MASTER

Determining a method for calculating CO2 emissions in transport and the effect of emission regulations on supply chain design for a chemical company

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Determining a method for calculating CO_2 emissions in transport and the effect of emission regulations on supply chain design for a chemical company

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Abstract

This Thesis describes the project conducted at Dow Chemical as part of the Carbon Regulated Supply Chains project initiated by the European Supply Chain Forum. The thesis has three main goals. The first goal is to determine a method for calculating CO_2 emissions from transport. This methodology is converted in a calculation tool which can be used to calculate the emissions for a large dataset. The methodology is based on the NTM methodology with some additions (cleaning, temperature control and vertical handling).

The second goal of the project is to get a better understanding of the CO_2 emissions regulations that are currently developed or implemented. The study focuses on European rules and regulations. There are several options for emission regulations that are currently discussed or implemented. The main regulations are; Emission Trading Scheme, Euro-Vignette and a diesel taxation. These are all under discussion at the moment and the manner of implementation can have a significant effect on companies.

Combining these two previous goals leads to the third goal; what is the effect of the emission regulations on supply chain design. Based on the data it can be concluded that switching modalities can be a worthwhile approach for companies in an effort to reduce emissions. With regard to the emission it can be stated that in many cases the regulations lead to significant cost increases but limited incentive to reduce emissions.

Management Summary

This Master Thesis describes the calculation of CO_2 emissions in transport, both a method of calculating the emissions as well as a case study to determine how the method works in practice. The second part of the Thesis describes how the knowledge of the emissions can be used to reduce emission and assess the impact of EU regulations on the emissions. The lack of a calculation methodology, case studies and knowledge of the impact of regulations make it difficult for companies to determine a strategy to reduce emissions and costs.

Study

This Master Thesis is part of the Carbon Regulated Supply Chains (CRSC) project initiated by the European Supply Chain Forum. The CRSC project is the overall project focussed on the influence of carbon dioxide emission or regulations on supply chains. In the initial set up four Master Theses have been conducted as part of the research. This Thesis is one of these four and has been conducted at Dow Chemical. The goal of the four Theses is to determine and validate a method for calculating CO_2 emissions in transport. The second goal is to identify possible regulations and determine how these will impact supply chain decisions. Part of the Thesis consists of conducting a case study. The case study and research scope are limited in several areas. The project will only consider CO_2 emissions, not all GHG emissions. The reasons are that the other emissions are low compared to CO_2 emissions and the current regulations only take CO_2 into account. The scope is limited to all polyol shipments ex. Terneuzen without customer pick-ups till the customer.

Research

At the moment there are several gaps in current literature with regard to calculation, regulation and reduction of emissions in transport. The focus of the study is to provide more knowledge for several of these gaps. The first goal of the study is to develop a calculation methodology and tool to be able to calculate the CO_2 emissions during transport. In the second part, the study aims to get a better insight into the influence the rules and regulations have on the supply chain. This is analysed based on the case study and using several scenarios. The last part is the identification of business opportunities. Knowing the emissions during transport is the first thing, knowing how to use this information is the most important part for companies. The study aims to provide a better insight in how the information about emissions can be used to reduce emissions and to reduce the effect of the regulations.

Two main research questions where defined with regard to these topics; w*hich factors will have a substantial impact on the overall emissions during transportation* and *what opportunities arise with the implementation of new regulations.*

Methodology

The calculation methodology is mainly based on the NTM methodology. This methodology is developed by a Swedish non-profit organisation. The methodology was chosen from a set of five available methodologies and was modified in some places. Some additions were made to the existing model, for example three new categories were added; Cleaning, Heating/Refrigerating and Vertical Handling. This methodology is used for calculating the emissions for the case study.

Data collection

When using the basic methodology the amount of data that is needed is very high. One can use less information but then it is necessary to use the averages and assumptions that are discussed in the methodology. Using the real values leads to more accurate results but retrieving these is time consuming. The data collection was split up into two parts; the internal data collection and the external data collection.

The internal data collection consists of collecting data from the internal systems. The data that are retrieved from the internal system are from and to locations, type of product, dates, weight shipped and mode of transport. This data was collected and processed by a Dow employee. The data had to be modified slightly; the outgoing shipments of the terminals had to be allocated to the Terneuzen facility if more than one facility supplied the terminal with the same product.

The external data collection consists of collecting data at the Logistic Service Providers (LSP's). The data was collected via an extensive questionnaire consisting of the lane information and several questions necessary to calculate emissions. The questionnaire was sent to 35 LSP's within the scope of the project.

The responses to the questionnaire were varying; most of the LSP's were willing to cooperate in the questionnaire (75%). However, the amount of information each of the LSP's was able to retrieve varied as well. For some of the questions in the questionnaire no responses or few responses (<10 weight% represented) could be given. In those cases it was not possible to use the data to verify the assumptions of the methodology. For road transport almost all LSP's were able to retrieve the necessary information. For water transport the data collections was more difficult. The amount of data that was available to the LSP's and the amount of data that they were willing to share was very low for water transport (often less than 10%).

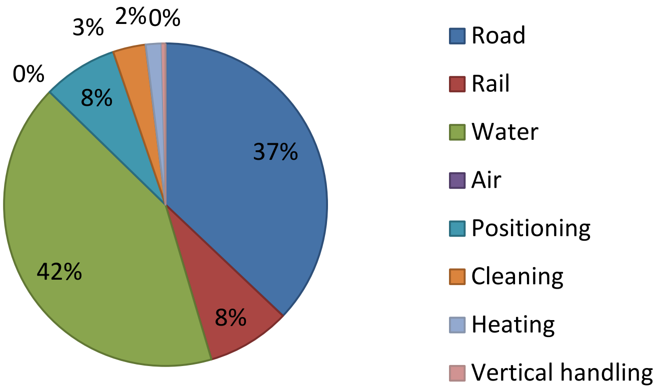
The general conclusion of the case study with regard to the data collection is that it is time consuming and often difficult to retrieve all the data. The reason is that the data is either not readily available or due to commercial value of the data.

Tool

Several tools are available at the moment for calculating CO_2 emissions in transport. None of the tools available uses the NTM methodology at the moment nor do they allow batch processing of data. Because both features are needed in this project the decision was made to build a tool with the CRSC project group. The tool uses the methodology described in this Thesis and features both batch processing as well as single lane comparison.

Results

Based on the collected data and the developed tool the emissions were calculated. The calculations showed that most emissions arise in water and road transport as can be seen in the figure below. This is mainly caused by the large amounts of products transported via water transport and the high emissions in road transport.



Next, a sensitivity analysis was conducted to determine which factors are worthwhile to collect and for which factors assumptions can be used. Based on the sensitivity analysis it can be stated that there are several key factors that are necessary to be included. These are the mode of transport, weight of the shipment and the distance travelled. Other factors that are important to take into account are; the distance per country for rail transport, the load factor and positioning distance. For the two last factors assumptions are given, however, the sensitivity analysis showed that there is still a large variation to these factors. Therefore, it would be best to use real values although assumptions can be used. The emissions from rail transport vary significantly when calculating the emissions per country compared to using an EU average. For the other factors where sufficient information was available to do a sensitivity analysis it is sufficient to use assumptions.

Business Opportunities

In the Thesis two options for business opportunities are identified and discussed; reduction opportunities and supply chain redesign options. The first is the identification of reduction opportunities in a dataset. The case study contained several thousand shipments on hundreds of lanes. Sorting through all these lanes to identify the reduction opportunities manually would be very time consuming. To reduce the number of lanes that have to be checked to determine whether there are reduction opportunities several methods have been proposed to identify reduction opportunities. These methodologies have been tested on the database to determine which of the proposals was best suited. The proposed method uses a decision tree structure, where the decisions lead to an opportunity score for each lane. These lanes are the lanes that are worthwhile to investigate for reduction opportunities. Based on this method a set of lanes was identified where emission reduction is possible.

The second business opportunity was the supply chain redesign, where two options were identified. In the first option a terminal was placed at Ludwigshafen for container storage. In that case the customer close to Ludwigshafen could be supplied by the terminal and the terminal could be supplied using rail transport instead of using road transport from Terneuzen to the customer. This option was not cost-effective under none of the scenarios and other options should be found to deal with this (i.e. longer lead time). The second redesign option was placing a tank at one of the production locations and supply the tank with bulk vessels. Transport from the tank would take place by road transport. The analysis showed that this would increase the emissions for a part of the region. The advice would be to use the tank for the country of the production location and use regular transport for the other countries. This would still lead to a reduction of emissions at a cost effective way.

Rules and Regulations

The European Union is currently designing and discussing several regulations with regard to CO_2 emission reductions. Four main regulations were identified and have been combined into six scenarios. These six scenarios were analysed to see both the impact of the scenario on the costs as well as the CO_2 reductions. Based on the scenario analyses it can be stated that the effect of the scenarios on the number of reductions are marginal. The scenarios hardly influence the percentage of reductions at minimum costs. This means that in general the regulations lead to increased cost but not to reduced emissions. The best option seems to be to have high road emission costs in combination with low rail and water emission costs.

Conclusions and Recommendations

One of the important findings of the study was that using all details for the emission calculations would be very time consuming due to the manual labour involved in retrieving these data. Therefore it is recommended to use the assumptions in the overall emission calculation and identify reduction opportunities on these data. For the actual improvement calculations the detailed approach should be used to determine the actual gains from the reduction.

The two main research questions of the study were; w*hich factors will have a substantial impact on the overall emissions during transportation* and *what opportunities arise with the implementation of new regulations.*

The first question was formulated with regard to the emission calculations, it is important to know which factors should be taken into account when calculating CO_2 emissions. Based on the study it can be stated that the main parameters are;

- Distance
- Weight
- Modality
- Empty kilometres
- Load factor

The three parameters that are added in this study (heating, cleaning, vertical handling) are not very influential on the final result (0.5 – 3 % of all emissions). In total the three categories can add up to almost 5% of all emissions.

For almost all parameters that have been investigated in the study it is sufficient to use the assumptions used in the method. However, there is one main exception the emission for electric rail transport. Calculating this with the EU average will lead to significantly different emissions than calculating the emissions for each country. Therefore the advice is to calculate the emissions per country for rail transport and add those up instead of using the EU average.

The second research question concerned the opportunities that possibly arise with the implementation of emissions regulations. The study focuses on emission reduction opportunities and involved costs. Four main new regulations were identified in the study as being likely to be implemented;

- ETS (currently implemented)
- ETS (including aviation and sea navigation or including all transport)
- Transport ETS (separate system comparable to ETS only including transport)
- Diesel Tax (regulations forcing governments to have a higher diesel tax than petrol tax)
- Euro-Vignette (exists at the moment but modifying the current vignette such that CO_2 emissions are taken into account)

These regulations were combined into six scenarios where several price levels have been investigated for each scenario. The results showed that the scenarios all lead to increased costs (up to 12.5% of transport costs) but have little effect on the reductions at minimum costs. This means that in practice the costs increase significantly but there is no additional incentive to reduce emissions.

The scenario analysis showed that the best option is to have high road costs compared to rail and water costs. This combination leads to the best incentive for additional reductions. However, since most companies have a high share of road transport this will also mean that the costs increase significantly at high road costs. Therefore it would be a better option to increase the road costs while reducing the rail and water costs. This leads to a high incentive for CO_2 reductions at lower costs.

Preface

This thesis is the result of the graduation project for the MSc program in Operations Management and Logistics. The thesis is part of the Carbon Regulated Supply Chains projected initiated by the European Supply Chain Forum. The project was conducted at Dow Chemicals at their Terneuzen facility.

I would like to take the opportunity to thank my supervisors of the project. First of all I want to thank Jan Fransoo for giving me the opportunity to work with him and to work on this project. I have enjoyed working with him during the MSc program and my graduation project in particular. I want to thank him for his role in the opportunities I have been granted, my semester at DTU (Copenhagen), the CRSC project and the facilitation of the project at Dow. His directions and enthusiasm during our meetings have been an inspiration throughout the project. Furthermore, I would like to thank Ton de Kok for his role in the graduation project. His critical reflections on the report and methodology have lead to a better report and project.

I would like to thank my colleagues and the stakeholders at Dow Chemical. I am especially grateful to Peter van Egerschot for his support and input during the weekly meetings and all other occasions. Your effort, stories, questions and the cooperation have been a great motivation and inspiration. I would like to thank the people of the “Werkgroep Keten Efficiency” for their support and especially the input provided which made it possible to do this project. Furthermore I would like to thank my roommates for the fun and their help during the project. Last but not least I want to thank all the colleagues that helped with getting to this result and that made it possible for me to conduct the project at Dow Chemical.

A special thank you to LHC Consulting, Richard van Dijk in particular, for providing the support and the creativity to make it possible to do this project.

I owe many thanks to all my friends who have made these six years of college the great years that they have been. Thank you Roel, Inge and Hakkih for the cooperation, brainstorming and support during the project.

Finally, the biggest thank you goes to my parents and family for supporting me in all the choices I made whether it was spending a semester abroad or starting a Master in a new field. Thank you, I owe all of this to you.

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1 Introduction

In the last decades people have come to realise that the choices and actions of people affect the earth and the climate. This has lead to numerous researches and projects that aimed to explain these changes and to determine ways to counter them. One of the commonly accepted methods to reduce the climate change is the reduction of so called Greenhouse Gas (GHG) emissions. Several companies, governments and NGO's have made agreements or developed methods to reduce the GHG emission. One of these agreements was the Kyoto protocol, which runs till 2012 (UNFCC, 1998). The countries that signed the Kyoto protocol agreed to reduce their collective CO_2 emissions with 5.2% compared to the emissions in 1990. During the coming years a new agreement will probably be signed as the Copenhagen protocol, to set the post Kyoto targets.

The European Union (EU) decided to take its responsibility in the reduction of CO_2 emissions and as part of this effort the EU has established the Emission Trading Scheme (ETS). The scheme aims to reduce the emissions of GHG's throughout the industries, the ETS is introduced in several stages and in each of the stages new industries are included. The scheme works as a resource market, there is a limited number of allowances for emitting one tonne of CO_2. Companies are not allowed to emit more CO_2 than they have allowances. The scheme also introduced a market where these allowances can be traded. Over time the different transportation modes could be included as well. However, there is some discussion with regard to including the transport sector in the current ETS. To reduce the emissions in transport other regulations are being announced and enforced as well. For example the Euro-Vignette, the vignette already exists but is likely to be modified such that it will take into account the cost of emitting CO_2.

This study focuses on two parts of the challenges involved in dealing with these regulations. The first part is the calculation of emissions during transportation; therefore the first goal is to develop a model to calculate emissions in transportation. The second part is to understand how the new regulations will impact supply chain design and what companies can do to reduce their emissions and therefore reduce increased costs due to the new regulations.

1.1 General CRSC Project

The Eindhoven based European Supply Chain Forum (eSCF) initiated the Carbon Regulated Supply Chains (CRSC) project in the summer of 2008. The first goal of the project is to identify a methodology for determining CO_2 emissions during transportation. The second goal of the project is to gain a better insight in the effect that new regulations will have on the way business is conducted. The third goal is to identify business opportunities and supply chain redesign opportunities to deal with and profit from regulations and CO_2 emission reduction.

In the initial setup of the project four Master Theses will be conducted in parallel at four companies. The four companies, all members of the eSCF, which are participating are:

- Dow Chemical
- Bausch & Lomb
- Cargill
- Unilever

These initial studies will result in a methodology for calculating emissions and preliminary conclusions with regard to business opportunities. This research is one of the Master Theses in the initial set up and is conducted at Dow Chemical. For the other three projects we refer to the Theses by Te Loo (Te Loo, 2009), Van den Akker (Van den Akker, 2009) and Ozsalih (Ozsalih, 2009). The project management of the CRSC project is done by LHC Consulting.

1.2 Research Scope

The topic of emission trading and calculation is very recent and therefore the literature is not as extensive as is the case in many other fields of operations management and logistics. In the current literature there are some articles and publications on methods to determine the emissions. However, there has been little research with regard to the implications of these emissions and the consequential costs. The aim of the study is therefore to add to this literature and to determine what effect this can have for companies. Having additional costs for transportation due to the costs of emissions can lead to different solutions for supply chain designs. For example, determining the location of production locations or warehouses could change if the costs of transportation become higher for the company. Another option could be that the mode of transportation is changed. For example, the change from carbon intensive modes like air and road to less carbon intensive modes, rail or water. This will change the transportation routes and the lead times of the process which potentially results in different service levels and costs as well. Therefore it is not clear whether the new costs for emissions will only lead to additional costs or that there are opportunities to reduce those costs or even profit from the regulations. This is a very extensive scope and is narrowed down as described below.

The first focus of the project is the method of calculating the emissions and mapping the emissions for one of the business units of the company. This is done to give an idea of how this can be done and what challenges arise with these calculations. There are several methods that are proposed as a basis for measuring the emissions, for example EcoTransIT (EcoTransIT, 2008), NTM (NTM 2008), and GHG Protocol (GHG Protocol, 2005). The decision was made to use the NTM method in this project because of the reasons that are mentioned in section 3.2. Due to the fact that not all assumptions hold in the project, changes have been made to the data and assumptions; this will be mentioned where appropriate. The emission calculation is based on the weight of the shipment, the type of transport and the distances that are travelled. The emissions mainly depend on these factors but other factors have to be taken into account as well, such as the terrain type, the traffic density, the speed and so on. In the first pass, the emissions have been calculated taking into account all available information. Based on these calculations the impact of the factors is determined.

The way in which (future) emission regulations impact the supply chain design and operations is another part where there is currently little information available. The regulations could lead to a change of strategy for the companies with regard to supply chain design. At the moment it is unclear which regulations will be implemented. For example, whether transport will be included in the ETS or whether separate regulations will be enforced. These different approaches could have a significant effect on the way companies are influenced. Therefore the project aims to give a better insight in the effects of these different regulations by setting up scenarios and determining the effect of these scenarios.

Another part where literature is lacking is in the field of business opportunities for the companies. This applies to both how companies can reduce their emissions or can identify reduction opportunities, as well as how they can use information about emissions. The new regulations will lead to both challenges and opportunities but at the moment it is still unclear which those will be. One of the aspects which is often associated with green production or green products is the marketing of that aspect. This could be an opportunity for the company to use these data and these strategies to market the product as a green product or supply chain. Other opportunities could lie in the field of supply chain design. Decisions with regard to opening new locations could be influenced by the additional emission costs for transport. Other opportunities could be that anticipating the regulations could lead to making decisions at this moment that will lead to lower costs once the regulations are in effect. For example, if a company is changing its network design it would be beneficial to take into account the regulations in the upcoming years. There is only a limited amount of literature available on this topic at the moment and it is therefore worthwhile to see what effect this could have.

1.3 Company Description

The Dow Chemical Company was founded by Herbert H Dow in Midland (Michigan, USA) in 1897. Global headquarters is still located in Midland. Dow is the second largest chemical company in the world, with annual net sales of more than $ 58 billion in 2008. The company is a diversified, global manufacturer and supplier of base chemicals, specialty chemicals, plastics and agricultural products for customers in 160 countries. The customers are served from over 100 production locations employing around 46,000 employees. On April 1, 2009, Dow acquired Rohm and Haas Company, a global specialty materials company with sales of $10 billion in 2008 and 15,000 employees worldwide.

The European division of the company, Dow Europe GmbH, has been involved in the chemical market in Europe since 1952. The current sales of Dow Europe GmbH are over $ 21.8 billion and with around 13,500 employees it delivers products to customers throughout EMEA countries. The biggest production location outside the USA is located in Terneuzen (The Netherlands). The Terneuzen site is the location of the case study for this project. Due to the environmental challenges arising lately, the site has decided to set up a group focussing on Energy and Climate Change. One of the subgroups is the "Werkgroep Keten Efficiency" (Supply Chain Efficiency workgroup) and this study will be part of the effort of this group.

Within Dow the products are divided into seven different industry segments; Performance Plastics, Performance Chemicals, Agricultural Sciences, Basic Plastics, Basic Chemicals, Hydrocarbons and Energy and Unallocated and Other.

The activities are subdivided into several business units and within the Performance Plastics segment there is the Polyurethane (PU) business unit. This business unit is the BU where the case study of this project will be conducted.

1.4 Project Approach

The study is divided into two sub phases. Phase I consists of the development of a method to calculate emissions during transport. Phase II focuses on determining how the new regulations will impact supply chain design and determining opportunities arising with the new regulations. The two phases will be discussed separately below. As mentioned before, the study will be conducted at four companies in parallel. Throughout the project the researchers will cooperate both in methodology development as well as analysing the data. The scenarios in of the second part will be generated in cooperation. This means that the methodology (Chapter 3) is a joint effort. Sections 3.2-3.7 are identical to the methodology described in the overall report of the CRSC project (CRSC 2009).

1.4.1 Phase I

For the development of a method to determine emissions during transportation the study uses the NTM (see chapter 3) approach as a basis. The methodology proposed by NTM is used and other parts are added to the methodology (heating, cleaning and vertical handling). The methodology has an extensive database with values and assumptions required to calculate the emissions. The data from NTM can be used for the calculations. However, to be able to determine the validity of these values, data is collected from within Dow and the Logistic Service Providers (LSP's) of Dow. Those data are used to validate the values proposed by NTM.

The data from Dow are retrieved from the internal SAP system and includes essential data for the calculation (i.e. mode of transport, weight). For the external data collection an extensive questionnaire was sent to the LSP's of the PU business, the questionnaire is send to over 35 LSP's.

Parallel to the data collection, a tool was developed in MS Access (Chapter 5) to calculate the emissions once the data collection is finished. The tool is used for both calculating the emissions as well as for phase II.

1.4.2 Phase II

The second phase starts with determining which regulations will likely be implemented in the near future with regard to the emissions in transport. This is done via information gathered from university contacts at Eindhoven University of Technology as well as information retrieved form the EU and European lobbyists. Scenarios were set up to determine the effect of these regulations on the business. The tool that is developed in the first phase is used to determine the effects.

In the second phase a method is developed to identify reduction opportunities. There is little research in this field and the study aims to provide companies with a guide on how lanes can be identified where reductions can likely be achieved.

During the second phase a list will be made with the reduction opportunities for the PU business. The list will contain easy targets for the company to reduce their emissions. This will lead to a lower environmental impact and will help the company to meet their self set targets of emission reduction.

1.5 Project Scope

The scope is divided into two parts; the scope for the case study at Dow Chemical and the scope for the type of emissions that are taken into account. These are discussed below.

1.5.1 Scope at Dow Chemical

The scope for the project at Dow Chemical is the polyurethane business unit located in Terneuzen. The project only focuses on the outbound transport of products to the customers. All transport legs between the site and the consuming customer is in scope. This means that for the products which are stored at one of the storage facilities and then shipped to the customer all transport is taken into account, not just the part to the storage facility. The reason for this decision is that Dow Chemical has several storage facilities throughout Europe from where several products are shipped. The overall emissions from transport would not reflect the true emissions if only considering the first part. The final scope is displayed in Figure 1.

The scope of the project is gate to gate, which means that the transportation from the gate at the Terneuzen location till the gate of the customer will be taken into account. The onsite logistics will not be taken into account; the distances travelled there are marginal compared to the distances travelled towards the customer.

At the facility in Terneuzen there are also customers that come to collect the products; these are so called customer pick-ups. These customer pick-ups are not part of the scope because the company can not influence the mode of transport nor the emissions.

Transportation via pipeline is not taken into account because this is only used for transportation from the Terneuzen facility to the Oil Tanking facility, which is approximately 5 km. This is both a short distance and small volumes and therefore this part is excluded from the scope. Another transportation method that is excluded is Air Parcel services, the main reason is that this is not a common mode of transport and only used for samples. Secondly, the total volume of Air Parcel services is less than 0.01% of total shipments.

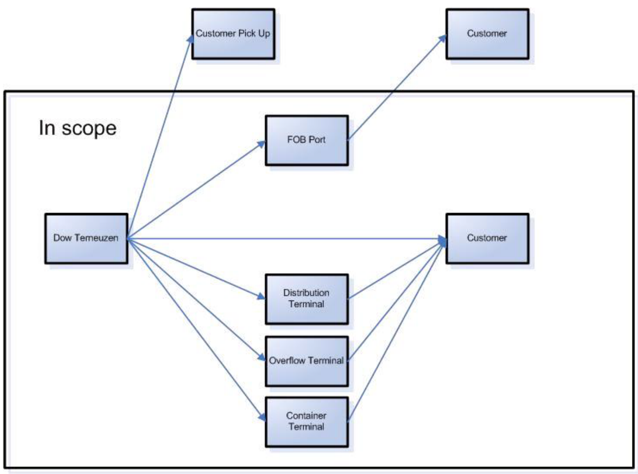

Figure 1: Case study scope

1.5.2 GHG

The decision was made to focus on the CO_2 emissions during transport. There are several gases emitted during transport that contribute to global warming but only the CO_2 emissions will be calculated. The first reasons for this decision is that the emissions of other gases compared to the CO_2 emissions are relatively small as can be seen in Table 1. Here we can see the emissions of methane (CH_4) and other hydro carbons (HC, excluding methane) compared to CO_2. However, this does not mean that the impact on global warming is small as explained below.

Table 1: Relation GHG emissions

	Emission			GWP		
Mode	CO_2	CH_4	HC	CO_2	CH_4	HC
Truck (NTM Road, 2008)	1	1.17E-05	4.92E-04	1	4.69E-05	1.82E-03
Rail - Electric (NTM Rail, 2008)	1	-	1.46E-04	1	-	5.41E-04
Rail - Diesel (NTM Rail, 2008)	1	3.79E-05	1.55E-03	1	1.52E-04	5.75E-03
Water (NTM Water, 2008)	1	5.98E-06	2.96E-04	1	2.39E-05	1.09E-03
Air (NTM Air, 2008)	1	-	3.59E-04	1	-	1.33E-03

It is commonly accepted that not all greenhouse gases have the same contribution to global warming and therefore there is a CO_2 – equivalence scale where data are given to determine the relative impact of the GHG's on global warming compared to CO_2. This factor is the Global Warming Potential (GWP). The GWP of the emitted gasses are 4 for CH_4 and 3.7 for HC, the values are retrieved from the Danish LCA research conducted by Wenzel (Wenzel et. al., 2001). A GWP of two means that emitting one kilogramme of that gas has a double impact compared to emitting one kilogramme of CO_2. Based on these values the GWP of Table 1 is calculated. Here one can see that those gasses have a negligible effect on the total emission.

2 Research Plan

In this chapter the research plan is described. In the first section the problem definition is given. In the second section the research domains are explained in more detail. In the third section the research questions are presented and this is followed by a section explaining how the research is conducted.

2.1 Problem Definition

There are several problems involved with the upcoming regulations and the calculation of CO_2 emissions during transport. There are three problems this study will address and these are explained below.

