ERASMUS SCHOOL OF ECONOMICS

The Environmental Performance of Inland Shipping

Development and Application of a Framework to Compute Emissions in the Inland Shipping Transport Chain

Master Thesis

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May 2011

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"Sustainability is a vague concept. It is intrinsically inexact. It is not something that can be measured out in coffee spoons. It is not something that you could be numerically accurate about. It is, at best, a general guide to policies that have to do with investment, conservation and resource use."

Robert M. Solow (1993)

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Jos Nellen

SUMMARY

Inland shipping is widely regarded as a sustainable, environmental friendly way of transport. Looking at emission factors of transport, inland shipping's scale advantage seems to create an advantage over other modes of transport. However, inland shipping requires multiple transshipments that consume energy which in turn can be related to emissions. These emissions are usually not included when comparing different types of transport. However, this thesis argues that including these emissions makes for a fairer comparison. Therefore, the research question of this thesis is formulated as follows:

How can the sustainability (environmental performance) of the inland shipping transport chain be measured and thereby create a fairer environmental overview of the different transport modalities?

Therefore, to reach a satisfying answer, the emissions of transshipment should be included. To do this, a framework has been adapted from a model that already has been used in the Port of Rotterdam terminals. This framework computes the energy consumed by equipment in the terminal. Using emission factors, the energy consumption can be transformed into estimated emissions. These emissions are then added to known emission factors of transport. Together these emissions form the emissions in the total transport chain, which are compared to other transport chains; in this thesis the trucking transport chain.

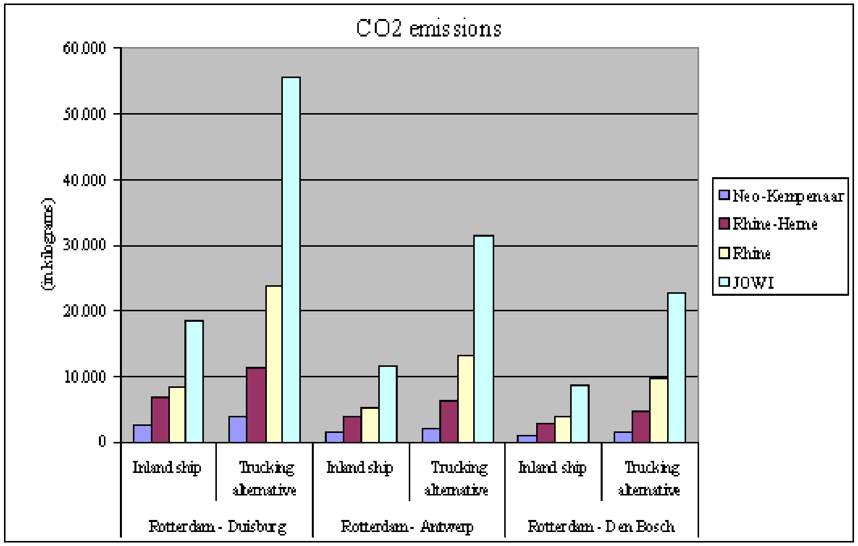
The modeling of the processes in inland terminals has needed adaptation from the original model. Not surprisingly, since both the equipment and the way the equipment is used differs from the terminals in Rotterdam. After adjustments, the computed energy consumption more closely resembled (<10% regarding kWh and <13% regarding diesel) the energy consumption as specified by the inland terminals involved in this research. The terminals involved in this thesis are the terminals located in Nijmegen, Den Bosch and Veghel. These terminals represent the extremes of the terminal population in The Netherlands regarding size and age. The extremes of the population were used so that they arguably encompass most of the inland terminal aspects used in this thesis in order to generalize results.

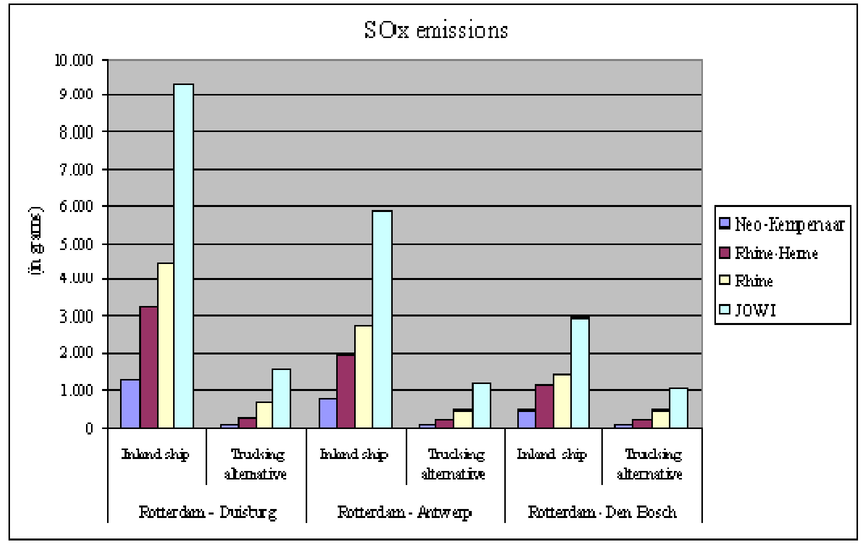
When the emissions caused by transshipment and by transport have been added together, the outcomes have been projected on multiple example routes; Rotterdam – Duisburg, Rotterdam – Antwerp and Rotterdam – Den Bosch. Although it is impossible to compare the environmental friendliness of inland shipping to trucking in general, due to the dependency of the environmental performance on a wide array of factors and the subsequent assumptions made in this thesis, the example routes show interesting results. These can be seen on the next page.

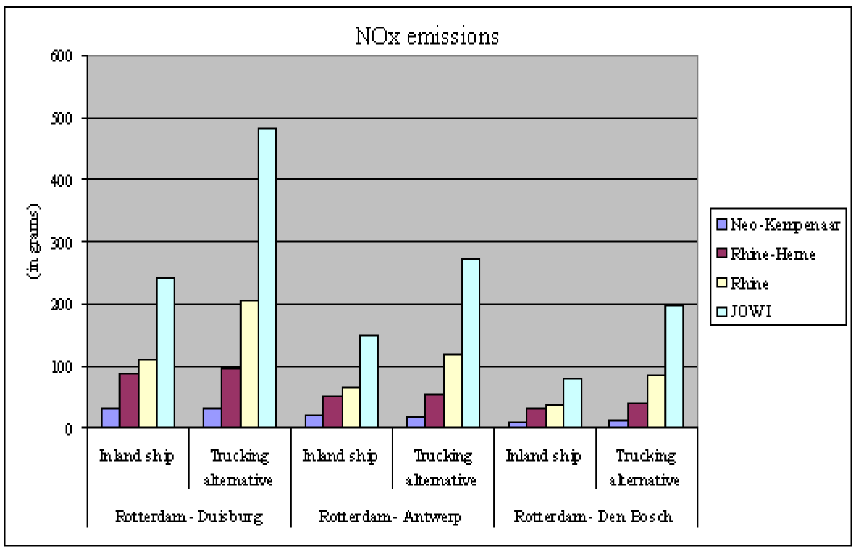
It becomes clear that every inland vessel type emits 1.4 to 3.5 times as less CO_2 on every route. The scale advantage of inland shipping more than offsets the disadvantage of multiple transshipments. The same holds for NO_x on a smaller scale; while the smaller ship types emit slightly more NO_x, the larger inland vessels emit up to 2.2 times less than the trucking alternative. Another example of the scale advantage of inland shipping is presented by the emission of PM10 on the selected routes; the two smallest inland ship types emit almost 2 times as much PM10 than the trucking alternative, while the two larger vessels emit slightly less (up to 1.2 times). Unexpectedly, when looking at the transport emission factors, inland shipping can not compete with the trucking alternative in regard to the emission of SO_x. Every ship type on every distance will emit more than trucking on the selected routes.

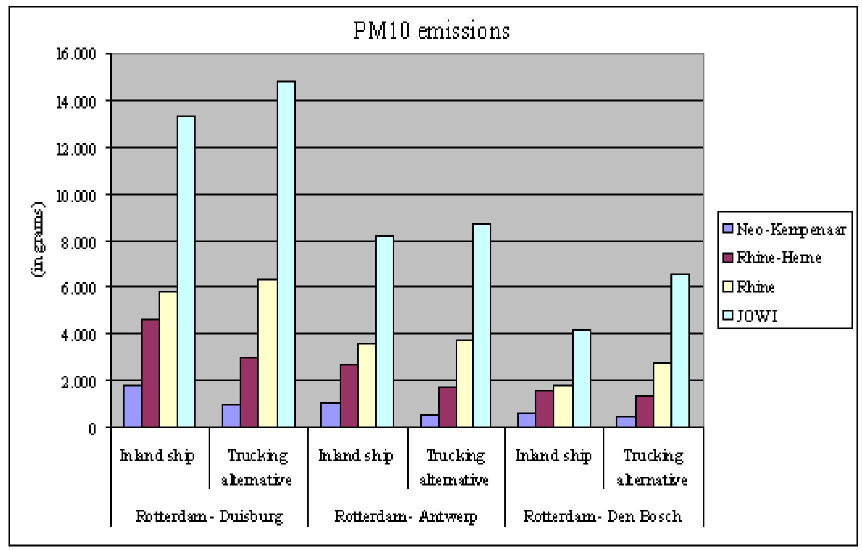
The contribution of emissions caused by transshipment in comparison to the total amount of emissions in the transport chain ranges considerably from 6% to 54%. It is impossible to draw any conclusions from this, since the contribution is relative to the distance of transport; it decreases as the transport distance increases. Additionally, the relative amount of emissions caused by transshipment increases as vessel size increases. This seems illogical at first, but can be simply explained; while the emissions caused by transshipment remains constant (per container), the transport emissions decrease. The result will be a relative increase of emissions caused by transshipment.

Keywords: sustainability; environmental performance; inland container terminals; inland shipping transport chain.


CO2 emissions
(in kilograms)
60.000
50.000
40.000
30.000
20.000
10.000
0
Inland ship
Trucking alternative
Rotterdam - Duisburg
Rotterdam - Antwerp
Rotterdam - Den Bosch
Neo-Kempenaar
Rhine-Herne
Rhine
JOWI


SOx emissions
(in grams)
10.000
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0
Inland ship
Trucking alternative
Rotterdam - Duisburg
Rotterdam - Antwerp
Rotterdam - Den Bosch
Neo-Kempenaar
Rhine-Herne
Rhine
JOWI


NOx emissions
(in grams)
600
500
400
300
200
100
0
Inland ship
Trucking alternative
Rotterdam - Duisburg
Rotterdam - Antwerp
Rotterdam - Den Bosch
Neo-Kempenaar
Rhine-Herne
Rhine
JOWI


PM10 emissions
(in grams)
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0
Inland ship
Trucking alternative
Rotterdam - Duisburg
Rotterdam - Antwerp
Rotterdam - Den Bosch
Neo-Kempenaar
Rhine-Herne
Rhine
JOWI

1. INTRODUCTION

1.1 Introduction

As sustainability and sustainable development remain a much-debated issue in society, political thinking will be influenced by this phenomenon. Along these lines, the Dutch government has written a policy memorandum ('Zeehavens als Draaischijven naar Duurzaamheid') concerning seaports. In this memorandum the Ministry of Transport, Public Works and Water Management voices its aspiration to promote sustainable development in the Dutch ports. To quote this policy letter: "Given the government's ambitions, the expected economic development and the present potential for the Dutch seaports and businesses located there, the government concludes that promotion of sustainable development of ports is desirable, possible, necessary and attractive" (Ministry of Transport, Public Works and Water Management [Dutch abbreviation: V&W], 2008a; p. 10). The desire of the Dutch government to promote sustainability is a phenomenon that has become a trend in recent times. It fits into the government's guidelines on social entrepreneurship and its views on the 'livability of the environment'. However, sustainability is not something only governments care for. Indeed, listed companies recently "have introduced performance on sustainability criteria as a benchmark for bonus payouts" (Tamminga, 2010). This indicates that there is a growing awareness that sustainability is not only essential, but also desirable. New opportunities for inland shipping therewith arise, since this modality is regarded as an environmental friendly way of transporting goods. Additionally, inland shipping in The Netherlands is seen as an important modality to relieve pressure from the (over-)use of the roads (National Ports Council, 2008) and it forms a "crucial part of the important Dutch and European supply chains" (V&W, 2007; p. 9). However, is the entire inland container shipping transport chain as environmental friendly as is often claimed?

Although inland shipping and its related emissions have received a considerable amount of attention in literature, the rest of this transport chain, and in particular inland container terminals, have not. Nevertheless, inland ports and container terminals form a significant part of the inland shipping transport chain (Notteboom & Rodrigue, 2005). Inland ports certainly did not receive much attention, until several years ago when multiple institutions tried to create awareness in the municipalities with inland ports. Sadly, the earlier mentioned policy memorandum points out that innovations (also on sustainability) in ports are still inadequate. “Many companies need an external stimulus to improve the sustainability of their activities” (V&W, 2008a; p. 44). This, combined with the prognosis that “all scenarios predict mild to very strong growth in container transport by inland shipping”, even when the agreements between the Port Authority Rotterdam and inland shippers on hinterland transport from the new to be build Maasvlakte II are not included (Ecorys, 2010; p. 22), has prompted the authorities to respond: “From the viewpoint that further growth should be accommodated, the government has combined this ambition with the explicit intention to make the Dutch ports more sustainable” (V&W, 2010).

1.2 Objective

Part of a sustainable port is organizing environmental friendly ways of hinterland transport. Inland shipping has such an image (V&W, 2007; Dutch Inland Shipping Information Agency [Dutch abbreviation: BVB], 2010; A&S Management, 2003), although there is critique as well (RIVM, 2002). However, this environmental friendly image is (mainly) created by comparing the emissions of transport only. Transshipment of goods, which is necessary when transporting by inland ship, is not taken into account. Therefore, this study aims to make a fairer comparison by adding emissions that are caused by transshipment to inland shipping transport. Moreover, this study is undertaken to create more awareness. Although inland shipping is regarded as an environmental friendly way of transport, it is unclear if this is true for the rest of the activities in the transport chain. In order to achieve above described objectives, this study intends to develop a concise method to determine sustainability in inland container terminals, in a quick and user-friendly way.

That inland ports, as part of the inland shipping transport chain, are worthy of receiving attention is made clear in a study performed by TNO INRO in 2005. Together the 389 identified inland ports in this report formed a considerable part of the Dutch economy. It states that these inland ports form a direct added value of € 5.7 billion, on a total added value of € 456.2 billion in The Netherlands, which makes it 1.3% of the total Dutch economy (Central Bureau of Statistics, 2010). Furthermore, these ports collectively have a direct employment of over 66,000 employees. These figures only serve to illustrate the significance of inland ports for the Dutch economy and the transport sector in particular. More attention to sustainability in this sector thus has considerable potential and will result in better insight of the level of sustainability of the inland shipping transport modality.

1.3 Research Question

The before mentioned, in combination with the objective of this research leads to the following research question:

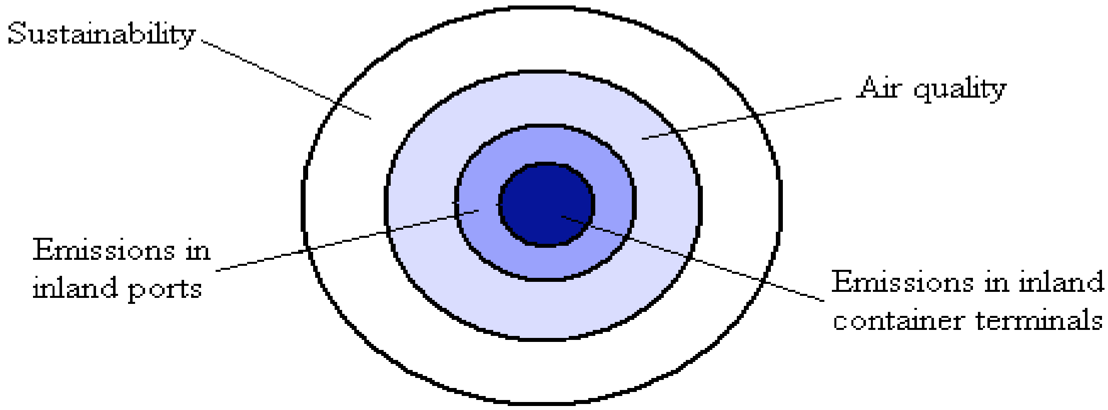
How can the sustainability (environmental performance) of the inland shipping transport chain be measured and thereby create a fairer environmental overview of the different transport modalities?

In order to find a satisfactory answer, the following sub-questions will help to build structure in this report and aid in finding the necessary information:

1. Are there existing examples of sustainability (environmental) performance indicators in use in inland container terminals or elsewhere and are they usable in this research context?
2. How to measure the environmental performance of the inland shipping transport chain?
3. How to compare the different transport modalities in a fair way?

This research starts with a broad view on sustainability, but limits the research scope during its course. The literature review, found in chapter 2, further explains this delimitation. Figure 1 depicts the final scope of this research; it is concentrated on the inner dark blue circle.

Figure 1: Research scope



Source: Author

1.4 Report Structure

In summary, the objective of this study is to find a way to compare the sustainability of the inland shipping transport chain to different transport modalities, in a fairer way, by incorporating the transshipment of goods into this comparison. Therefore, the emission of pollutants of inland container terminals, where the transshipment of goods takes place, is modeled. By doing so, it helps policymakers to get a better insight in the sustainability (environmental performance) of the inland shipping transport chain. In order to answer the research question, the subsequent structure will be followed; first of all, the concept of sustainability is defined. This can be read in chapter 2. The research methodology used to determine the level of sustainability in container terminals is the focus of chapter 3. Chapter 4 presents the results of this methodology by presenting the final framework and analyzes the case studies that have been undertaken to test the framework's applicability. Chapter 5 reflects back on this study by drawing conclusions and presenting recommendations for further improvements.

