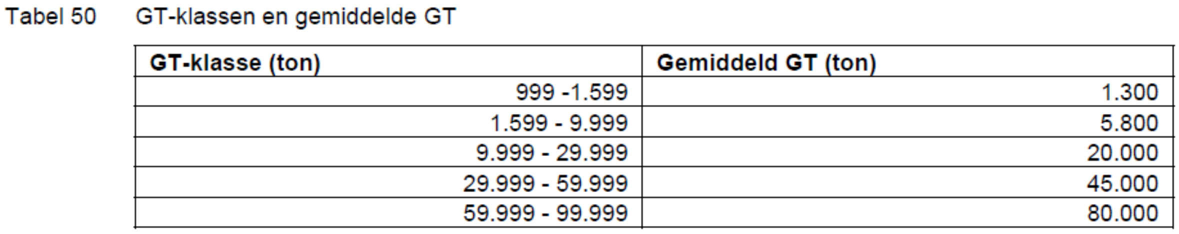
Zeescheepvaart	Energiegebruik	Emissiefactor			
		CO_2	NO_x	PM_{10}	SO_2
	MJ/km	kg/km	kg/km	kg/km	kg/km
Droge bulk					
1.300 GT	693	54	1,2	0,09	0,66
5.800 GT	1.113	87	2,3	0,20	1,39
20.000 GT	1.886	147	4,3	0,34	2,29
45.000 GT	2.381	186	5,4	0,39	2,64
80.000 GT	3.503	273	8,0	0,63	4,27
Containers					
1.300 GT		59	1,2	0,06	0,48
5.800 GT	754	116	2,3	0,10	0,82
20.000 GT	1.484	208	5,9	0,37	2,59
45.000 GT	2.672	358	10,5	0,81	5,47
80.000 GT	4.595	573	15,4	0,82	5,98

Bron: EMS-model; eigen analyse.

Tabel 49 Energiegebruik op verschillende vaarwegen voor verschillende scheepstypen



Scheeps-type	Waal	Kanaal I	Kanaal II	Kanaal III	Kanaal IV	Kanaal Va	Kanaal Vb	Kanaal VI	Gemiddeld
	MJ/km	MJ/km	MJ/km	MJ/km	MJ/km	MJ/km	MJ/km	MJ/km	MJ/vkm
Bulk									
M1	77	163	134						113
M2	150		171	238					178
M6	358						480	451	412
C3L	487						906	744	656
BII-4	759							1181	970
Containers									
M2	123		152	198					149
M6	321						412	398	363
M8	501						700	577	570
M8	702						1.656	1.100	1.040



Tabel 50 GT-klassen en gemiddelde GT

GT-klasse (ton)	Gemiddeld GT (ton)
999 -1.599	1.300
1.599 - 9.999	5.800
9.999 - 29.999	20.000
29.999 - 59.999	45.000
59.999 - 99.999	80.000