Calculating CO_2 emissions in transport

The first problem is the calculation of emissions in transport; there are several methodologies available for calculating the emissions. However, none of the methods has had a case study to validate the assumptions made in the methodology. Another issue is the varying level of detail of the methodologies as well as the unclearness with regard to the validity of assumptions in many cases. In this study a methodology will be chosen and validated through an extensive case study to determine a method of calculating emissions in transport.

Influence of rules and regulations

At the moment there is limited understanding of the how planned or discussed emission rules and regulations will affect supply chains. The first step is to determine which rules and regulations are likely to be implemented with regard to emissions in the near future. The second step is to determine how these emission rules and regulations potentially influence the supply chain design and operations of a company.

Business Opportunities

Knowing the emissions of the supply chain is only the first step, the second step is to determine how one can use this information. Based on a case study the researcher will look into possible business opportunities arising with the availability of this knowledge. One of the aspects is reducing the emissions in the current supply chain design. One of the attention areas is a process for easy identification of lanes with promising emission reduction opportunities. In the process, the cost and service should be taken into account when determining whether these lanes can be modified.

2.2 Research Questions

The questions that the project will aim to answer are subdivided in two categories; research questions addressed in the CRSC project and research questions specific to Dow. Note that the results only hold for the Dow case study, for generalised results over the four projects the reader is directed to the overall publication (CRSC 2009).

2.2.1 CRSC

In this subsection the research questions concerning the overall CRSC project are discussed. These are the questions that are looked into in the other projects as well and apply to the general research.

1. ***Which factors will have a substantial impact on the overall emissions during transportation?***

The project aims to determine which factors are important in the overall emission calculations and which factors can be neglected. In the latter case assumptions could also be used.

a. What is the effect of positioning distances on the overall emissions?

The positioning distance is defined as the distance that has to be travelled to get the mode of transport to the loading location. In the case of road transport this could be a truck that has to come from a LSP to the shipping company. The distances involved for this part of the transport could have a significant impact on the overall emissions as the NTM data show [NTM 2008].

b. What is the effect of the load factor on the overall emissions?

One of the more important aspects that determine the level of emissions is the load factor for the transport. The load factor is the percentages of the maximum load the transport mode uses during the transportation. Having a higher load factor, meaning a higher capacity utilisation, will lead to a lower emission per tkm. This means that there are less emissions arising from the same transport if the load factor is higher. The NTM model shows a large difference for several transport modes for different load factors [NTM 2008].

c. What is the effect of using assumptions instead of real values on the results of the calculations?

Apart from the three main factors (distance, modality, weight) a sensitivity analysis will be conducted to determine whether other factors could potentially be influential as well. The sensitivity analysis will also be used to determine whether it is worthwhile to collect all data or whether using assumptions will suffice.

d. What is the effect of cleaning on the overall emissions?

The models known to the researcher do not take into account the emissions during the cleaning of the transport equipment. The reason for this omission is often that these emissions are supposed to be very low compared to other emissions from transportation (NTM, 2008, IFEU, 2001). The study aims to determine whether the cleaning emissions can indeed be neglected.

e. What is the effect of vertical handling on the overall emissions?

In current models there is no or little information about emissions in vertical handling. Vertical handling is the handing that arises due to modality shifts during transport, i.e. loading a container from a truck onto a vessel. In the research the emissions during vertical handling will be investigated to determine whether these should be taken into account. Due to the relatively short distances involved in vertical handling these emission can probably be neglected.

f. What is the effect of temperature control (either heating/cooling during or after transport) on the overall emissions?

The known models do not take into account the emissions for heating or cooling of the freight during or after transport. The research will focus on the heating after transport because the other types of heating/cooling are not in the scope of the project. Due to the fact that the temperature decreases only slightly over time and the relatively low emissions for heating it is often assumed that these emissions can be neglected. This will be investigated in more detail in this research.

2. What opportunities will arise when the new emission regulations are implemented?

The project will aim to find several opportunities to reduce the CO_2 emissions during transport. The two opportunities below were identified and will be answered based on the case study.

a. Is shifting modalities from road to rail/water transport an option to reduce the CO_2 emissions during transport?

The emissions for rail and water transport are lower per tonne kilometre than the emissions for road and air transport. Therefore it is often suggested that switching modalities leads to lower CO_2 emission. However, one has to take into account that most companies do not have a rail/water terminal and this means that shifting to rail/water will mean shifting to intermodal transport with road and rail/water transport. For short distances this could mean that the emissions will rise instead of decrease. For longer distances shifting modalities could lead to significant reductions.

b. How can one easily identify lanes where reductions opportunities are possible?

After calculating the emissions for a dataset there is a wealth of information available but how does one easily identify the big reduction opportunities. The study will determine a method to help companies in identifying easy reduction opportunities.

Dow

In this subsection the research questions that are specific to the case study are discussed. These are the research questions that are important to Dow.

c. Which lanes can be changed and how should those be changed to reduce the emissions?

Based on the method mentioned before reduction opportunities are identified for the dataset. Analysing these data will lead to a recommendation on which lanes emissions can be reduced and where more information is needed before conclusions can be drawn.

d. How will future regulations effect supply chain design for Dow?

Based on a scenario analysis the effect of the new regulations is determined. Will new regulations only increase costs or will it lead to different decisions. The analysis will focus on costs for Dow and opportunities to reduce the costs and emissions.

2.3 Research Design

In this section, a short description is given of how the research questions will be answered.

To be able to answer question 1a and 1b (with regard to positioning distances and load factors) the data collection, methodology and tool development are necessary. The questions are answered based on the data collected during the data collection phase. The data is used to calculate the emissions by using the tool that was developed. Based on this calculation it is determined how influential the factors are. Next to these categories the assumptions of the methodology are used to determine whether that will vary the result with regard to the significance of the categories.

For answering question 1c (with regard to which factors should be taken into account) the same phases are needed. These are the data collection, tool development and methodology. The data will be used to validate the assumptions of the model and determine whether it is worthwhile to retrieve real data. This is based on the calculations conducted with the tool and a sensitivity analysis.

To answer questions1d, 1e and 1f (with regard to the impact of cleaning, vertical handling and heating/cooling) the data collection phase and the tool development are needed. Based on the data collected and the calculations performed by the tool the impacts of the three categories will be assessed. To develop the tool a methodology for calculating CO_2 emissions has to be developed and used. This was done in the first part of the study and is discussed in Chapter 3.

To be able to answer questions 2a until 2d (with regard to reduction opportunities) the tool development and scenario analysis are necessary. Based on the dataset and the calculations with the tool a method was developed to identify reduction opportunities. Based on information on the future rules and regulations with regard to emissions, scenarios are developed and used to determine the effect of these regulations.

3 Phase I: Measurement Methodology

This chapter consists of three parts. The first part contains a summary of the existing methodologies, a short description as well as a comparative table. The second part consists of a description of the chosen methodology. In the following sections (3.2-3.7) the general parameters and the mode specific parameters are described. In those sections the assumptions and factors are discussed as well.

3.1 Current Methodologies

At the moment there are several methodologies available for the calculation of CO_2 emissions. The level of details and the aims of the methodologies vary significantly. Since the topic of the research is CO_2 emissions in transport the discussion will only involve this part of the methodologies. The detailed description of the methodologies can be found in Appendix 12.

Comparison

Each of the methodologies has its advantages and disadvantages. The main points are summarised in Table 2.

Table 2: Available Methodologies, summary

Method	***Scope***	***Detail***	***Date***	***Developer***
STREAM	NL	Medium	2008	CE Delft
GHG Protocol	Global - US based	Low	Ongoing	Governments, NGO's
EcoTransIT	Europe	Medium	Ongoing	IFEU
NTM	Europe	High	Ongoing	Swedish non-profit organisation
Artemis	Europe	Extreme	2007	Funded by European Union

Based on the information available for the methodologies and the requirements for this research the decision was made to use the NTM model as a basis for the research.

There are several reasons for this decision:

- High level of transparency for the collected data and calculations
- Varying levels of detail can be used for the calculations
- Well documented assumptions
- Alignment with several European studies
- Cooperation with CEN to set a standard for emissions during transport

3.2 Calculation Methodology

As described above, NTM will be used as a basis for the methodology development. This chapter describes the methodology that is used to calculate the carbon dioxide emissions resulting from transport. First, general parameters are discussed and secondly the methodologies to calculate the emissions for the four different transport modes are given. The calculation methodology is mainly based on the NTM methodologies (NTM Air, 2008; NTM Rail, 2008; NTM Road, 2008; NTM Sea, 2008). First the emissions for the total means of transport (truck, train, vessel or aircraft) are calculated and then these emissions are allocated to the shipment of interest. For example, in the case of less than truckload (LTL) shipments the emissions have to be allocated to the freight of the shipper instead of using the total emissions.

In the methodology, several average values are given and assumptions are made. It is very important to keep in mind that these values and assumptions are only used if no actual data is available. The use of actual data will always lead to equally reliable and mostly even more reliable and accurate results.

Because air transport and heating during transport are not part of the scope of this project the methodology for those can be found in Appendix 11.

3.3 Transport parameters

Transport parameters that are used for more than one modality are described in this section. Specific issues with these parameters or parameters that are unique to one transport mode are described later on in this chapter.

3.3.1 Load factors

For road, water and air transport load factor is defined as the percentage of the capacity of the vehicle used, where capacity is expressed in weight, lane metres or twenty-foot equivalent units. The exact factor used will be explained in the different transport types below. Because of practical reasons (modularity), load factor is defined differently for rail transport. Here, load factor is defined as the ratio of the net-weight of the cargo to the gross weight of the train.

In the methodologies of road and air transport the value of the load factor is used both in calculating the carbon dioxide emissions and in allocating the emissions to the cargo. In the rail and water transport methodologies the load factor is only used in allocating the overall carbon dioxide emissions to the company cargo.

In the following sections the average load factor values that are used in case no actual data is available are described for each mode of transport.

Road transport

NTM distinguishes between frequent and single shipments and suggests the following load factors for road transport (Table 3).

Table 3: Load factors for road transport

Type of transport	Load Factor
Frequent shipment	75%
Single Shipment	50%

Note that if the total weight of the shipment is known this value will be used instead of the assumed load factor.

Rail transport

Assumptions for the load factors of trains are based on the data from EcoTransIT (EcoTransIT, 2005, which is also used by NTM) and summarised in Table 4. The assumptions are based on a study conducted by the IFEU.

Table 4: Load factors for rail transport

Type of cargo	Load factor
Bulk cargo	0.72
Average cargo	0.58
Volume cargo	0.44

Water transport

The load factor of a vessel is calculated according to the unit that is used for expressing the capacity. For tankers and bulk carriers the unit is tonnes, for container vessels it is twenty-foot equivalent units and for Ro-Ro cargo vessels and ferries it is lane meters.

Apart from the different vessel types, vessel transport is subdivided into two categories: water direct and water shuttle. Based on NTM (NTM Water, 2008), load factors have been set for each category. The load factors are shown in Table 5.

Table 5: Load factors for water transport

Type of transport	Load factor
Water direct	0.80
Water shuttle	0.50

3.3.2 Terrain factor

Transport in mountainous areas has higher fuel consumption than transport in flat countries. Therefore, a terrain factor is used in the calculations of the carbon dioxide emissions. This terrain factor only holds for rail and road transport, because water and air do not have to cope with height differences in the terrain. NTM defines three categories: flat countries (Denmark, Sweden and The Netherlands), mountainous countries (Austria and Switzerland) and hilly or average countries (all other countries in Europe). NTM proposes different terrain factors for rail and road transport.

The calculation for rail transport as described in section 3.4 is the emission calculation for hilly countries, no terrain factor is included. Emissions increase with 20 percent for mountainous and decrease with 20 percent for flat countries (NTM Rail, 2008).

The calculation for road transport as described in section 3.5 is the emission calculation for flat countries, no terrain factor is included. Emissions increase with 5 percent for hilly countries and increase with 10 percent for mountainous countries (NTM Road, 2008).

3.3.3 Positioning

In many cases, the means of transport is not at the same location as the cargo. As a result, the means of transport has to be transported to the cargo location. The distance travelled by the means of transport, in order to reach the cargo location, is called positioning distance. In case of rail, water and air transport, the positioning distance is often zero, because the cargo is transported to the location of the means of transport (terminal or (air)port). However, this does not mean that positioning never takes place in rail, water and air transport, but that positioning is more common in road transport.

The NTM methodology describes positioning for air, road and water transport: “NTM suggests that the emissions related to the positioning trip before the transport are calculated and added to the emissions from the vehicle during the actual transport” (NTM Air, 2008; NTM Road, 2008; NTM Water, 2008). In the next section, the way positioning is included in the emission calculations for the different transport modes in this project, is described.

Rail transport

The NTM methodology does not give any information about including emissions from positioning in rail transport. In academic literature no information about this subject can be found either. Two international rail cargo companies were asked whether they could give any information about this subject. The rail companies indicated that it was hard to give a reasonable figure for this, but they indicated that in most cases the positioning distance is negligible in comparison to the total distance (because much rail transport is operated on schedule on a fixed route). Therefore it is assumed that there is no positioning in rail transport.

Road transport

For road transport, NTM gives different values for average positioning distances for frequent and single road transport. Transport data of three companies, with each at least 100 lanes (both frequent and direct transport), showed average positioning distances of 25, 24 and 16 percent. This is in line with the NTM assumption of 20 percent positioning distance for frequent road transport.

For single road transport, NTM does not provide a reliable assumption. Based on the company data, without distinction between different transport modes, the assumption of 20 percent is used in this case as well.

Water transport

Water transport is often operated on regular routes, where there is no need for positioning. However, in some cases there is positioning in case of tramp traffic (transport on non-regular routes). However, tramp traffic does not occur very often and company data, from the case study, does not show any example for tramp traffic. Therefore it is assumed that there is no positioning for water transport.

Allocation

Who should take responsibility for the emissions from positioning can be debated. Some argue that the logistics service providers are responsible for the emissions, using the following reasoning:

- Logistics service providers can combine different shipments, so theoretically they can take a shipment on the route to pick up another shipment. If the logistics service provider does not do this, it is its own responsibility and therefore the logistics service provider is responsible for the emissions resulting from positioning.
- The customer requests a shipment from a certain origin to a destination. Whatever happens before or after the transport is the responsibility of the logistics service provider and the customer cannot influence it.

Others argue that the customers are responsible for the emissions resulting from positioning because:

- The customer chooses the logistics service provider and in this choice the customer can take into account the distance between (the nearest hub of) the logistics service provider and the location where the cargo has to be picked up. This means that the customer can influence the emissions from positioning and is therefore (partially) responsible for the emissions.
- The logistics service provider is not able to find a shipment on the route to pick up the customer's shipment in most cases, due to the relatively small positioning distance.

In this study, carbon dioxide emissions resulting from positioning are included in the total emission calculation. Based on discussions with stakeholders it can be concluded that the latter arguments outweigh the former arguments.

3.3.4 Empty return trips

After transporting a shipment from the origin to the destination, usually the equipment has to return to the origin where the shipment was picked up or to the logistics service provider. Sometimes another shipment is taken on the way back and sometimes the means of transport is returning empty: the latter is called an empty return trip. During an empty return, no cargo is transported, so the emissions need to be allocated in a different way.

However, as discussed in the chapter on the emissions resulting from positioning, there are different opinions about whether the emissions from empty return trips are the responsibility of the customer or the responsibility of the logistics service provider. In this project it is assumed that when the transport is dedicated to the customer on request of the customer, the emissions from empty return trips are allocated to the customer. However, if the logistics service provider has the possibility to take another shipment on the return trip, the emissions are allocated to the logistics service provider, no matter whether the logistics service provider takes another shipment or not.

Trade imbalances

In case of container transport sometimes containers have to be transported empty because of trade-imbalances. For example, in general there is more cargo transport from Asia to Europe than from Europe to Asia, which means that there is a surplus of containers in Europe and a shortage in Asia and that containers have to be transported empty from Europe to Asia. As described in the previous section, empty returns are only taken into account if equipment is dedicated on customer's request. This also holds for the transport of empty containers: only if they are transported empty on the request of the customer the emissions are allocated to the customer.

3.3.5 Cleaning

In several industries the equipment has to be cleaned after usage to prevent contamination of the next load. This is the case in most of the bulk food industries where food resources are transported, for example sugar, cacao and so on. The transport of other products, like plastics and medical equipment requires cleaning after transport as well. Based on a case study involving four members of the European Federation of Tank Cleaning Organisations (the Belgian, Dutch, Italian and Swedish agencies) the conclusion can be drawn that cleaning is in most cases performed using steam. The steam is always generated by burning fossil fuels. Based on the case study it is assumed that an average of 680 Mega Joules of steam (equivalent to 2 cubic metres at 90 degrees Celsius) is needed for cleaning one unit (i.e. container). The process of burning natural gas to get this amount of energy (for cleaning one unit) leads to an emission of 38 kilograms of carbon dioxide. In the calculation of the emissions, this value is used for steam cleaning.

3.3.6 Heating

There are several products that need temperature control during (Appendix 11) or after the transport of the product. The methodologies to determine the extra emissions resulting from temperature control during and after transport are different and therefore they will be discussed separately below.

After transport

Temperature control after transport means that the product is cooled or heated after it has been transported. In practice it hardly occurs that a product is cooled after transport and therefore this is not taken into account in this study. Heating after transport on the other hand is used in several cases in practice. For example, several liquids do not change permanently by the reduced temperature but are hard to extract from the transport equipment at lower temperature due to increased viscosity.

Based on a case study among five service providers it is concluded that the main method of increasing the temperature after transport is steam heating and that a small percentage of containers is heated electrically. The steam is generated by using fossil fuels (i.e. natural gas). Based on the case study an average value of 22 kilograms of carbon dioxide per container is determined and this value is used in the calculations. In practice this value is subject to several parameters, such as the weight of the product and the temperature increase. However, because no data is available for these different factors, an average value is used.

3.3.7 Vertical handling

Intermodal transport is the transport of cargo using multiple modes of transport without any handling of the product itself (like sorting and repacking) when changing modes. In most cases the cargo is packed in containers or on pallets and the containers or pallets are handled. This handling takes place at a terminal and is called vertical handling.

Containers

Normally, vertical handling of containers is operated in one of two ways: by a crane or by a reach stacker. A crane can be powered using electrical energy or using a diesel engine. Reach stackers are powered by a diesel engine in most cases.

Vertical handling itself consumes energy and thus leads to extra carbon dioxide emissions. To assess the importance of taking vertical handling into account, the emissions need to be quantified. Two transport terminals have been contacted to find an average carbon dioxide emission of a reach stacker and this value can be found in the table below. For the emissions of a crane, the average value of a report by IFEU is used (IFEU, 2001) and also this value can be found in Table 6 below.

Table 6: CO_2 emission handling

Handling equipment	Average CO_2 emission (tonne/handling)
Crane	0.002
Reach stacker	0.007

To come up with final values that can be used in the calculation, another assumption has been made: moving a container from water transport to road, rail or water transport and vice versa is performed with a crane. All other types of vertical handling are assumed to make use of a reach stacker.

Pallets

In case pallets are used, forklifts and pallet jacks are used for handling. For forklifts and pallet jacks, no reliable data could be obtained. It is assumed that this type of vertical handling emits the same amount of carbon dioxide as a reach stacker. The emission per handling (per pallet) is lower, but more handlings are needed to empty or load one truck.

3.4 Rail transport methodology

Rail transport is defined as cargo transport over land using railroad tracks. There are two types of trains that can be used, either diesel or electricity powered locomotives. At the European continent rail transport is most often carried out by national railway operators active within national borders. In some cases, this means that the train has to stop at the border to switch locomotives (NTM Rail, 2008). Furthermore, not all countries use the same track width and this means that the carts should be changed at the border (this is seen as vertical handling). There are several parameters that influence the emissions during rail transport and these will be discussed below.

3.4.1 Mode specific parameters

General transport parameters were discussed in the beginning of this chapter. Rail transport has several specific transport parameters, which are discussed in this section.

- *Traction type:*

  The engine type of the locomotive is one of the most influential parameters for the carbon dioxide emissions. Usually it is not known which part of the route is carried out by a diesel locomotive and which part by an electric locomotive. In the assumptions below it is stated how the methodology deals with this lack of information.

- *Size of the train:*

  The size of the train is defined as the gross weight of the total train. This is the weight of the train and all cargo on it. In the calculations the specific gross weight of the train is used. If this is not available the user will have to specify one of the train sizes as specified in NTM; short (500 tonnes), average (1000 tonnes) and long (1500 tonnes). (NTM Rail, 2008).

- *Type of cargo:*

  Another factor that should be taken into account is the type of cargo that is transported. For products with a low density, the capacity is limited by volume while the capacity limitation for high density products is weight.

- *Electricity generation:*

  In case an electric locomotive is used, the emissions during transport depend on the way the electricity is generated. The method of electricity generation varies per country and can lead to significant differences in emissions. In Europe the carbon dioxide emission factors for electricity generation vary between 0.00 kg/kWh (Norway, hydropower) and 0.94 kg/kWh (Poland, coal) (EcoTransIT, 2005).

3.4.2 Calculation

This section gives the formulas for the emission calculation for both diesel and electrical trains. First the formulas for both calculations are given, followed by the explanation of the symbols used.

The formula used for diesel transport:

$$TE = W_c \cdot D \cdot \frac{EF_{CO_2}}{1 \cdot 10^6} \cdot \frac{153.07 \cdot c_t \cdot W_{gr}^{-0.5}}{LF}$$

For electrical trains, the formula is given by:

$$TE = \sum_z W_c \cdot D_z \cdot \frac{EF_{z,CO_2}}{1 \cdot 10^6} \cdot \frac{675 \cdot c_t \cdot W_{gr}^{-0.5}}{LF \cdot (1 - TL)}$$

Where:

TE	Total emission for the customer's cargo (tonne carbon dioxide)
W_c	Weight of the customer's cargo (tonne)
D	Total transport distance (kilometre)
D_z	Transport distance per country (kilometre)
EF_{CO2}	Emission factor for diesel (kilogram carbon dioxide per kilogram diesel)
$EF_{z,CO2}$	Emission factor for electricity generation in country z (kilogram carbon dioxide per kilowatt hour
c_t	Terrain factor as explained above
W_{gr}	Gross weight of the total train (tonne)
LF	Load factor
TL	Electricity lost due to transportation losses
z	Country

The total emission for diesel trains is based on the weight of the company cargo multiplied with the distance travelled. This is multiplied with the emission factor for diesel. The last part of the formula is the calculation of the energy usage per tonne cargo. This is based on the load factor of the train and the total weight of the train.
For the electric rail emissions the formula is more or less the same, the only difference is that the formula is summed over all the countries. This is done because the emission factor is based on the method for electricity generation in each country.

Eurotunnel train

A special type of train is the Eurotunnel train between Coquelles (France) and Folkestone (Great-Britain) since the total emissions are more or less the same on each trip, slightly varying with the load of the train. The Eurotunnel has a length of 50.5 kilometres. There are two types of trains in the Eurotunnel: passenger trains and cargo trains. Both are electrical trains. Since the beginning of 2008 al electricity is fed from the French electric sub-station.

A cargo train in the Eurotunnel has an average length of 720 meters and weighs maximally 4000 tonnes when loaded. All of the cargo is loaded onto the train in trucks; the cargo is never unloaded from the trucks. The trucks can maximally be 18.75 meters long (with a maximum height of 4.2 meters and a maximum width of 2.6 meters) and the weight of the truck can maximally be 44 tonnes. Using the Eurotunnel will lead to a fixed emission for that part. The emissions will be allocated based on the cargo weight and capacity utilisation of the truck.

3.4.3 Assumptions

Most assumptions in the rail transport calculation have been made in the transport parameters section. An assumption specific for rail transport is the amount of electric trains and diesel trains used.

- *Diesel-electrical split:*
  In most countries in the European Union, electrical locomotives are used. However, some parts of the railway system do not have overhead lines. On these parts, or on entire transport routes containing such parts, diesel locomotives are used. For companies it is often hard to obtain data on the diesel-electrical split of rail transport. Therefore an assumption is made. Based on data on European rail transport data of the year 2005 (Eurostat, 2009), it is assumed

that 75 percent of rail transport is electrical. This means that if no data is available for the percentage of electrical emissions the emissions will be calculated based on the diesel emission formula multiplied by 0.25 and adding the emissions calculated based on the electrical emission formula multiplied by 0.75.

3.5 Road transport methodology

Road transport is defined as transport over road. Road transport services are carried out around the world with vehicles ranging from small distribution vans to long road trains. Road transport has the advantage that it is very flexible and has the ability to reach remote locations. On the other hand, the loading capacity is limited by regulations and there might be increasing congestion problems for some regions.

3.5.1 Mode specific parameters

In addition to the general transport parameters described in the beginning of this chapter, this section describes parameters specific to road transport.

- *Vehicle type:*

  Road transport can be operated using different vehicle types. Ten different vehicles are identified, from a small pick-up to a large sixty tonnes truck-trailer combination.

- *Road type:*

  Road transport can be operated on different road types. Based on the NTM methodology (NTM Road, 2008), three road types are used: motorways, urban roads and rural roads.

3.5.2 Calculation

For each vehicle type on each road type, fuel consumption values for empty and fully loaded vehicles are given. To calculate the fuel consumption of the specific vehicle and load factor, the following formula is used:

$$FC_{LF} = FC_{empty} + \left(FC_{full} - FC_{empty}\right) \cdot LF$$

Where:

FC_{LF}	Fuel consumption at the specified load factor
FC_{empty}	Fuel consumption of the empty vehicle
FC_{full}	Fuel consumption of the fully loaded vehicle
LF	Specified load factor

In case of heating, cooling or freezing during transport, the fuel consumption increases. The values have been described before.

Using the fuel consumption per kilometre, calculated in the previous steps, the fuel consumption for the entire trip can be calculated. The fuel consumption is directly linked to the carbon dioxide emissions. Diesel fuel used in Europe emits on average 2.64 kilograms of carbon dioxide per litre.

In case the company cargo is only part of the cargo transported using the vehicle, the emissions should be allocated to the cargo. Allocation is either based on weight or on volume (volumetric weight); therefore two steps can be used:

Step 1: Compare the physical weight of the cargo to the volumetric weight (volume multiplied with 250 kilograms per cubic metre)

Step 2: Allocate based on the highest value

3.5.3 Assumptions

The assumptions specific to road transport are described in this section. The assumptions described in the transport parameters section are also valid for road transport.

- *Load factor linearity*:

  A truck that transports a heavier load has higher fuel consumption due to increased rolling resistance and dynamic weight. In this methodology, the increase in fuel consumption is approximated by a linear function.

- *Traffic situations*:

  The fuel consumption values for different road types is extracted from ARTEMIS and based on multiple roads within each road type. The fuel consumption values are averages for Europe and do not take into account differences between countries or specific traffic conditions.

- *Idling of the truck:*

  The fuel consumption resulting from idling of the truck is not taken into account in the carbon dioxide emissions calculation from road transport.