2. LITERATURE REVIEW

Chapter 2 starts with a short overview of what is meant with sustainability in this thesis. After presenting a definition of sustainability, chapter 2 continues with a review of the environmental friendly image of inland shipping. The last section of this chapter consists of comments on this image of inland shipping.

2.1 Introduction

Since sustainability is a rather vague concept, it seems sensible to first address its meaning in this research context. While an extensive review of the concept sustainability can be found in appendix A the following standard definition (WCED, 1987) is used in this thesis:

Development which meets the needs of the present, without compromising the ability of future generations to meet their own needs, concerning the emissions of CO_2, NO_x, SO_x and PM10.

This definition has been chosen, because it does not explicitly specify what sustainability contains. This seems suitable, since new insights on climate science (or sustainability itself) obviously influence the level of sustainability of the different transport modes. Furthermore, not only new scientific insights influence the desired level of sustainability, but also the economic and political climate (Adam & Traynor, 2010). Therefore, since sustainability is subject to varying influences from different viewpoints, this rather ambiguous definition is found to be appropriate for this thesis.

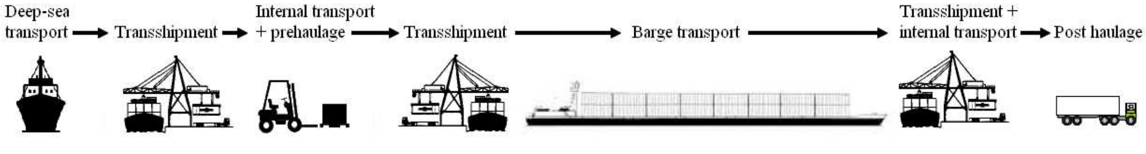
However, although the exact level of sustainability might be different in the future due to new insights and political desires, it does have to be measured in an explicit way. While reviewing the literature on sustainability and the current aims of the Ministry responsible for regulating the environmental aspect of transport, the following particles have been selected in filling in the concept of sustainability; CO_2, NO_x, SO_x and PM10. Appendix A provides more insight into the selection of these specific particles.

2.2 A Fairer Comparison

Focusing on the climate and the emission of CO_2, inland shipping seems to have an advantage over trucking (CE, 2008; Royal Haskoning, 2004; IFEU Heidelberg, 2010). Due to the amount of containers an inland ship transports at the same time, the energy consumed per container is lower than in trucking. This makes up for the age disadvantage of the general inland ship motor in comparison to the general age of a trucking motor. However, other pollutants are also important. Looking at environment and health related emissions like SO_x, NO_x and PM10 the environmental friendly image of inland shipping becomes more complicated (CE, 2008). Especially the emissions of SO_x are problematic for the inland shipping sector. Due to the high sulfur content of the fuel used compared to truck fuel, the emissions of SO_x are generally higher per unit of measure.

The CO_2 emission performance is likely the reason why inland shipping often is recognized as an environmental friendly way of shipping. For instance, the BVB (2010, p. 32) states: "Being the most sustainable method of transport, the inland vessel can increasingly pose [as] an alternative to road transport, without the ill effects of traffic jams, environmental taxation, traffic risks or noise pollution." Another example is given by Royal Haskoning (2004, p. viii): "… a modal shift towards inland shipping contributes to the improvement of the environmental performance of the whole transport chain". Yet, no attention is given to the extra handlings needed in the inland shipping transport chain. Therefore, this thesis argues that it is not only transport itself that matters when comparing inland shipping to other modes of transport; the whole transport chain should be taken into account. Especially in the case of inland shipping, since this transport mode generally needs more handlings before the goods can be delivered to the final user. Figures 2 and 3 show the extra handlings in the inland shipping chain.

Figure 2: Representation of an intermodal barge transport chain



Source: Adapted from Konings (2009)

Figure 2 shows the general working process of transporting a container from the port of Rotterdam to the hinterland. When a deep-sea vessel loaded with containers arrives at the port of Rotterdam it is (partially) unloaded. Next, the containers are stacked at the container terminals, causing internal transport. In the optimal circumstances, before an inland ship comes to collect containers the containers are internally transported to a single barge terminal. However, in practice it is the inland ship that calls in at multiple container terminals which causes considerable problems in the port of Rotterdam (see Konings, 2009). Finally, the containers are transported from Rotterdam to an inland port in the vicinity of the destination of the goods. There, the containers are once again unloaded to wait for a truck to pick them up to deliver the containers to their final destination.

Figure 3: Representation of a trucking transport chain

Source: Author

Figure 3 shows the less complicated transport chain for a container transported by truck. As with a container transported by inland ship, the container arrives at the port of Rotterdam by deep-sea vessel. The container is unloaded and stacked at a container terminal in which it waits until a truck comes to pick it up. Per internal transport the container is transshipped onto a truck which directly transports the container to its final destination.

As Geerlings & van Duin (2010) have shown, extra handlings (e.g. internal transport and transshipments) in a seaport consume substantial amounts of energy which in turn influences the environmental friendliness of a transport chain. These extra handlings take place in inland terminals, an important part of the inland shipping transport chain. Comparisons of inland shipping with other modes of transport, with regard to the environmental friendliness of transporting goods do not take this into account; certainly not at the level as in this thesis. To include these sources of energy consumption therefore make for a fairer comparison.

2.3 Case Study Research Design

Case studies and interviews have been conducted for this research. Why case studies have been selected as research design is clarified in this section. Additionally, it describes the setting and decision making process in which inland container terminals have been selected to serve as case studies.

Since this thesis researches a relatively new area, a case study method is fitting. "Case studies have powerful advantages in the heuristic identification of new variables […] in the course of field work – such as archival research and interviews with participants, area experts and historians" (George & Bennett, 2005; p. 20). Eisenhardt, (1989; p. 548) agrees about the suitability of case studies in new study areas; "There are times when little is known about a phenomenon. […] In these situations, theory building from case study research is particularly appropriate, because theory building from case studies does not rely on previous literature or prior empirical evidence". Four case studies have been carried out, since, according to George & Bennet (2005; p. 31), "case study methods involve a trade-off among the goals of attaining theoretical parsimony, establishing explanatory richness, and keeping the number [of] the cases to be studied manageable." Furthermore, the case studies serve not only to test if the developed framework includes all the necessary sources of emission (or has too many), but also tests the applicability. For, if the framework is theoretically sound, but is impractical, it hardly helps to reveal areas in which to improve sustainability

The four inland container terminals that would serve as case studies are pre-selected. The criterion used in this selection is the expectations about their information. This means that case studies are selected along two dimensions; age and size. By selecting case studies that reflect the extremes of these two dimensions, it is theorized that the rest of the inland container terminals will have characteristics that are encompassed by these extremes. Consequently, the case studies do not have to be representative of the population, like in statistical sampling (Yin, 1994; Flyvbjerg, 2006; George & Bennett, 2005). "The goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory" (Eisenhardt, 1989; p. 537).

Unfortunately, the newest of these inland terminals indicated[1] that they do not have the required information available and was subsequently removed from the case study sample. The remaining case studies have been conducted in August and September 2010. The case studies have been selected in cooperation with my thesis supervisors and discussed with the chairman of VITO, the Dutch association of inland terminal operators. The inland container terminals are thereafter individually phoned in order to arrange a meeting. Key individuals are selected to interview in order to help build a better portrait of the functioning of the container terminals.

After conducting the case studies, both within-case analysis (appendix C) as well as cross-case analysis (appendix D and chapter 4) has been performed. "Within-case analysis typically involves detailed case study write-ups for each site. These write-ups are often simply pure descriptions, but they are central to the generation of insight (Gersick, 1988; Pettigrew, 1990) because they help researchers to cope early in the analysis process with the often enormous volume of data" (Eisenhardt, 1989; p. 540). "Also, within-case analysis often leads to the finding that the researcher's (or the literature's) preliminary knowledge […] was incomplete or simply wrong, and case study researchers sometimes conclude that none of the proposed theories adequately explains a case" (George & Bennett, 2005; p. 24). Cross-case analysis is conducted to find similarities and striking differences in the way the selected inland ports understood sustainability. Furthermore, there is "a growing consensus that the strongest means of drawing inferences from case studies is the use of a combination of within-case analysis and cross-case comparisons within a single study or research program" (George & Bennett, 2005; p. 18).

[1] After personal communication with Marnix Vos (Alpherium).

In summary, this chapter explains the theoretical foundations for this research. It shortly reviews what is meant with sustainability. Additionally, section 2.2 observes that some sources of energy consumption are not taken into account when comparing the environmental friendliness of inland shipping to other modes of transport. Finally, section 2.3 clarifies why the case study research design has been chosen. The next chapter elaborates on the methodology used to develop a framework to make this comparison fairer.

3. METHODOLOGY

Chapter 3 focuses on the setting and the framework used in this thesis. Section 3.1 describes the decision to select the inland ports to be studied in this thesis. The last section shows the model used in this thesis to calculate the emissions caused by handlings in inland ports.

3.1 Setting and Deciding on Inland Ports

After finishing the literature review on sustainability (to create a general understanding of the concept) and inventorying existing performance indicators on air quality in container terminals, inland ports or elsewhere, a workshop has been carried out with the thesis supervisors and other parties involved in this thesis. Among those parties are the Directorate-General for Aviation and Maritime Affairs (DGLM), the policymakers of V&W concerning inland shipping, and the Erasmus University Rotterdam (EUR). After careful deliberation 4 inland container terminals have been selected to be investigated further. The grounds on why these container terminals are selected are explained hereafter.

According to Yin (1994), the selected case studies should reflect characteristics identified in the underlying conceptual framework. Since this framework is intended to be able to be applied in every inland container terminal, the cases should reflect this. Therefore, each selected case has different aspects with respect to the size (in TEU[2] throughput) and age of the terminals, thereby arguably encompassing most of the aspects to be measured in container terminals, as represented in table 1. Finally, after taking all of the above in consideration, the following container terminals have been selected:

[2] "Standard unit for counting containers of various capacities and for describing the capacities of container ships or terminals. One 20 Foot ISO container equals 1 TEU" (OECD, 2007; p. 809).

Table 1: Research dimensions of inland terminals taken into account

Dimension	Terminal Location	
Age	**Nijmegen (old)**	**Alphen aan den Rijn (new)**
Size	**Veghel (small)**	**Den Bosch (large)**

Source: Author

- *Nijmegen (Container Terminal Nijmegen, CTN)*

The CTN is one of the first terminals that opened up activities regarding container transshipment. In later years, more efficient designs and work processes could have been developed, that have not been incorporated in the building of the CTN. In order to include this into a general framework, CTN has been selected as case study.

- *Den Bosch (Bossche Container Terminal, BCT)*

The BCT is one of the largest inland container terminals, with regard to the number of TEU handled. Due to its size, it may possess other equipment compared to smaller terminals. To take this difference in equipment, and possibly work processes, into account, the model requires input from one of the larger container terminals.

- *Veghel (Inland Terminal Veghel, ITV)*

ITV is a relatively small inland container terminal in terms of TEU handled per year. Consequently, it is likely that the equipment used by ITV reflects this situation. Since the framework is to be designed to be able to be applicable in every inland container terminal, it is important to include a smaller terminal, with different work processes. Therefore, ITV has been selected as one of four case studies.

- *Alphen aan de Rijn (Alpherium)*

OTA is an inland terminal which started its activities on October 1, 2010 (Municipality Alphen aan de Rijn, 2010). This terminal is incorporated into the framework to test if there are new equipment or work processes planned in the new terminal. Unfortunately, Alpherium indicated that it did not have the required information available for this research and therefore has not been included in the development of the framework.

3.2 Developing a Framework

In their paper, Vis & de Koster (2003) present an overview of relevant activities that are related with the transshipment of containers onto other modes of transportation. This overview, together with a methodology based on Geerlings & van Duin (2010) form the basis of this framework, as shown in figure 4 on the next page. This framework uses a bottom-up approach and utilizes macro-economical data, available from inland container terminal companies, to determine the total amount of electricity and diesel used based on the presence and usage of equipment. This framework has been applied on container terminals located in the port of Rotterdam and therefore is likely to contain comparable sources of emission, although the scale of the container terminals in the port of Rotterdam is larger than those located in inland ports. Therefore, it is to be expected that this framework encompasses sources of emission that do not occur in inland container terminals and thus needs adaptation. The average energy consumption per type of equipment present in the container terminals in the port of Rotterdam are shown in table 2.

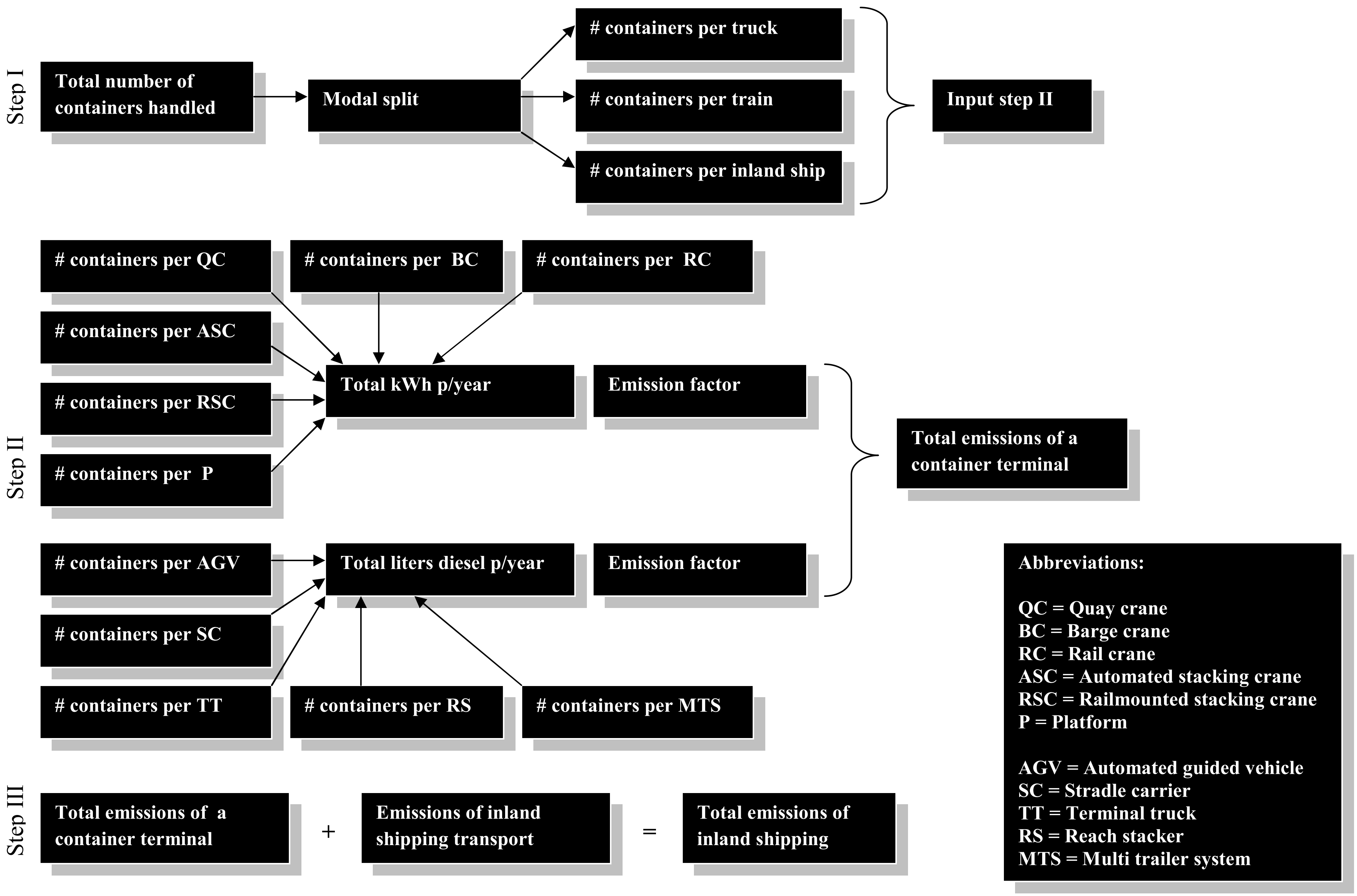
Table 2: Energy consumption per type of equipment

Energy	Type of equipment	Fixed consumption per containermove	Variable consumption	Terminals	Source
ELECTRIC	QC: Quay Crane	6.00 kWh		ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP	(TNO, 2006)*
	BC: Barge Crane	4.00 kWh		ECT-D, APM, BCT, CTN, WIT	(TNO, 2006)*
	RC: Rail Crane	5.00 kWh		ECT-D, APM	(TNO, 2006)*
	ASC: Automated Stacking Crane	5.00 kWh		ECT-D	(TNO, 2006)*
	RSC: Railmounted Stacking Crane	7.25 kWh		ECT-Ha, RST, UNP	ASC**
	P: Platform	5.00 kWh		RST	ASC**
DIESEL	AGV: Automated Guided Vehicle	1.10 l	1.80 l/km	ECT-D	(TNO, 2006)*
	SC: Straddle Carrier	0.80 l	3.50 l/km	ECT-D, ECT-Ho, APM, RST	(TNO, 2006)*
	TT: Terminal Tractors		4.00 l/km	ECT-D, ECT-Ho, ECT-Ha, RST, UNP	(TNO, 2006)*
	MTS: Multi Trailer System		4.20 l/km	ECT-D, ECT-Ho, APM, UNP	(TNO, 2006)*
	RS: Reach Stacker / Top Lifter		5.00 l/km	ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP, BCT, CTN, WIT	(TNO, 2006)*

* Based on op TNO project by Oonk **(TNO Built Environment and Geosciences, 2006)**
** Based om a comparision with the ASC on the ECT Delta terminal, in which the reach of the equipment (stack length) is taken into consderation.

Source: Geerlings & van Duin (2010)

Figure 4: Framework to determine emissions at the port of Rotterdam container terminals



Adapted from Geerlings & van Duin (2010)

The case studies serve to test if it is possible to apply this general framework in multiple types of inland container terminals and to see which adaptations are necessary to model the emission of pollutants in the best way possible. The desired outcome of this framework is the emission of the following pollutants;

- Carbon dioxide (CO_2)
- Sulfur oxides (SO_x)
- Nitrogen oxides (NO_x)
- Particle matter (PM10)

The emission of pollutants is computed by multiplying an energy carrier with its emission factor (EF), like equation (1) demonstrates:

$$emission\left[\frac{kg}{year}\right] = energy\ consumption\left[\frac{l\ or\ kWh}{year}\right]\ x\ emission\ factor\left[\frac{kg}{l\ or\ kWh}\right] \qquad (1)$$

Equation (1) also shows that the two energy carriers computed are kWh and liters (of diesel), depending on the activity modeled. Each energy carrier has its own emission factor (EF) as is shown in equation (2) and (3).

$$emission_D\left[kg\right] = diesel\left[l\right]\ x\ f_D\ \left[\frac{kg}{l}\right] \qquad (2)$$

Where:

$emission_D$ = emission of pollutants in kilograms by diesel powered equipment

$diesel$ = diesel consumption in liters

f_D = EF in kilograms per liter diesel

$$emission_E\left[kg\right] = electricity\left[kWh\right]\ x\ f_E\ \left[\frac{kg}{kWh}\right] \qquad (3)$$

Where:

$emission_E$ = emission of pollutants in kilograms by electric powered equipment

$electricity$ = electricity consumption in kilowatt-hours

f_E = EF in kilograms per kilowatt-hour

Equations (2) and (3) model the amount of energy used by activities in an inland container terminal. The amount of energy used depends on the lay-out of the terminal, what type of equipment is used and how it is deployed. Subsequently, the terminal lay-out and the deployment of equipment directly influence the modeling of driving distances. These in turn are the main contributor to the amount of liters of diesel used which are multiplied by an emission factor per pollutant. While Geerlings & van Duin (2010) assume that reach stackers and top lifters are only used for transport (indicated by a variable amount of liters of diesel used per kilometer), this framework assumes that these types of equipment also consume a fixed amount of diesel. This assumption is made because of the difference in deployment; in inland terminals these are the only equipment, next to the barge cranes, that can lift containers, in contrast to the other equipment present at the container terminals in the port of Rotterdam. Therefore, equations (4) and (5) model this as follows:

$$diesel\left[l\right] = number\ of\ containermoves\ x\ fixed\ consumption\left[\frac{l}{move}\right] + average\ driving\ distance\ x\ variable\ consumption\left[\frac{l}{km}\right] \quad (4)$$

$$electricity\left[kWh\right] = number\ of\ containermoves\ x\ fixed\ consumption\left[\frac{kWh}{move}\right] \quad (5)$$

By substituting equation (4) into (2) and equation (5) into (3), adding equations (2) and (3) together and multiplying those results with an emission factor, the total emission of pollutants in an inland terminal can be estimated. To make a fairer comparison between the environmental friendliness of different transport modalities the emissions of these pollutants should be added to the transport emissions of inland shipping, shown in equation (6).

$$emission_T\left[kg\right] = \left(diesel\left[l\right]\ x\ f_D\left[\frac{kg}{l}\right] + electricity\left[kWh\right]\ x\ f_E\left[\frac{kg}{kWh}\right]\right) + transport\left[km\right]\ x\ f_M\left[\frac{kg}{km}\right] \quad (6)$$

Where:

$emission_T$	=	*emission of pollutants in kilograms in a transport chain*
electricity	=	*electricity consumption in kilowatt-hours*
diesel	=	*diesel consumption in liters*
f_M	=	*EF per modality in kilograms per kilometer*
transport	=	*transport distance in kilometers*

Equation (6) incorporates the emissions caused by handlings in inland terminals and thereby makes a fairer comparison across different transport chains. However, the emissions in a transport chain are largely influenced by the emission factors used. The full set of emission factors used in this thesis can be seen in appendix F. In table 3 below, the maximum difference between comparable emission factors calculated by different studies can be seen. The emission factors of 'Rijkswaterstaat Emissieregistratie en – Monitoring Scheepvaart' (2003) are not presented in this table, since these emission factors are incomparable to the ones presented in table 3, due to a insurmountable difference in levels of measurement (e.g. CO instead of CO_2, HC instead of SO_x).

Table 3: Comparable emission factors per pollutant and their maximum differences

Max. difference	kWh	Die-sel	Road	Neo-Kempenaar	Rhine-Herne canal	Rhine	JOWI
CO_2	**36%**	**18%**	**48%**	**6%**	**12%**	**51%**	**17%**
SO_x	**n.a.**	**n.a.**	**n.a.**	**47%**	**43%**	**74%**	**55%**
NO_x	**n.a.**	**n.a.**	**24%**	**15%**	**10%**	**59%**	**22%**
PM10	**n.a.**	**n.a.**	**33%**	**8%**	**14%**	**38%**	**45%**

Source: Adapted from CE (2008), ECN (2001), Geerlings & van Duin (2010), IEA (2009), IFEU Heidelberg (2010), MEET (1997), Royal Haskoning (2004) & Stimular (2010).

Strikingly, when the emission factors are compared, there seem to be considerable differences. However, a substantial amount of these differences can be explained by the underlying assumptions, in particular the loading factor. For example, CE calculates its emission factors for inland shipping with a loading factor of 65%, IFEU Heidelberg with a loading factor of 70% and Royal Haskoning uses a loading factor of at least 90%, depending on the inland ship type. Interestingly, according to Konings (2009; p. 33), "operators estimate the break-even loading degree to be 75%". So, at face value, CE and

IFEU Heidelberg essentially calculate their emission factors with a loading factor below operating break-even point. On the other hand, Royal Haskoning calculates their emission factor with a loading degree which seems unusually high (up to 95%, indicating almost full load return shipments). The loading factor however, is influenced by a number of variables; the limitations of the waterway infrastructure (width, depth, obstacles etc.) and the weight of cargo are two prominent examples of these variables. However, when the difference in loading factors is taken into account the differences between the emission factors will converge.

Even when the emission factors are adjusted to a single loading factor, there remains a remarkable difference in the emission of SO_x according to the various research institutions. This can be explained by a difference in level of measurement; while CE and Royal Haskoning specifically refer to SO_2, IFEU Heidelberg refers to SO_x. SO_x contains more than SO_2 emissions, although it is the predominant air polluter (World Bank Group, 1999). However, the most striking difference is the assumption made regarding the sulfur content of fuel. While IFEU assumes 1,000 parts per million (ppm), Royal Haskoning assumes 500 ppm and CE computes with 10 ppm[3]. Understandably, this creates variation in the amount of SO_2 emitted. Other prominent factors that influence the amount of emissions are the cruising speed and the routing (e.g. river or canal). To take the variation in emission factors into account, the average emission per pollutant of different sources will be used in this thesis.

3.3 Three Example Routes

The framework, as described in the previous section, will be applied to two routes as examples of the output the framework can give. The first example is the route from the port of Rotterdam to Duisburg, one of the largest inland ports in the world and destination of many containers from the port of Rotterdam for inland ships. The route and distance for inland ships and trucks carrying containers from Rotterdam to Duisburg (or vice

[3] During personal communications with a professional of TNO (Jan Hulskotte), there was the notion that 10 ppm is not a representative number of the sulphur content in fuel used at the moment.

versa) are shown in figures 5 and 6. These figures show that the distance traveled by inland ship is approximately 12 kilometers longer.

Figure 5: Rotterdam – Duisburg by inland ship (~217 km)

Source: IFEU Heidelberg (2010)

Figure 6: Rotterdam – Duisburg by truck (~209 km)

Source: Google maps

The second example route concerns the route of Rotterdam to Antwerp (see figures 7 and 8 on the next page); another important destination for many containers that have been transported to the port of Rotterdam. The route and distance for inland ships and trucks carrying containers from Rotterdam to Antwerp (or vice versa) is shorter than that to Duisburg, but likely transports more containers. The route for inland ships is approximately 6 kilometers longer. In this case, a container transported by inland ship therefore has to compensate not only for more handlings, but also for a slightly longer route.

Figure 7: Rotterdam – Antwerp by inland ship (~122 km)

Source: IFEU Heidelberg (2010)

Figure 8: Rotterdam – Antwerp by truck (~116 km)

Source: Google maps

The third example is the route is the route from Rotterdam to Den Bosch (see figures 9 and 10 on the next page); a relatively short route. The route to Den Bosch is selected to observe the impact of emissions caused by transhipment on the total amount of emissions in a transport chain. This impact is likely to be larger on shorter routes.

Figure 9: Rotterdam – Den Bosch by inland ship (~82 km)

Source: IFEU Heidelberg (2010)

Figure 10: Rotterdam – Den Bosch by truck (~82 km)

Source: Google maps

The framework will be applied to the three routes described above. In both cases, it is assumed that trucks have a load factor of approximately 40%, while inland ships have a load factor of roughly 66% (CE, 2008). Furthermore, calculations have been made with containers weighing 10 tonnes on average (CE, 2008). Additionally, emission averages of the current trucking fleet are used. The result will be an overview of the total amount of emissions in the whole transport chain, indicated by the following four particles; CO_2, SO_x, NO_x and PM10. This can be read in chapter 4.

Chapter 3 clarifies the methodological foundations of this research. Section 3.1 explains why certain inland ports have been selected as case studies. Furthermore, section 3.2 shows the framework to compute the emissions of pollutants at inland container terminals and describes the methodology to perform these computations. Finally, section 3.3 comments on the differences between various emission factors. The next chapter applies the methodology, shows the results and analyzes them.

4. RESULTS AND ANALYSIS

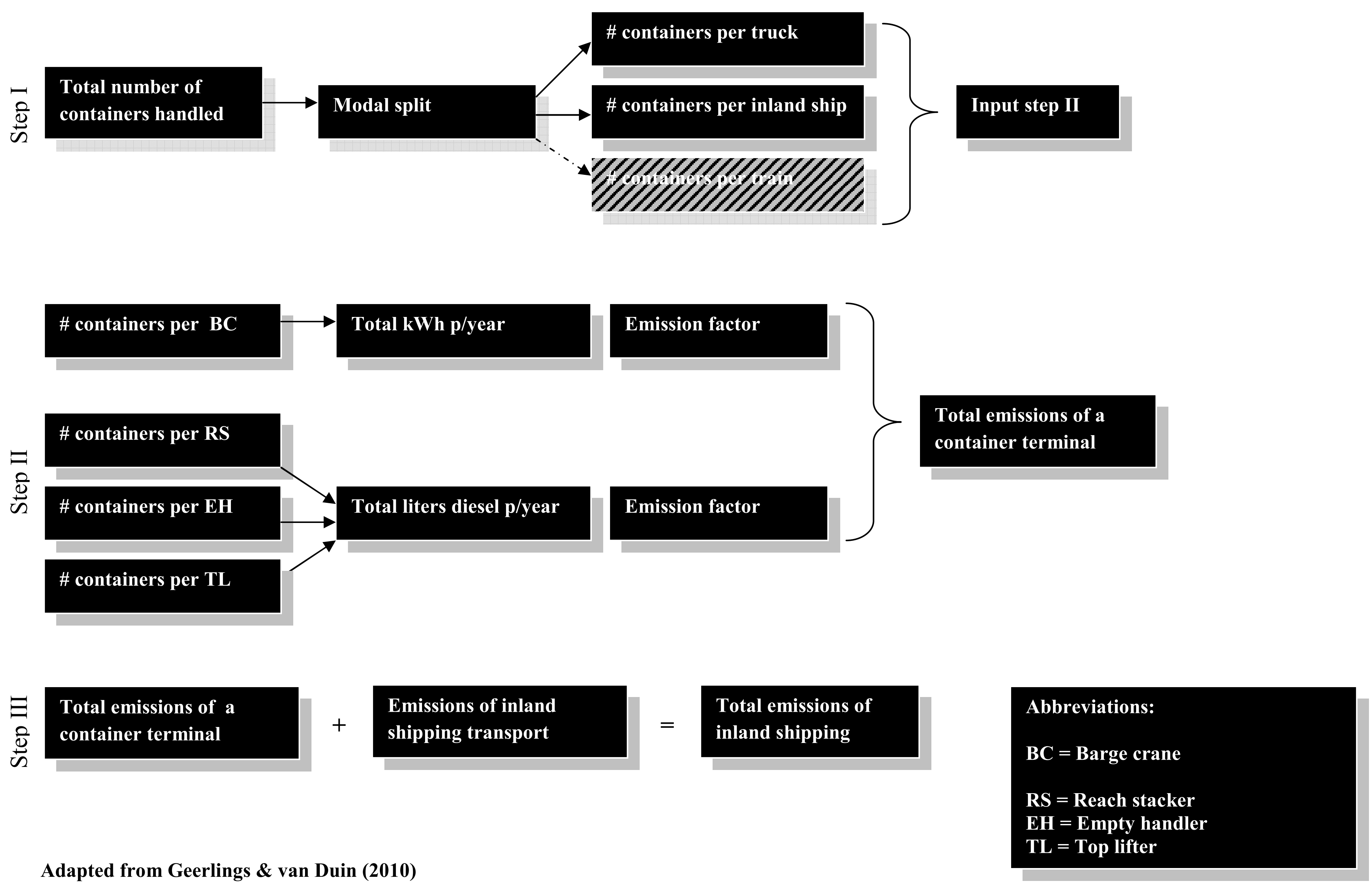
In this chapter the results will be presented and analyzed. Section 4.1 describes the application of the framework, as described earlier in chapter 3. The results of this application are presented in section 4.2. The final section of this chapter consists of analysis of those results.

4.1 Application of the Framework

After development of the earlier mentioned framework, this has been tested in container terminals located in the inland ports as mentioned in paragraph 3.2. During testing, it became apparent that the framework clearly included too many sources of emission. The equipment present at inland terminals is not comparable to container terminals located in the port of Rotterdam. Therefore, the model has been adjusted to represent this, see figure 11 on the next page. Furthermore, using the original parameter values, the amount of electricity modeled notably differed (>30% difference) from the specified quantity, as supplied by the terminals. However, the original parameter value had also been part of discussion in the interviews, where it was assessed as too high in relation to parameter values generated from practice. After adjustment, the modeled values were notably closer (<10% difference) to the values as specified by the inland container terminals.

Also, during application of the framework with the original parameter values regarding the consumption of diesel, the amount of liters used by an inland container terminal differed substantially (>60% difference) from the amount of liters specified by the inland terminals. Certainly when the terminal lay-out is not compactly designed and thus has larger driving distances, the modeled and specified amounts show considerable disparity. However, there are some likely explanations for this. First, the original framework has been developed to model the energy use of container terminals located in the port of Rotterdam. These container terminals are not comparable to inland terminals, in terms of size and TEU handled. Furthermore, because of this difference in size, the equipment is used in a different manner; there are no automated guided vehicles or multi trailer systems that transport containers at an inland terminal. However, the original framework

Figure 11: Framework to determine emissions at inland container terminals



Adapted from Geerlings & van Duin (2010) assumes that this is the way that transport usually takes place at a terminal and is therefore modeled as such. However, due to the lay-out of (smaller) inland terminals and no specific truck loading areas it is plausible that driving distances of container handlers (reach stackers, empty handlers) are estimated incorrectly. This causes a difference in consumption of diesel. Additionally, linked to the different way of moving containers at an inland terminal are the driving distances. In general, shorter driving distances translate into a higher average use of energy per kilometer. Furthermore, the equipment that uses diesel is not standardized; there are different types of container handlers, with each a different energy use. Lastly, the original framework models container handlers consuming diesel only by transporting containers. However, container handlers (un)load a considerable amount of trucks in inland terminals. Therefore, a fixed consumption per container handling, on top of the variable consumption per driving distance, seems warranted. After adjustment of the parameters the values of consumption of diesel more accurately (<13% difference) reflect the specified consumption of inland terminals.