- *Speed and driver behaviour*:

  Speed and driver behaviour influence the fuel consumption. These factors are not considered in this methodology. The reason not to consider this part is because it varies per driver and per route and so on. The values used in the calculations lead to an average emissions under average driving behaviour. If one wants the exact emissions based on the driver behaviour one can use the real values as well.

3.6 Water transport methodology

Water transport is defined as transport over sea or inland waterways with diesel oil-powered vessels. To calculate the carbon dioxide emissions from water cargo transport, several parameters are taken into account. These parameters are described in the next section.

The type of vessel has a large impact on the carbon dioxide emission. Each vessel is unique in its fuel consumption, but since vessel information is often hard to obtain, several general vessel types have been used. These vessel types were taken from the NTM methodology [NTM Sea, 2008]. Most vessels have a main engine that produces the power to move the vessel and one or more auxiliary engines that are used for electricity generation that is used by the crew and passengers.

3.6.1 Mode specific parameters

Real values for load factor and average cruise speed are hard to obtain. Furthermore, the impact of a change in these parameters on the fuel consumption is hard to predict, because this differs for each individual vessel. NTM has chosen to use default values for load factor and speed and to give a vessel’s fuel consumption per kilometre based on these default values.

For vessels used in inland waterways, three fuel consumption values are given; upstream transport, downstream transport and an average value.

3.6.2 Calculation

Based on the vessel type, the fuel consumption value is given. This fuel consumption value is multiplied by the distance and the carbon content of the fuel and this results in the carbon dioxide emissions for the vessel.

The total emission needs to be allocated to the cargo of different companies that is transported by the vessel. Allocation is done in different ways for different vessel categories:

- Bulk vessels; are vessels used to transport bulk cargo in tanks or holds. The allocation is based on weight.

- Container vessels; transport containers. The allocation is based on the number of twenty-foot equivalent units (TEU), which are containers with a length of twenty feet.
- Roll-on/roll-off vessels (RoRo); are vessels that transport trucks or train carts which can drive on and off the vessel. The allocation is based on lane metres (lanem), so the length of all lanes on the vessel.

With the basis for allocation known, the allocation is done by dividing the capacity used for the company cargo by the total used capacity (one of the three capacity types as described above) and multiplying this value with the total emission of the vessel calculated in the previous step.

A problem with this way of allocating emissions to cargo occurs if a vessel transports multiple kinds of cargo and/or passengers In this case the total emission is divided between the number of decks and for each deck the allocation is done using the method described above.

3.6.3 Assumptions

In the above description of calculating carbon dioxide emissions from water transport, four assumptions are used. This section discusses these assumptions.

- *Load factor and speed are fixed:*

  For each vessel type the fuel consumption is given for a fixed load factor and a fixed average speed. In reality, an increase in load factor or speed will result in an increase in the fuel consumption. The values that are used are averages based on a case study. These averages are used since it is often not possible to gather real data because those are not available.

- *Only main engine taken into account:*

  The main engine is the engine that generates power to move the vessel. This engine consumes most of the fuel. The fuel consumed by the auxiliary engines depends on the vessel size and type. A passenger ferry that offers entertainment to its passengers will consume a lot more energy than a bulk vessel with only a small crew. Taking the auxiliary engines into account will increase the carbon dioxide emission of the vessel. In the case study data will be gathered to determine the influence of this assumption.

- *Allocation of mixed-cargo vessels based on number of decks:*

  Allocating carbon dioxide emissions evenly over multiple decks assumes that the impact on fuel consumption of all decks is equal. In practice there can be a variation in the emissions per deck (i.e. entertainment at passenger deck). The reason not to take this into account is that there is no data available for this division and the fact that the truck drivers use the facilities of the passenger deck as well. This means that part of the extra emissions should be allocated to the truck as well.

- *Inland waterways use average flow conditions:*

  Water transport via inland waterways depends on more parameters than used in the calculation. Besides load factor, speed and auxiliary engines, the flow of the inland waterway also influences the fuel consumption. The flow of an inland waterway, in turn, depends on the season, the depth of the inland waterway, the location in the inland waterway (more upstream the current will be stronger), the direction of travel (upstream or downstream) and the waterway itself. Only the direction of travel is taken into account in the value for the fuel consumption. The values for upstream and downstream fuel consumption are averages of different waterways and different locations on the waterway.

4 Phase I: Data Collection

In the first part of the chapter a description of the data collection will be given. The second part will give the results of the data collection and in the final part the learning's from the data collection will be stated.

4.1 Data collection procedure

As mentioned in section 1.4 are there two parts to the data collection, the data collection within Dow and the external data collection. In the first subsection the data collection phase at Dow will be discussed. Some assumptions had to be made during this phase to get the dataset. In the second section the external data collection will be discussed, this was collected via a questionnaire and contact with the LSP's.

4.1.1 Internal Data Collection

The internal data collection concerns the shipments that have been transported for the PU business during 2008 ex. Terneuzen in accordance with the scope defined in subsection 1.5.1. The data was gathered and processed by a Dow employee. The data was collected from the Dow SAP system. This means that all shipments entered for that business during 2008 are retrieved from invoiced shipments. The data had to be processed because there were some mistakes in invoices and some data was inaccurate. Two major modifications had to be made to the dataset and these are discussed below.

The first modification was based on the fact that there are several storage locations throughout Europe. These storage locations are served by multiple locations and there is no real distinction which product is going where afterwards. This means that the shipments coming from the terminal (originating at the Terneuzen facility) had to be estimated. This was done by taking the percentage of certain products coming from the Terneuzen site and allocating that percentage of the product leaving the terminal to the Terneuzen facility. For example if Terneuzen delivers 100 mT of product A to Terminal X where the total delivery of A is 200 mT. In that case 50% of the shipments A going out of the terminal are randomly assigned to Terneuzen. This means that for some shipments not the true distances will be used. However, the terminals mainly supply a local market and therefore the emissions involved are relatively low. Next to that, the amount of products delivered via a terminal is less than 15 weight% as can be seen in Figure 2. The biggest terminal ships 8 weight% but is located just outside the Terneuzen location and only ships products produced in Terneuzen for this scope. This means that the allocation is only necessary for less than 5 weight% of the shipments. If one looks at the distance the products have to be transported from each location than the two Terneuzen facilities (plant and terminal) account for more than 98% of transported kilometres. This indicates that the overall effect of the allocation will be very small since the emissions are mainly based on distance and weight as can be seen in Chapter 6.3.

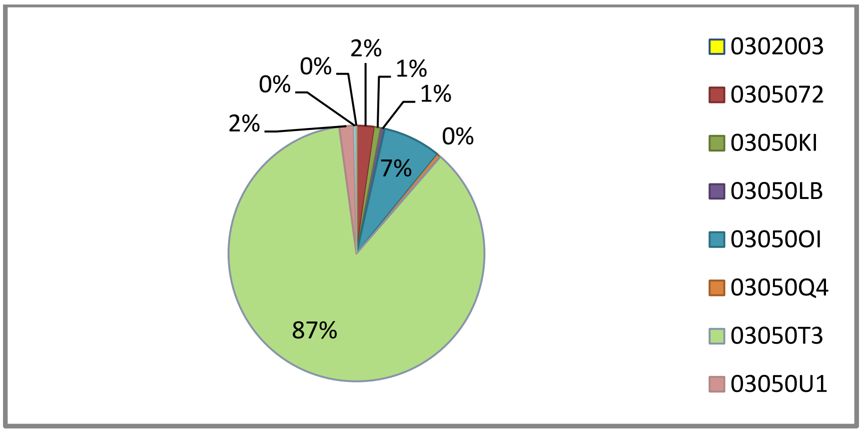

Figure 2: Weight% of shipments served from locations

The second modification was based on the fact that distances automatically calculated in the SAP system were in some cases not realistic and these had to be recalculated manually. The calculation of the distance is based on the Greater Circle Distance (GCD). Due to European geography, waterways and infrastructure density the GCD is not always an accurate way of calculating distances. In the case study calculations, the actual distances were used in all cases. These distances were retrieved via the LSP's and route planning software. These distances will be compared with the distances calculated from SAP in Chapter 6.3.

Based on the resulting dataset after these two modifications the calculations were made.

4.1.2 External Data Collection

The external data collection was based on information gathered at several companies. Dow makes a distinction between three groups; Road&Warehouse (includes road transport, and intermodal rail, intermodal vessel and ferry), Marine Packed Cargo (MPC, includes transport via container vessels) and Bulk Vessel (this is vessel transport in holds). For each of these categories a questionnaire was made which was sent to the LSP's of that mode.

When setting up the questionnaire it became clear that it would be very labour intensive for companies to provide all information on all lanes. The reason for the high workload is that most data is not readily available and the fact that for most non-road data the LSP has to contact the company conducting the transport (subcontractors). The latter means that the other company should be willing to share the data if it is available at all. Therefore it was decided to send a pilot version of the questionnaire to the two biggest LSP's. The LSP's were asked to provide information on the questionnaire with regard to the availability of the data, whether the questions were clear and the estimated workload. Based on that information the decision was made to limit the questionnaire in some cases;

- During 2008 the PU business unit has had a road tender, meaning that some of the LSP's are no longer serving the same lanes after October of that year. This means that for those lanes there are multiple carriers on the same lane. The decision was made to only send the questionnaire to the LSP serving after the tender in those cases and extrapolate these data to shipments before that time.
- The bigger LSP's often have over 100 lanes which would lead to a very high workload in data collection. This is caused by the fact that most data has to be retrieved manually. Often there are many lanes that serve customers in locations in the same area. In that case the biggest lane in the area was included and the data from that lane are extrapolated to all lanes to customers in that area.
- For several lanes there are emergency shipments or cases were a LSP takes over a shipment once. In those cases the lane is only included in the dataset for the main LSP and not for the backup or emergency LSP. The retrieved data are extrapolated.

For Road&Warehouse the questionnaire can be found in Appendix 1, the questionnaire was send to 27 LSP's. The request was to fill in all data that are requested in the questionnaire. Some of the LSP's (representing 18 weight% of shipments) indicated that they could not cooperate in this matter due to economic circumstances or availability of resources. In those cases a limited questionnaire was sent to be able to include the exact route of the shipment, which was returned in all cases. The questionnaire contains several questions for the following four categories; road, intermodal rail, intermodal short sea and road with ferry transport. For each of theses categories the questions vary slightly as can be seen in the appendix.

For MPC the questionnaire was send to five LSP's, two LSP's that charter vessels and three LSP's that own vessels. The questionnaire can be found in Appendix 2, as one can see the questionnaire is smaller than the other due to the fact that there is only one mode of transport.

For the Bulk Vessels the questionnaire can be found in Appendix 3, the questionnaire was send to three LSP's, all of them owning vessels. The questionnaire is again smaller than the Road&Warehouse questionnaire due to the fact that there is only one mode of transport (only water).

4.2 Data collection results

In total the questionnaire was send to 35 LSP's with varying results. In Table 1 below the response of the LSP's is depicted. Displayed is the percentage of the weight of shipments which has been accounted for. This is displayed in weight percentage because otherwise it could be that only the small shipments are returned which leads to a poorer validation overall The main reason for LSP's not to cooperate were the current economical environment or not being able to free resources for this request. Another reason for not responding was the unwillingness of third party providers (such as rail and ferry operators) to provide data. This unwillingness is mainly caused by the potential commercial implications.

Table 1: Questionnaire Response

Cooperating	74%
Not cooperating	26%

This is the overall response, meaning whether the LSP has filled in some additional information. However, to determine whether these data can be generalised a more thorough analysis is needed. Therefore the data response was analysed according to five categories; the modality, the country, the region, the carrier size and whether the carriers offers intermodal transport. In Figure 3 below one can see the responses per modality. The modality is displayed as the coding according to Dow standards. In Appendix 10 the explanation of these codes can be found.

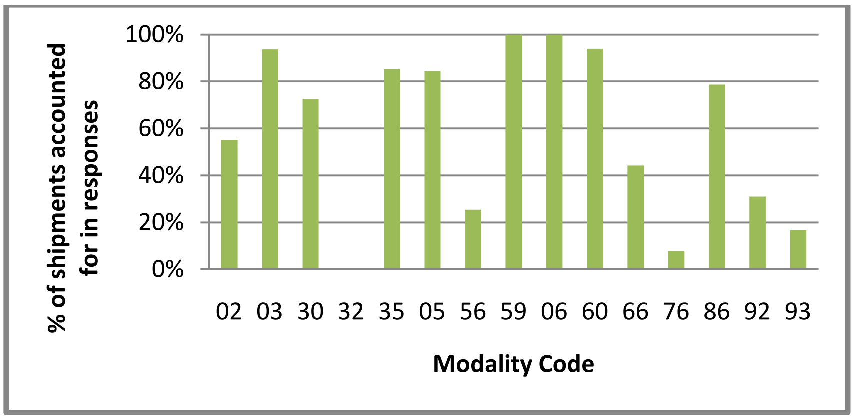

Figure 3: Response per modality

One can see that the responses vary per type of transport but the responses are over 80% in several categories. For some of the modalities the responses are very low (with the minimum of 0%). The modality with 0% response is transport via a barge, which goes to two of the terminals located in the proximity of the production facility (<150 km). These are bulk barges that transport large quantities of products at the same time. The total weight% of all shipments that use this dispatch code is around 1%. The other modality that has a very limited response is code 76, which is transport of a tank truck that uses a ferry. The LSP's involved were not able to retrieve information from their subcontractors in those cases. The main reason for the low values of code 92 and 93, representing LTL shipments, is that most of these shipments were not included in the questionnaire because of the low volumes. Note that most of the LTL shipments are transported on the same lanes as the FTL shipments. If data is available for FTL shipments this is extrapolated to the LTL shipment. If this extrapolation would be taken into account the responses would increase to 77% and 19% respectively.

Not all modalities are completely different, for example 02, 03, 92 and 93 are all road transport. The only difference is whether it is container or tanker and FTL or LTL. Therefore the decision was made to aggregate the data over certain categories. These categories will give a better idea of the response rates.

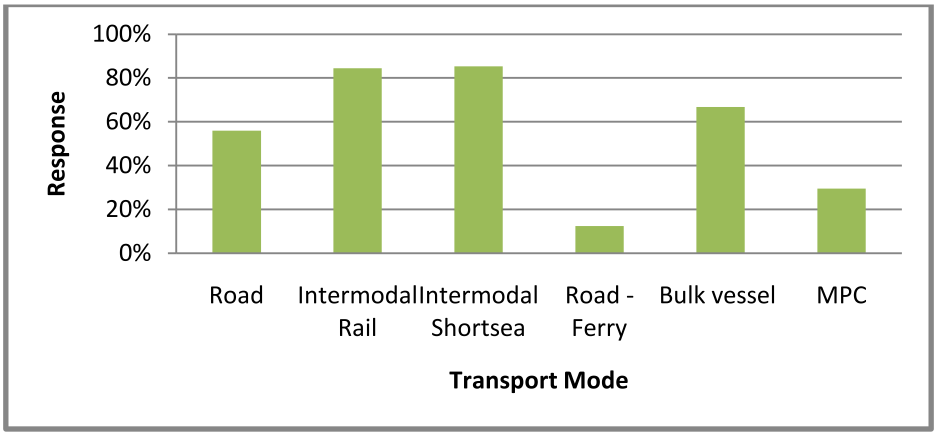

Figure 4: Percentage of shipments accounted for in responses per transport mode

The responses for these aggregated categories can be found in Figure 4. The responses for Road-Ferry and MPC are relatively low and this indicates that there is a higher level of uncertainty when generalising these data. For intermodal rail, intermodal short sea and Bulk vessel the responses are very high and this means that generalising these data will give data with relative low uncertainty.

The second dimension from which the responses will be analysed is the customer country dimension. If all data are provided for one country but not for the other this could mean that the data could not be aggregated for the entire dataset. In Appendix 4 one can see that there is a wide variation in responses. For some countries all shipments are included whereas other countries are not included in the questionnaire or none of the carriers has responded. The countries that are not included have no large shipments and were therefore not worthwhile to include in the questionnaire.

Because the country level is probably too detailed the decision was made to aggregate the countries into regions and see the responses for these regions. The regions are purely based on the dataset. This means that for example Denmark is counted as the same region as Germany/Belgium. This is based on the fact that those are easy to reach by road and relative short distance. The list with all twelve identified regions and the countries included in each region can be found in Appendix 5. In Figure 5 below one can see the responses per region. As can be seen the response still vary significantly. For Oceania the response is 0%. There is only one carrier towards Oceania for the case study and this carrier decided not to cooperate and therefore there is no data available for this region. The volume shipped to Oceania is very limited with less than 0.1 weight% of all shipments. The decision was made to extrapolate the data from the Americas to Oceania. The shipments are originating from the same location as shipments to the Americas, the modality is equal as shipments to the Americas and the distance is in the same order as the Americas.

For the UK&Ireland-region the response is very low as well. This being because there is one main LSP to the region and they were not able to retrieve the requested data within the given time. Note that this is the same carrier as for the ferry data, the main mode of transport towards the UK&Ireland is ferry transport. For the other regions there is a relatively high response and those data are aggregated. The exact data can be found in Appendix 10 where it can be seen that the responses for the four largest regions are relatively high (>69%).

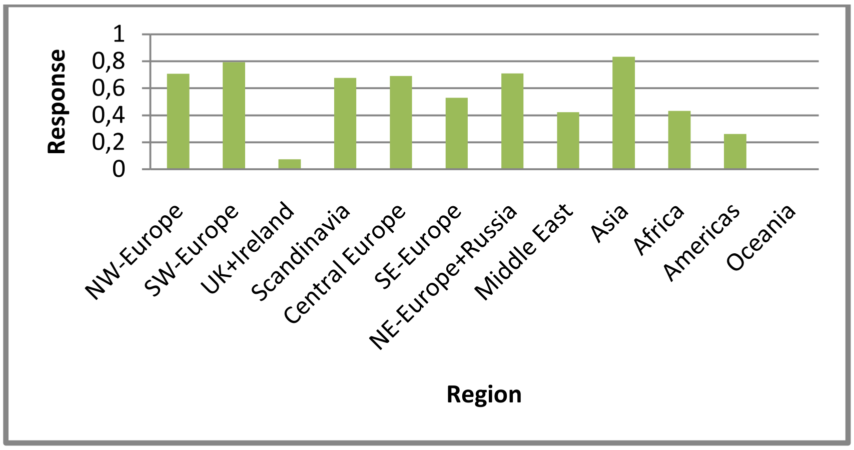

Figure 5: Response per region

The percentage of responses is the average percentage, not all elements requested in the questionnaire had the same response percentage. The response for all questions can be found in Appendix 6. Here one can see that there is a varying level of response throughout the questionnaire. Some of questions have been filled in by all the LSP's while other questions have no or limited response. Some of the questions have such a low response that those can not be used for the data validation. In those cases only the NTM values will be used. One can see that for all the road questions (i.e. fuel consumption, load factor) the responses are relatively high. The main difficulty lies in the vessel and ferry data, especially the engine consumptions have very low responses. These questions/categories are given in Appendices 3 and 4.

To determine whether there is a link between the size of the LSP and the level of cooperation, the LSP's were divided into categories based on their annual revenue in 2008. The size categories were defined as small (<€100 mln.), medium (€100-500 mln.) and large (>€500 mln.). The percentage of LSP's cooperating in each of these categories is shown in Table 7. Here one can see that the response per carrier seems to be higher for larger LSP's. The reason for this could be that the larger LSP's often have an environmental department or someone focussing on GHG emissions. Therefore, they can more easily cooperate in this research.

Table 7: Response per LSP size

LSP Size	% Cooperating
Small	75
Medium	88
Large	89

To determine whether there is a link between the LSP offering intermodal options and the cooperativeness the LSP's were divided into two groups; LSP's offering intermodal and LSP's not offering intermodal. In Table 8 one can see that the cooperation is higher for LSP's that offer intermodal transport. The reason could be that studies with regard to CO_2 emissions favour intermodal transport due to the lower emissions. LSP's that do not offer intermodal transport might hesitate in sharing data or have less information because they do not focus on this topic.

Table 8: Response intermodal

LSP offers intermodal	% Cooperating
Yes	87
No	70

In conclusion it can be said that the response to the questionnaire was varying. For the questions and categories where significant amount of data is collected these will be extrapolated. In the cases where insufficient information is available the assumptions of chapter 3 will be used.

4.3 Data collections problems

During the data collection it became obvious that there are several difficulties involved in the collection of all data. The difficulties will be discussed in two subsections below, one related to Dow specific and one related to general difficulties.

4.3.1 Dow Data Collection Problems

The availability of data at Dow Chemical is very extensive which makes it much easier for the company to calculate the emissions during transportation with relative high accuracy. All the necessary data like weight, distance and modality can be retrieved from the internal SAP system.

However, there is still some manual labour involved in retrieving all the right data from the system. The total amount of time needed for retrieving and modifying the dataset was 116 hours. This does not include the external data collection, processing and calculations. The time does not include the time needed to determine all the distances either (this was approximately 25 hours). The first part is the fact that for warehouses and terminals there is no real distinction in the outgoing products with regard to the source. This means that if a terminal is served from location A and B then it is impossible to differentiate in outgoing shipments where those were originally produced. Note, this is only the case for this specific case study. In general, the information is often available as it is already requested by customs. This leads to difficulties challenge if one wants to calculate all downstream emissions for one business unit/production location to the customer. For example, the case study in the report takes into account all PU shipments from the Terneuzen facility. The shipments that have to be allocated represent 6% of all tonne kilometres. This means that this could at most affect the emissions of these 6%.

The second area relates to the distances to be used. The SAP system has the coordinates of the from and to locations and these are used to calculate the Greater Circle Distance (GCD). The problem is that the distance is not always realistic due to two causes. First, there are sometimes errors in the entered data (latitude/longitude coordinates). Secondly, there are some distances that become unrealistic due to geographical features, for example going by truck from Spain to Italy. In that case the GCD does not take into account that there is the Mediterranean Sea in between and one has to drive via France.

With regard to distances there is another problem in the case of intermodal transport, there is only a distance from A to B. The distance is not specified per mode of transport. This means that one does not know which part of the transport is done by road and which part by rail for example. This can have a significant impact on the result if the wrong assumptions are made since the emission factor for road is much higher than that of rail. In this study the real data are used and therefore this has no impact. The impact in general will be discussed in section 6.3.

Main Dow problems;

- Difficulty in calculating emissions if terminals are used that are supplied from multiple locations.
- Difficulties with regard to distances, both for calculating the total distance and differentiating distances between modes of transport.

4.3.2 General Data Collection Problems

There are several difficulties in retrieving all the necessary data for calculating the emissions. For the current methodology it is possible to do the calculations with data availability of high or low level. In the case of high availability this means that very detailed data has to be collected. The data collection is a very time consuming business, both for the company conducting the calculations and the third parties involved (like LSP’s).

The second difficulty is that one often has to rely on other parties for some of the essential data. In that case it is often impossible to validate how accurate the data are. Note, this is if the companies are even willing to share the data at all, in many cases the data (like fuel consumption) is market sensitive.

Therefore companies are reluctant to share. In other cases the LSP buys the transport at another company and during the case study it became apparent that those companies are often not willing to share the necessary data. The impact is discussed in section 6.3.

In general it can be said that the main problems are;

- Very labour intensive to collect all the necessary data
- Not always possible to retrieve all necessary data, especially the vessel and ferry data are difficult to retrieve (often less than 10% response).

5 Phase I: Tool development

Next to the different calculation methodologies there are also several calculation tools available. The main disadvantage of the calculation tools that are known to the researcher at the moment is that none of the tools uses the NTM methodology. The second disadvantage is the fact that these tools only allow one to enter one lane at a time. With the thousands of shipments in the current dataset this would be very time consuming. Therefore the decision was made to develop a new calculation tool to deal with these disadvantages.

5.1 Methodology

The methodology that is used in the calculation tool is the NTM methodology as already described in Chapter 3. The general approach is that a batch of shipments is uploaded into the tool. The tool processes all the shipments into lanes and splits the lanes up into the different phases in the case of intermodal transport. The calculation then uses the data that were entered in the dataset for the calculations, if no data are entered the tool uses assumptions or average values to calculate emissions.

The emissions are displayed separately for the four modalities as well as heating, cleaning and vertical handling. Next to these the overall emission is displayed as well. The tool will be used for the calculations of the emissions, determining the influence of the scenarios and identifying reduction opportunities.

5.2 Data

The data that is used in the calculation tool consists of two parts; the company data and the tool data. The tool data is the data that was entered in the tool as default values and the assumptions in the tool. The data used in the tool is already discussed in Chapter 3.

The data that should be provided by the company is data with regard to the route, the weight of the shipment, distances travelled and so on. The data should be provided in an Excel sheet. The company can choose to only fill in the minimum data or can choose to fill in all the available data. In both cases assumptions and default values will be used for the missing data.

5.3 Functionality

The functionality of the tool is the calculation of CO_2 emissions during transport based on data provided by the company. There are two types of calculations, the calculations per lane and the calculations in batch. In the first option one enters data for one lane and for two different routes (i.e. road and intermodal option). Based on the result one can see which of the options has a lower CO_2 emission.

In the second case an entire dataset is uploaded in the tool and the calculation is performed in one go. This type of calculations can be used to calculate the emissions for a business or for a country. The results can be used to report emission or to identify reduction opportunities. The reduction opportunities can then be calculated in the comparison manner discussed before to determine what savings could be achieved.

For Dow Chemical the tool was modified such that it is possible to calculate the emissions based on a predefined Business Objects dataset. When making a new dataset the only change will be that the constraints for the dataset have to be changed to retrieve the correct data. Furthermore, other additional functionalities have been added to the process. Only the total distance has to be filled in and by using modality specific parameters the distances will be divided over the different transport modes. Another additional function is that the distance calculated via the GCD is modified according to modality specific parameters. This is done to correct for geographic differences and limitations and availability of infrastructure.

6 Phase I: Results

This chapter describes the results of the first phase of the project. In the first section the results of the calculation with the theoretical model are discussed. In the second section the results from the calculation with the data from the data collection are described. The third part compares the results of the two calculations and consists of a sensitivity analysis with regard to the input data. In the last section the factors from the questionnaire are analysed.

6.1 Theoretical Model Values

The theoretical model uses only the route data from the company. This means that the data provided by the company consists of the route, weight, modality and distance (for rail the distance is given per country). Furthermore it is specified whether cleaning or heating takes place. For all the other data like positioning, load factors, gross weight of a train and so on assumptions and default values will be used.

Based on this method of calculations the total emissions are calculated to be 14,382 mT of CO_2. The emissions are the total emissions for all factors and all modes. If one looks at the distribution of the emissions over the different categories one can see that those vary significantly. This can be seen in Figure 6 below. The emissions are largest for water and road, which can be expected as these are the major modes of transport.