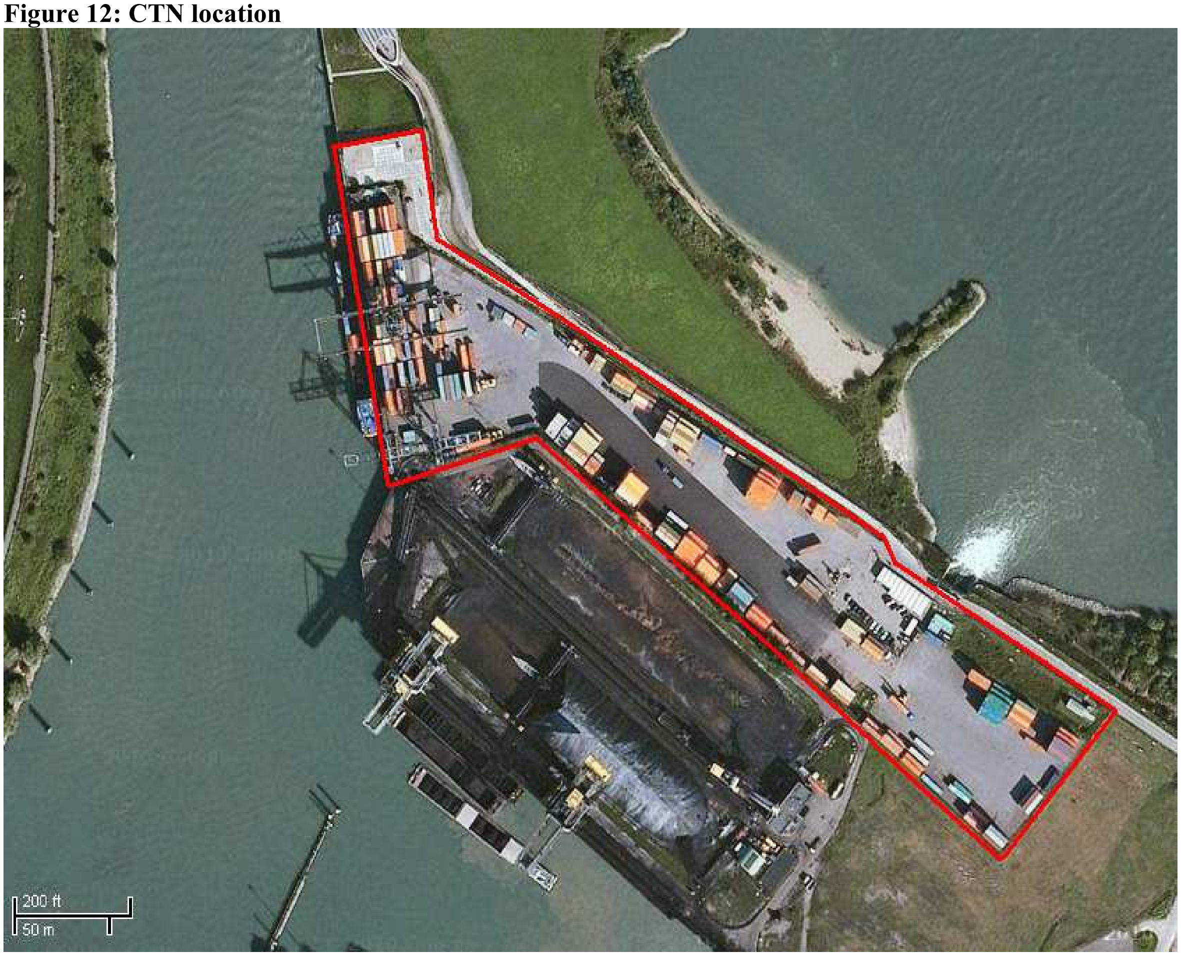
Another noteworthy issue concerning the original framework is the modeling of transshipment of containers onto a freight train. Although the adapted framework still supports the ability to transship containers onto this modality, it hardly occurs in practice in The Netherlands at the moment. Not unexpectedly, since it seems illogical to transport containers with an inland ship to an inland terminal and then transship it onto a train to further transport it to its end destination or vice versa. It is likely easier and less expensive to directly transport containers with a train, decreasing the number of transshipment moves within the transport chain. Therefore, train transport is not taken into account in this study.

4.2 Framework Results

4.2.1. Container Terminal Nijmegen (CTN)[4]

CTN is one of four terminals operated by Binnenlandse Container Terminals Nederland (BCTN). It is one of the first terminals that opened up activities regarding transport of containers per inland ship. Operational since 1987, it transferred approximately 140,000 TEU in 2009. CTN mainly focuses on inland container transport towards Rotterdam and Antwerpen and incidentally transports to Amsterdam. The terminal is located along the river Waal, near the entrance of the Maas-Waal canal, see below figure 12.

Figure 12: CTN location



Source: Google maps

[4] Based on: TNO INRO (2005), http://www.bctn.nl (retrieved August 24, 2010) and personal communication with Thijs van den Heuvel (BCTN).

CTN configuration

CTN equipment consists of two barge cranes, two empty handlers and one toplifter. The containers that arrive by inland ship are transferred into a stack and then onto a truck. No other modalities are involved. The average distance from the gate to an (un)loading location is 400 meters. In the model it is assumed that this is the average riding distance of the container handlers. Trucks are loaded by barge crane or any of the three container handlers. Therefore, the following subprocesses are recognized:

- Transshipment from inland ship to stack, or vice versa: Barge crane
- Transfer of containers from stack to truck, or vice versa: Barge crane or container handler

The deployment of equipment is explained hereafter:

Every container that is transshipped onto or from an inland ship is handled by a barge crane. The container is then placed in a stack, which is within reach of a barge crane. When a truck arrives, either a barge crane or any of the container handlers (un)loads the truck. Therefore, the following deployment of equipment is modeled:

- Barge cranes handle 25% of transshipment onto trucks
- Container handlers handle 75% of transshipment onto trucks

Above configuration, in combination with the number of TEU throughput, gives the following energy output:

Table 4: Energy consumption CTN (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**308,614**	**281,540**	**+9.7%**
Diesel (liter)	**85,589**	**76,503**	**+12.6%**

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

The energy consumption as shown in table 4 translates into the following emissions caused by transshipment at the inland terminal, depending on the emission factor used:

Table 5: Modeled emissions CTN

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

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

As table 5 shows, inland shipping transport needs to compensate on average 4.27 – 6.65 kg CO_2 per container handling with environmental friendlier transport. Emissions of SO_x, NO_x and PM10 seem negligible. However, on a local scale these pollutants could be significant, if they surpass the local threshold of emissions.

4.2.2. Bossche Container Terminal (BCT)[5]

BCT is one of four terminals operated by Binnenlandse Container Terminals Nederland (BCTN). It is currently one of the largest terminals regarding transport of containers per inland ship. Operational since 1995, it transferred approximately 220,000 TEU in 2009. BCT mainly focuses on inland container transport towards Rotterdam and Antwerpen and incidentally transports to Amsterdam. The terminal is located along the river Maas, see figure 13 on the next page.

BCT configuration

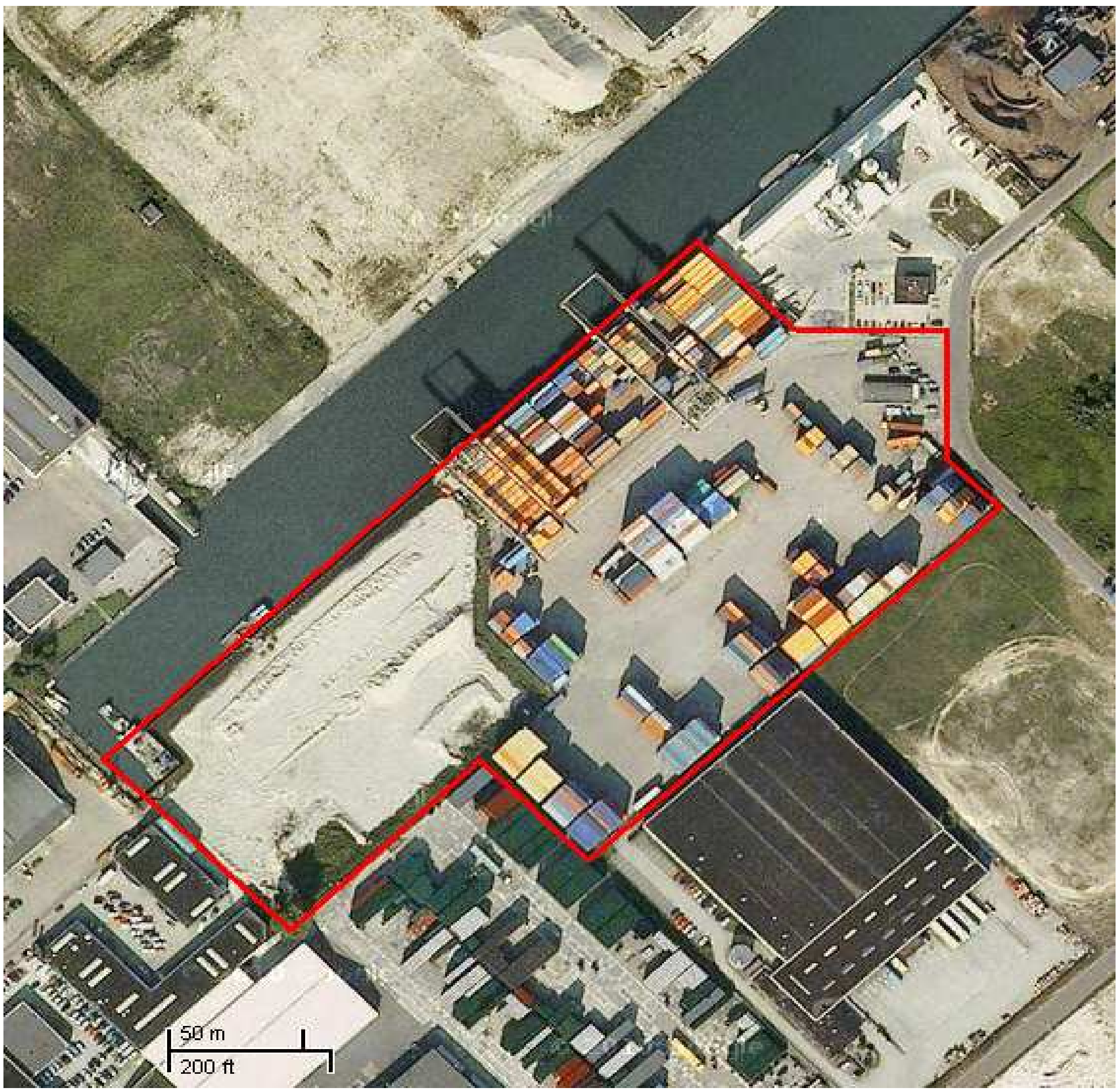
BCT equipment consists of two barge cranes, two empty handlers and one reach stacker. The containers that arrive by inland ship are transferred into a stack and later onto a truck. No other modalities are involved. The average distance of a truck from gate to an (un)loading location is 200 meters. In the model it is assumed this is the average driving

[5] Based on http://www.bctn.nl (retrieved August 24, 2010) and personal communication with Thijs van den Heuvel (BCTN).

distance of the container handlers. Trucks are (un)loaded by barge crane or any of the three container handlers. Therefore, the following subprocesses are recognized:

- Transshipment from inland ship to stack, or vice versa.: Barge crane
- Transfer of containers from stack to truck, or vice versa: Barge crane or container handler

Figure 13: BCT location



Source: Google maps

The deployment of equipment is explained hereafter:

Every container that is transshipped onto or from an inland ship is handled by a barge crane. The container is then placed in a stack, which is in the reach of a barge crane. When a truck arrives, either a barge crane or any of the three container handlers (un)loads the truck. Therefore, the following deployment of equipment is modeled:

- Barge cranes handle 25% of transshipment
- Container handlers handle 75% of transshipment

Above configuration, in combination with the number of TEU throughput, gives the following energy output:

Table 6: Energy consumption BCT (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**465,790**	**445,053**	**+4.7%**
Diesel (liters)	**95,642**	**101,204**	**-5.5%**

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

The energy consumption, as shown in table 6, translates into the following emissions caused by transshipment at the inland terminal:

Table 7: Modeled emissions BCT

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

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

Table 7 shows that, in the case of BCT, inland shipping transports needs to compensate on average at least 5.37 – 7.29 kg of CO_2 per container handling. Once again, emissions of SO_x, NO_x and PM10 seem negligible. Nevertheless, these pollutants are significant if they surpass the local maximum of these emissions.

4.2.3. Inland Terminal Veghel (ITV)[6]

ITV is a relatively small container terminal in comparison to Den Bosch and Nijmegen. Operational since 2005, it handled approximately 27,500 TEU in 2009. ITV primarily focuses on transport towards Rotterdam and incidentally transports to Antwerpen. The terminal is located along the Zuid-Willemsvaart, a canal shortcut between the Belgian part and the Dutch part of the river Maas, see figure 14.

Figure 14: ITV location

Source: Google maps

ITV configuration

ITV equipment consists of two reach stackers. The containers that arrive by inland ship are transferred into a stack and later onto a truck. No other modalities are involved. The average distance of a truck from gate to an (un)loading location is 67 meters. In the model it is assumed this is the average driving distance of the container handlers. Trucks are (un)loaded by any of the two container handlers. Therefore, the following subprocesses are recognized:

[6] Based on: TNO INRO (2005), http://www.inlandterminalveghel.eu (retrieved September 7, 2010) and personal communication with Michel van Dijk (ITV).

- Transshipment from inland ship to stack, or vice versa.: Reach stacker
- Transfer of containers from stack to truck, or vice versa: Reach stacker

The deployment of equipment is explained hereafter:

Every container that is transshipped onto or from an inland ship is handled by a reach stacker. The container is then placed in a stack, from which containers are (un)loaded. When a truck arrives, any of the two reach stackers (un)loads the truck. Therefore, the following deployment of equipment is modeled:

- Reach stackers handle 100% of transshipment

Above configuration, in combination with the number of TEU throughput, gives the following energy output:

Table 8: Energy consumption ITV (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**0**	**0**	**n.a.**
Diesel (liter)	**18,343**	**19,753**	**-7.2%**

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

The energy consumption, as shown in table 8, translates into the following emissions caused by transshipment at the inland terminal:

Table 9: Modeled emissions ITV

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

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

Table 9 shows that, in the case of ITV, inland shipping transport needs to compensate on average at least 3.28 – 3.95 kg of CO_2 per container handling. The amount of NO_x and PM10 per container seem negligible. However, on a local scale these emissions might be considerable. The amount of SO_x is unexpectedly low, since this terminal only uses diesel powered equipment. Additionally, it is striking that the amount of CO_2 per container is considerably lower at ITV than at the other terminals.

4.3 Comparing Emissions

With the emissions, as calculated in the previous section, and the emission factors of transport, as shown in appendix F, the total amount of emissions per route, as described in section 3.3, are computed. The emissions in a transport route are computed according to the methodology described in section 3.2. For reasons mentioned in section 4.1, only the trucking and inland shipping transport chains are compared. Emissions are computed for four different pollutants (CO_2, SO_x, NO_x and PM10).

As tables 5, 7 and 9 show, the minimum amount of emissions of CO_2 per container handling, caused by transshipment at an inland terminal in the inland shipping transport chain is 3.28 kg, while the maximum amount is 6.65 kg. The emission factors concerning CO_2 are presented in table 10. The emission factors for the remaining pollutants are shown in appendix F.

Table 10: Data used to determine CO_2 emissions

CO_2 emission factors	Minimum	Average	Maximum
Truck (1.7 TEU)	**643 g/km**	**937 g/km**	**1,230 g/km**
Neo-Kempenaar (32 TEU)	**10,877 g/km**	**11,244 g/km**	**11,611 g/km**
Rhine-Herne (96 TEU)	**26,499 g/km**	**28,379 g/km**	**30,258 g/km**
Rhine ship (200 TEU)	**24,922 g/km**	**33,266 g/km**	**41,610 g/km**
JOWI (470 TEU)	**68,902 g/km**	**72,411 g/km**	**75,920 g/km**

Source: CE (2008), ECN (2001), IFEU (2010), Royal Haskoning (2004), Stimular (2010) and author's own calculations

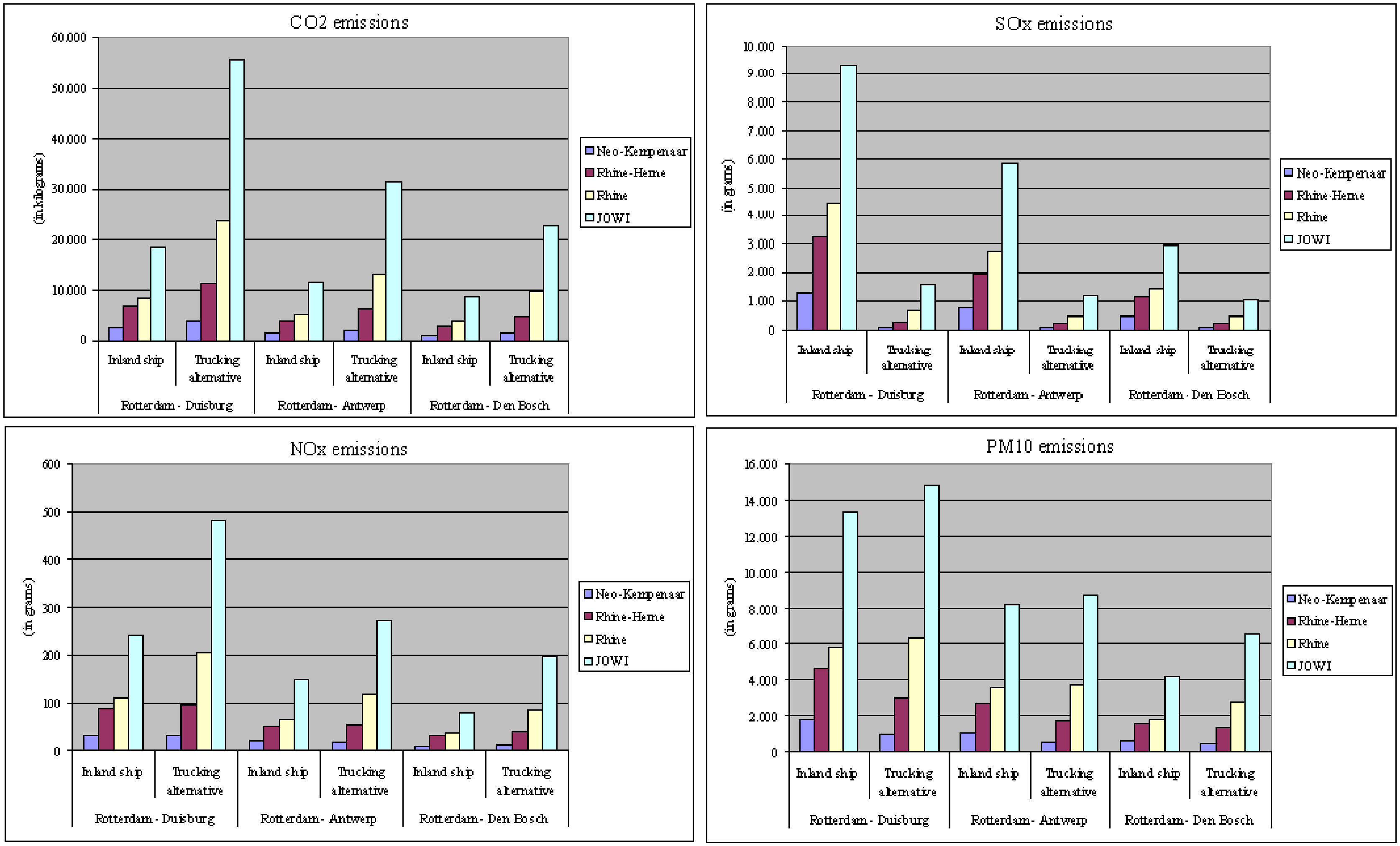
While at first sight it seems that inland shipping is less environmental friendly, it should be remembered that an inland ship transports a multitude of containers in one time. At closer look, table 10 shows clear scale advantages by transporting more containers at the same time. Therefore, table 10 shows how much an average inland ship compensates CO_2 emissions per kilometer, according to the different studies' assumptions (see section 3.2).

Figure 15 shows, depending on ship type, the emissions in the earlier mentioned example routes as calculated by the methodology explained in the previous chapter. It is assumed that a truck transports on average a container weighing approximately 10 tonnes (CE, 2008). If the transport is not performed by inland ship, but per truck, the alternative emissions that would be released are also shown in figure 15. This figure makes it clear that inland shipping, including transshipments, emits less CO_2 than its trucking alternative; 1.4 to 3 times as less. The same is true for NO_x; while the smallest ship with the smallest scale advantages emits approximately the same amount of NO_x as its trucking alternative, the larger inland ships emit 1.1 to 2 times as less NO_x. The results for PM10 are mixed; only the two largest inland ships emit less PM10 than its alternative transport possibility. However, this advantage is rather weak, as the largest inland ship emits only 1.1 times as less PM10 than its alternative, while the smallest inland ship emits almost twice as much, compared to trucking. The results for SO_x are clear; inland shipping is at a clear disadvantage compared to trucking, with emissions 6 to 11 times as high. The results that have been shown so are based on the example routes earlier mentioned in section 3.3. A more detailed overview of the model outcome can be seen in appendix G.

4.4 Analysis

Although the outcome of the modified framework, as presented in section 4.2, shows promising results, certain remarks are necessary. This analysis is divided into two sections; section 4.4.1 analyzes the application concerning the framework, section 4.4.2 analyzes the remaining issues.

Figure 15: Overview of emissions on different routes



Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

4.4.1 Framework Application Analysis

The amount of electricity modeled with the original parameters, shown in table 3, are, as applied in the selected terminals, consequently too high when compared with the amount of electricity as specified by the inland terminals. Therefore, on basis of interviews with the inland terminals a lower parameter value has been modeled, which resulted in a considerable improvement of results. These results are shown in section 4.2. Model results with the original parameters are presented in appendix D.

The original parameter value of diesel consumption of container handlers (reach stackers, top lifters) has also been modified. While the original parameter only modeled driving distances, given by a certain amount of diesel consumed per kilometer, the adapted parameter also models consumption of diesel caused by the lifting of containers. This is certainly necessary in the case of Veghel, where no barge cranes are present and therefore all containers are lifted by container handlers. Additionally, the driving distances in inland terminals are difficult to model, since there is no fixed (un)loading location for trucks. In comparison with the container terminals in the port of Rotterdam, inland terminals have a certain flexibility that allows trucks to drive up on their terminals, so that the driving distances of container handlers becomes variable. This is particularly crucial, since the driving distances seem to considerably influence the performance, in relation to the amount of emissions at a terminal.

That the lay-out, and therefore driving distances, affect the environmental performance in such a way is linked to the minor (modeled) difference in lifting containers by electric or diesel powered equipment. The generation of electricity in The Netherlands is, in comparison to other EU countries, environmental unfriendly. In terms of CO_2 emissions the generation of electricity in The Netherlands is 19% (IEA, 2009) to 38% (MEET, 1997) higher than EU average. Therefore, the difference in lifting containers with electric or diesel powered equipment in The Netherlands is fairly small. Would the generation of electricity be more environmental friendly, then the model would favor electrical equipment more. Certainly on a local scale, since electric powered equipment has no emissions at the point of use.

While the model shows promising results (maximum difference of 13%, looking at the modeled and indicated energy consumption of a terminal), it is also possible to simply multiply the total amount of diesel and kWh consumed at a terminal with an emission factor. Although this is a simpler and quicker method to compute the emissions of a terminal, it is questionable if all these emissions should be added to the inland shipping transport chain. As one interviewee pointed out; an inland terminal has multiple functions (e.g. storage and planning of transport). Even though all the energy consumed at an inland terminal is ultimately related to the transport function, not every emission should be added to the transport chain. Therefore, although the model is a more complicated method, it is fairer in distributing the energy consumed over the different functions of a terminal.

4.4.2 General Analysis

It is important to remark that the environmental performance (or sustainability) of transport per inland ship and truck depends on a wide array of factors. To overcome these difficulties, assumptions have been made in this research. However, due to these largely differing factors and the assumptions made, it has become impossible to compare the environmental performance of inland shipping to trucking in general. Furthermore, these emissions are theoretical and are no guarantee for actual emissions; new tests could alter the results (see for example TNO, 2010).

That being said, the environmental friendly image of inland shipping does not completely match with the results as shown in section 4.3. As the example routes show; inland shipping emits less CO_2 and NO_x, but more SO_x and PM10. This is not surprising, looking at the emission factors of transport and the limited influence of emissions caused by transshipment. The influence of emissions caused by transshipment are minimal compared to the scale advantage of transporting a multitude of containers at the same time. So, although the emissions caused by transshipment are larger as a percentage of the total transport chain with larger vessels, this is offset by the even larger scale advantages of these vessels. Figure 15 clearly shows the scale advantages; while a Neo-

Kempenaar only emits less CO_2 than its trucking alternative, a Rhine-Herne emits less CO_2 and NO_x and a Rhine canal ship emits less CO_2, NO_x and PM10 than its alternatives.

That larger inland ships have a higher percentage of emissions caused by transshipment as part of the total transport chain (see table 11 and appendix G for the other particles) might seem counter-intuitive at first, but can be simply explained; while the transshipment emissions remain constant (per container), the transport emissions become smaller due to scale advantages. This results in a higher relative amount of emissions caused by transshipment.

Table 11: Relative amount of CO_2 emissions caused by transshipment as part of the total emissions

Relative amount of CO_2 emissions caused by transshipment	Rotterdam – Duisburg	Rotterdam – Antwerp	Rotterdam – Den Bosch
Trucking alternative	**2.6%**	**4.5 %**	**6.3 %**
Neo-Kempenaar	**7.2 %**	**12.1%**	**17.0%**
Rhine-Herne	**8.4%**	**14.0%**	**19.6%**
Rhine	**14.0%**	**22.5%**	**30.6%**
JOWI	**15.0%**	**23.9%**	**31.8%**

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Lastly, future developments in both forms of transport should be shortly discussed. Since the average lifespan of a truck is shorter than that of an inland ship, it is no surprise that (technical) developments are faster implemented in trucking. Together with upcoming stricter rules regarding emissions, this will help both transport modalities to become even more environmental friendly. While this attention to emissions is nothing new to trucking, it has only been a decade or so since inland shipping has gotten around the same amount of attention. That there is currently considerable attention for the environmental performance of inland shipping becomes evident when listing the (major) various upcoming initiatives or initiatives that have been undertaken, i.e.:

- *Green awards*

Multiple awards for promotion of 'green' related transport (including inland shipping) projects currently exist. Perhaps one of the most notable awards is the 'Green Award', promoted by the Green Award Foundation. Currently, the award is only for sea going vessels, but the foundation is looking into possibilities to set up a certification scheme for inland shipping (Green Award Foundation, 2010). Another noteworthy award is the 'Lean & Green Award', promoted by Connekt (2010). This award stimulates companies to improve their logistics processes to be sustainable.

- *Environmental Shipping Index (ESI)*

The ESI is an initiative linked to the World Port Climate Initiative (WPCI), mainly aimed at reducing the amount of emissions from sea borne ships (WPCI, 2010). Ports reward ships, which perform better than the environmental standard, with incentives (e.g. rebate on port tariffs or service charges). However, the way the ESI is arranged, it could also include inland ships.

- *(EU) Directives*

A concrete example of an initiative that directly influences the environmental performance of inland shipping are (EU) directives, such as directive 2005/33/EG (European Union, 2005), which limits the maximum sulfur content of fuel. Effective from 1 January 2010 onwards, the maximum sulfur content of inland shipping fuel is 1,000 ppm, aiming to limit the emission of SO_x. Naturally, directives aim to regulate more than SO_x emissions.

- *Innovative shipping concepts*

During the course of this research, some innovative inland shipping concepts have been encountered, such as the barge truck (MARIN, 2009) and a new use of push barges. Certainly, this innovative use of push barges (concept remains unnamed) seems promising, with fuel savings of 35% (MCA, 2009), thereby improving the already existing image of environmental friendly inland shipping transport. Additionally, one interviewee pointed out that it is technically possible to transport containers on narrow, long inland ships, thereby saving considerable amounts of fuel, while transporting the same number of containers. However, this is economically not interesting, since this requires more crewmembers, due to EU directives concerning the number of crewmembers and the length of (inland) ships.

- *Promotion of environmental friendly fuel (EN590)*

In 2008, the Central Bureau for Rhine- and Inland shipping (Dutch abbreviation; CBRB) informed inland shippers about the benefits of using EN590 instead of regular diesel (CBRB, 2008). At the same time the 'Scheepvaartkrant' (an independent journal for, among others, inland shippers) published a comparable article, promoting EN590. This type of fuel is both economically as well as environmentally advantageous for inland shippers (Scheepvaartkrant, 2008).

- *Shore connected power (Dutch: Walstroom)*

Shore connected power is promoted actively by multiple organizations, such as V&W and the Port of Rotterdam. Shore connected power is used instead of onboard diesel generators, saving emissions of mainly CO_2, SO_x and PM10. Additionally, using shore connected power helps to prevent sound pollution (Walstroom, 2010). Studies show promising results in preventing pollution and the economic feasibility of this concept (Waterstroom, 2009).

- *Temporary subsidy fuel saving project (Dutch: Voortvarend besparen)*

Started in 2008, the Dutch government subsidized inland shippers in acquiring tools to help save fuel. Goal of this subsidy is to alter behavior of inland shippers and ultimately save 5% on fuel consumption. The project continues at least until 2011 (V&W, 2009).

Above mentioned initiatives are an indication of the projects undertaken to make the (inland) shipping sector a more environmental friendly performing sector. As such, this will certainly have an impact on the environmental break-even distance, even though improvements in the other transport modalities continue as well. However, it is difficult to foresee the impacts of these improvements. Therefore, the calculated break-even distances in section 4.3 are a rendering of current environmental performances of the different modalities. One that may considerably change in the future.

Chapter 4 explains the need for modifications of the original framework and its original parameter values. Section 4.2 shows the results, after modification, and computes the amount of emission of pollutants in inland terminals. These results are added to known emission factors to make a comparison between different transport chains in section 4.3. Finally, section 4.4 analyzes both the application of the framework as well as its implications. The end of this chapter lists (major) recent or upcoming initiatives in relation to improving the environmental performance of inland shipping. The next chapter draws conclusions from these findings, discusses the limitations of this research and suggests further research opportunities.

5. DISCUSSION AND CONCLUSION

This final chapter summarizes the main findings of this thesis. Furthermore, it discusses the implications of the research performed, mentions the limitations and indicates future opportunities for further research.

5.1 Main Findings

This thesis has started with the notion to map the sustainability of inland shipping. However, during the course of this thesis it became apparent that, although there has been a substantial amount of research on sustainability (especially from the mid 80' to the early 1990's) it is difficult to come to a satisfactory definition of this concept. Therefore, sustainability has also been equated to environmental performance in this thesis. That is a reason why this thesis uses the perspective of policymakers and port related associations to determine the context. This results in the following definition:

Development which meets the needs of the present, without compromising the ability of future generations to meet their own needs, concerning the emissions of CO_2, NO_x, SO_x and PM10.

Although inland shipping is widely regarded as an environmental friendly form of transport, the literature review shows that inland shipping needs more transshipments than its counterpart; trucking. These transshipments are often not included in the analysis of the environmental performance of inland shipping, while studies have shown that transshipment consumes energy and thus causes emissions. When these emissions are included in the analysis, a fairer comparison is made across transport modalities.

A framework has therefore been developed, as an adaptation from an earlier framework that has been used in the Port of Rotterdam terminals. It was necessary to alter the sources of emission as well as some of the original parameter values, since (the use of) equipment is incomparable to that in inland terminals. After adjustment in consultation with the inland terminals, the computed energy consumption of the inland terminals more accurately reflected the specified data as given by the terminals (<10% for kWh and <13% for diesel).

After transforming these energy consumptions into emissions using emission factors, these emissions have been added to the transport emissions to map the emissions in the total transport chain of inland shipping. However, it is important to remark that the environmental performance (or sustainability) of transport per inland ship and trucking depends on a wide array of factors. To overcome these difficulties, assumptions have been made in this thesis. Due to these largely differing factors and the assumptions made, it has become impossible to compare the environmental performance of inland shipping to trucking in general.

However, using example routes (Rotterdam – Duisburg and Rotterdam – Antwerpen) the framework shows interesting results. The CO_2 emission of inland shipping is lower for all ship types on the example routes, differing from 1.4 to 3 times as less emission than the trucking alternative. Furthermore, the example routes show that inland shipping emits more SO_x for all ship types, except the smallest. This is to be expected, due to the high sulphur content of inland ship fuel. This also holds for NO_x, where every ship type except for the smallest emits more NO_x than the trucking alternative. Additionally, the example routes also show the scale advantages of inland shipping; while the two smallest vessels emit more PM10 than the trucking alternative, the two larger vessels emit less.

Finally, the percentage of emissions caused by transshipment in relation to the emissions in the total transport chain of inland ships increases per ship type. This seems illogical at first, but is caused by constant transshipment emissions per container, while the transport emissions per container decrease as the number of containers transported at one time increases.

5.2 Discussion & Future Research

While the model shows promising results, it has only been applied in three inland container terminals. Since the original parameter values used in the framework have been modified, in consultation with the inland terminals, to compute results that more closely resemble the specified results as presented by the terminals, it is debatable if these parameter values are also useful in different container terminals. Although this research tries to prevent this generalization difficulty by examining extremes in the population, it remains unsure. It is recommended to expand this research by observing more inland terminals to obtain more data and thereby most likely a more accurate result.

Furthermore, the emission factors used in this thesis vary considerably. Data from (mainly) three different sources are used with different assumptions, making it difficult to establish a single emission factor that holds true to differing circumstances (like loading factor, cruise speed etc.). Additionally, that emission factors are reported in different values (e.g. CO instead of CO_2) makes it even more difficult to get a satisfying overview. Consistent reporting is recommended.

Finally, the results from this framework could be used to determine (part of) the external costs of transport. The author knows that cost factors per specific emission particles are available. These cost factors only have to be multiplied by the amount of emissions that are computed by the framework developed in this thesis. This would result in an overview of external costs of transport, which would make it easier to compare the different alternatives since they are expressed in a single unit. Although the author is aware of this possibility, it is not shown in this thesis as the focus of this thesis is clearly on the environmental performance. However, it would be interesting to see which type of transport is the most environmental friendly in an economic sense.

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APPENDICES

APPENDIX A: Sustainability

Appendix A starts with a general introduction of sustainability; why sustainability is important and how it has become popular in recent times. The following section reviews mainstream literature on sustainability and describes what is meant with this concept. Finally, the last section presents the working definition of sustainability used in this research, shows the areas of sustainability which are currently seen as important and elaborates on how to measure sustainability in practice.

Introduction

Sustainability is almost universally considered to be a good thing, there are few who would defend unsustainability (Jamieson, 1998). Why is this? Most likely because it is common to view sustainability from an anthropocentric perspective (see Jamieson, 1998; Mebratu, 1998; Brown, Hanson, Liverman & Merideth, 1987). From this perspective, it is humans who are responsible for the degradation of the environment, since "the human economy is a subsystem of a finite global ecosystem which does not grow […] it is clear that growth of the economy cannot be sustainable over long periods of time" (Daly, 1991; p. 6). Goodland (1995; p. 13) stipulates that "the scale of throughput [a function of population growth and consumption] has exceeded environmental capacities: that is the definition of sustainability". Furthermore, according to Bartlett (1998) in a society with a growing population and / or growing rates of consumption of resources, the larger the population, and / or the larger the rates of consumption of resources, the more difficult it will be to transform the society to the condition of sustainability. Considering the human population growth trend, it is not difficult to imagine the growing importance of sustainability.

That is most likely why concepts like sustainability and sustainable development have become popular in recent times. Undeniably, the publication of the 'World Conservation Strategy' (1980) by the IUCN (International Union for the Conservation of Nature) and 'Our Common Future' (1987) by the WCED (World Commission on Environment and Development) has helped in this regard (Mebratu, 1998). This is apparent in the amount of literature on this topic to be found from the mid 1980's and early 1990's. To quote

Lélé (1991; p. 607): "SD [sustainable development] has become the watchword for international aid agencies, the jargon of development planners, the theme of conferences and learned papers, and the slogan of developmental and environmental activists." Although sustainability has been a much-debated topic, few academics have been able to come up with a satisfying, all compassing definition. Indeed, various papers discuss this very same topic in length. However, since the main goal of this thesis is to develop a way to measure the sustainability of the operations performed at inland container terminals, it is necessary to come to a clear (working) definition. For, "setting the priorities for sustaining or being sustained, and at what costs, is a value-laden process that can only be accomplished within the context of a clearly stated definition of sustainability" (Brown et al., 1987; p. 718).

What is Sustainability?