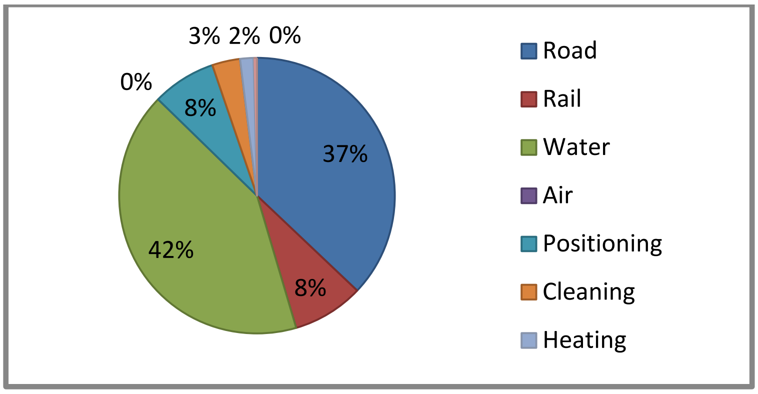

Figure 6: Emissions per source

For road this includes all the emissions of road transport during intermodal transport. In Figure 7 the amount of tonne kilometres is given per modality. One can see that most tonne kilometres are transported via water. Next to the figure is another figure displaying the emissions per modality. Here one can see that the percentage of emissions is much higher for road than the percentage of tonne kilometres transported via road. The reason is that the emission factor (g CO_2 / tkm) is higher for road than for water transport. The same holds for ferry transport because the lanes where a ferry is used mainly use road transport and use the ferry only over short distances.

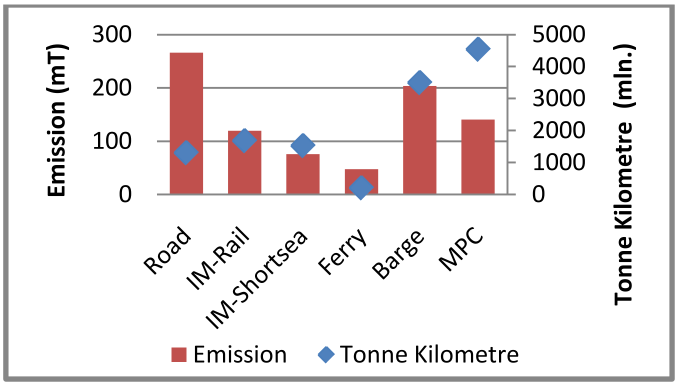

Figure 7: Tonne kilometre and Emissions per transport type

The two figures show that the emissions per tonne kilometre change significantly between the various transport types. In Figure 8, one can find the emissions factors for the different transport types. The graph shows that the emission factors are high for road and ferry as explained and lower for the other transport types.

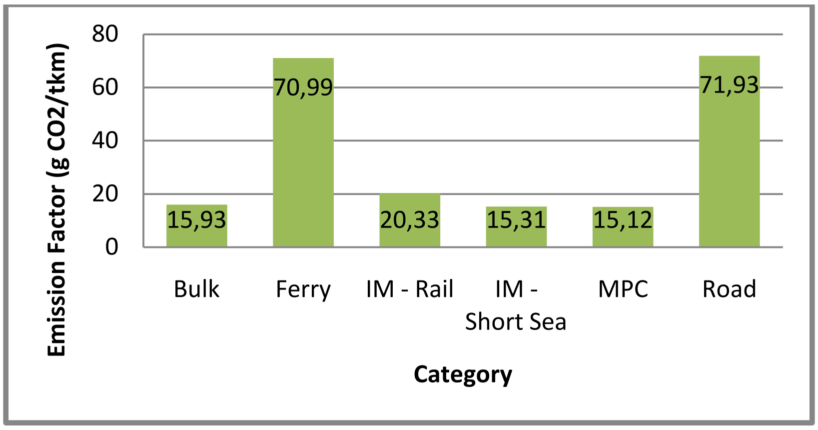

Figure 8: Emissions factor per transport type

Figure 9 shows the tonne kilometres and the emissions for several countries. Displaying these for all countries would lead to a very large (and difficult to interpret) figure due to the number of countries. The countries were selected based on total tonne kilometres and emissions. The top 15 of both categories is displayed in the figure, since some countries appeared in both top 15's the number of countries listed is less than 30. As can be seen in the graphs the main countries are;

- Turkey; due to high volume (almost 14 weight%) and relatively high distance (around 6000 km) this is the largest destination when looking at tonne kilometres (29.8%) and emissions (24.1%). Mostly it is an internal sale to other Dow plants via a terminal (>80 weight%).
- Germany; due to high volume (almost 17 weight%) and mainly road transport (>96%), the emissions add up to 10.4% of all emissions.
- Italy; due to high volume (almost 14 weight%) and moderate distance (average 1250 km), it is a big destination when looking at tonne kilometres (7.6%) and emissions (9%).
- France; due to high volume (almost 7 weight%) and only using road transport the emissions add up to 5.2% of all emissions.

Shipments to these four countries account for almost half of the total emissions (48.6%). For Turkey and Italy there is little that can be changed, besides lowering volumes, to reduce emissions. This is because most shipments are already intermodal towards these two countries. For Germany and France it would be possible to reduce emissions by switching to another mode of transport since most transport (96% and 100% respectively) is conducted via road. This is discussed in more detail in chapter 7.

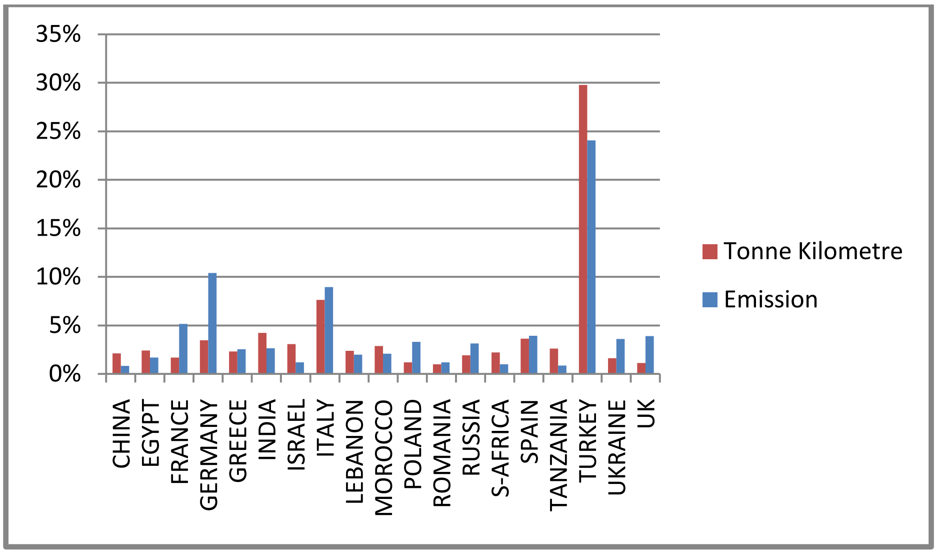

Figure 9: Tonne kilometres and Emissions per country

6.2 Data Collection Values

During the data collection phase a large amount of data was collected for the calculation of emissions. The emissions based on the real values amounted to 14,858.74 mT of CO_2 emitted. This is a difference of almost 3% compared to the value found in the theoretical model. Based on these two values one could say that there is no significant difference between collecting the real data and using the assumptions from the methodology. However, this is the overall result. To determine whether there are no underlying effects that even out, the database is compared at several different factors as well. The results can be found in Figure 10. In this figure eight different calculations are displayed. The additional categories are;

- No Real Fuel Data: This is the calculation where the values from NTM are used instead of the fuel consumption as provided by the LSP's.
- No Real Vessel Data: In this calculation the values from NTM are used instead of the emission values provided by the LSP's.
- No Clean/Heat: In this calculation the emissions from cleaning and heating are not taken into account.
- Rail only EU: In this calculation the rail emissions are not calculated per country but the overall emission value for the EU is used.
- No real load factor: In this calculation the load factors are based on assumptions instead of the real values.
- NTM Theory + Rail EU: In this calculation none of the real values are used, only assumptions. On top of that the rail distances are all assumed to have EU average emissions.
- NTM Theory: This is the calculation as described in the previous section.

As can be seen is there no or limited difference for two categories; road and water. The biggest difference is in the rail emissions. This varies significantly in two of the calculations, in both cases the distance travelled by rail is calculated using EU average emission. The reason for this increase is mainly due to the dataset under investigation. Most of the rail transport is travelling through countries with lower emissions per kWh than the EU average. The average is 0.41 g CO_2 / tkm, while in the dataset there is a lot of transport going through France which has an emission factor of 0.11 g CO_2 / tkm. This means that using the EU average over estimated the emissions. When looking at a dataset for Europe instead of one origin as is the case here, this should even out in theory. However, the transport volumes via rail vary significantly per country and therefore it is recommended to use real distance per country for rail if data is available.

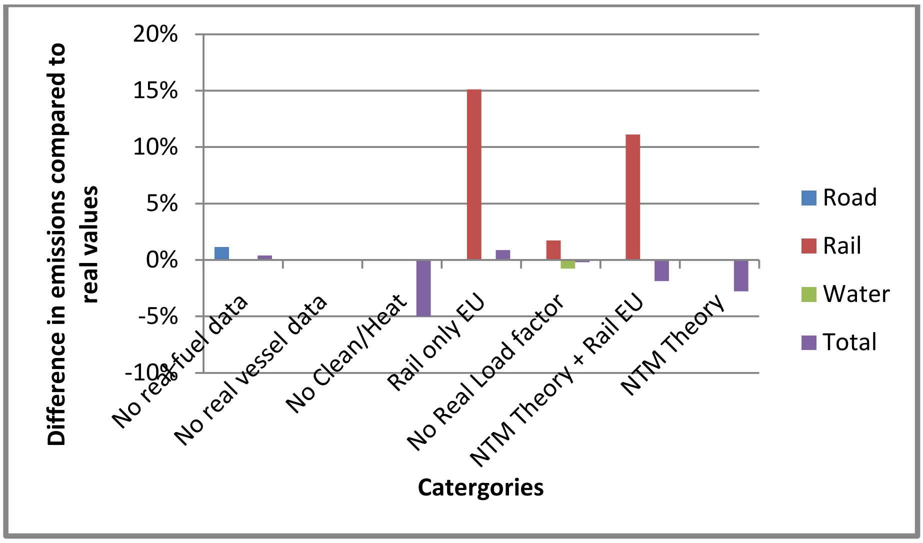

Figure 10: Variation in emission calculations

A more detailed analysis of the assumptions is done in the next section where a sensitivity analysis is conducted to determine whether the assumptions could be influential on the end result.

6.3 Sensitivity Analysis

For the sensitivity analysis several factors have been identified that could have an influence on the calculation results. For most of the factors data has been collected in the data collection phase. In those cases the assumptions will be compared with the values form the case study as well.

Distance

This is one of the key factors, the uncertainty in the distance will lead to the same uncertainty in the calculation results. This is the case for all modalities, note that this does not affect the "static" emissions (i.e. cleaning). The internal data at the company includes distances as well. However, the data is calculated using the greater circle distance which leads to a variation in the distances compared to the real distances. The 95% confidence interval contains variations in the range from 3% to -55% with a mean of -26%. This means that the average emissions would be 26% too low when using the distance from the system compared to the real distance. This is a more or less European specific problem due to the geography of the continent. For an American sample the distance would be closer to the real values. As mentioned before, relates this 26% lower distances to an almost 26% lower emission. This means that using the internal data will lead to a much lower emission than in practice. In the study the real distances are used and therefore this does not influence the emission in this report.

Weight

The weight of the shipments is another important factor. The weight data in the system is retrieved from the weighting when the goods leave the plant. For packed goods the drums are weighted and for trucks the truck is weighted on entering the site and once loaded. This means that the uncertainty is very low. The assumption has been made that the weight can vary up to 1%, which is relatively high. On a full truck this would mean a difference of around 250 kilograms of product. As can be seen in Table 9 the emissions vary only slightly. The rail emissions vary with the same percentage as the weight difference, the other vary much less. Based on the information that the data in the internal system is very accurate for weights the conclusion is that this variation will not significantly impact the overall emissions.

Table 9: Variation in emission based on weight uncertainty

Weight	Road	Rail	Water	Total
+1%	0.34%	1.00%	0.53%	0.44%
-1%	-0.34%	-1.00%	-0.53%	-0.44%

Fuel Consumption Road

In the questionnaire the LSP's were requested to give information with regard to the fuel consumptions to verify the assumptions made in NTM. The data provided by the LSP only give an average for the total emissions whereas NTM provides an emission value for an empty and a full vehicle. Based on the capacity utilisation the emission is calculated. Calculating the emission using the data provided by the LSP's the emissions would lead to a 7.6% lower emission for road with a standard deviation of 18.3%. Analysis of the two datasets (LSP data and NTM data) showed that there is no significant difference between the two means (Alpha = 0.95 P(t-test) = 0.304). However, one should note that these LSP values are averages and do not take into account the load factor. The emissions provided by carriers are often averages for all of their trucks, lanes and distances. Therefore it is still recommended to use the NTM values.

Positioning Distance

The positioning distance is split up into two parts; the positioning distance for pure road transport and the positioning distance for intermodal transport.

In the case of pure road transport there is only one positioning distance, the distance a truck has to travel to get from the LSP to the shipping company. For this situation the dataset had a response of over 56% of all shipments. The positioning distances provided by the LSP's had a mean value of 21% after removing outliers. This varies only 1% from the assumption provided by NTM. However, the standard deviation of the set was 21% which indicates that there is a large variation in the dataset and therefore a high uncertainty with regard to the results.

In the case of intermodal transport there are two positioning distances, once for picking up the cargo at the shipping company and once for picking up the cargo at the unloading terminal. In this situation the positioning distance can be calculated using two approaches, a percentage of the total distance or a percentage of the distance by road. Using the first option one gets an average positioning distance of 14% with a standard deviation of 14%. This is a bit lower than the 20% proposed by NTM and still has a high variation. Using the latter method the average is 95% with a standard deviation of 37%. This is much higher than the value proposed by NTM and has a high variation as well.

This means that a variation of 100% in the positioning distances would be a reasonable sensitivity analysis. Using these values leads to the changes found in Table 10. The impact of the high variation in positioning distances is significant. Further research is needed to establish a better understanding of the positioning emissions and to determine what approach will lead to more accurate results.

Table 10: Sensitivity results positioning

Category	Positioning Distance	Dif Positioning Emissions	Dif Total Emissions
Lower bound	0%	-100%	-7.2%
Upper bound	40%	+100%	+7.2%

Cleaning

The emissions arising from cleaning are relatively small compared to the total emissions. The cleaning emissions account for 3% of total emissions. The value used in the data collection is based on contact with several cleaning companies. However, there is still a large uncertainty in the value. Due to the large uncertainty a variation of 50% is used to determine the effect of the uncertainty on the results. The results can be found in Table 11 below. Here one can see that the 50% difference also results in a 50% difference in the cleaning emissions. For the overall emissions the variance is relatively low (1.6%) as can be seen in the table. However, the total emissions are in the range of 1.4% - 4.6% and can not be neglected.

Table 11: Difference in cleaning emissions with uncertainty

Emission value	Difference Cleaning Emissions	Difference Total Emissions
-50%	-50.0%	-1.6%
Standard	0%	0%
+50%	+50.0%	+1.6%

Heating

The emissions from heating are relatively low compared to the overall emissions, with only 2% of total emissions. The value used in the calculations is based on contact with several companies that heat tanks. There is still a large uncertainty in the value and therefore the sensitivity analysis is done with a difference of 50%. As one can see in Table 12, the 50% difference leads to a difference of 50% in the total emissions as well. On the overall emissions the difference is relatively low with only 0.8% difference. With a range of 1.2% - 2.8% the impact is relatively low.

Table 12: Difference in heating emissions with uncertainty

Emission value	Difference Heating Emissions	Difference Total Emissions
-50%	-50.0%	-0.8%
Standard	0%	0%
+50%	+50.0%	0.8%

Vertical Handling

The other parameter that was added to the calculations was the vertical handling emissions. Again the values are based on contacts with companies and the uncertainty in the data is relatively high. Therefore the decision was made to use an uncertainty factor of 50% for this factor as well. In Table 13 the 50% difference leads to a high variance in the vertical handling emissions as well. For the overall emissions the effect is relatively small at 0.2%. This means that the variance in vertical handling emissions will hardly influence the end result. With a range of 0.1% - 0.5% of the total emission this factor can be neglected.

Table 13: Difference in vertical handling emissions with uncertainty

Emission value	Difference Vert, Hand. Emissions	Difference Total Emissions
-50%	-50.0%	-0.2%
Standard	0%	0%
+50%	+50.0%	0.2%

Load Factor

The default load factors were taken from the NTM methodology. The load factors have been based on research by NTM. The uncertainty in the load factors is relatively high because the factors do not take into account the different products and so on. In Table 14 one can find the load factors that are used as default values for the different transport types.

Table 14: Load factors

Transport type	Load factor
Road	0.75
Rail	0.72
Water	0.8

For road the load factors are based on the weight of the shipment and the capacity of the truck for all FTL shipments. For LTL shipments the load factor of 75% is used. In the sensitivity analysis this is increased and decreased with 15%. This value is based on the results retrieved from the LSP's.

For rail the load factor is only used if there is no information with regard to the gross weight of the train. Due to the level of uncertainty the variation for the sensitivity analysis is also set at 15%.

For water transport the load factor is always used, except for bulk barges since there is only a PU shipment transported or the real load factor is known. For all other shipments the default load factor is used. Again a variation of 15% is used in the sensitivity analysis.

The results can be found in Table 15. As can be seen in the results, is the variation only significant for the water transport. Road transport is not significantly impacted due to the high percentage of FTL shipments and these are not impacted. As mentioned before the real values are hard, if not impossible, to retrieve for water transport and therefore further research would definitely be needed to verify the assumptions used by NTM.

Table 15: Difference in emissions with uncertainty in load factors

Type	Load Factor	Difference Type specific Emissions	Difference Total Emissions
Road	60%	+0.2%	+0.1%
	90%	-0.2%	-0.1%
Rail	57%	+1%	+0.1%
	87%	-0.7%	-0.1%
Water	65%	+21.6%	+9.5%
	95%	-14.8%	-6.5%
All	Low	-	+9.6%
	High	-	-6.6%

Percentage Electric

The percentage of trains that are powered using electricity is set at 75% as default. This is based on the total tonne kilometre shipped via electric rail in the EU compared to the total volume shipped. This number is based on 2008 values and there is a relatively low uncertainty in the value. However, the value can vary significantly per country. The factor is varied by 10% to determine what the effect is on the overall emissions. The results can be found in Table 16 below. The effect on the overall emissions is relatively low at 1%. However, the impact on the rail emissions is quite significant and there the advice is to use the real data if possible. If not the assumption can be used but one should take the variation into account.

Table 16: Difference in emissions with % rail electric uncertainty

Percentage Elec	Difference rail emissions	Difference Total Emissions
65%	+10%	+1%
0%	0%	0%
85%	-10%	-1%

Other

For the questions with regard to vessels the number of responses was too low to be able to state something with regard to the impact of the assumptions. The values that where retrieved had too much variation although the emission for the container vessels seem to be in the right order of magnitude.

6.4 Effective use of methodology

Collecting all the necessary data for a detailed calculation is very labour intensive as mentioned before. Doing this kind of study for the entire site or for an entire region would require a huge amount of resources. To determine whether all these data are needed the sensitivity analysis was conducted. Based on that analysis it is concluded that it is not necessary to collect all data. In many cases the assumptions can be used to calculate the emissions. It is recommended to use all the available data if possible since this always leads to a more accurate result than using the assumptions. The following information is absolutely needed to get to an accurate result. Although these might sound quite trivial, retrieving it is often not as trivial.

- Mode of transport
- Distance per transport mode
- Weight of shipment

The main factor is the mode of transport that is used. This should be known otherwise it is not possible to calculate the emissions. This should be specified up to detailed level. For example in the case of intermodal rail transport this should be specified that it consists of road-rail-road transport. The second factor is the distance that the goods are transported over. All the emissions during transport are calculated via the distance that is travelled. Having a difference of 10% in the distance will lead to a difference of 10% in the emissions as well. The third factor is the weight of the shipment, this is needed to calculate the emissions and the allocation of the emissions in all modes except for some water transport. In some water transport the allocation is based on lanem or TEU as explained in section 3.6

Based on these factors the emissions can be calculated but differ slightly from the actual data (see previous sections). Another important factor, especially in this dataset, is the rail distance per country. When looking into specific lanes or biased datasets the emissions for rail transport can vary significantly when using the EU average instead of the national emission factors per country. Therefore it is recommended to use the emissions per country and the country distances if possible. For the vessel data the responses were too low to be able to give better estimates to use in the calculations. Therefore the decision was made to use the NTM assumptions in those cases. Further research is needed to be able to verify the NTM assumptions in those cases.

Emissions from cleaning and heating should be taken into account as those can have a significant impact. The emissions for vertical handling can be ignored due to the very small impact on the total emissions (<0.5%).

7 Phase II: Business Opportunities

There are two types of opportunities arising with knowing the emissions during transport. The first type is reductions opportunities, by which is meant identifying lanes where the CO_2 emissions can be reduced by for example switching modalities. The other opportunity is using the emission information, for example in contact with customers. This could be used when conducting a payload project. In that kind of project the goal is to increase the payload, having a higher payload will lead to lower emissions per tonne. When contacting customers with a request to increase the payload, the reduced emissions can be used as a factor as well. To get a better understanding of whether it would be possible to use this information is such a way a meeting was set up with three Dow employees. The result of these meetings was that there is currently not much interest with this regard, at least for this business. Therefore the decision was made to focus on the first opportunity mentioned. The second part could be of great interest but is not in scope of the project and needs further research.

As described in the introduction the availability of literature is rather limited for the project scope. In that respect there is almost no literature available with regard to identifying reduction opportunities. This means that a method had to be developed by the researcher for identifying reduction opportunities. Several methods were developed and those will be discussed below. In the first section the different methodologies are described. In the second section the results of the different methodologies are discussed. In the third section the reduction opportunities will be discussed in detail.

7.1 Identifying Opportunities Method

Two different methods where looked into for identifying opportunities. The first method identifies opportunities by looking at the tender data. The tender data include all the lanes and transport methods that LSP's have offered during the tender. With this method one looks at all these lanes to identify targets. The other method is by giving all lanes an opportunity score. This score is generated via a stepwise plan. Both methods will be explained and discussed below.

Option 1

In the first option only the tender data is used. The opportunities are identified by looking at the data collected in the tender. The general principle is to look at all lanes and mark all lanes where road transport is used but intermodal transport is offered as well. These lanes are identified as opportunities. The intermodal and road offers are then compared to determine whether the emissions can be reduced in those cases.

The disadvantage of this methodology is the fact that this is a labour intensive approach. The lanes where multiple options are available have to be determined manually. The advantage is that the percentage of lanes where reductions are really possible increases. This is caused by the fact that most lanes where emissions can not be reduced are filtered out manually.

Option 2

The second option uses the opportunity score, which is a value that indicates how likely it is that the emissions on that lane could be reduced. The general idea is that one looks at several factors and determines whether the lane has reduction opportunity based on these factors. This is done by determining whether the factor has a higher value than a certain threshold. If that is the case it is more likely that the reductions on that lane can be reduced effectively. Based on the data four factors were identified that could indicate opportunities;

- Emission Factor; The emission factor is the CO_2 emission per tonne kilometre. A high emission factor indicates that the manner of transport is perhaps not optimal.

- Distance; Optimising or improving transport that takes place over large distances leads to higher reduction compared to the same transport on shorter distances.
- Weight; High volume shipments have (on average) larger emissions than small volume shipments. Besides, the low volume shipments in the case study are non-normal shipments (i.e. rush orders, samples).
- Alternative; If there already are other alternative methods of transport on the same lane there is a higher chance that it is a good option to switch to another mode of transport.

For these four factors a step plan was designed which can be seen in Figure 11. For each factor the value is determined per lane, if it is above a certain value the opportunity score for that lane is increased. If the value is not above the value than the opportunity score is not changed. As can be seen in the figure X1, X2 and X3 are mentioned in the figure. These values change throughout the different methodologies and can be found in Table 17.

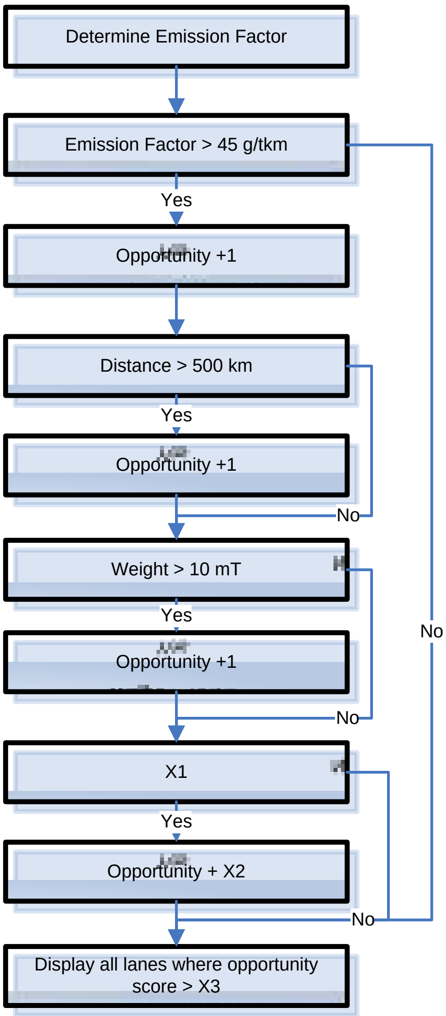

Figure 11: Step plan

The boundaries for the score are based on data from the case study and the reader is advised to use appropriate data when using the step plan. The emission factor of 45 g CO_2 / tkm is a general value, most carbon intensive transport scores higher than this value. This can be seen in Figure 12. For almost all the shipments the division is clear. There are some road shipments with lower emission factors and some rail shipments with higher emission factors (caused by the high percentage of road transport in that case). The ferry shipments are most often above the boundary as well, this is mainly caused by the fact that the largest part of the transport is conducted by road transport.