First of, sustainability and sustainable development are concepts that are interchangeably used in this thesis. According to Lélé (1991; p. 614) "removal of poverty (the traditional development objective), sustainability and participation are really the three fundamental objectives of the SD [sustainable development] paradigm". Considering this thesis' goal is to find a way to measure sustainability in inland container terminals in The Netherlands, the first (removal of poverty) and third (participation) objectives of sustainable development make little sense in this context. Therefore, only the second objective is left, viz. sustainability. In addition, Sneddon (2000; p. 525) argues that "both 'sustainable development' and 'sustainability' are at root normative concepts, describing visions of how human activities and ecological processes might be reconciled for the 'good' of both". Keeping this in mind, sustainable development can be seen as the movement towards sustainability. Development is the way to reach the ultimate goal; sustainability. Moreover, Jamieson (1998) notes that sustainable development has given way to sustainability. Furthermore, Gatto (1995; p. 1182) notes that "in general economists and politicians tend to use the term 'sustainable development' rather than 'sustainability', thus reflecting their greater attention towards socioeconomic than towards environmental issues". This also indicates some notion of interchangeability of the terms, albeit with different connotations. This however, is not true for this thesis.

Since sustainability is a rather vague concept, there are many definitions to be found in academic literature (Bell & Morse, 2008). Another reason for this multitude of definitions is the popularity of sustainability. This is likely related to its image as a powerful tool for consensus. Repetto (1986) has tried to formulate this, but Lélé rephrased Repetto into the following: "The current state of scientific knowledge (…) about natural and social phenomena and their interactions leads inexorably to the conclusion that anyone driven by either long-term self interest or concern for poverty, or concern for intergenerational equity should be willing to support the operational objectives of SD [sustainable development]" (Lélé, 1991; p. 612). Sneddon (2000; p. 522) shares similar thoughts in his review on sustainability: "A third trend is the increasing visibility of interdisciplinary research and the recognition that significant social and environmental problems confronting societies are multicausal and demand attention from multiple disciplines. Sustainability as a general frame of reference may facilitate this process by helping to break down traditional dualisms in the sciences." V&W (2008a) recognizes this in their policy memorandum by promoting sustainability as a means of growth.

However, what is meant with sustainability? At first view a simple question, since everyone has a general idea when the term is mentioned, but below the surface a difficult question to answer. Indeed, "sustainable development is a term which is subject to considerable interpretation, depending on the context of the discussion, and the audience for the debate" (Redclift, 1992; p. 395). Redclift further states that, although with the absence of any agreement about what sustainable development is, the concept is not useless. Brown et al. (1987) reach a similar conclusion in their review on sustainability: "Tisdell (1985) notes that, while sustainable development is an important goal of the World Conservation Strategy, sustainability is not defined. Pearson (1985) feels that the concept of sustainable development is elusive, … [but] important and does deserve attention". This is just an illustration of the numerous authors who have contemplated on the concept of sustainability and find it complicated to define. However, Shearman (1990, p. 1) "disputes this conclusion by maintaining that it is not the meaning of sustainability that changes with respect to context, but rather our understanding of the context itself".

An often-recurring theme in literature on sustainability is that this concept is used in varying contexts. Usually, a division is made along three lines; a social definition, an ecological definition and an economic definition. This division into three aspects of sustainability later gained popularity by the phrasing ‘people, planet, profit’ (Elkington, 1994). Essentially, it is the same; people equals the social part, planet substitutes the ecological part and profit replaces the economic part.

The social definition revolves around the survivability (and happiness) of individuals. Barbier (1987, p. 103) argues that “the primary objective is reducing the absolute poverty of the world’s poor through providing lasting and secure livelihoods”. To quote Redclift (1992, p. 396): “the emphasis [in Barbier’s definition] is clearly on social (and economic) objectives, rather than ecological ones”. Unsurprisingly, it remains difficult to entirely separate sustainability into one category, be it social, ecological or economic. Bossel (1999; p. 2) gives a clear of this: “If we would achieve environmental sustainability coupled with a continuation of present trends, where a small minority lives in luxury, partly at the expense of an underprivileged majority, this would be socially unsustainable in the long run because of the stresses caused by the institutionalized injustice”.

Next to the social definition there is the ecological definition. According to Lélé (1991) most proponents of sustainability actually refer to this definition of sustainability. Ecological sustainability focuses on the preservation of ecosystems. Interestingly enough, there is an inherent flaw in this type of definition. As Brown et al. (1987, p. 716) state: “In many cases, short-term variability is necessary for the long-term sustainability of the eco-system. By attempting to reduce this variability […], we may, in fact, threaten the long-term persistence of the system”. However, this problem is overcome by differentiating between weak and strong sustainability (Dietz & Neumayer, 2007). Weak sustainability proponents adhere to the hypothesis that ecological capital can be substituted by different kinds of capital, be it economical or social. Strong sustainability proponents support the notion that substitution is not possible and every different type of capital should be independently supported (Ayres, van den Bergh & Gowdy, 1998). Nevertheless, ecological sustainability is linked to other aspects of the same concept. To quote Goodman: “Ultimately, there can be no social sustainability without environmental sustainability [ecological sustainability] (1995, p. 3).

Lastly, there is the economic definition. Gatto (1995, p. 1181) formulated it as follows: “sustained economic development, without compromising the existing resources for future generations”. Or, to use the quote which put sustainability definitively on the agenda and therefore may be with us for all time (O’Riordan, 1993) from the WCED (1987): “development which meets the needs of the present, without compromising the ability of future generations to meet their own needs”. This definition clearly shows the tension between the ecological and economical aspects of sustainability; ecological sustainability is desired so that future generations can meet their own needs, but it should not hamper present needs.

However, it is not the goal of this thesis to provide the ‘ultimate’ definition of sustainability. To quote Solow (1993; p. 1002): “sustainability is an essentially vague concept, and it would be wrong to think of it as being precise, or even capable of being made precise. It is therefore probably not in any clear way an exact guide to policy. Nevertheless, it is not at all useless”. Shearman (1990, p. 7) has similar thoughts: “For instead of trying to come to terms with some ambiguous meaning of sustainability as it is set in various and conceptually distinct contexts, our task becomes one of ascertaining the implications of a commonly understood notion of sustainability as applied to these various contexts”. And the context regarding this study is created by the Ministry of Transport, Public Works and Water Management in its policy memorandum.

How to Measure Sustainability?

Now that it is made apparent that sustainability encompasses a wide array of processes, the question becomes how to measure this concept. Since it is evident that it is impossible to measure sustainability as a whole, this research focuses on one particular aspect of this concept. As “progress in European port environmental management has been driven by increasing legislation and regulation” (Wooldridge & Stojanovic, 2004; p. 208), it seems sensible to start with what aspects of sustainability are seen as important by the regulators; the Ministry of Transport, Public Works and Water Management. Fortunately, this ministry provides a good starting point by listing the policy themes that they will focus on in the coming years (V&W, 2008a, p. 10), viz.;

1. Air quality
2. Energy, CO_2 emission and residual flows
3. Area use
4. Nature preservation and development
5. Water quality and management.

Strikingly, the themes that the ministry focuses on are essentially forms of ecological sustainability. However, there is an overlap in these five themes; energy, CO_2 emissions and residual flows (theme 2) are an essential part of air quality (theme 1). Furthermore, area use (theme 3) is linked with nature preservation and development (theme 4) and air quality (theme 1). Despite this overlap between themes, it indicates that air quality is seen as an important issue. Furthermore, in the same memorandum, the ministry expands on the previous mentioned themes and finds it desirable to "take concrete steps in four lines to a sustainable society" (V&W, 2008a; p. 35). These four lines are:

1. Reduction of greenhouse gas emissions and the accelerated transition to more sustainable energy sources
2. Frugal use of (raw) materials and energy
3. Sustainable use of scarce area/space
4. Integrated water management

Clearly, in both approaches air quality is an essential part of sustainability. In addition, the European Sea Ports Organisation [ESPO] together with EcoPorts (2009) give another indication of vital aspects of ecological sustainability. In their environmental review they named the top 10 priorities in ports, see table A1. Moreover, an overview of priorities over time is presented, which indicates that air quality in ports is becoming increasingly important.

Table A1: Top 10 environmental priorities of the European port sector over time

	1996	2004	2009
1.	Port development (water)	Garbage / Port waste	Noise
2.	Water quality	Dredging: operations	Air quality
3.	Dredging disposal	Dredging disposal	Garbage / Port waste
4.	Dredging: operations	Dust	Dredging: operations
5.	Dust	Noise	Dredging: disposal
6.	Port development (land)	Air quality	Relationship with local community
7.	Contaminated land	Hazardous cargo	Energy consumption
8.	Habitat loss / degradation	Bunkering	Dust
9.	Traffic volume	Port development (land)	Port development (water)
10.	Industrial effluent	Ship discharge (bilge)	Port development (land)

Source: ESPO / EcoPorts (2009).

However, in the same policy memorandum it is mentioned that sustainability should also be attractive from an economic point of view. This shows that ecological sustainability is not to be achieved by all means necessary. It has to be economically feasible, which creates a certain tension between ecological and economical sustainability (for more on this discussion, see paragraph 2.2). Therefore, considering all of the above, the definition of sustainability used in this thesis is the following:

Development which meets the needs of the present, without compromising the ability of future generations to meet their own needs, concerning the emissions of CO_2, NO_x, SO_x and PM10.

In a meeting with my thesis supervisors, it has been decided to focus on one notable aspect of the inland shipping transport chain; container terminals. These terminals are important with respect to the logistics and handling companies in the region, "since loading/discharging operations form fundamental components of intermodal transportation" (Notteboom & Rodrigues, 2005). Additionally, container transport has grown strongly in the past couple of years and is also expected to grow in coming years. "The expectations of container transport by water from and to inland terminals are in most regions very positive" (Ecorys, 2010; p. 36). This growth is expected to last at least until 2020.

Even when the scope of this research is limited to measuring pollutants at inland container terminals, it still needs to measure the emissions of numerous activities. In practice this is not viable, due to the complexity of reality and, consequently, the information gathering costs. A simple and user-friendly tool is desirable, seeing as it is meant to point out areas in which sustainability improvements are worthwhile (if an improvement is actually worthwhile is decided by tensions between the economic and ecological aspect). As a result, indicators are a quick and useful way to provide information about the sustainability performance of container terminals.

Indicators

"In general, one organisation undertaking an environmental analysis in an attempt to find and to consider all the variables that determine status, environmental behaviour and temporal development, would prove to be a difficult task as seaports are complex and dynamic entities" (Peris-Mora, Diez Orejas, Subirats, Ibáñez & Alvarez, 2005; p. 1650). The same can be said for container terminals, although they operate on a smaller scale. Nevertheless, measuring every activity in container terminals still seems impractical, not only because of data collectivity constraints, but also because it would likely be inefficient, due to the complexity of processing all this data. However, it is possible to substitute those activities by a limited number of indicators. Additionally, "developing indicators […]will help focus appropriate attention on ecological conditions, providing clues that could help guide significant and informed policy choices" (National Research Council, 2000; p. 1).

Indicators are a way to simplify a complex reality. By gathering data on certain relevant aspects of an (eco-)system it gives concise information about the system as a whole. "Environmental indicators communicate those aspects regarded as critical or typical for the complex interrelations between natural species and abiotic components of the environment" (European Environment Agency, 2003). A detailed definition of an indicator is given by the Organisation for Economic Cooperation and Development: *"A parameter, or a value derived from parameters, which points to/ provides information about/ describes the state of a phenomenon/ environment/ area with a significance* *extending beyond that directly associated with a parameter value"* (OECD, 1993). Although this definition sums up the most vital aspects of an indicator, it does not include all of its characteristics. This is reviewed in the next section.

- *Characteristics of indicators*

Indicators are helpful tools when used appropriately. To determine if they are useful, an indicator should have certain characteristics. Appendix B shows multiple sets of indicator characteristics from different sources. A concise list, based on the similarities between the different sources, follows in table A2.

Table A2: Characteristics of an indicator

Criterion	Description
Representativeness	**Provide a representative picture (of environmental conditions, pressures on the environment or society's responses)**
Reliability	**In obtaining and developing the data**
Interpretation	**Be simple, easy to interpret and able to show trends over time**
Responsiveness	**Be sensitive (to environmental changes) with fast, adaptable and appropriate responses**
Comparability	**Show the development of a phenomenon over time (within regional, national and international frameworks)**
Scientific	**Be theoretically well founded in technical and scientific terms**
Usefulness	**The indicator should be a useful tool for the activity**
Cost effectiveness	**Regarding the costs involved in obtaining the data and usefulness of the information**
Measurability	**Measurable in qualitative or quantitative terms**

Source: Based on Peris-Mora (2005), OECD (1993), European Environment Agency (2003), Niemeijer & de Groot (2008) and Dale & Beyeler (2001)

Unfortunately, in practice it is not always possible to satisfy all criteria, as described above. The OECD recognizes this by having a disclaimer, stating: "These criteria describe the 'ideal' indicator and not all of them will be met in practice" (OECD, 1993).

Although literature exists on environmental indicators in (sea-)ports, and thereby on the air quality of container terminals, it is difficult to find concrete examples. The indicators found in literature that deal with air quality are presented in appendix B. Notable examples include a study performed in the ports of Rotterdam and Oslo (C40 World Ports Climate Conference, 2007), environmental reports of the ports of Houston (Port of Houston, 2009) and Los Angeles (Port of Los Angeles, 2010) with very detailed emission calculations and the Port Environmental Review System (Ecoports, 2006). Regrettably, the study performed in the ports of Rotterdam and Oslo are too focused on the emissions of the Port Authority and is therefore too limited in scope to be applicable in container terminals. The studies performed in the ports of Houston and Los Angeles encompass emissions from sources in the entire port area, but are too complicated to be applied in smaller inland ports where the necessary data to perform the same calculations are unlikely to be present. Additionally, this research was unable to obtain insight into the environmental review system of Ecoports. Fortunately, a study by Geerlings & van Duin (2010) which measured the carbon footprint of container terminals in the port of Rotterdam contains a detailed framework. As a result, the framework of Geerlings & van Duin forms the basis of this research to compute emissions in inland container terminals. However, it likely needs to be modified so that it takes into account that the framework used in this study should be relatively easy to use, to understand and to apply with the data available.

APPENDIX B: Characteristics of Indicators

This appendix will briefly elaborate on the characteristics of indicators. An overview will be given of Peris-Mora's et al. (2005), the Organisations for Economic Co-operation and Development's (1993), the European Environment Agency's (2003), Niemeijer & de Groot's (2008) and Dale & Beyeler's (2001) view of 'good' indicators.

Table B1: Indicator criteria according to Peris-Mora et al. (2005)

Criterion	Description/ Explanation
Representativeness	**The indicators should represent environmental behavior as accurately as possible**
Conciseness	**The indicator should allow for the simplification of the number of variables, which characterizes a phenomenon of condensing the information with the least possible loss of information**
Purpose	**The indicator should allow an activity to be evaluated in such a way that goals are accomplished**
Usefulness	**The indicator should be a useful tool for the activity**
Relevance	**Within the environmental awareness framework**
Adaptability	**Being adapted or easily adapted to other indicators, models and prediction systems (EEA, OCDE, EC, etc.)**
Comparability	**Over time (the development of a phenomenon), and within regional, national and international frameworks**
Sensitivity	**The indicator should be sensitive to environmental changes with fast, adaptable and appropriate responses to them. Thus, they should have variable values according to the changes in the phenomenon**
Clarity	**The system should be coherent and focus on essential data. The indicators should be concise, accurate, simple and easy to interpret**
Reliability & objectivity	**In obtaining and developing the data**
Easy to obtain	**From the phenomenon being evaluated**
Continuity	**The collecting data criteria should be constant over time in order to compare results**
Regularity	**The indicators should be determined at appropriately short intervals for the purpose of having the opportunity to actively pursue and influence the desired data**

Scientific verification	**The indicator should be preferably quantitative. If this were not possible, it should be hierarchically categorized**
Well-defined limits	**The indicator should provide information about its own limitations**
Cost-effectiveness	**The indicator should be administratively efficient in terms of the costs involved in obtaining the data and use of the information**

Source: Peris-Mora et al. (2005)

Table B2: Indicator criteria concerning policy relevance and utility for users

Criterion	Description/ Explanation
Representativeness	**Provide a representative picture of environmental conditions, pressures on the environment or society's responses**
Interpretation	**Be simple, easy to interpret and able to show trends over time**
Responsiveness	**Be responsive to changes in the environment and related human activities**
Comparison	**Provide a basis for international comparisons**
Scope	**Be either national in scope or applicable to regional environmental issues of national significance**
Reference	**Have a threshold or reference value against which to compare it so that users are able to assess the significance of the values associated with it**

Source: OECD (1993)

Table B3: Indicator criteria concerning analytical soundness

Criterion	Description/ Explanation
Founded	**Be theoretically well founded in technical and scientific terms**
Standardized	**Be based on international standards and international consensus about its validity**
Usefulness	**Lend itself to being linked to economic models, forecasting and information systems**

Source: OECD (1993)

Table B4: Indicator criteria concerning measurability

Criterion	Description/ Explanation
Data cost	**Readily available or made available at a reasonable cost/benefit ratio**
Data quality	**Adequately documented and of known quality**
Data regularity	**Updated at regular intervals in accordance with reliable procedures**

Source: OECD (1993)

*These criteria describe the "ideal" indicator and not all of them will be met in practice.