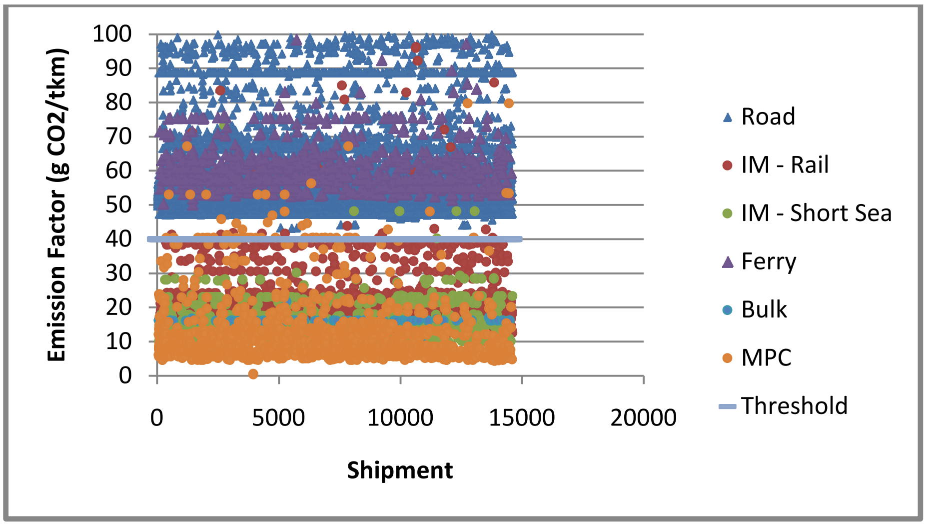

Figure 12: Emission Factors per mode

The second factor is the distance and there are two reasons for including this factor; at short distances it is less likely that reductions are possible and the reductions possible at short distances are less. Reducing emissions at a lane of 200 km in general leads to lower reductions per tonne than reducing at a lane of 2000 km. In Figure 13 the distances are displayed for the lanes identified as reduction opportunities. Here it can be seen that setting the threshold at 500 km leads to a good division in the lanes where reductions can be achieved and where no reductions can be achieved.

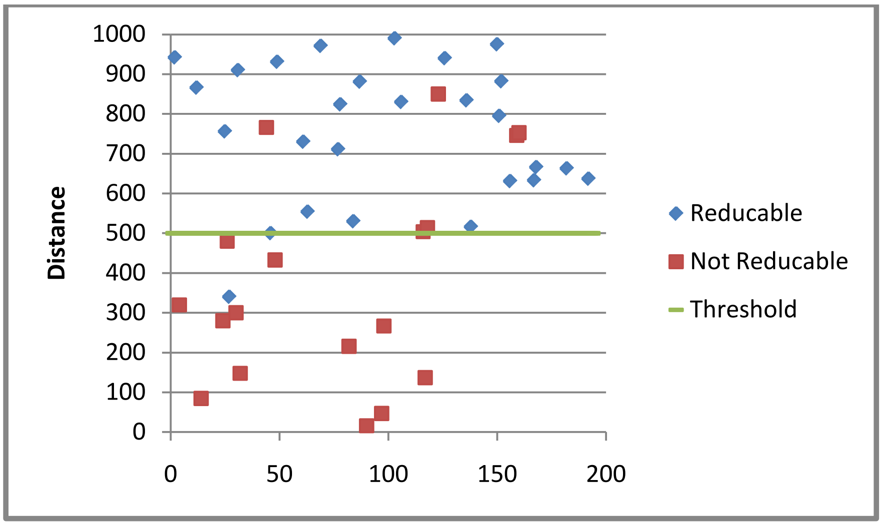

Figure 13: Distance versus reductions possible

For the case study one can state that shipments below ten tonne are non-regular shipments. In the case of foams this will probably not be the case and the reader should define a more appropriate value. The advice is to choose a value that filters out non regular shipments. All lanes with an opportunity score of 3 or higher are identified as reduction opportunities.

Table 17: Values for the step plans

Method	X1	X2	X3
Option 2	Other modality available at lane	1	2
Option 3	Other modality available at lane	1	2
Option 4	Other modality available at lane	1	3
Option 5	Intermodal alternative available at lane	2	3
Option 6	Intermodal alternative available at lane	2	2
Option 7	Intermodal alternative available at lane	1	2

Option 3

This is a combination of the first two options, in this option only the lanes that are identified in both cases are marked as a reduction opportunity. This means that that the lane has an opportunity score of 3 or higher (based on the original step plan) and there is an alternative available on the lane.

The disadvantage of this methodology is the fact that this is a labour intensive approach. The lanes where multiple options are available have to be determined manually. The advantage is that most lanes where no real reductions can be achieved are filtered out (manually) already.

Option 4

This is method is almost identical to the second option. The only difference is that another limit will be used to mark lanes as a reduction opportunity. The opportunity score has to be at least 4 for a lane to be identified as a reduction opportunity. This means that the lane should have values higher than the limits set in option 2 for all four factors (emission factor, weight, distance and alternatives). The advantage compared to Option 2 is that less lanes are identified and there is a higher likelihood that the opportunity will lead to possible reductions.

Option 5

This option is similar to option 2; the difference is that a changed step plan is used. The basis of the step plan is displayed in Figure 11. The new values can be found in Table 17. As can be seen in the table, the main difference is that the step looking for an alternative route is made more specific. The new step plan only increases the opportunity score if the alternative route is an intermodal route. Furthermore, the plan takes into account that having an intermodal alternative means that there is a high likelihood of having an alternative with lower emissions. This is taken into account by increasing the opportunity score with two if there is an intermodal alternative. By adding two instead of one the chance is higher that a lane with an intermodal alternative is identified. All lanes with an opportunity score of 4 or higher are identified as reduction opportunities.

Option 6

This option is similar to option 5. The only difference is that the limit for the opportunity score is varied. Only the lanes with an opportunity score of 3 or higher are identified as reduction opportunities. This means that more lanes will be identified as being reduction opportunities.

Option 7

The seventh and last option is similar to option 6, the difference is that the preference for the intermodal route availability is reduced. This is done by giving only a score of one instead of two to routes were an alternative intermodal route is available. This means that the values in the step plan are changed to the values in Table 17. The lanes with an opportunity score higher than two are identified as reduction opportunities.

In the next section the different options and how these methodologies perform is discussed. Furthermore, a recommendation is made on which methodology to use in practice.

7.2 Business Opportunities

The chapter is divided into two parts, in the first part the base case will be described. The base case is the identification of all lanes where there are reduction opportunities. The second part of the chapter is the discussion of the seven methodologies that were described before. The methodologies will be compared on several factors.

7.2.1 Base Case

As a base case for the reduction opportunity identification the researcher identified the reduction opportunities by hand and by all seven methodologies. The combination of all these lanes is seen as the base case for reduction opportunities. The base case consists of 194 lanes which is almost 10% of all lanes. There is a possibility that not all lanes have been identified in the base case scenario. However, all the major lanes where most of the reductions can be achieved have been identified. This can be stated because all large lanes (volumes and distances) have been looked at during the base case identification. Cases that are perhaps not included have low emissions factors, small distances and small weights. Hence the opportunity of reduction is low as well as the amount that could be reduced. The 194 lanes that have been identified account for 58.7 weight% of all shipments. This indicates that all the big lanes have been identified. Note that most intermodal shipments have no reduction opportunity either.

The lanes that were identified for the base case have been analysed. The lanes were checked to determine if reduction opportunities are available. In the case that there were no reduction opportunities it was indicated why not. In Figure 14, one can see the result of this analysis.

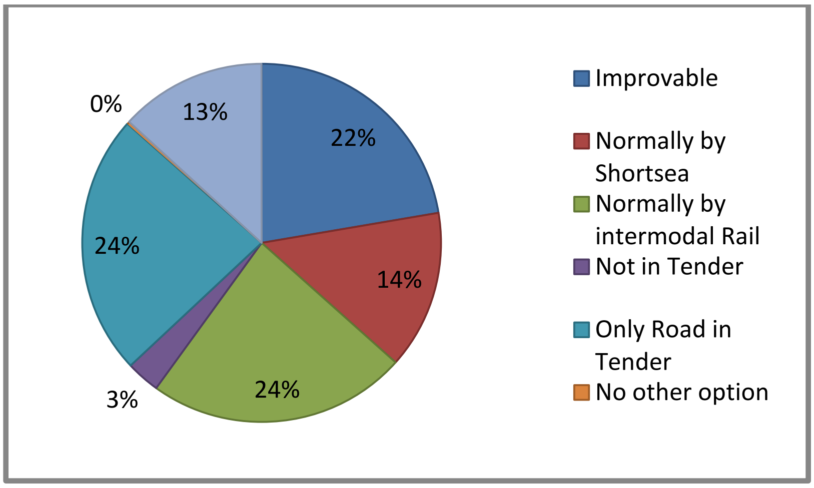

Figure 14: Analysis of reduction opportunities

There are four categories that account for most of the lanes. Some of the identified lanes cannot be improved (13.5%) either because none of the alternatives is better or there are no alternatives possible. For the latter, one could think of locations with no or limited intermodal terminals in the area. For a quarter of the shipments more information is needed (26.5%), this means that not enough information could be retrieved to determine whether the emissions can be reduced or not. The largest part (37.7%) consists of lanes that are already intermodal but where one or more shipments were carried out by road (i.e. rush orders). The emissions can be reduced for the lane but those are already lower in the general case. These are easily dismissed since information about the standard transport method is readily available. The last part (22.3%) consists of lanes where sufficient information (i.e. alternatives) is available and the emissions can truly be reduced. This is a bit more than one fifth of all identified lanes which means that for each reduction one has to look at four options that lead to no reduction for the base case. The seven methodologies are discussed in the next subsection and will be analysed with regard to their hit rate (i.e. the percentage that can be reduced).

7.2.2 Methodologies

The seven methodologies that were identified in the previous chapter will be discussed and compared to determine which method should be used. The comparison will take place on six different factors;

- Truly improvable; this is the number of lanes that have been identified and where reductions are actually possible.
- Perhaps improvable; this is the number of lanes where more information is necessary before a conclusion can be drawn.
- Exception; this is the number of lanes that are normally conducted by another modality but that pop up as opportunities. These are actually opportunities where changes have been made already or some shipments have been transported using different modalities than regular.
- Not improvable; these are the lanes that were identified but where it is not possible to reduce emissions.
- Number of identified lanes; this is the number of lanes that has been identified in the methodology.
- Non-identified CO_2 emissions; this is the percentage of CO_2 emission reduction that was not identified in the methodology.

One of the most important categories to grade the methodology is the percentage of the emissions that are identified in the methodology. Therefore, the results for this category are used to make a first selection of methodologies. The reason this is important is that the goal is emission reduction. Not identifying a large part of the reduction will lead to the wrong conclusions. In Figure 15 below, one can find the percentage of emissions that were not identified in the methodology. In the graph one can easily see that methodology 4 (Step plan 1, Opportunity score ≥4) and especially methodology 5 (Step plan 2, Opportunity score ≥4) have a very high percentage of emission reduction that is not identified. On the other hand methodology 6 (Step plan 2, Opportunity score ≥3) and methodology 7 (Step plan 3, Opportunity score ≥3) have a very low percentage of missed reductions (both 0%).

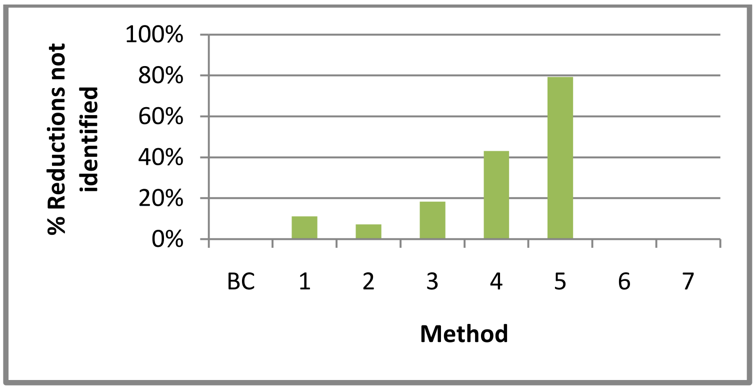

Figure 15: The percentage of emission reduction not identified

Another important aspect is the number of lanes that are identified. The number of lanes that are identified represent more or less the workload of looking into the opportunities. Each of the identified lanes has to be looked into manually to determine whether reductions can be achieved. This means that less lanes leads to a lower work load. However, the percentage of emissions accounted for should not become to low. In Figure 16, one can find the number of lanes identified by each of the methodologies. The number of lanes is very low for methodology 4 (Step plan 1, Opportunity score ≥4) and 5 (Step plan 2, Opportunity score ≥4). This means that these two methodologies lead to a low number of lanes but the percentage of CO_2 reduction identified is low as seen in Figure 15.

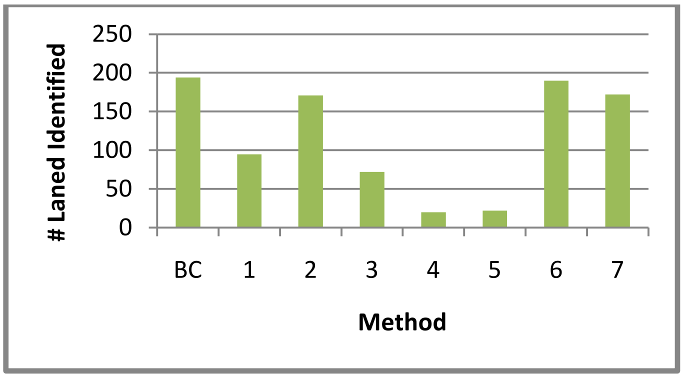

Figure 16: The number of lanes identified by each methodology

The other important factors are the percentage of identified lanes where emissions can be reduced or can possibly be reduced. This signals the number of lanes were it is useful to look at a very detailed level (including service levels etc.) whether the reductions could be achieved. The results are displayed in Figure 17. Here one can see that methodology 1 (Tender based) and methodology 3 (Combining Tender and Step plan 1) have high scores for the percentage of lanes that can truly be improved. Note that part of this increase is due to the fact that all lanes identified via the tender data have an alternative mode of transport. This leads to a higher percentage of truly improvable lanes and a decline in the number of lanes that perhaps can be improved.

As can be seen are the percentage of exceptions coming up relatively low for methodology 2 (Step plan 1, Opportunity score ≥3). However, as mentioned before having higher percentage of exceptions will not cause significant problems because of the relatively easy manner of dismissing those.

Another important aspect is the number of lanes that can not be improved but that are still identified in the methodology. As can be seen in Figure 17 is the percentage of lanes that can not be improved low for methodology 5 (Step plan 2, Opportunity score≥4). However, this methodology misses almost 90% of the reduction opportunities. Methodology 1 (Tender based) and methodology 3 (Combining Tender and Step plan 1) also have a relatively low score which is caused by the fact that most lanes that can not be improved do not have other offers in the tender. This is caused by the fact that most of these cases can not be improved due to costs, higher emissions or lack of availability of transport modes.

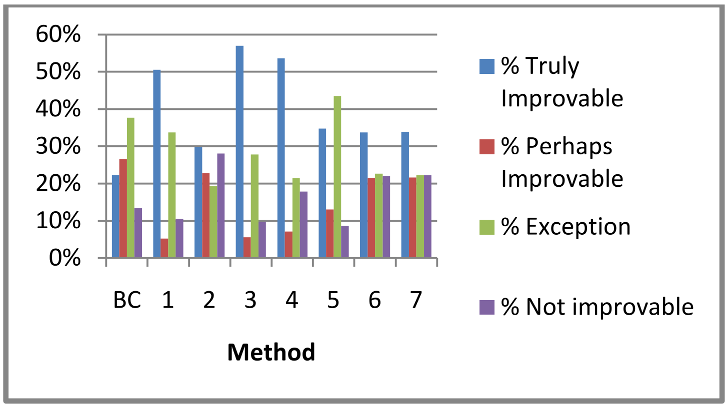

Figure 17: Comparing different methodologies

7.2.3 Conclusion

Based on the analysis of the methodologies two different strategies are proposed; one for easy targets and one extensive approach.

There are two options for the easy targets approach, methodology 4 (Step plan 1, Opportunity score ≥4) and 5 (Step plan 2, Opportunity score ≥4). Based on the fact that methodology 4 has a higher hit rate than methodology 5 and the fact that methodology 4 identifies a higher percentage of the total emissions it is recommended to use methodology 4 to identify easy targets. Note that the percentage of reductions identified with this methodology is only 56%.

This leaves five options for the extensive approach. Of these five options two options have a different approach. These are methodology 1 (Based on tender data) and methodology 7 (Step plan 3, Opportunity score≥3). The other three methodologies work in the same manner as these two but perform worse and are therefore not discussed. The percentage of CO_2 reduction identified was 88.9% for methodology 1 compared to 100% for methodology 7. When comparing these two options on the number of lanes that are identified there is a large difference the first identifies 95 lanes whereas the latter identifies 171 lanes.

In Figure 17 one can see that the percentage of lanes identified that can truly be improved is much higher for the first methodology. As mentioned before this is caused by the fact that only lanes are identified where alternatives are available. Methodology 7 has a much higher percentage of lanes where more information is needed before it can be stated whether reductions could be achieved.

In conclusion it can be stated that methodology 1 has a high workload in pre-processing whereas methodology 7 has a high workload in post-processing. This means that the number of lanes are first filtered and than looked into whereas the first option does not use a filter. The percentage of reductions that can be achieved is even higher for the latter. Based on these facts and a discussion with the people involved in the case study the decision was made to recommend methodology 7. Another advantage is that this can be build into the calculation tool that has been developed.

7.3 Reduction Opportunities

In the previous chapters it was already discussed that two types of reduction opportunities were identified. Opportunities where sufficient data is available and the reductions can be achieved and lanes where not enough data is available but reductions possibly could be achieved. The results will be discussed separately.

7.3.1 True reduction opportunities

In this part the lanes that were identified and where reductions can be achieved are discussed. In Appendix 15, the complete list of reduction opportunities can be found. There are two types of reductions in this dataset; reductions that can be achieved at no costs or reductions that lead to higher freight costs. In the first case the lanes are not using intermodal transport due to service constraints or availability of intermodal options. In the latter case road transport is cheaper than intermodal transport and possibly for other reasons as well. In total a reduction of 849.15 mT CO_2 could have been achieved via these reduction opportunities. This is a saving of 6% of all CO_2 emissions for the case study. A saving of 6% of CO_2 emissions is actually not that large but indicates that the current supply chain is already relatively optimal towards CO_2 emissions. In total a bit more than 3% of the total emissions can be reduced at the minimum cost point by switching modalities.

7.3.2 Possible reduction opportunities

The second type of reduction opportunities are the reduction opportunities where more information is needed before it can be concluded whether the emissions can be reduced at all. As mentioned before this could be lanes where no intermodal alternative is offered. For the larger lanes (>100 mT/year) in this subset the researcher determined whether alternatives could be available. For example, if there is a lane towards city A and there is no alternative available. If there is a city B close by where an intermodal alternative is offered, it should be possible to use the intermodal alternative for city A as well. These alternatives have been identified by hand and can be found in Appendix 7. These alternatives could lead to an additional saving of 280 mT CO_2 emissions. This means that in total an emission of 1129.15 mT (7.85% of all emissions) could be reduced by using other means of transport.

7.3.3 General Insights

Based on the reduction opportunities that were identified several insights could be gained in the reduction opportunities and the costs involved. The EU is aiming to increase the costs of environmentally unfriendly modalities (i.e. air and road) compared to less unfriendly modalities (i.e. vessels and rail). However, it is still unclear how new regulations should be implemented to encourage companies to switch to less carbon intensive modalities. Based on the reduction opportunities identified before, it was analysed what the cost of the CO_2 should be to make sure that it is profitable to switch modalities. As mentioned before this is not the only trade off in these decisions but having the opportunity to switch without additional costs will always be an additional incentive.

Almost 55% of the reductions identified can already be reduced without additional costs. As mentioned before are the service constraints the limiting factor in those cases. The decision was made not to include these data in the analysis. In Figure 18, one can see the reductions that can be achieved without increasing costs at certain costs of emission. At low carbon emission costs there is no change in reductions, only at high prices cost effective reductions can be achieved. Note that in those cases the total freight costs increase significantly. In the scenario analysis in Chapter 8.2 the effect of the carbon prices is discussed in more detail.

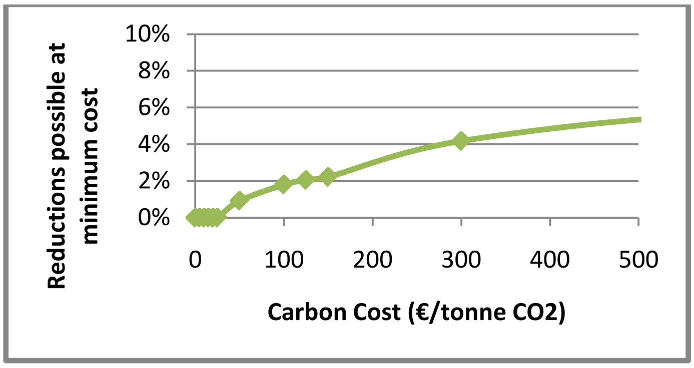

Figure 18: Percentage of reductions at minimum cost

7.3.4 Supply chain redesign

Based on the data collection and communication with Dow employees two options were identified where reductions could possibly be achieved by changing the supply chain design. More options could be identified by thorough analysis of the supply chain. The first option uses a storage location for containers. The second uses a tank at another production location.

Option 1

One of the options that was mentioned in several cases, in the lanes identified in subsections 7.3.1 and 7.3.2, was switching to intermodal rail via Antwerp-Ludwigshafen or Terneuzen-Ludwigshafen. This option arose for all customers near to Ludwigshafen. The total reduction opportunity was almost 10% of all identified reduction opportunities. Switching from road transport to intermodal rail for these options means that the transit time increases with 1 day. The costs increase or even decrease at a varying level for the different customers.

To be able to deliver the goods at the same terms (i.e. transit time) on has to look at the supply chain design. To have the same transit time it would be an option to use a container storage location at Ludwigshafen. This terminal should be able to store several containers and when customers order the product it is delivered from the terminal. Based on the demand pattern in 2008 and a basic inventory policy using a safety stock, fixed reorder point, 98% on time delivery and variable reorder quantity and a daily reorder period the inventory was calculated. The calculations will only be conducted for the products where more than 250 mT is shipped every year. In section 8.3 the results will be discussed for the different scenarios. In the current situation and with current regulations this option is not profitable.

Option 2

The second option is the placement of a terminal at another production facility. The polyol business unit contains several products. One of the products is currently produced in multiple production locations. Due to the increase in production volume at the Terneuzen facility that product will no longer be produced at the other location (X) and this means that all deliveries will be made from the Terneuzen facility. Because of the relatively long distances it might be an option to reduce emissions by placing a tank at X and replenish the tank using a bulk tank vessel. In that case the product will be produced at Terneuzen shipped to location by a vessel and from there it will be distributed via road. This will be compared to the current case where the products will be produced in Terneuzen and shipped directly to the customer via road, intermodal-rail or intermodal short-sea transport.

The calculations are based on real distances (in case of rail per country), weight and modes of transport. For all other factors, assumptions will be used as discussed in the previous chapters.

The results of the calculations showed that it would not be profitable to use this approach. The total emissions would increase by almost 9% for the shipments to that region. The first reason that the emissions increase is that due to geographic reasons the transport distance increases significantly when using the vessels. The second reason is that the shipments are all transported to the tanker and from there use road transport towards the customer, which has a higher emission per tonne kilometre. In the case of intermodal rail or intermodal short-sea transport from the Terneuzen facility the road distances are lower because there are multiple rail stations and ports in the region, whereas there is only one tank.

However, when looking into the results in more detail it could be seen that there were opportunities for reduction. In Figure 19 below the difference in emissions compared to the original situation are displayed. As can be seen do the emissions increase again after some reductions. These cases were identified as lanes to one specific country (Y). The reason for these high emissions is that these shipments are currently delivered by a vessel (intermodal short-sea). Using the new design (vessel to tank and then road transport) will mean that a vessel is going to the tank location, which is further from the Y than the current port. This increases the road transport with several hundreds of kilometres causing the higher emissions.

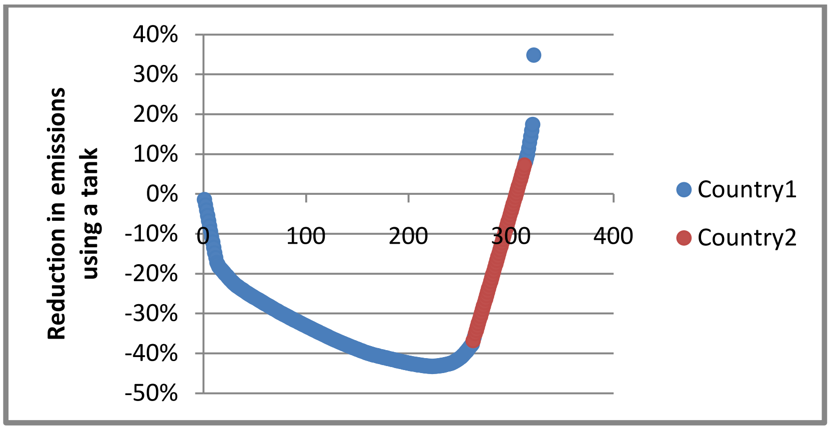

Figure 19: Difference in emissions, using tank

Therefore an alternative is proposed; use the tank for all shipments except for the shipments to Y. For that country transport will be done as is currently the case, using intermodal transport instead of the tank. The reduction for the involved lanes is 15.4% of the emissions for transport to that region. This is equal to a total emissions reduction of 0.3%. This is a relatively low saving but it can be achieved cost effectively. Placing a tank at the specific location has been investigated prior to this research by the company. This would be cost effective at around 6,000 mT of product per year. With the new proposal (excluding the shipments to Y) the total volume would be around 6,300 mT per year. This is higher than the threshold and therefore it would be worthwhile to investigate this option in more detail.

8 Phase II: Rules & Regulations

This chapter describes different possible scenarios for the future and gives insights in what the consequences of these scenarios are for companies. All scenarios are based on possible upcoming governmental regulations; this means that other factors that can effect carbon dioxide emissions are not taken into account. An example of another effect is the oil price; the oil price is expected to rise the coming years and this can have a similar effect as for example a diesel tax, because the fuel price will increase in both cases.

As part of the global initiatives to reduce GHG emissions the European Union has initiated several projects and is still developing and improving projects. At this moment the main initiative is the European Union Emission Trading Scheme (ETS). This scheme limits the amount of carbon dioxide a company can emit. The ETS was started in January 2005 as the first international carbon dioxide emissions allowance trading system. The system works by supplying companies with emission allowances (the right to emit 1 tonne of carbon dioxide). Companies can either sell their allowances when they have not emitted the allowed quantity of carbon dioxide or they can buy extra allowances from other companies when these are needed. The amount of allowances that is supplied to companies (given, sold or auctioned) will decrease each year to reach the emission targets set by the Kyoto Protocol (UNFCC, 1998).

At the moment the ETS covers the following major industry sectors;

- Power
- Chemical
- Steel
- Paper and Pulp
- Aluminium
- Cement

As can be seen the only transport included in the ETS is electrical rail transport (because of the inclusion of the power section). However, the EU is discussing to include aviation and sea navigation (both short sea and deep sea) in the near future. At this moment there are no concrete plans to include emissions from road and diesel rail transport in the ETS. However, the EU does have other, further developed, plans for road and diesel rail transport: diesel tax and the Euro-vignette.

8.1 Upcoming Rules & Regulations

In this chapter the rules and regulations that could be implemented in the near future are discussed. One of these has already been implemented but is changed in such a way that the global warming potential is taken into account as well. The other is not implemented at the moment but discussion has progressed and the general idea is that it could be implemented in the near future.

8.1.1 Diesel tax

The diesel tax is a way of increasing the price of diesel and with that reducing the amount of diesel consumed. There are two ways to implement this: with a new carbon tax or by increasing the current national excises. By implementing the diesel tax the EU hopes to reduce the amount of diesel consumed. The most likely scenario is that the EU will enforce regulations to oblige countries to make the excise tax on diesel equal or higher than excise tax on petrol.

8.1.2 Euro-Vignette

One of the regulations that already has been implemented is the Euro-Vignette (EU, 2006). The current Vignette has no cost with regard to CO_2 emissions implemented. During the meeting of July 8 (2008) the Council revealed the new proposals to include the CO_2 emissions in the directive. This means that an additional cost is implemented that takes into account the emissions of the vehicle. During 2008 and 2009 the proposals were and are reviewed and discussed, at the end of 2009 the directive is scheduled to be agreed on.

The goal of the directive is to apply the “polluter pays” principle, where “the variation of the tolls will take into account the environmental burden of the vehicle” (EU, 2006). The member states are free to set the cost for the environmental burden within the boundaries as stated by the EU directive. This means that the emission costs will vary per Member State. To be able to implement the scenario, regardless of the country the LSP is based, the decision was made to use European wide values in the scenario analyses.

8.1.3 EURO-norms

The most well known EU initiative is probably the regulations with regard to the emissions in vehicle engines, known as EURO-norms (i.e. EURO-IV). These norms have been set to reduce the environmental burden of vehicles by setting an upper value to the emissions of a vehicle. Implementing new norms and reducing the number of old engines one would expect the CO_2 emissions to be reduced. However, this is not part of the scope of these EURO-norms. As can be seen in Table 18 below do the emissions of CO_2 not decrease due to the EURO-norms (NTM Road 2008). Therefore these regulations will not be taken into account in the scenario analyses. Note that the regulations do not mention the fuel consumption per kilometre. The regulations only apply to the emissions per fixed amount (litre or kWh). Having a lower fuel consumption will lead to lower emissions, but this is not covered in the EURO-norms.

Table 18: Emissions (g/l) of pollutants for truck (28-40 mT) on a highway

[g/l]	Euro0	Euro1	Euro2	Euro3	Euro4	Euro5
HC	1.56	1.69	1.06	0.92	0.05	0.05
CO	6.75	6.75	5.83	6.32	0.36	0.35
NOx	35.20	27.00	28.00	21.70	14.80	8.35
PM	1.41	1.25	0.69	0.50	0.08	0.08
CO2	2621.00	2621.00	2621.00	2621.00	2621.00	2621.00
CH4	0.0313	0.0338	0.0212	0.0183	0.0010	0.0010
SOx	0.0033	0.0033	0.0033	0.0033	0.0033	0.0033

8.2 Scenarios

The scenarios that are analysed in the report are discussed below. The scenarios will be discussed in general and the values that are used in the analyses are given. Because rail electric is already included in the ETS at the moment (with a price of around 15 €/tonne CO_2) all the prices mentioned in the scenarios will be reduced with € 15 for rail electric. The current electric rail prices already include these costs and charging those twice would give a wrong impact.

In this section the scenarios are defined and analysed. For each of the scenarios the effect on the current dataset will be given. This means that the price increase will be determined if the scenario had already been implemented before 2008. The price increases can be found in the appendices. In the description the terms marginally (<2.5% increase) and significant (2.5 – 10 % increase) and large (>10%) will be used. The exact values are stated in Appendix 13. In the second part the influence on reduction opportunities will be discussed.

8.2.1 Scenario 1

This scenario represents the current situation with only the current ETS. This means that no emissions resulting from transport, except for the emissions resulting from electrical transport, are limited. This seems to be a strange situation, since the use of electrical transport modes is discouraged compared to the other transport modes while electrical transport has relatively low carbon dioxide emissions. However, it is interesting to look at this scenario, because it represents the current situation. For this scenario three different prices to emit one tonne of carbon dioxide are set. The lower bound price is the current ETS price, which is 15 Euros (ECX, 2009). Based on the average of multiple sources (CE Delft, 2008 (I), Carbon Trust, 2006) the expected average price is set at 50 Euros and the upper bound price is set at 100 Euros per tonne of carbon dioxide emitted.

Table 19: Emission prices scenario 1

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 0	€ 0	€ 0
Rail - Electric	€ 15	€ 50	€ 100
Road	€ 0	€ 0	€ 0
Water	€ 0	€ 0	€ 0

Influence on current supply chain

In scenario 1, three levels for the costs have been stated, these costs only apply to electrical rail transport. In Appendix 13 one can find the additional costs that would have occurred if the scenario had been implemented at the time. One can see that the increase is only marginally compared to the total freight cost. This means that in this scenario Dow will hardly be affected.

Impact on reduction opportunities

There are two ways in which the reduction opportunities can be influenced; the percentage of reductions that can be achieved cost effectively and the cost of reducing the lanes that are not cost effective. In Table 20 one can see the percentage of CO_2 reductions that can be achieved without increased costs at the current scenario. As one can see the percentage of reductions that can be achieved at no additional costs decreases when the CO_2 price increases. This is caused by the fact that only the rail emissions are taxed and therefore it becomes less profitable to switch to intermodal transport at higher CO_2 prices.

Table 20: minimum cost reduction scenario 1

Price Level	Reduction at minimum costs
Currently	3.3%
Lower bound	3.3%
Expected	3.3%
Upper bound	3.0%

The other part is the costs of reducing the CO_2 emissions on the lanes that are currently not cost-effective. In Figure 20 one can find the result of the first scenario on the costs for reducing emissions. In the upper bound case, 100 €/tonne CO_2, the reductions that can be achieved cost effectively decrease to 50.7% and this means that the minimum is more to the left in Figure 20. This indicates that the amount of reductions at minimum cost is lower than in the other two options.

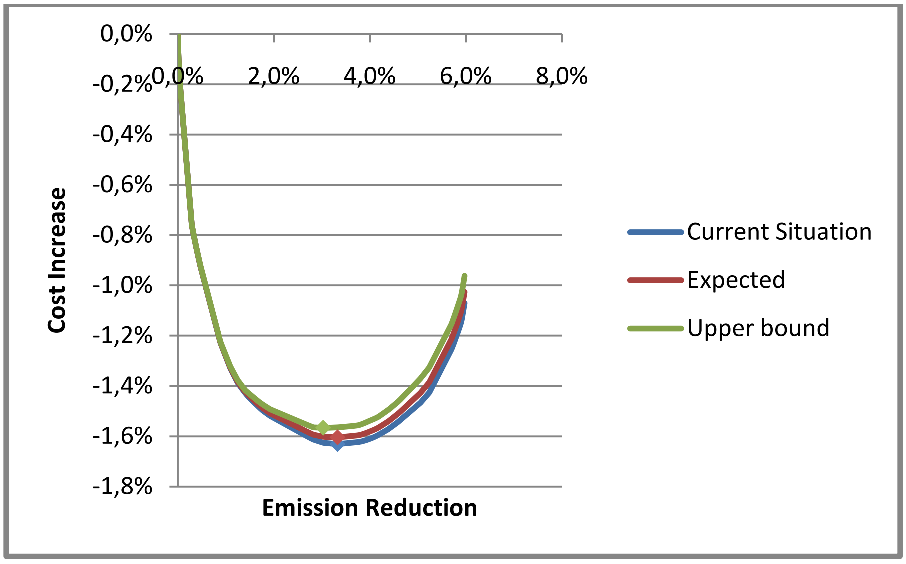

Figure 20: Emission reductions and costs in scenario 1

8.2.2 Scenario 2

The current ETS does only include emissions from electrical transport, but not from other types of transport. The EU is planning to include emissions from air and sea transport in the current ETS. Other plans of the EU are the implementation of the Euro vignette and the implementation of the carbon tax. This scenario represents the situation where all of these initiatives are implemented in parallel. This means that emissions resulting from electrical transport, air transport and sea transport will be included in the current ETS and that the emissions resulting from diesel road transport and diesel rail transport are covered by the Diesel Tax. The emissions from road transport are also included in the Euro-Vignette, meaning that road transport is charged twice.

The prices for the ETS will increase slightly due to the extra emissions that are added to the market. The lower bound price is the current ETS price, which is 15 Euros (ECX, 2009). Based on the average of multiple sources (CE Delft, 2008 (I), Carbon Trust, 2006) the expected average price is set at 50 Euros without aviation and navigation. The price is assumed to increase with 10% when aviation and navigation are included.

The general idea of the Diesel Tax is that the tax on diesel will have to be at least equal to the tax on petrol. The assumption is made that the diesel tax will be set at the same level as the petrol tax. Based on the current EU-27 taxes and diesel/petrol prices the average increase per litre of diesel is determined. The diesel price would increase with around 30 eurocents per litre in that case. This is equal to 110 €/tonne CO_2, based on an emission of 2.642 kg CO_2 per litre diesel.

Minimum prices for the Euro-Vignette are set by the European Union. The price is fixed per country and each country can decide how much they ask. Only part of this price can be allocated to carbon dioxide emissions. This means that only the part of the Euro-Vignette price for CO_2 emissions will be used in the scenario. For the Euro-Vignette the price is derived as the total social cost of carbon dioxide emissions as determined in the IMPACT study (Maybach *et. al.*, 2008). The assumption is made that the EU will set the cost of the Euro-Vignette such that the cost will cover for all social cost of the emission. This means that the cost of the Euro-Vignette becomes 70 €/tonne CO_2.

Table 21: Emission prices scenario 1

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 110	€ 110	€ 110
Rail - Electric	€ 15	€ 55	€ 110
Road	€ 180	€ 180	€ 180
Water	€ 15	€ 55	€ 110

Influence on current supply chain

In Appendix 13, one can find the additional costs that would have incurred if the scenario had been implemented at the time. The increase in costs is significant in this scenario and this is caused by the fact that the price for emissions is very high, especially for road (30% of total emissions).

Impact on reduction opportunities

In Figure 21, one can see the percentage of CO_2 reductions that can be achieved without increased costs at the current scenario. It might seem strange that the percentage first increases but later stabilises. The reason is that the road and diesel rail costs are at the same level all the time. The rail electric and water costs are increasing and in the beginning some of the lanes where there is both water and rail can be switched. But after a certain price the intermodal is coming to close to the road again and hence the stagnation in cost effective reductions. If the prices increase even further the percentage will start decreasing again as shown in Figure 21. The two increases that are visible are caused by lanes that use a ferry where it becomes profitable to use a container vessel due to the increased costs for emissions in water transport.

Table 22: minimum cost reduction scenario 2

Price Level	Reduction at minimum costs
Currently	3.3%
Lower bound	4.4%
Expected	4.8%
Upper bound	4.8%

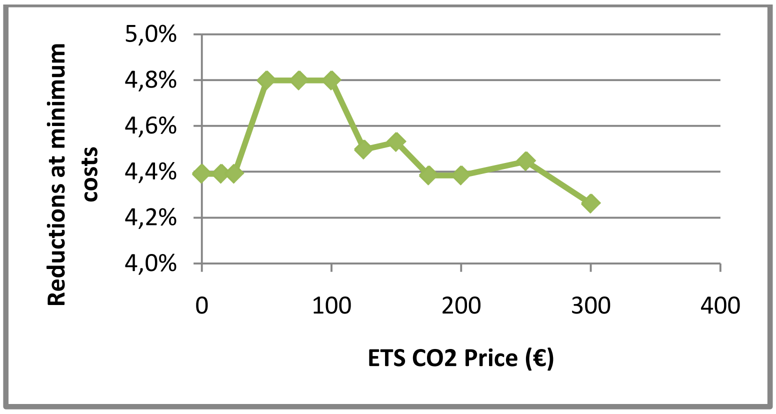

Figure 21: % reductions possible at minimum costs

In Figure 22, one can find the result of the second scenario with regard to the reductions and the associated costs.. In the graph one can see that the costs increase significantly for all price levels of the ETS. This is caused by the high costs of road transport that lead to a high cost increase. Furthermore, one can see that the minimum cost point shifts to the right. This indicates that there is a bigger incentive to reduce emissions in those cases.

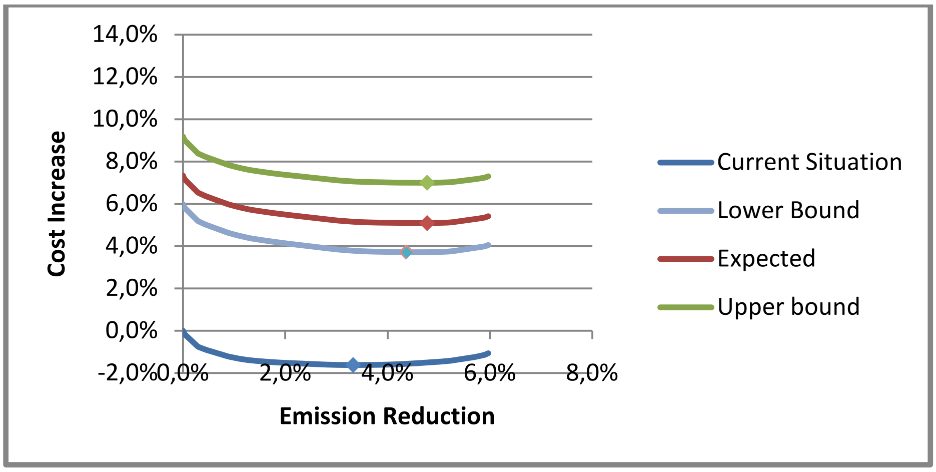

Figure 22: Emission reductions and costs in scenario 2

8.2.3 Scenario 3

This scenario is similar to the previous scenario. The difference is that in this scenario the diesel tax will not be taken into account. The scenario is that air and water transport will be included in the existing ETS. Road transport will be covered via the Euro-Vignette. The values used in scenario 2 (70 €/tonne CO_2) will be used as an upper bound in this scenario. A lower bound will be set at 40 €/tonne CO_2. This is based on communications with EU representatives. Based on their information they expected the price to increase with 4-5 cents per kilometre. Taking an average of emitting around 1 tonne of CO_2 for driving a truck for 1000 km (based on data from case study) this means that 1 tonne of CO_2 will cost 4 cents (minimum of estimate) times 1000 kilometre is around 40 €/tonne CO_2.

Table 23: Emission prices scenario 3

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 0	€ 0	€ 0
Rail - Electric	€ 15	€ 55	€ 110
Road	€40 / €70	€40 / €70	€40 / €70
Water	€ 15	€ 55	€ 110

Influence on current supply chain

In Appendix 13, one can find the additional costs that would have incurred if the scenario had been implemented at the time. There are two areas in the table the upper for road price of 40 €/tonne CO_2 and one for road price of 70 €/tonne CO_2. The additional costs would have been significant but varying depending on the legislation. The general price increase is lower than is the case in the previous scenario. The costs of emissions rise marginally with increased Euro-Vignette costs.

Impact on reduction opportunities

There are two ways in which the reduction opportunities can be influenced; the percentage of reductions that can be achieved cost effectively and the cost of reducing the lanes that are not cost effective. In Table 24, one can see the percentage of CO_2 reductions that can be achieved at minimum cost for this scenario. As can be seen for both instances of the Euro-Vignette costs the percentage that becomes cost effective reduces when the price increases. This is logical because the gap between road and intermodal decreases or road emissions becomes even cheaper. At high road cost there is a larger percentage of emissions that can be reduced at minimum costs.

Table 24: minimum cost reduction scenario 2

	Eurovignette 40 €/kg CO2	Eurovignette 70 €/kg CO2
Price Level	Reduction at minimum costs	Reduction at minimum costs
Currently	3.3%	3.3%
Lower bound	3.5%	3.6%
Expected	3.8%	3.9%
Upper bound	3.8%	3.9%

In Figure 23, one can find the result of the third scenario (Road 40 €/tonne CO_2) on the costs for reducing the emissions on the identified lanes. In the graph one can see that the price increase is less than in scenario 2. The reductions at minimum cost decrease significantly as well. This indicates that this scenario leads to a lower incentive to reduce emissions than scenario 2.

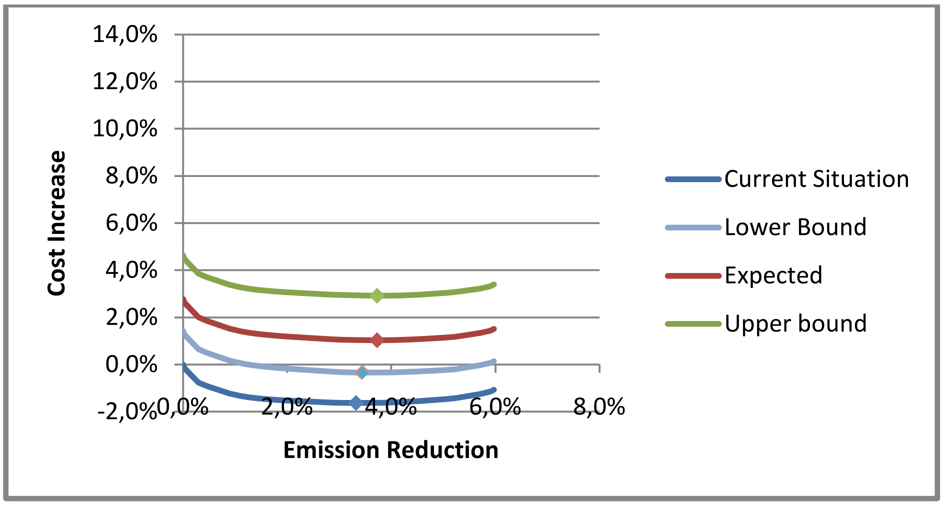

Figure 23: Emission reductions and costs in scenario 3 (Road 40)

For the case where the Euro-Vignette leads to an increase in the price for road emissions to 70 Euro the results are almost identical. This can be seen in Figure 24. The biggest differences are that the costs are higher (lines are higher) and the percentage of reductions that can be achieved without additional costs increases (the minimum shifts to the right).

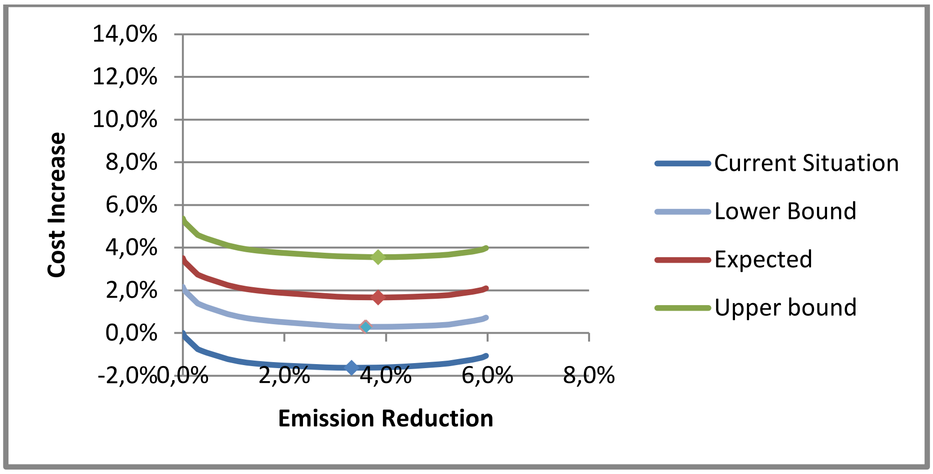

Figure 24: Emission reductions and costs in scenario 3 (Road 70)

8.2.4 Scenario 4

This scenario is similar to the previous scenarios. The difference is that in this scenario the Euro-vignette will not be taken into account. The scenario is that air and water transport will be included in the existing ETS. Road and diesel rail transport will be covered via the Diesel tax. The other value is determined based on an increase in oil prices. In that case setting the diesel tax at a higher level will lead to an additional increase. If diesel prices increase by 25% the additional costs will be increased with 25% as well since the tax is a percentage of costs. Therefore an upper bound is set of 137.50 €/tonne CO_2.

Table 25: Emission prices scenario 3

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 0	€ 0	€ 0
Rail - Electric	€ 15	€ 55	€ 110
Road	€110 / €137.50	€110 / €137.50	€110 / €137.50
Water	€ 15	€ 55	€ 110

Influence on current supply chain

In Appendix 13, one can find the additional costs that would have occurred if the scenario had been implemented at the time. There are two areas in the table the upper for diesel transport price of 110 €/tonne CO_2 and one for diesel transport price of 137.50 €/tonne CO_2. The additional costs would have increased significantly depending on the legislation. In the table it is obvious that the costs increase more with a higher diesel tax price.

Impact on reduction opportunities

In Table 26, one can see the percentage of CO_2 reductions that can be achieved at minimum costs. As can be seen in both cases the reduction first increases and then stagnates or decreases. The reason is that there is some transport via ferries that can be done via container vessels (lower emission than ferry), therefore increased water emission prices favour these reductions. However, after a certain price the intermodal comes to close to the road and it is no longer favourable to switch from road to intermodal (rail or short sea).

Table 26: minimum cost reduction scenario 2

	Diesel 110 €/kg CO2	Diesel 137.50 €/kg CO2
Price Level	Reduction at minimum costs	Reduction at minimum costs
Currently	3.3%	3.3%
Lower bound	3.6%	3.8%
Expected	4.0%	4.2%
Upper bound	4.0%	4.0%

In Figure 25, one can find the result of the third scenario (Road 110 €/tonne CO_2) on the costs of reduction. The minimum cost point shifts slightly to the right but at a significant cost increase as can be seen in the graph.

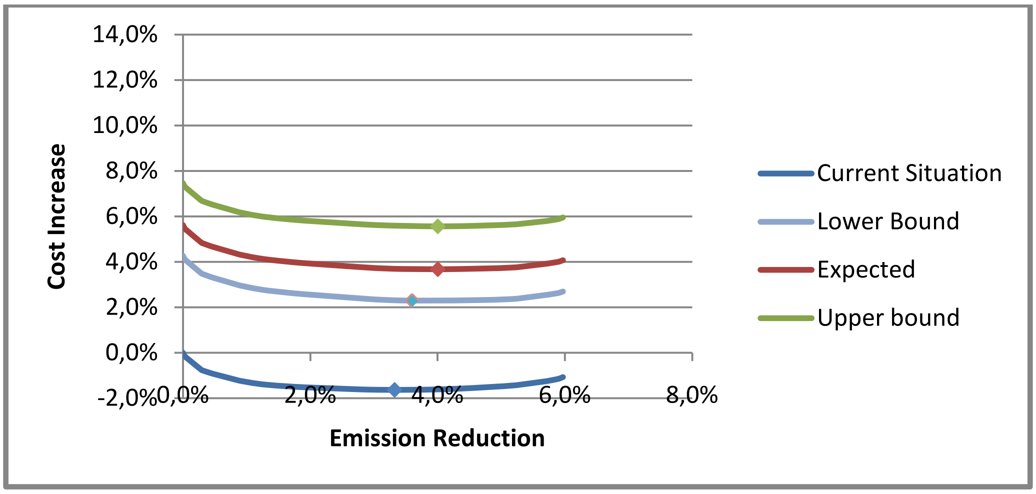

Figure 25: Emission reductions and costs in scenario 4 (Diesel 110)

For the case where the Diesel tax leads to an increase in the price to € 137.50 the results are almost identical. The difference between the options is that the price change slightly. This can be seen in Figure 26. Secondly the percentage of reductions that can be achieved at minimum cost is slightly higher which is depicted by the right shift in the lines.

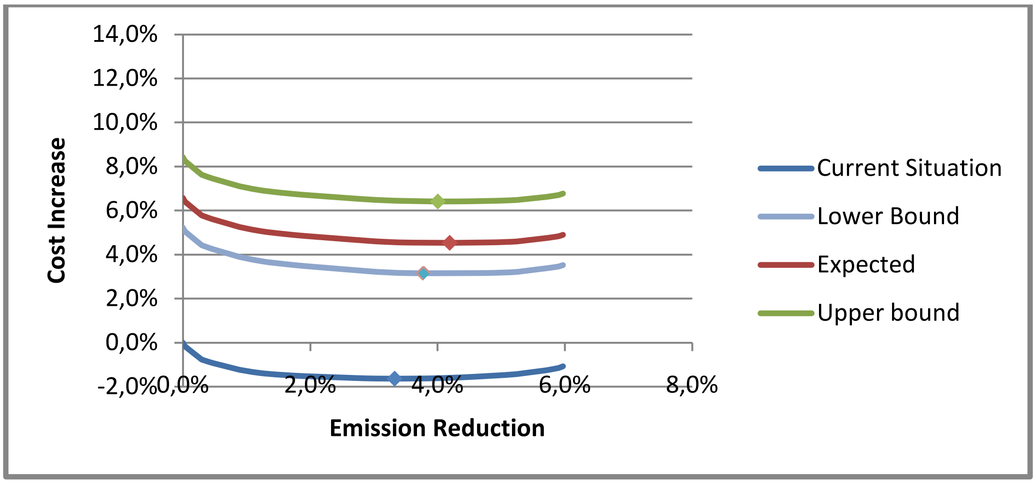

Figure 26: Emission reductions and costs in scenario 4 (Diesel 137.50)

This scenario can be compared with an increase in the diesel prices. In this upper bound case this would correspond to a price increase in diesel with around 43 cents per litre. In the case of even higher increases in diesel prices the costs for companies will increase significantly and the incentive to reduce emissions will be slightly higher.

8.2.5 Scenario 5

In this scenario all modes of transport will be included in the current ETS. At this moment electrical transport is already included in the ETS. The other transport modes (air, diesel rail, road and water) will all be included in the current ETS as well. This means that the emissions resulting from transport are in the same ETS as the emissions resulting from the production. The prices per tonne of carbon dioxide emitted that are expected if transport is included in the ETS are based on a report of CE Delft (CE Delft, 2007).

Table 27: Emission prices scenario 5

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 15	€ 65	€ 130
Rail - Electric	€ 15	€ 65	€ 130
Road	€ 15	€ 65	€ 130
Water	€ 15	€ 65	€ 130

Influence on current supply chain

The increase in costs can be found in Appendix 13. The costs increases are comparable to the increases in scenario two for the high emissions prices. The lower emission price hardly influences the total costs. For the expected values and the upper bound the price increases are significant.

Impact on reduction opportunities

In Table 28, one can see the percentage of CO_2 reductions that can be achieved without increased costs at the current scenario. Since all modalities have equal emission costs the option with the lowest emissions is favoured. Therefore the percentage that can be reduced without additional costs is increasing at higher carbon prices. An emission price of 15 €/tonne CO_2 hardly influences the prices as stated but it does not affect the percentage of emissions that can be reduced at minimum costs either. The higher carbon prices clearly lead to increased emission reduction at minimum costs.