The European Environment Agency (2003; p. 5) presents the following attributes of good indicators: "An indicator that communicates in a sound way a simplified reality should":

1. match the interest of the target audience
2. be attractive to the eye and accessible
3. be easy to interpret
4. invite action (read further, investigate, ask questions, do something)
5. be representative of the issue or area being considered
6. show developments over a relevant time interval (a period on which changes can be shown)
7. go with a reference value for comparing changes over time
8. go with an explanation of causes behind the trends
9. be comparable with other indicators that describe similar areas, sectors activities
10. be scientifically well-founded
11. be based on sound statistics

Niemeijer & de Groot (2008) have found and counted the following environmental selection criteria:

Table B5: Indicator criteria concerning scientific dimension

Criterion	Count	Description/ Explanation
Analytically soundness	**4**	**Strong scientific and conceptual basis**
Credible	**1**	**Scientifically credible**
Integrative	**1**	**The full suit of indicators should cover key aspects/ components/ gradients**
General importance	**1**	**Bear on a fundamental process or widespread change**

Source: Niemeijer & de Groot (2008)

Table B6: Indicator criteria concerning historic dimension

Criterion	Count	Description/ Explanation
Historical record	**2**	**Existing historical record of comparative data**
Reliability	**2**	**Proven track record**

Source: Niemeijer & de Groot (2008)

Table B7: Indicator criteria concerning systemic dimension

Criterion	Count	Description/ Explanation
Anticipatory	1	Signify an impending change in key characteristics of the system
Predictable	1	Respond in a predictable manner to changes and stresses
Robustness	1	Be relatively insensitive to expected source of interference
Sensitive to stresses	1	Sensitive to stresses on the system
Space-bound	1	Sensitive to changes in space
Time-bound	4	Sensitive to changes within policy time frames
Uncertainty about level	1	High uncertainty about the level of the indicator means we can really gain something from studying it

Source: Niemeijer & de Groot (2008)

Table B8: Indicator criteria concerning intrinsic dimension

Criterion	Count	Description/ Explanation
Measurability	4	Measurable in qualitative or quantitative terms
Portability	1	Be repeatable and reproducible in different contexts
Specificity	1	Clearly and unambiguously defined
Statistical properties	3	Have excellent statistical properties that allow unambiguous interpretation
Universality	1	Applicable to many areas, situations, and scales

Source: Niemeijer & de Groot (2008)

Table B9: Indicator criteria concerning financial and practical dimensions

Criterion	Count	Description/ Explanation
Costs, benefits and cost-effectiveness	1	Benefits of the information provided by the indicator should outweigh the costs of usage
Data requirements and availability	3	Manageable data requirements (collection) or good availability of existing data
Necessary skills	1	Not require excessive data collection skills
Operationally simplicity	2	Simple to measure, manage and analyse
Resource demand	5	Achievable in terms of the available resources
Time demand	1	Achievable in the available time

Source: Niemeijer & de Groot (2008)

Table B10: Indicator criteria concerning policy and management dimensions

Criterion	Count	Description/ Explanation
Comprehensible	2	Simply and easily understood by target audience
International compatibility	2	Be compatible with indicators developed and used in other regions
Linkable to societal dimension	1	Linkable to socio-economic developments and societal indicators
Links with management	3	Well established links with specific management practice or interventions
Progress towards targets	1	Links to quantitative or qualitative targets set in policy documents
Quantified	1	Information should be quantified in such a way that it significance is apparent
Relevance	4	Relevance for the issue and target audience at hand
Spatial and temporal scales of applicability	2	Provide information at the right spatial and temporal scales
Thresholds	1	Thresholds that can be used to determine when to take action
User-driven	1	User-driven to be relevant to target-audience

Source: Niemeijer & de Groot (2008)

Dale & Beyeler (2001) list the following criteria for ecological indicators:

1. Indicators are easily measured
2. Are sensitive to stresses on system
3. Respond to stress in a predictable manner
4. Are anticipatory: signify an impending change in the ecological system
5. Predict changes that can be averted by management actions
6. Are integrative: the full suite of indicators provides a measure of coverage of the key gradients across the ecological systems (e.g. soils, vegetation types, temperature, etc.)
7. Have a known response to natural disturbances, anthropogenic stresses, and changes over time
8. Have low variability in response

APPENDIX C: Indicators Found in Literature

In below table indicators can be seen which have been found in existing literature on sustainability, with respect to air quality. The indicators found in the environmental reports of the ports of Houston and Los Angeles are not included in this appendix, because they are too numerous and complex to describe here. However, they can be downloaded from http://www.portofhouston.com/pdf/environmental/PHA-GM-Air Emissions-07.pdf and http://www.portoflosangeles.org/DOC/REPORT_Air_Emissions Inventory_2009.pdf.

Table C1: Air quality indicators

Nr.	Potential environmental impacts	Environmental indicators
1.01	Emission of particles from storage, loading and unloading of bulk solids	Air quality (atmospheric contaminant emissions: CO, NOx, SO, O, PM10)
1.02	Emission of combustible gasses OC, NOx, SO2 and HC from vehicular traffic on land	
1.03	Emission of particles from the handling and transformation of bulk solids	
1.04	Emission of VOCs in loading and unloading combustible materials in activities with oil products	Atmospheric contaminant emissions: VOCs and particles
1.05	Emission of VOCs in storage tanks from oil product activity	
1.06	Emission of combustible gasses CO, NOx, SO2 and HC from maritime traffic	
1.07	Emission of combustible gasses CO, NOx, SO2 and HC from loading and unloading machines (cranes, water spouts, ramps, etc.) for containerised merchandise	
1.08	Emission of other gasses which are harmful for human health and/or the environment (VOCs) in building and repairing vessels	
1.09	Emission of particles from civil works	Gas emissions with Greenhouse effect (CO2, CH4, N2O)
1.10	Emission of particles from vehicular land traffic	
1.11	Emission of particles from handling general containerised merchandise	

1.12	**Emission of particles from building and repairing vessels**	
1.13	**Km driven (by car on diesel) by employees of PA**	
1.14	**Km driven (by car on petrol) by employees of PA**	
1.15	**Km driven (by car on LPG) by employees of PA**	
1.16	**Fuel (diesel) usage by operational vehicles of PA**	
1.17	**Fuel (petrol) usage by operational vehicles of PA**	
1.18	**Fuel (diesel) usage by machines and cranes of PA**	
1.19	**Fuel (diesel) usage by operational vessels of PA**	
1.20	**Fuel (natural gas) usage for heating buildings owned by PA**	
1.21	**Fuel (propane) usage for heating buildings owned by PA**	
1.22	**Fuel (oil) usage for heating buildings owned by PA**	
1.23	**Electricity usage by operations (e.g. buildings, bridges, public lightning) owned by PA**	
1.24	**Electricity usage by cranes owned by PA**	
1.25	**Electricity usage by lighthouse of PA**	
1.26	**Electricity usage from other sources of PA**	
1.27	**Electricity usage in offices of PA**	
1.28	**District heating in offices of PA**	
1.29	**Km flown for business flights**	
1.30	**Kilometers driven (by car) by commuting employees**	
1.31	**Kilometers driven (by public transport) by commuting employees**	
1.32	**Fuel (diesel) used for dredging**	
1.33	**Fuel (diesel) used for equalizing after dredging**	
1.34	**Fuel (diesel) used for construction of quays**	
1.35	**Km of new roads realized on Maasvlakte 2**	

Source: Peris-Mora et al. (2005), C40 World Ports Climate Conference (2007)

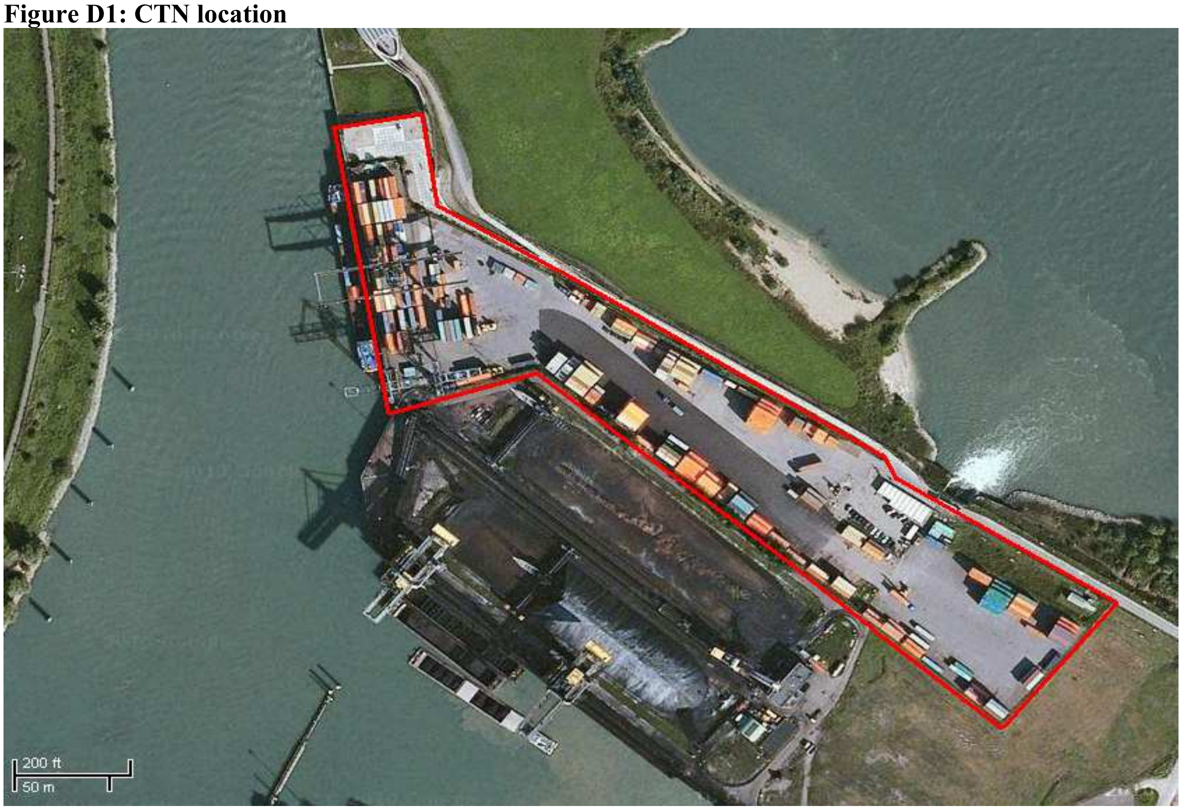
APPENDIX D: Case Study Within-Case Analysis

During the course of this thesis 4 case-studies have been undertaken. In this appendix these four cases will be individually analyzed.

1. Container Terminal Nijmegen (CTN)[7]

CTN is one of four terminals operated by Binnenlandse Container Terminals Nederland (BCTN). It is one of the first terminals that opened up activities regarding transport of containers per inland ship. Operational since 1987, it transferred approximately 140.000 TEU in 2009. CTN mainly focuses on inland container transport towards Rotterdam and Antwerpen and incidentally transports to Amsterdam. The terminal is located along the river Waal, near the entrance of the Maas-Waal canal, see figure D1 below.

Figure D1: CTN location



Source: Google maps

[7] Based on: TNO INRO (2005), http://www.bctn.nl (retrieved august 24, 2010) and personal communication with Thijs van den Heuvel (BCTN).

CTN configuration

CTN equipment consists of two barge cranes, two empty handlers and one toplifter. The containers that arrive by inland ship are transferred into a stack and then onto a truck. No other modalities are involved. The average distance from the gate to a loading / unloading location is 400 meters. In the model it is assumed that this is the average riding distance of the container handlers. Trucks are loaded by barge crane or any of the three container handlers. Therefore, the following subprocesses are recognized:

- Transshipment from inland ship to stack, or vice versa: Barge crane
- Transfer of containers from stack to truck, or vice versa: Barge crane or container handler

The deployment of equipment is explained hereafter:

Every container that is transshipped onto or from an inland ship is handled by a barge crane. The container is then placed in a stack, which is in the reach of a barge crane. When a truck arrives, either a barge crane or any of the three container handlers loads/unloads the truck. Therefore, the following deployment of equipment is modeled:

- Barge cranes handle 25% of transshipment onto trucks
- Container handlers handle 75% of transshipment onto trucks

Above configuration, in combination with the number of TEU throughput, gives the following output:

Table D1: Energy consumption CTN (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**411,485**	**281,540**	**+46.2%**
Diesel (liter)	**123,446**	**76,503**	**+62.4%**

Source: BCTN and author's own calculations

There is a striking difference between the modeled use of diesel and what is used in practice. However, there are some likely explanations for this. First, this model has been developed to model the energy use of container terminals located in the port of Rotterdam. These container terminals are not comparable to CTN, in terms of size and TEU handled. Furthermore, because of this difference in size, the equipment is used in a different manner; there are no automated guided vehicles or terminal trucks that transport the containers at CTN. However, the model assumes that this is the way that transport usually takes place at a terminal and is therefore modeled as such. However, due to the lay-out of the terminal it is plausible that driving distances of container handlers are overestimated. This causes a substantial difference in use of liters diesel. Linked to the different way of moving container on a terminal are the driving distances. In general, shorter driving distances translate into a higher average use of energy. Additionally, the equipment that uses diesel is not standardized; there are various different types of container handlers, with each a different energy use. The difference between the modeled use of electricity and the amount used in practice is also substantial. No likely explanations exist for this difference, except for the instance that the original parameter value of energy consumed for moving a container is too high. This seems to be the case, as it was mentioned in one of the interviews. There is a 25% difference between the original modeled parameter value and the value observed in practice. After adjustment the modeled consumption and consumption in practice should therefore significantly converge.

With above energy consumption, the emissions of CTN concerning the transshipment of containers are:

Table D2: Modeled emissions CTN

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	**493.8**	**654.1**	**6.00 – 7.95**
SO_x	**0.45**	**n.a.**	**0.0054**
NO_x	**5.74**	**n.a.**	**0.0698**
PM10	**0.46**	**n.a.**	**0.0056**

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

2. Bossche Container Terminal (BCT)[8]

BCT is one of four terminals operated by Binnenlandse Container Terminals Nederland (BCTN). It is currently one of the largest terminals regarding transport of containers per inland ship. Operational since 1995, it transferred approximately 220.000 TEU in 2009. BCT mainly focuses on inland container transport towards Rotterdam and Antwerpen and incidentally transports to Amsterdam. The terminal is located along the river Maas, see figure D2 on the next page.

BCT configuration

BCT equipment consists of two barge cranes, two empty handlers and one reach stacker. The containers that arrive by inland ship are transferred into a stack and later onto a truck. No other modalities are involved. The average distance of a truck from gate to a loading / unloading location is 200 meters. In the model it is assumed this is the average driving distance of the container handlers. Trucks are loaded / unloaded by barge crane or any of the three container handlers. Therefore, the following subprocesses are recognized:

- Transshipment from inland ship to stack, or vice versa.: Barge crane
- Transfer of containers from stack to truck, or vice versa: Barge crane or container handler

The deployment of equipment is explained hereafter:

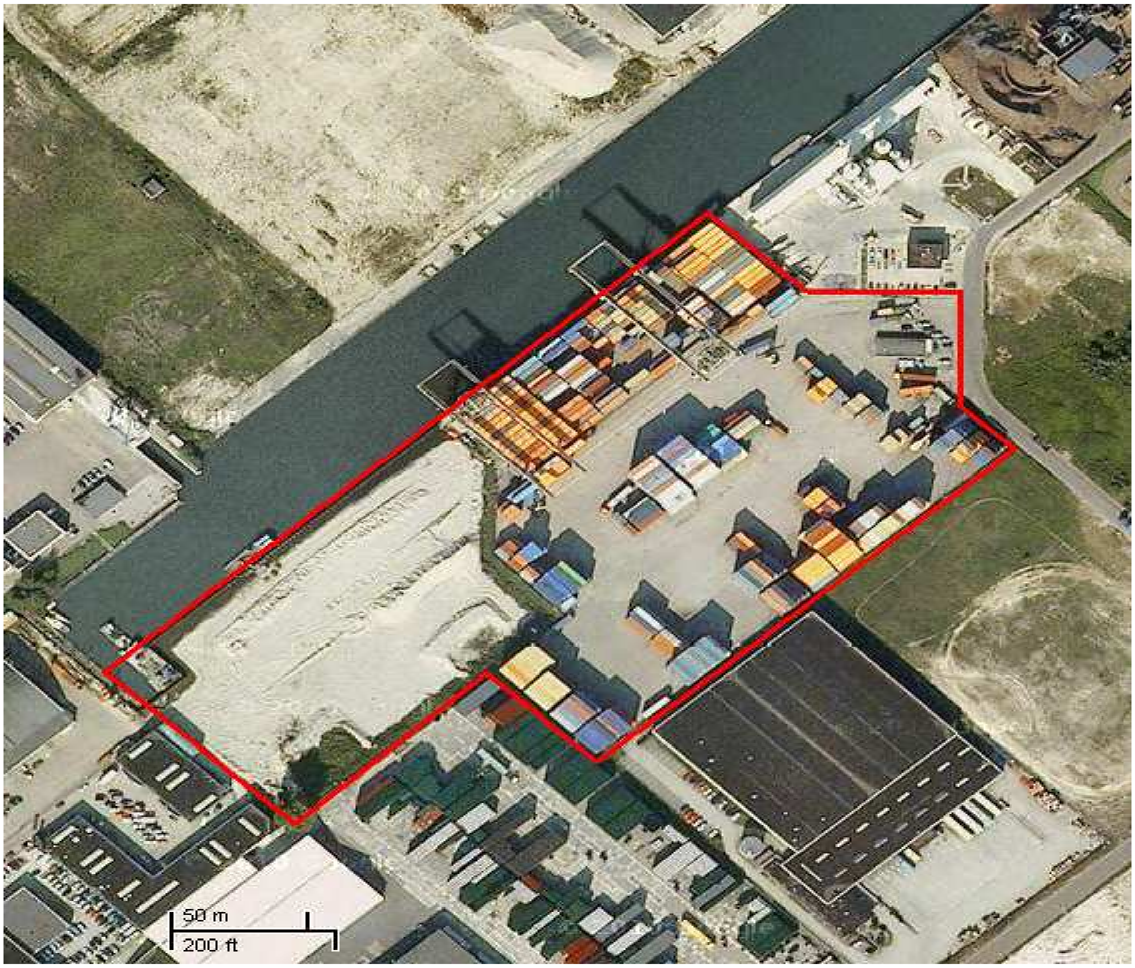
Every container that is transshipped onto or from an inland ship is handled by a barge crane. The container is then placed in a stack, which is in the reach of a barge crane. When a truck arrives, either a barge crane or any of the three container handlers loads/unloads the truck. Therefore, the following deployment of equipment is modeled:

- Barge cranes handle 25% of transshipment

[8] Based on http://www.bctn.nl (retrieved august 24, 2010) and personal communication with Thijs van den Heuvel (BCTN).