Table 28: minimum cost reduction scenario 5

Price Level	Reduction at minimum costs
Currently	3.3%
Lower bound	3.3%
Expected	3.9%
Upper bound	4.2%

In Figure 27, one can find the result of the fifth scenario on the costs for reducing the emissions. Here one can see that the lower bound hardy affects the costs of transport nor does it influence the minimum cost point. The other two options lead to a significant cost increase but a low increase in the number of reductions at minimum cost.

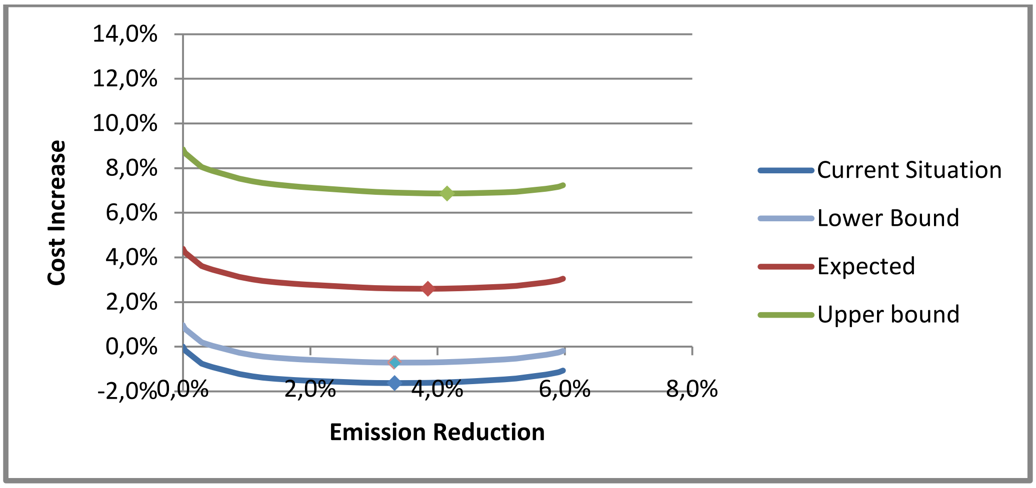

Figure 27: Emission reductions and costs in scenario 5

8.2.6 Scenario 6

All modes of transport, except for electrical transport will be included in a separate transport ETS. Electrical transport can not be included in the transport ETS because electricity is already included in the current ETS. If electrical transport would be included in both the current ETS and the transport ETS the emissions resulting from the generation of the electricity would be covered twice.

Table 29: Emission prices scenario 6

Transport Mode	Lower Bound	Expected	Upper Bound
Rail - Diesel	€ 15	€ 90	€ 180
Rail - Electric	€ 15	€ 50	€ 100
Road	€ 15	€ 90	€ 180
Water	€ 15	€ 90	€ 180

Influence on current supply chain

The increase in costs is significant or even large in this scenario and this is caused by the fact that the price for emissions is very high in the upper bound. The exact values can be found in Appendix 13 and here one can see that the increase per scenario is very high.

Impact on reduction opportunities

In Table 30, one can see the percentage of CO_2 reductions that can be achieved without increased costs at the current scenario. Since all modalities have equal emission costs the one with the lowest emission is favoured. Therefore the percentage that can be reduced without additional costs is increasing at higher carbon prices.

Table 30: minimum cost reduction scenario 6

Price Level	Reduction at minimum costs
Currently	3.3%
Lower bound	3.3%
Expected	4.1%
Upper bound	4.4%

In Figure 28, one can find the result of the sixth scenario on the costs for reducing the not cost-effective lanes. Again the cost increase is significant in this scenario but the incentive to reduce emissions is very low as can be seen at the minimal shift of the minimum cost reductions.

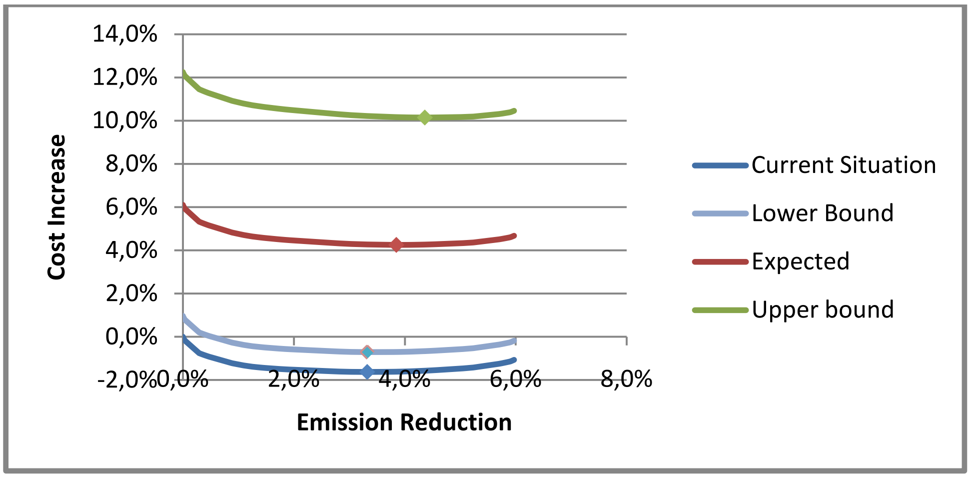

Figure 28: Emission reductions and costs in scenario 6

8.2.7 Insights from scenarios

Based on the scenarios several insights could be gained. Most of the insights are based on the single scenarios and were discussed before. However, there are some general insights that can be drawn from this scenario analysis and these will be discussed in this chapter.

The first part that will be discussed is how well the different scenarios/approaches work. The goal of the regulations is to reduce the emissions in transport. The data for the analysis mainly consisted of road transport being shifted to intermodal rail or intermodal short sea transport. One method of measuring the effectiveness of a scenario is looking at the emissions that can be reduced at minimum costs. This is represented by the tables with reduction opportunities possible cost effectively as shown in the previous subsections.

As mentioned before, the percentage of reductions that can be achieved at minimum cost has a more or less parabolic function in some cases. This is the case if one looks at fixed road/diesel prices and variable water/electric prices. In the case that the prices are the same for all transport modes it is much easier. In that case the lowest emission has a preference regardless of the sources of emission. In Figure 29, one can see the percentage of all reductions that can be achieved at minimum costs for different carbon dioxide prices. The 3.3% at zero costs is caused by the fact that for the current supply chain already 3.3% of reductions can be achieved at lower costs. The carbon dioxide prices have to increase significantly before all reductions can be achieved at minimum cost. Note that the total emission cost will be very high in that case as well.

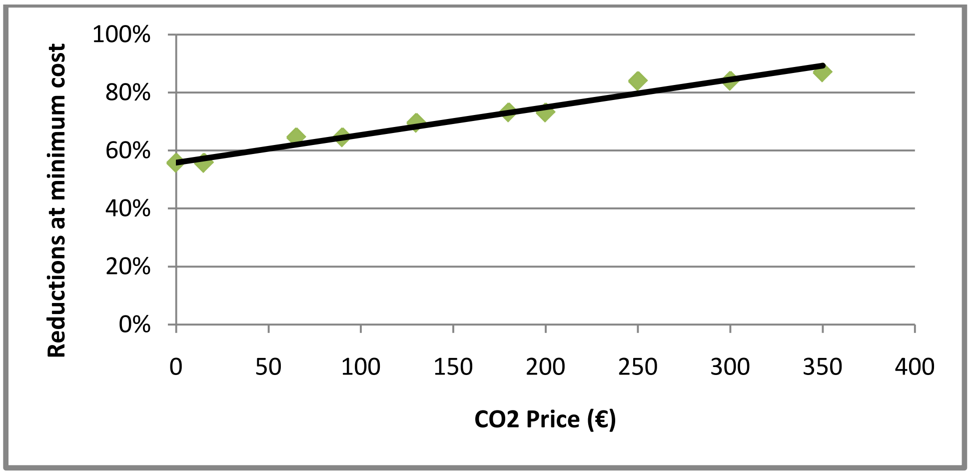

Figure 29: % of all reductions possible at minimum cost for different emission prices

The effectiveness of a scenario could also be measured by how steep the line is for the emission reduction set out against the cost increase. In Figure 30 below one can find these trade-off curves for scenarios 1 and 5. Note that the first scenario has a negative slope meaning the increased prices would lead to lower reductions that can be achieved cost effectively. This implies that it will become more worthwhile to use polluting modes of transport, which is not the goal of the regulations. This means that scenario 1 (current situation) has a negative impact on CO_2 emission reductions and should not be implemented. Scenario 5 has a positive slope, but this is still very low, this means that the costs have to increase significantly to increase the reductions slightly.

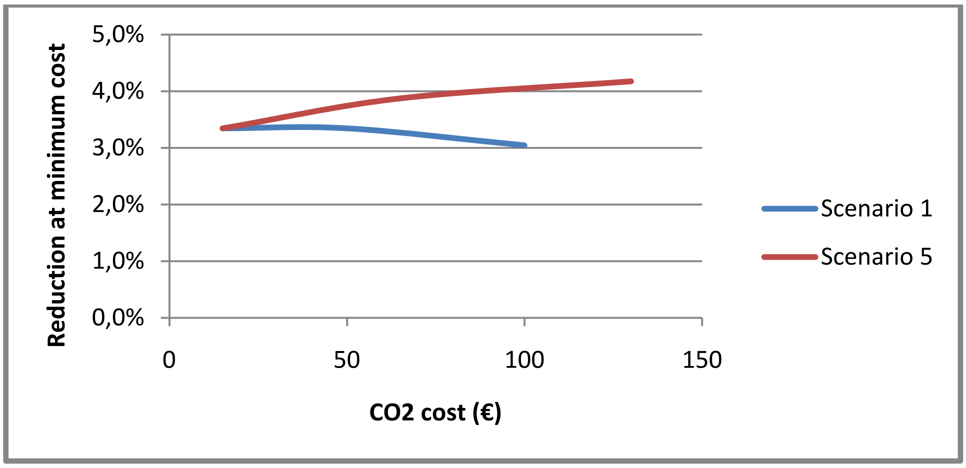

Figure 30: % of reduction cost effective for scenarios 1 and 5

Scenarios 2, 3 and 4 work in the same manner namely fixed prices for carbon intensive modes and varying prices for the low carbon intensive modes. Scenario 2 leads to very high price increases and will not be taken into account. The other two are analysed in more detail (Figure 31) and compared to the other option as used in scenario 5 (all transport emissions same price). In the graph one can see the percentage of reductions that can be achieved at minimum costs and the associated costs. The lines for scenario 3 and 4 represent the different price levels for the fixed costs. For example in the lower bound of scenario 3 the left point is a Euro-Vignette price of € 40 and the right point is a price of € 70. Based on this dataset the conclusion can be drawn that the best option is to increase the prices for diesel rail and road compared to electric rail and water. A trade off has to be made with regard to the reductions and the increase in total costs.

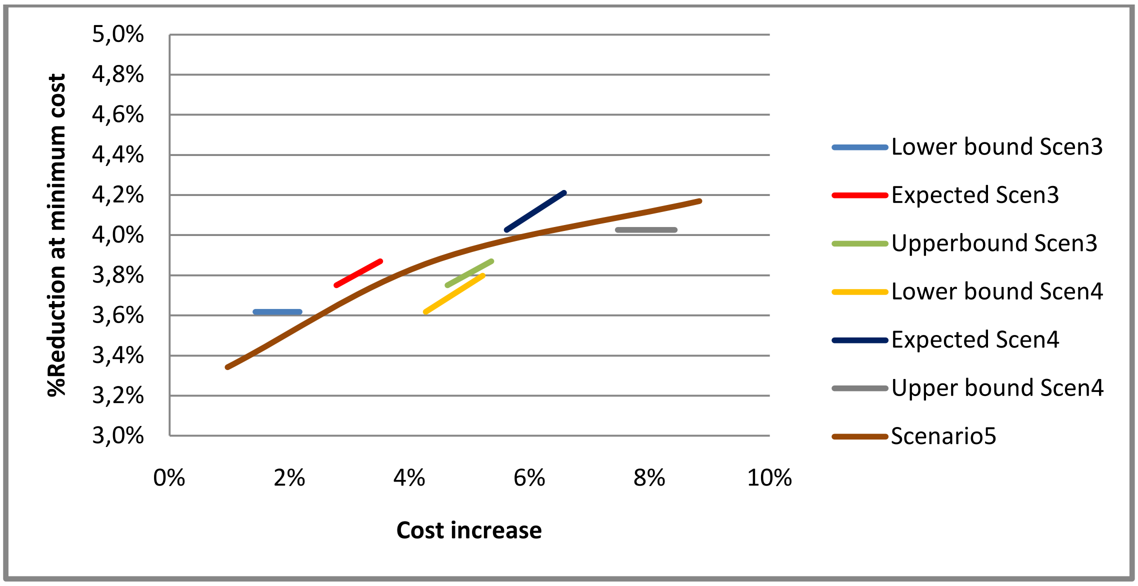

Figure 31: Cost effective increase at price increase for scenario 3+4+5

8.3 Supply chain redesign

In subsection 7.3.4 a new supply chain design was discussed (Option 1) that involved using a container storage location at Ludwigshafen. This terminal should be used as a storage location for the containers. Using this storage location will make sure that the lead times do not increase for the customer. However, the costs of inventory increase due to the terminal usage. To determine under which scenario the terminal would become cost effective the inventory costs are compared to the emission costs under different scenarios. In total there are 40 different products shipped towards the region. The decision was made that only the 25% highest volume products will be considered for storage at the terminal.

In Appendix 9 one can find the costs of implementing the terminal for the different scenarios. In the first column the scenario is displayed. In the next columns the prices for the different modalities are given. The last columns contain the costs increases of using a terminal at Ludwigshafen. This is displayed for both the increased costs for the terminal as well as the total freight costs. The terminal costs is defined as inventory and handling costs plus carbon cost, this decreases in many cases due to the fact that the emissions are reduced by using the terminal. The lower emission result in lower costs.

In the Appendix one can see that none of the scenarios will lead to a cost effective use of the terminal. The inventory costs are too high compared to the emission costs to make it profitable to use the terminal. However, one should note that using the terminal will lead to a reduction of almost 1% of the total emissions in 2008. This decrease will occur at relatively low total cost increase (0.1 – 0.5%).

This means that if Dow wants to reduce emissions by switching to intermodal transport for this area they should invest in a storage location which will increase the total freight cost of the business with 0.5% at most depending on the EU regulations.

Another option, as mentioned before, could be to discuss the options with the customers. If the customers are willing to increase the transit time with one day there is no need for a terminal. In that option the reduction of 1% of all emissions could be achieved at no additional costs. Note that the reliability (i.e. on time delivery) is lower than is the case with road transport. An option would be to increase the transit time with another 1 day to incorporate a “safety day” which would increase the reliability of the intermodal transport.

The carbon reduction could be used as an argument for the customers. Depending on the customer location and the LSP that is chosen the reductions can be up to 30% per shipment. The costs can even decrease in some cases due to the fact that intermodal rail transport is cheaper than road transport in those cases.

8.4 Conclusions

Based on the scenario analysis in the previous sections it can be stated that the current regulations and CO_2 prices do not lead to an incentive for reducing CO_2 emissions. The current system actually favours road transport over electric rail transport. This means that if the EU wants to give companies an incentive to reduce CO_2 emissions they should implement new regulations. As can be seen in scenarios 2 to 4 is the best option to have high prices for road and diesel rail transport in combination with low electric rail and water emission prices. Due to the level of emissions in air transport the same will hold (high price for air) but there is no air transport in this study. The costs could become quite high for companies depending on the implemented regulations. This can vary between an increased freight cost of 0.1% and 12.3% for the dataset in the case study.

However, this is the purely theoretical analysis where the assumption is made that the prices of other modalities do not increase except for the carbon prices. In reality it is possible that if the prices of road increase the intermodal transporters will increase the prices as well to increase their margins. This effect is not covered in the scenario analysis but one could see this as having a lower difference between the modes. This means that the incentive to switch from road to intermodal will be lower than expected. In most sectors this would be limited by the market due to competition. However, in the intermodal sector this could have a bigger effect due to the lack of resources. The availability of rail tracks, rail stations, ports and overhaul locations is limited. This means that the intermodal companies can increase their prices significantly because of the lack of resources. Having overcapacity of these limited resources would lead to a higher incentive but this is not likely to happen within the next decade.

As seen in the scenario analysis the reductions for Dow could total up to 6% of the total emissions. This could even increase to 7.9% if more information is available for some of the lanes. These reductions can all be achieved at zero additional costs compared to not changing the lanes in all scenarios. In some scenarios there will be a net increase and in some a decrease of costs. However, this is mainly caused by the fact that for some lanes the freight costs are much lower for the new option than for road transport.

Therefore, the important part will be to look at the service and lead time constraints in those cases because those are more important in some cases.

9 Conclusions and Recommendations

In the first part of this section the conclusions of the report are stated. The first part of the section will discuss the research questions and the second part will discuss additional conclusions that can be drawn based on the study. The second part of the chapter states the recommendations that are given based on the study. The last part of the section will discuss which parts need further research.

9.1 Conclusions

The first part of the research consisted of determining a method for the calculation of CO_2 emissions in transport. Several research questions were defined while setting up the research and these will be discussed first.

The first part of the research questions focussed on the emission factors that are used in the calculations. There are four factors that are always needed to calculate emissions.

- Distance
- Modality
- Weight
- Transport Type

The factors that were taken into account next to these four categories are discussed below.

- Positioning Distance
  - Important factor, however, based on case study it can be stated that the assumptions suffice for road transport on average but vary significantly per lane. In the case of intermodal transport the assumption leads to lower positioning distance with high variation.
- Load Factor
  - Important to use real data in the case of LTL shipments and intermodal transport.
  - Using the shipment weight divided by total capacity suffices for road transport
- Rail Emissions
  - Use the distance per country for calculating rail emissions.
  - The effect of averages will have a small effect on total emissions but has a high effect on the rail emissions for a lane. Using the averages is possible for batch calculations, for detailed comparisons distances per country should be used.
- Temperature Control
  - Has a significant influence on total emissions and emissions per lane and is therefore important to take into account.
- Cleaning
  - Has a significant influence on total emissions and emissions per lane and is therefore important to take into account.
- Vertical Handling
  - Has a very small effect on total emissions and can be neglected. In the tool the emissions will be taken into account since there is no additional effort needed and it leads to more accurate results.

The second part of the research focussed on what can be done with the knowledge of transport emissions. Before looking at how emissions can be reduced it is important to identify lanes where reductions could be achieved. Because it would be time consuming to look into all lanes, it would be easier to get a group of likely reduction opportunities. Seven methods for reduction opportunity identification are developed and were discussed in section 7.2. One of the methodologies is finally proposed as the best method for identifying reduction opportunities. This one is described as option 7 in section 7.1, the advantage is that the method identifies almost all reduction opportunities. The disadvantage is that the methodology has higher post-identification manual labour. This means that the methodology identifies a high number of lanes where around 30-50% of the lanes is not improvable because it already is intermodal or the lane cannot be improved at all because there is no better option.

Based on the identified lanes as described before an analysis was made on how the emission can be reduced. One option that was looked into was whether switching modalities would reduce the emissions. Based on the dataset it can be stated that in many cases switching from road to intermodal transport will lead to reduced emissions. However, in other cases the switch will not lead reduced emissions. There are two main reasons for intermodal options having higher emissions than road transport; too short distances and too high percentage of road transport. In the first case the distance is so short that the distance to and from the terminal is higher than the reductions achieved by the rail/water transport. This is actually similar to the second case (too high percentage of road transport), where the high percentage of road leads to higher emissions than directly transporting by road.

Another goal of the study was to get a better idea of the upcoming regulations from the European Union. There is only one set of regulations that is implemented; the EU-ETS. The EU-ETS only involves the electric rail transport, however, there are plans to include the aviation and navigation sectors as well. This would mean that the emissions from aviation and navigation are included in the current regulations and companies have to pay for the emission allowances. For road and diesel rail transport the regulations are currently not certain. There are two main options; the Euro-Vignette and the Diesel tax. Another option would be a separate transport ETS, however, this is not likely to be implemented in the near future. The most likely scenario at the moment seems to be that aviation and navigation are included in the EU-ETS and the Euro-Vignette is adjusted to account for carbon dioxide emissions. The Diesel tax is an option but the implementation is relatively uncertain.

The effect of EU legislations on the supply chain design will vary significantly with the approach that is chosen. In section 8.2 several scenarios have been analysed to determine the effect on reduction opportunities and supply chain design. Based on scenario 1, it can be stated that the current regulations and carbon prices (15 €/tonne CO_2) have no influence. The reductions that can be achieved at minimum costs do not increase due to the carbon price. The prices for reducing the CO_2 emissions increase slightly, the prices have to increase to around 100 €/tonne CO_2 before there is a small change in the reduction curve. This means that new regulations will have to be implemented to give companies an incentive to reduce emissions. As seen in scenarios 2 to 4 having a large increase of road or diesel prices in combination with low rail and water prices will lead to an incentive for reducing CO_2 emissions. Scenario 5 and 6 showed that having the same price for all types of emissions will lead to a slightly lower favourability of intermodal transport. However, in that case the option with the lowest emissions is favoured regardless of the emission source.

9.2 Recommendations

Several recommendations can be given based on the research; these are split up into two parts. The first part discusses the recommendations for the company and in the second part recommendations with regard to regulations are given.

- When calculating emissions use the most detailed data that is readily available. For the parameters that are not available internally use the assumptions given in the methodology. When comparing two options for a lane use as much detail as possible to get the most accurate reductions.

- Shifting modalities can save up to 7.8 % of all emissions. These reductions can be achieved without additional costs but a careful consideration with regard to service is necessary.
- Other options for reduction are payload increase, using additional terminals or storage tanks. Two options are given but additional opportunities should be looked into.
- Use the tool and the opportunity score to calculate emissions for other businesses and identify emissions reduction opportunities for those datasets. The tool can also be used to evaluate the alternatives in the case of reduction opportunities.

Recommendation with regard to the regulations can be stated as follows.

- Setting a high price for emissions in road transport and aviation in combination with a low price for emissions in navigation and electricity generation will lead to the best incentive for emission reduction. Due to the high costs involved in this option zero or very low costs for emissions in the latter case will reduce the financial burden for companies in this respect.

9.3 Further Research

As mentioned in section 6.3, the sensitivity analysis, there are several factors with a high uncertainty at the moment. For these factors it is necessary to conduct further research to get more accurate estimates and values. The factors that should be investigated in further detail are in order of priority (based on effect on total emissions);

- Positioning Distances
- Cleaning Emissions
- Heating/Refrigerating Emissions
- Vertical Handling Emissions
- Vessel data
- Allocation for ferries

These are all factors where further research is necessary in order to get more accurate emission calculations.

The second part where further research is needed is the field of rules and regulations. In this report six different scenarios were developed to determine the effect of rules and regulations that are discussed at the moment. It would be worthwhile to determine whether other options are discussed as well and what the impact of those regulations would be on the emission and reduction opportunities. Next to this more insights could be gained by analysing the current scenarios in more detail. As mentioned before, there is no restriction for intermodal companies to increase prices as well, when road transport becomes more expensive. Getting a better understanding of how this would influence the scenarios could lead to a better understanding of implementing these specific regulations. Furthermore, the focus could be on what regulations most effectively lead to the highest reductions at the lowest cost.

Another part where further research could lead to better insights is the field of business opportunities. This topic was briefly touched in this report but not discussed in detail. However, looking at business opportunities could lead to another incentive for emission reductions. An option could for example be green marketing. Now that more and more companies are focussing on GHG emissions, both in their own processes as well as upstream processes, having information available or focussing on this part could lead to additional benefits.

The last topic that can benefit from further research is the field of supply chain redesign. Two options were discussed in the report to redesign the supply chain. In the first case high reductions could be achieved at high costs. In the second option low reductions could be achieved cost effectively. Having a better understanding which conditions and which solutions lead to high reductions at low or no additional costs would provide companies with a guide on how and where to reduce emissions.

10 Glossary

CO_2	Carbon dioxide
eSCF	European Supply Chain Forum
ETS	Emission Trading Scheme
EU	European Union
GHG	Greenhouse Gases
IFEU	Institüt fur Energie- und Umweltforschung
LSP	Logistic Service Provider
NTM	Nätverket för Transporter och Miljön, a Swedish non-profit organisation that developed a methodology for calculating CO_2 emissions in transport
mT	Metric Tonne
tkm	Tonne Kilometre, a scale that is often used in emission calculations and equivalent to one tonne of cargo transported over one kilometre
TU/e	Eindhoven University of Technology
GHG	Greenhouse Gas
GWP	Global Warming Potential

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12 Appendices

Appendix 1

GHG Protocol

The GHG protocol is a high level approach to the calculation of emissions. The GHG protocol advises to divide the emissions in three different scopes, scope 1 till scope 3. The first scope contains the emissions from sources and processes directly controlled by the company. The second scope contains the emissions from purchased electricity. The third scope contains the emissions of all indirect sources. In the case of Dow the emissions from transportation should be placed in the scope 3 category. This means that they are not part of the company's core business and the company is not obliged to report those. The GHG protocol bases the emissions during transport solely on the type of transport and the distance. No other factors are taken into account (GHG Protocol, 2005).

CE Delft

This methodology is developed by an independent Dutch consultancy and research organization. The methodology is described in the STREAM report and is solely based on Dutch data and averages (CE Delft, 2008 (II)). The study is quite extensive and several modalities are discussed. However, the data are applicable to The Netherlands and there is limited knowledge on how they can be generalized to the EU or global.

EcoTransIT

Several European railway companies started a joint effort to create the Ecological Transportation Information Tool (EcoTransIT). The goal of the effort is to determine a method for calculating emissions during transport. The research is delegated to the Institut für Energie- und Umweltschutzung (IFEU) located in Heidelberg. The methodology requests the user to provide more detailed information on the type of cargo and uses this information to determine the emissions based on averages. It only takes into account one type of road vehicle and automatically selects the type of train, either diesel or rail based on the traction for the route.

NTM

The NTM methodology is developed by a Swedish non-profit organization. The method is based on studies conducted by this organisation. The data are in most cases retrieved from or aligned with renowned European studies. In the case of road the data are aligned with ARTEMIS (ARTEMIS, 2007) and HBEFA (HBEFA, 2004). For the rail emissions the study is aligned with the methodology provided by EcoTransIT.

The NTM methodology has several levels of detail, it is possible to use general values and averages or more specific values for more detailed calculations can be used.

ARTEMIS

The project is funded by the European Union and aims to develop a harmonised model for emissions in different transport modes. The project mainly delivers a very detailed database with emission factors for many different transport modes and modalities. The level of detail needed to calculate emissions is very high (ARTEMIS, 2007). The main goal of the ARTEMIS project is to collect a database with emission factors for different transport modes.

Appendix 2

3.3.1 Load Factors

Air transport

Two types of aircrafts are used for cargo transport: cargo aircrafts and combined passenger and cargo aircrafts. For cargo aircrafts a single load factor indicating the capacity utilisation is necessary. In combined passenger & cargo aircrafts both a load factor for the passenger part of the aircraft and a load factor for the cargo part of the aircraft are needed.

NTM Air (2008) does not give average load factor values. Therefore, field data has been gathered and based on that an assumption about the average load factor values for air transport was made. A case study resulted on the assumption of load factors of 80 percent for cargo capacity and 85 percent for passenger capacity. The case study included an airline company and a logistics service provider.

3.3.3 Positioning Distances

Air transport

NTM assumes that air transport is always operated using scheduled flights, which means that there are no positioning distances. Company data of the companies included in the case study also showed that all cargo is flown on scheduled flights. Therefore, this assumption is made in this project as well.

Air transport methodology

In this section the methodology that is used for calculating the carbon dioxide emissions from air transport is described. In this section a general description of air transport is given, followed by air transport specific parameters that are used in the calculation. Next, the calculation formula is given and finally the assumptions that are used are described and discussed. This structure is also used in the descriptions of the methodologies for the other transport modes.

Air transport is defined as all cargo that is transported by an aircraft through the air. Air transport has the advantage that it is very fast and therefore has a low delivery time for transport over large distances. However, one of the disadvantages is that it has higher fuel consumption and, with that, more carbon dioxide emissions per tonne kilometre compared to the other transport modes.

Cargo that is transported via air can be transported in two ways:

- In a dedicated cargo aircraft;
- In the cargo hold of a passenger aircraft (this is called belly cargo).

The calculation of the carbon dioxide emissions from air transport is, if not stated differently, based on the NTM air methodology (NTM Air, 2008). For the calculation the following parameters are necessary:

- Type of aircraft;
- Load factor;
- Weight of the shipment;
- Distance.

The parameters specific to air transport that need additional explanation are described in the next section.

Mode specific parameters

If no distance is given but the origin and destination are known, for air transport the distance can easily be calculated using the great circle distance (GCD). The formula for this is:

$$D = acos(sin(lat1) \cdot sin(lat2) + cos(lat2) \cdot cos(lon1 - lon2)) \cdot r$$

where:
D Transport distance in kilometres
lat1 Latitude of the origin location
lon1 Longitude of the origin location
lat2 Latitude of the destination location
lon2 Longitude of the destination location
r Radius of the Earth in kilometres

Calculation

The emissions during takeoff and landing of an aircraft are relatively high compared to the emissions during the part of the flight where the aircraft is cruising. Therefore, the calculation of the total emission is split up into two parts: the constant emission part (which corresponds with the emissions during takeoff and landing) and the variable emission part (which corresponds with the constant emissions per kilometre during cruising). The total emission of an aircraft can be calculated using the following formula (NTM Air, 2008):

$$TE = CEF + VEF \cdot D$$

Where:
TE Total Emissions in kilograms
CEF Constant Emission Factor in kilograms
VEF Variable Emission Factor in kilograms per kilometre
D Transport distance in kilometres

The NTM methodology gives different values for the constant and variable emission factors for several aircrafts and for different load factors. In case of dedicated cargo aircrafts the values are given for load factors of 50, 75 and 100 percent.

In order to be able to use load factors that are different than the three given above, NTM provides interpolation formulas. Below the interpolation formula for calculating the constant emission factors (NTM Air, 2008). Interpolation for the variable emission factor is done in the same way.

$$CEF_{x\%} = \frac{CEF_{y\%} + \left(CEF_{z\%} - CEF_{y\%}\right)}{(z\% - y\%) \cdot (x\% - y\%)}$$

In the formula x is the load factor for which the constant emission factor needs to be calculated, y is the load factor smaller than x for which the constant emission factor is known and z is the load factor larger than x for which the constant emission factor is known.

The total emission calculated above needs to be allocated to the cargo that is transported. In air transport allocation is based on weight, because weight is the main factor determining the amount of carbon dioxide emissions.

The allocation can be done based on physical weight or on volumetric weight. In the air industry the generally used conversion factor for volumetric weight is 167 kilograms per cubic meter (kg/m^3). In the cases where the volumetric weight is larger than the physical weight, the volumetric weight is used for the allocation [NTM Air, 2008].

Assumptions

The following assumptions are specific for air transport:

- *Linearity between emissions for different load factors*:
  As was described in the calculation paragraph above, using the interpolation formula assumes linearity between emissions for different load factors. NTM indicated that this actually is not the case. However, because linearity between smaller intervals is used (between 0 and 50%, between 50 and 75% and between 75 and 100%), the effect of this assumption is smaller than assuming linearity between 0% and 100%.
- *Type of fuel:*
  It is assumed that all aircrafts use JetA-1 fuel. JetA-1 fuel is the most commonly used fuel in air transport, in the calculations the assumption is made that all aircrafts use this type of fuel.

3.3.6 Heating

During transport

Certain products need to be delivered at a specified temperature because otherwise they can deteriorate or their physical properties can change. There are three methods of temperature control during transport, this can be heating, cooling or freezing. These three categories are discussed separately below.

- Heating: products usually are heated to prevent them from becoming solid (this occurs if the temperature falls below a certain temperature). Heating is not used very often and no relevant information is found, so therefore no average value is given.
- Cooling: with cooling is meant the temperature control to keep the product within a specific temperature range above zero degrees Celsius. This is often necessary in food, beverage and medical industries where products often deteriorate at higher temperatures. Field values show an average increase in fuel consumption of 25 percent in case of cooled transport and this value is also used in the calculations. The calculations take into account that the temperature control is using the truck engine, in reality other methods are available (i.e. auxiliary power unit) but these are not considered in this study.

Freezing: with freezing is meant the temperature control to keep products within a specific temperature range below zero degrees Celsius. This is necessary for all frozen products, like ice-cream. Two average values for the increase in fuel consumption due to freezing during transport were obtained: McKinnon and Campbell (1998) give a value of 26 percent and a logistics service provider gives a value of 20 percent. Therefore an average value of 23 percent is used in the calculations. The value for freezing is smaller than the value for cooling due to colder loading and better isolation.

Appendix 3: Questionnaire Road & Warehouse

The Excel file contains lanes that were served by your company during the period 2008 for the polyol business and are relevant for this project. The Excel file contains four different worksheets named; Road, Intermodal Rail, Intermodal Short Sea and Intermodal Ferry. These four worksheets correspond to the different types of modes that are used during transport.

Due to the fact that during the first nine months the dispatch codes for intermodal rail (Dispatch Type 5) and intermodal short sea (Dispatch Type 35) were identical it is possible that shipments that took place by short sea are stated in the rail worksheet. In case you identify these cases please add those to the intermodal short sea section of the file and delete those from the intermodal rail worksheet.

All four worksheets contain the same basic information:

- Column A (Plant Area) contains the 2 digit postal code area where the shipping point is located.
- Column B (Plant City) contains the name of the city were the origin is located
- Column C (ConsArea) contains the 2 digit postal code area where the customer is located.
- Column D (Consignee City) contains the city were the customer is located.
- Column E (Consignee Name) contains the name of the customer.
- Column F (Carrier Name) contains the name of your company and is included for administrative reasons.
- Column G (Dispatch Type) contains the dispatch type of the shipment.
- Column H (Shipments) contains the number of shipments your company has transported on that lane during 2008.
- Column I (Qty-MT) contains the total weight of the shipments your company has transported on that lane during 2008 (in MT).

In the following pages you will find a brief explanation of the columns that are specific to each worksheet and where additional information is needed.

Road

Fuel Consumption

This is the actual fuel consumption for the lane. This means the fuel consumption during the transportation from the loading to the unloading location.

Getting these data would lead to a much better understanding of the fuel consumption during transportation. In current models there are only rough data with many assumptions, the actual data could lead to a huge improvement of the data.

The unit for fuel consumption is l/km.

Positioning Distance

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. If no accurate data are available please give an estimation.

The unit for positioning distance is km.

Actual Payload

This is needed if there are combination shipments for this lane. This means that if there is a less than truckload (LTL) shipment the actual payload is needed.

The payload is the weight percentage of the shipment compared to the weight of the total shipment and is needed to determine what percentage of the emissions should be allocated to our product.

The unit for the payload is %.

Percentage dedicated

This is the percentage of containers that is dedicated. This means that the container is dedicated to a specific product/lane and that it is empty during the return trip. For example, if there is only one truck serving the lane that is driving from A to B and back which has a load on the way there but is empty on the way back this percentage will be 100%.

Actual Distance

This is the distance that is travelled during the road transport from pick-up location to drop-off location.

The unit is km.

Intermodal – Rail

The questionnaire actually consists of two parts for the intermodal worksheet, the road and the rail part. The relevant columns in the excel sheet for road are coloured gray and for rail are coloured green.

Road

Fuel Consumption 1

This is the actual fuel consumption for the lane. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit for fuel consumption is l/km.

Fuel Consumption 2

This is the actual fuel consumption for the lane. Part 2 is the transportation from the intermodal discharge point to the unloading destination at the consignee.

The unit for fuel consumption is l/km.

Positioning Distance 1

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 1 is for the truck driving from shipping location to the intermodal ship point.

The unit for positioning distance is km.

Positioning Distance 2

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit for positioning distance is km.

Actual Payload

This is needed if there are combination shipments for this lane. This means that if there is a less than truckload (LTL) shipment the actual payload is needed.

The payload is the weight percentage of the shipment compared to the weight of the total shipment and is needed to determine what percentage of the emissions should be allocated to our product. The unit for the payload is %.

Percentage dedicated

This is the percentage of containers that is dedicated. This means that the container is dedicated to a specific product/lane and that it is empty during the return trip. For example, if there is only one truck serving the lane that is driving from A to B and back which has a load on the way there but is empty on the way back this percentage will be 100%.

Actual Distance1

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit is km.

Actual Distance2

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit is km.

Rail

Engine Type

The type of engine is a very important factor for determining the emissions during rail transport.

Please fill in whether the engine type is diesel or electrical.

Gross weight

Fill in the gross weight of the total train. This is the total weight of the train, including cargo, cars and so on. Please fill in the average gross weight over 2008, if no data are available give an estimation. The unit for the gross weight is metric ton (Mt).

Cargo weight

This is the total weight of the cargo on the train. Please fill in the average cargo weight on the train for the lane over 2008, if no data are available please give an estimation.

The unit for the cargo weight is metric ton (Mt).

Empty Transport

Please indicate the percentage of containers that is returning empty. An average percentage for the number containers returning empty in 2008 is requested if no accurate data are available. For example, if two containers are transported from A to B and on the return trip one is used and one is empty the value will be 50%.

Loading terminal (2 digit postal area)

This is the 2 digit postal code area where the terminal where the goods are put on the train is located.

Loading terminal (city)

This is the name of the city where the terminal where the goods are put on the train is located.

Loading terminal (country)

This is the country where the terminal where the goods are put on the train is located.

Unloading terminal (2 digit postal area)

This is the 2 digit postal code area where the unloading terminal is located.

Unloading terminal (city)

This is the name of the city where the unloading terminal is located.

Unloading terminal (country)

This is the name of the country where the unloading terminal is located.

Rail distance

This is the actual distance the train has travelled from the loading terminal to the unloading terminal. The unit for the rail distance is km.

Intermodal – Short Sea

The questionnaire actually consists of two parts for the intermodal worksheet, the road and the water part. The relevant columns in the excel sheet for road are coloured gray and for short sea are coloured green.

Road

Fuel Consumption 1

This is the actual fuel consumption for the lane. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit for fuel consumption is l/km.

Fuel Consumption 2

This is the actual fuel consumption for the lane. Part 2 is the transportation from the intermodal discharge point to the unloading destination at the consignee.

The unit for fuel consumption is l/km.

Positioning Distance 1

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 1 is for the truck driving from shipping location to the intermodal ship point.

The unit for positioning distance is km.

Positioning Distance 2

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit for positioning distance is km.

Actual Payload

This is needed if there are combination shipments for this lane. This means that if there is a less than truckload (LTL) shipment the actual payload is needed.

The payload is the weight percentage of the shipment compared to the weight of the total shipment and is needed to determine what percentage of the emissions should be allocated to our product. The unit for the payload is %.

Percentage dedicated

This is the percentage of containers that is dedicated. This means that the container is dedicated to a specific product/lane and that it is empty during the return trip. For example, if there is only one truck serving the lane that is driving from A to B and back which has a load on the way there but is empty on the way back this percentage will be 100%.

Actual Distance1

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit is km.

Actual Distance2

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit is km.

Short Sea

Fuel Type Main

This is the type of fuel that is used on the container vessel for the main engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Main Engine Consumption

This is the fuel consumption of the main engine of the container vessel on the lane, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Main Engine Power

This is the maximum power for the main engine, give an average for the vessels that serve the specific lane.

The unit for the engine power is kW.

Main Engine Fuel Consumption

This is the fuel consumption of the main engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Main Engine Load

This is the average load at which the main engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Fuel Type Aux

This is the type of fuel that is used on the vessel for the auxiliary engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Aux Engine Consumption

This is the fuel consumption of the auxiliary engine on the vessel, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Aux Engine Power

This is the maximum power for the auxiliary engine, give an average for the vessels that serve the specific lane. The unit for the engine power is kW.

Aux Engine Fuel consumption

This is the fuel consumption of the auxiliary engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Aux Engine Load

This is the average load at which the auxiliary engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Cruise Speed

This is the cruise speed the vessel is sailing at on average during the trip, this does not include the speed in ports.

The unit for cruise speed is knots.

Cargo Weight

This is the weight of the total cargo on the trip, please give an average for the lane over 2008.

The unit of cargo weight is Metric ton (Mt).

Loading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is put on the vessel.

Loading Port (City)

Please give the name of the city of the port where the cargo is loaded onto the vessel.

Loading Port (Country)

Please give the name of the country of the port where the cargo is loaded onto the vessel.

Unloading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is loaded off the vessel.

Unloading Port (City)

Please give the name of the city of the port where the cargo is loaded off the vessel.

Unloading Port (Country)

Please give the name of the country of the port where the cargo is loaded off the vessel.

Intermodal – Ferry

The questionnaire actually consists of two parts for the intermodal worksheet, the road and the ferry part. The relevant columns in the excel sheet for road are coloured gray and for ferry are coloured green.

Road

Fuel Consumption 1

This is the actual fuel consumption for the lane. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit for fuel consumption is l/km.

Fuel Consumption 2

This is the actual fuel consumption for the lane. Part 2 is the transportation from the intermodal discharge point to the unloading destination at the consignee.

The unit for fuel consumption is l/km.

Positioning Distance 1

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 1 is for the truck driving from shipping location to the intermodal ship point.

The unit for positioning distance is km.

Positioning Distance 2

This is the distance that the truck is driving to get from the previous unloading location to the loading site. In case the truck is driving via a depot or cleaning station this needs to be added to the positioning distance. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit for positioning distance is km.

Actual Payload

This is needed if there are combination shipments for this lane. This means that if there is a less than truckload (LTL) shipment the actual payload is needed.

The payload is the weight percentage of the shipment compared to the weight of the total shipment and is needed to determine what percentage of the emissions should be allocated to our product. The unit for the payload is %.

Percentage dedicated

This is the percentage of containers that is dedicated. This means that the container is dedicated to a specific product/lane and that it is empty during the return trip. For example, if there is only one truck serving the lane that is driving from A to B and back which has a load on the way there but is empty on the way back this percentage will be 100%.

Actual Distance1

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 1 is the transportation from the shipping location to the intermodal ship point.

The unit is km.

Actual Distance2

This is the distance that is travelled during the road transport from pick-up location to drop-off location. Part 2 is for the truck driving from intermodal discharge point to the unloading location at the consignee.

The unit is km.

Ferry

Ferry Type

Please indicate which of the following descriptions suits the ferry that is used best;

- RoRo; A ferry that is mainly used for the transportation of passengers but transports freight as well.
- RoPax; A ferry that is mainly used for the transportation of freight.

Truck Included

Please indicate whether the truck is loaded onto the ferry as well or whether the ferry only transports the trailer.

Please indicate yes or no.

Ferry Capacity (truck)

Give the maximum capacity for trucks on the ferry. This is the number of truck lane meters available at the ferry.

The unit for ferry capacity truck is lanem.

Ferry Capacity (car)

This is the maximum capacity for cars available at the ferry in number of cars.

The unit for ferry capacity cars is number of cars.

Ferry utilization (truck)

This is the capacity utilization for the trucks on the ferry, this means the percentage of truck capacity that is used on average on that lane during 2008.

Ferry utilization (car)

This is the capacity utilization for the cars on the ferry, this means the percentage of car capacity that is used on average on that lane during 2008.

Fuel Type Main

This is the type of fuel that is used on the ferry for the main engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Main Engine Consumption

This is the fuel consumption of the main engine on the lane, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Main Engine Power

This is the maximum power for the main engine, give an average for the vessels that serve the lane. The unit for the engine power is kW.

Main Engine Fuel consumption

This is the fuel consumption of the main engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Main Engine Load

This is the average load at which the main engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Fuel Type Aux

This is the type of fuel that is used on the ferry for the auxiliary engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Aux Engine Consumption

This is the fuel consumption of the auxiliary engine on the lane, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Aux Engine Power

This is the maximum power for the auxiliary engine, give an average for the vessels that serve the specific lane.

The unit for the engine power is kW.

Aux Engine Fuel consumption

This is the fuel consumption of the auxiliary engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Aux Engine Load

This is the average load at which the auxiliary engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Cruise Speed

This is the cruise speed the ferry is sailing at on average during the trip, this does not include the speed in ports.

The unit for cruise speed is knots.

Boarding Location (2 digit postal code area)

Please give the 2 digit postal code area of the location where the cargo is put on the ferry.

Boarding Location (City)

Please give the name of the city where the cargo is put on the ferry.

Boarding Location (Country)

Please give the name of the country of the location where the cargo is put on the ferry.

Unloading Location (2 digit postal code area)

Please give the 2 digit postal code area of the location where the cargo is loaded off the ferry.

Unloading Location (City)

Please give the name of the city of the location where the cargo is loaded off the ferry.

Unloading Location (Country)

Please give the name of the country where the cargo is loaded off the ferry.

Appendix 4: MPC Questionnaire

Explanation Excel file

The Excel file contains some of the lanes that were served by your company during the period 2008 for the polyol business and are relevant for this project. The Excel file only contains the MPC worksheet where the data can be added.

All four worksheets contain the same basic information:

- Column A (Plant Area) contains the 2 digit postal code area where the shipping point is located.
- Column B (Plant City) contains the name of the city were the origin is located
- Column C (ConsArea) contains the 2 digit postal code area where the customer is located.
- Column D (Consignee City) contains the city were the customer is located.
- Column E (Carrier Name) contains the name of your company and is included for administrative reasons.
- Column F (Dispatch Type) contains the dispatch type of the shipment.
- Column G (Shipments) contains the number of shipments your company has transported on that lane during 2008.
- Column H (Qty-MT) contains the total weight of the shipments your company has transported on that lane during 2008 (in MT).

In the following pages you will find a brief explanation of the columns that are specific to each worksheet and where additional information is needed.

MPC

The questionnaire contains several questions with regard to the routes and emissions for the transport served by your company for PU business in 2008.

MPC

Loading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is put on the vessel.

Loading Port (City)

Please give the name of the city of the port where the cargo is loaded onto the vessel.

Loading Port (Country)

Please give the name of the country of the port where the cargo is loaded onto the vessel.

Unloading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is loaded off the vessel.

Unloading Port (City)

Please give the name of the city of the port where the cargo is loaded off the vessel.

Unloading Port (Country)

Please give the name of the country of the port where the cargo is loaded off the vessel.

Total Cargo Weight

This is the weight of the total cargo on the trip, please give an average for the lane over 2008.

The unit of cargo weight is Metric ton (Mt).

Cruise Speed

This is the cruise speed the vessel is sailing at on average during the trip, this does not include the speed in ports.

The unit for cruise speed is knots.

Type of Ship

Please indicate which of the following alternatives is most suitable for the ship that is used on the lane. If another type is more appropriate please feel free to add it. Otherwise choose from;

- Feeder Small

- Feeder A-type
- Panamax
- Post Panamax

Fuel Type Main

This is the type of fuel that is used on the container vessel for the main engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Main Engine Consumption

This is the fuel consumption of the main engine of the container vessel on the lane, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Main Engine Power

This is the maximum power for the main engine, give an average for the vessels that serve the specific lane.

The unit for the engine power is kW.

Main Engine Fuel Consumption

This is the fuel consumption of the main engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Main Engine Load

This is the average load at which the main engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Appendix 5: Bulk Vessel Questionnaire

Explanation Excel file

The Excel file contains all the lanes that were served by your company during the period 2008 for the polyol business and are relevant for this project. The Excel file only contains the Bulk worksheet where the data can be added.

All lanes contain the same basic information:

- Column A (Plant Area) contains the 2 digit postal code area where the shipping point is located.
- Column B (Plant City) contains the name of the city were the origin is located
- Column C (ConsArea) contains the 2 digit postal code area where the customer is located.
- Column D (Consignee City) contains the city were the customer is located.
- Column E (Carrier Name) contains the name of your company and is included for administrative reasons.
- Column F (Dispatch Type) contains the dispatch type of the shipment.
- Column G (Shipments) contains the number of shipments your company has transported on that lane during 2008.
- Column H (Qty-MT) contains the total weight of the shipments your company has transported on that lane during 2008 (in MT).

In the following pages you will find a brief explanation of the columns that are specific to each worksheet and where additional information is needed.

Bulk

Loading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is put on the vessel.

Loading Port (City)

Please give the name of the city of the port where the cargo is loaded onto the vessel.

Loading Port (Country)

Please give the name of the country of the port where the cargo is loaded onto the vessel.

Unloading Port (2 digit postal code area)

Please give the 2 digit postal code area of the port where the cargo is loaded off the vessel.

Unloading Port (City)

Please give the name of the city of the port where the cargo is loaded off the vessel.

Unloading Port (Country)

Please give the name of the country of the port where the cargo is loaded off the vessel.

Total Cargo Weight

This is the weight of the total cargo on the trip, please give an average for the lane over 2008. This is only needed if there are multiple products in the same vessel, if there are no other products on the vessel please indicate this by entering a -.

The unit of cargo weight is Metric ton (Mt).

Cruise Speed

This is the cruise speed the vessel is sailing at on average during the trip, this does not include the speed in ports.

The unit for cruise speed is knots.

Maximum Capacity

This is the maximum capacity of the vessel.

The unit for maximum capacity is mT.

Fuel Type Main

This is the type of fuel that is used on the vessel for the main engines, please choose the most appropriate from;

- RO; Residual Oil
- MDO; Marine Diesel Oil
- MGO; Marine Gas Oil

Main Engine Consumption

This is the fuel consumption of the main engine of the vessel on the lane, please give an average for 2008.

The unit for engine consumption is kg/km.

If this value is known the next three values are not needed

Main Engine Power

This is the maximum power for the main engine, give an average for the vessels that serve the specific lane.

The unit for the engine power is kW.

Main Engine Fuel Consumption

This is the fuel consumption of the main engine when it is using 100% of the capacity.

The unit for fuel consumption is g/kWh.

Main Engine Load

This is the average load at which the main engine is used, this means at what level of its capacity is the engine used on average.

The unit for engine load is %.

Appendix 6: Explanation of modality codes

Code	Description
18	Truck-Container (FlexiTank)
2	Road Transport Bulk Tank
20	Rail car
24	Rail container
28	Rail block train
3	Road Transport Packed
30	Vessel (Bulk)
31	Vessel (Container)
32	Barge (Bulk)
35	Intermodal road and shortsea (ISO-Tank)
4	Truck-Hopper/Silo
5	Intermodal transport by road and rail (Bulk)
56	Intermodal road and shortsea (Container)
59	Intermodal road and ferry (Packed)
6	Intermodal transport by road and rail (Packed)
60	Intermodal road and ferry (Packed LTL)
62	Parcel services road and air
66	Intermodal road and shortsea (ISO-Container)
7	Truck Parcel Service
75	Intermodal road and ferry (Bulk)
76	Intermodal road and ferry (ISO-Tank)
79	Intermodal rail car and ferry
8	Truck-Container (Hopper/Silo)
86	Intermodal road and shortsea (Flexi)
92	Road (Packed LTL)
93	Road (Bulk LTL)
99	Pipeline

Appendix 7: Confidential

Appendix 8: Regions

Regions:

Group 1: NW-Europe

Group 2: SW-Europe

Group 3: UK+Ireland

Group 4: Scandinavia

Group 5: Central Europe

Group 6: SE-Europe

Group 7: NE-Europe+Russia

Group 8: Asia

Group 9: Africa

Group 10: Americas

Group 11: Oceania

Group 12: Middle East

Countries in each region

COUNTRY	Region
ALGERIA	9
ANGOLA	9
ARGENTINA	10
AUSTRALIA	11
AUSTRIA	5
BELGIUM	1
BOSNIA & HERZEGOVINA	6
BRAZIL	10

BULGARIA	6
BURKINA FASO	9
CAMEROON	9
CHINA	8
CONGO	9
CZECH REPUBLIC	7
DENMARK	1
EGYPT	9
ESTONIA	7
FINLAND	4
FRANCE	5
GABON	9
GERMANY	1
GHANA	9
GREECE	6
HONG KONG	8
HUNGARY	6
INDIA	8
IRELAND	3
ISRAEL	12
ITALY	2
JAPAN	8
JORDAN	12
KAZAKHSTAN	8
KOREA, REPUBLIC OF	8
LATVIA	7
LEBANON	12
LIBYAN ARAB JAMAHIRIYA	9
LITHUANIA	7
MALI	9
MALTA	6
MEXICO	10
MOROCCO	9
NETHERLANDS	1
NEW ZEALAND	11
NIGER	9
NORWAY	4
OMAN	12
PAKISTAN	8

PHILIPPINES	8
POLAND	7
PORTUGAL	2
ROMANIA	6
RUSSIAN FEDERATION	7
SAUDI ARABIA	12
SERBIA	6
SINGAPORE	8
SLOVENIA	6
SOUTH AFRICA	9
SPAIN	2
SWEDEN	4
SWITZERLAND	5
SYRIAN ARAB REPUBLIC	12
TAIWAN	8
TANZANIA, UNITED REPUBLIC OF	9
THAILAND	8
TUNISIA	9
TURKEY	12
UGANDA	9
UKRAINE	7
UNITED ARAB EMIRATES	12
UNITED KINGDOM	3
UNITED STATES	10
VENEZUELA	10
YEMEN	12

Appendix 9: Confidential

Appendix 10: Confidential

Appendix 11: Confidential

Appendix 12: Confidential

Appendix 13: Confidential

Appendix 14: Confidential