- Container handlers handle 75% of transshipment

Figure D2: BCT location



Source: Google maps

Above configuration, in combination with the number of TEU throughput, gives the following output:

Table D3: Energy consumption BCT (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**621,053**	**445,053**	**+39.5%**
Diesel (liter)	**93,158**	**101,204**	**-8.0%**

Source: BCTN and author's own calculations

The model notably improves results for the BCT terminal, regarding the use of diesel. Although the same modeling difficulties apply as with CTN, the more compact lay-out of BCT makes it less difficult to estimate the driving distances of container handlers. However, the difference in electricity consumption modeled and in practice remains considerable. This also points into the direction of the original parameter value being too high.

With above energy consumption, the emissions of BCT concerning the transshipment of containers are:

Table D4: Emission BCT

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	498.4	690.0	4.01 – 5.56
NO_x	4.65	n.a.	0.0374
SO_x	0.54	n.a.	0.0044
PM10	0.37	n.a.	0.0030

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

3. Inland Terminal Veghel[9]

ITV is a rather small inland terminal located in Veghel. Operational since 2005, it transferred approximately 27,500 TEU in 2009. ITV's main focus is on the Port of Rotterdam and incidentally transports containers to the port of Antwerp. This terminal is located along the Zuid-Willemsvaart, a canal shortcut between the Belgian part and the Dutch part of the river Maas, see figure D3 on the next page.

[9] Based on: TNO INRO (2005), http://www.inlandterminalveghel.eu/ (retrieved august 24, 2010) and personal communication with Michel van Dijk (Inland Terminal Veghel).

Figure D3: ITV location

Source: Google maps

ITV configuration

ITV equipment consists of two reach stackers. The containers that arrive by inland ship are transferred into a stack and later onto a truck. No other modalities are involved. The average distance of a truck from gate to an (un)loading location is 67 meters. In the model it is assumed this is the average driving distance of the container handlers. Trucks are (un)loaded by any of the two container handlers. Therefore, the following subprocesses are recognized:

- Transshipment from inland ship to stack, or vice versa.: Reach stacker
- Transfer of containers from stack to truck, or vice versa: Reach stacker

The deployment of equipment is explained hereafter:

Every container that is transshipped onto or from an inland ship is handled by a reach stacker. The container is then placed in a stack, from which containers are (un)loaded. When a truck arrives, any of the two reach stackers (un)loads the truck. Therefore, the following deployment of equipment is modeled:

- Reach stackers handle 100% of transshipment

Above configuration, in combination with the number of TEU throughput, gives the following energy output:

Table D5: Energy consumption ITV (modeled and actual)

Energy consumption	Model	Actual	Difference
Electricity (kWh)	**0**	**0**	**n.a.**
Diesel (liter)	**9,842**	**19,753**	**-50.2%**

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

The energy consumption modeled, as shown in table D4, differs notably from the specified quantity of diesel by ITV. Not surprisingly, since ITV only uses diesel powered equipment to move and stack containers at the terminal, while the original parameter values do no give any weight to fuel consumption by stacking containers for diesel powered equipment. Therefore, an adaptation seems necessary. The energy consumption in table D4 translates into the following emissions caused by transshipment at the inland terminal:

Table D6: Modeled emissions ITV

Pollutant	Total (minimum in tonnes)	Total (maximum in tonnes)	Per container (in kg)
CO_2	**26.1**	**31.4**	**1.76 – 2.12**
SO_x	**0.01**	**n.a.**	**0.0009**
NO_x	**0.42**	**n.a.**	**0.0287**
PM10	**0.03**	**n.a.**	**0.0023**

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

APPENDIX E: Case Study Cross-Case Analysis

During the course of this thesis 4 case-studies have been undertaken. In this appendix these cases will be compared to each other and notable differences or similarities will be analyzed.

Similarities

In general, the work processes and equipment of inland terminals, except ITV, is rather similar to each other. A truck arrives at an inland terminal, is unloaded (by either a container handler or a barge crane) and the container is placed in a stack. Subsequently, the container is transshipped from the stack onto an inland ship (by a barge crane) or vice versa. Because the work process is rather similar, the equipment present at inland terminal is also similar. There is at least one barge crane present to (un-)load inland ships and there is at least one container handler. Container handlers are either top lifters, empty handlers or reach stackers.

Additionally, the focus of the inland terminals is mainly on the port of Rotterdam. To a lesser extent these terminals are focused on either Antwerp or Amsterdam.

Differences

Disregarding obvious differences due to case study selection on the dimensions age and size (see section 3.2), notable differences exist between the inland terminal of Veghel (ITV) and the other terminals. The equipment present at ITV is such, that every truck and inland ship is (un-)loaded by container handler. This implies that there is no electric energy consumption regarding the transshipment of containers. Therefore, it is to be expected that ITV is an environmental unfriendly terminal. However, on the other hand ITV is a compact terminal, thereby likely compensating emissions due to driving distances in comparison to the other terminals.

Other notable differences among the terminals is the ship size accessibility; due to obstacles on the waterways ITV is only able to receive smaller ship types in comparison to the terminals located in Nijmegen and Den Bosch. This is related to the way ITV handles ships (no barge cranes) and most likely to the amount of TEU handled.

APPENDIX F: Emission Factors

The comparable emission factors that have been found in this research are presented in this appendix per theme. The themes are: electricity, diesel, road transport, rail transport and inland ship transport per vessel type.

Table F1: Electricity emission factors

Emission Factors (kWh)	ECN	Geerlings & van Duin	IEA	MEET	Max. difference
kWh (CO_2)	600 g / kWh	520 g / kWh	405 g / kWh	633 g / kWh	36%
kWh (SO_2)	n.a.	n.a.	n.a.	0.7 g / kWh	n.a.
kWh (NO_x)	n.a.	n.a.	n.a.	1 g / kWh	n.a.
kWh (PM)	n.a.	n.a.	n.a.	0.07 g / kWh	n.a.

Source: ECN (2001), Geerlings & van Duin (2010), IEA (2009) & MEET (1997)

Table F2: Diesel emission factors

Emission Factors (Diesel)	CBS	ECN	Geerlings & van Duin	Stichting Natuur & Milieu[10]	Stimular	Max. difference
CO_2	n.a.	2620 g / liter	2650 g / liter	n.a.	3190 g / liter	18%
SO_x	1.4 g / liter	n.a.	n.a.	n.a.	n.a.	n.a.
NO_x	n.a.	n.a.	n.a.	3452 g / liter	n.a.	n.a.
PM10	n.a.	n.a.	n.a.	42.6 g / liter	n.a.	n.a.

Source: ECN (2001), CBS (2011), Geerlings & van Duin (2010), Stichting Natuur & Milieu (2009) & Stimular (2010)

[10] Based on an average density of diesel of 840 kg/m^3.

Table F3: Truck emission factors

Emission Factors Road	CE	ECN	Royal Haskoning	Stimular	Max. difference
CO_2	643 g / km	880 g / km	1230 g / km	984 g / km	48%
SO_x	0.014 g / km	n.a.	n.a.	n.a.	n.a.
NO_x	8.4 g / km	n.a.	6.4 g / km	n.a.	24%
PM10	0.27 g / km	n.a.	0.18 g / km	n.a.	33%

Source: CE (2008), ECN (2001), Royal Haskoning (2004) & Stimular (2010)

Table F4: Railway emission factors

Emission Factors Rail	CE	Stimular
General (CO_2)	n.a.	398 g / km
Electric	n.a.	n.a.
Diesel (CO_2)	193 g / km	n.a.
Diesel (SO_x)	0.095 g / km	n.a.
Diesel (NO_x)	3.7 g / km	n.a.
Diesel (PM10)	0.071 g / km	n.a.

Source: CE (2008) & Stimular (2010)

Table F5: Inland shipping (Neo-Kempenaar) emission factors

Emission Factors Inland Shipping	CE	Royal Haskoning	Stimular	Max. difference
General (CO_2)	n.a.	n.a.	489 g / containerkm	n.a.
Neo-Kempenaar (CO_2)	10,877 g / km	11,611 g / km	n.a.	6%
Neo-Kempenaar (SO_x)	7.2 g / km	3.8 g / km	n.a.	47%
Neo-Kempenaar (NO_x)	159.4 g / km	136.2 / km	n.a.	15%
Neo-Kempenaar (PM10)	7.3 g / km	7.9 / km	n.a.	8%

Source: CE (2008), Royal Haskoning (2004) & Stimular (2010)

Table F6: Inland shipping (Rhine-Herne canalship) emission factors

Emission Factors Inland Shipping	CE	Royal Haskoning	Max. difference
Rhine – Herne canalship (CO_2)	26,499 g / km	30,258 g / km	12%
Rhine – Herne canalship (SO_x)	17.4 g / km	9.9 g / km	43%
Rhine – Herne canalship (NO_x)	388.4 g / km	350.9 g / km	10%
Rhine – Herne canalship (PM10)	17.8 g / km	20.6 g / km	14%

Source: CE (2008) & Royal Haskoning (2004)

Table F7: Inland shipping (Rhine containership) emission factors

Emission Factors Inland Shipping	CE	Royal Haskoning	IFEU Heidelberg[11]	Max. difference
Rhine ship (CO_2)	41,610 g / km	24,922 g / km	50,582 g / km	51%
Rhine ship (SO_x)	27.4 g / km	8.2 g / km	31.7 g / km	74%
Rhine ship (NO_x)	609.9 g / km	295.8 g / km	729.6 g / km	59%
Rhine ship (PM10)	27.9 g / km	17.3 g / km	21.7 g / km	38%

Source: CE (2008), Royal Haskoning (2004) & IFEU Heidelberg (2010).

Table F8: Inland shipping (JOWI containership) emission factors

Emission Factors Inland Shipping	CE	Royal Haskoning	IFEU Heidelberg	Max. difference
JOWI (CO_2)	75,920 g / km	68,902 g / km	63,000 g / km	17%
JOWI (SO_x)	49.9 g / km	22.6 g / km	40 g / km	55%
JOWI (NO_x)	1,113 g / km	864 8 g / km	1,080 g / km	22%
JOWI (PM10)	51.0 g / km	50.8 g / km	27.8 g / km	45%

Source: CE (2008) & Royal Haskoning (2004)

[11] IFEU Heidelberg differentiates only two types of inland barge containers; Rhine type barges with a dead weight tonnage of over 2000 tonnes and a category ‘others’, with a dead weight tonnage of less than 2000 tonnes.

Although the ‘Rijkswaterstaat Emissieregistratie en –Monitoring Scheepvaart’ (2003) contains an extensive study into the emissions of multiple inland ship types, the results are incomparable to the other studies presented in this thesis, due to a difference in reporting emissions (e.g. CO instead of CO_2). Therefore, they are not presented in these tables.

APPENDIX G: Example Routes Outcomes

In this appendix, the estimated emissions and the relative amount of emissions caused by transhipment in relation to the emissions in the whole transport chain, on the example routes will be shown. The routes are Rotterdam – Duisburg, one of the largest inland ports, Rotterdam – Antwerp, a prominent inland shipping route, and Rotterdam – Den Bosch, a relatively short route. The route to Antwerp is perhaps the route with the most containers shipped from Rotterdam by inland ship. The route to Den Bosch is selected to observe the impact of emissions caused by transhipment on the total amount of emissions in a transport chain.

Table G1: Relative amount of SO_x emissions caused by transshipment as part of the total emissions

Relative amount of SO_x emissions caused by transshipment	Rotterdam – Duisburg	Rotterdam – Antwerp	Rotterdam – Den Bosch
Trucking alternative	**47.7%**	**62.2%**	**69.9%**
Neo-Kempenaar	**7.6%**	**12.8%**	**21.8%**
Rhine-Herne	**9.0%**	**15.0%**	**26.2%**
Rhine	**13.7%**	**22.0%**	**42.1%**
JOWI	**15.5%**	**24.6%**	**48.4%**

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G2: Relative amount of NO_x emissions caused by transshipment as part of the total emissions

Relative amount of NO_x emissions caused by transshipment	Rotterdam – Duisburg	Rotterdam – Antwerp	Rotterdam – Den Bosch
Trucking alternative	**3.0%**	**5.3%**	**7.3%**
Neo-Kempenaar	**5.7%**	**9.7%**	**15.9%**
Rhine-Herne	**6.7%**	**11.4%**	**19.1%**
Rhine	**10.9%**	**17.9%**	**32.5%**
JOWI	**11.7%**	**19.1%**	**35.0%**

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G3: Relative amount of PM10 emissions caused by transshipment as part of the total emissions

Relative amount of PM10 emissions caused by transshipment	Rotterdam – Duisburg	Rotterdam – Antwerp	Rotterdam – Den Bosch
Trucking alternative	**7.9%**	**13.3%**	**17.9%**
Neo-Kempenaar	**8.6%**	**15.0%**	**24.9%**
Rhine-Herne	**10.0%**	**17.3%**	**29.5%**
Rhine	**16.5%**	**27.0%**	**52.3%**
JOWI	**17.1%**	**27.8%**	**54.5%**

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G4: Overview of the emissions in the total transport chain on the route Rotterdam - Duisburg

Emissions	Transport				Transshipment				Total			
	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)
Truck	195.7	3	1.7	49	5.1	2.7	0.1	4.2	200.9	5.6	1.7	54
Neo-Kempenaar	2,440	1,188	32.1	1,649	188.5	98.0	1.9	155.0	2,629	1,286	34.0	1,804
Rhine-Herne	6,158	2,965	80.2	4,166	565.6	294.0	5.8	465.0	6,724	3,259	86.0	4,631
Rhine	7,219	3,854	98.3	4,904	1,178	612.6	12.1	968.8	8,397	4,466	110.3	5,873
JOWI	15,713	7,864	214.6	10,045	2,769	1,440	28.4	2,277	18,482	9,304	243.0	13,322

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G5: Overview of the emissions in the total transport chain when transporting by truck on the route Rotterdam - Duisburg

Emissions	CO_2		SO_x		NO_x		PM10	
	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck
Neo-Kempenaar	2,628	3,781	1,286	105	34.0	32.9	1,804	1,010
Rhine-Herne	6,724	11,343	3,259	316	86.0	98.6	4,631	3,030
Rhine	8,397	23,631	4,466	658	110.3	205.4	5,873	6,312
JOWI	18,482	55,533	9,304	1,547	243.0	482.6	13,322	14,833

Source: Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G6: Overview of the emissions in the total transport chain on the route Rotterdam - Antwerp

Emissions	Transport				Transshipment				Total			
	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)
Truck	108.6	1.6	0.9	27.4	5.1	2.7	0.1	4.2	113.8	4.3	1.0	31.7
Neo-Kempenaar	1,372	668.2	18.0	881.6	188.5	98.0	1.9	155.0	1,560	766.2	20.0	1,036
Rhine-Herne	3,462	1,667	45.1	2,227	565.6	294.0	5.8	465.0	4,028	1,961	50.9	2,692
Rhine	4,058	2,167	55.3	2,622	1,178	612.6	12.1	968.8	5,237	2,779	67.3	3,590
JOWI	8,834	4,421	120.6	5,04	2,769	1,440	28.4	2,277	11,603	5,861	149.0	8,181

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G7: Overview of the emissions in the total transport chain when transporting by truck on the route Rotterdam - Antwerp

Emissions	CO_2		SO_x		NO_x		PM10	
	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck
Neo-Kempenaar	1,560	2,142	766	81	20.0	18.7	1,036	596
Rhine-Herne	4,028	6,425	1,961	242	50.9	56.0	2,692	1,788
Rhine	5,237	13,385	2,779	505	67.3	116.7	3,590	3,724
JOWI	11,603	31,454	5,861	1,187	149.0	274.3	8,181	8,752

Source: Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G8: Overview of the emissions in the total transport chain on the route Rotterdam – Den Bosch

Emissions	Transport				Transshipment				Total			
	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)	CO_2 (kg)	SO_x (g)	NO_x (g)	PM10 (g)
Truck	76.8	1.1	0.7	19.4	5.1	2.7	0.1	4.2	81.9	3.8	716.9	23.6
Neo-Kempenaar	922.0	449.1	12.1	623.2	188.5	98.0	1.9	155.0	1,111	547.1	14.1	778.2
Rhine-Herne	2,327	1,121	30.3	1,574	565.6	294.0	5.8	465.0	2,893	1,145	36.1	2,039
Rhine	2,728	1,456	37.1	1,853	1,178	612.6	12.1	968.8	3,906	2,069	49.2	2,822
JOWI	5,938	2,972	81.1	4,174	2,769	1,440	28.4	2,277	8,707	4,411	109.5	6,450

Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations

Table G: Overview of the emissions in the total transport chain when transporting by truck on the route Rotterdam - Den Bosch

Emissions	CO_2		SO_x		NO_x		PM10	
	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck	Inland ship	Truck
Neo-Kempenaar	922	1,446	449	22	12.1	12.5	623	365
Rhine-Herne	2,327	4,337	1,121	65	30.3	37.5	1,574	1,095
Rhine	2,728	9,034	1,456	135	37.1	78.1	1,853	2,282
JOWI	5,938	21,231	2,972	317	81.1	183.6	4,174	5,362

Source: Source: CE (2008), IFEU (2010), Royal Haskoning (2004) and author's own calculations