A NEW METHOD FOR ASSESSING CO_2-FOOTPRINTS OF CONTAINER TERMINALS IN PORT AREAS; CASE-STUDIES APPLIED IN THE NETHERLANDS

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ABSTRACT

At present, the notion is generally accepted that societies have to combat climate change. The reduction of CO2-emissions, an important cause for global warming, has become a priority, and consequently there is increasing pressure on governments and industries to come forward with initiatives to reduce CO2-emissions. This is highly relevant for the transport sector, as the share of transportation is still increasing, while other sectors are reducing their CO2-footprint.
The main purpose of this paper is to present a methodology to analyse the CO2-emissions from container terminals and gain a better understanding of the CO2-emissions by container terminals in port areas. With a better understanding of the CO2-emissions, more effective solutions to reduce CO2-emissions by container terminals can be identified. The study provides insight into the processes of container handling and transshipment at the terminals and calculates the contribution of these processes to the CO2-emissions (or carbon-footprint) of the container terminals. Using these insights, potential solutions to reduce the CO2 at the terminals are identified and policy proposals are made for the operators of existing terminals and for governments.

Keywords: Container terminals, CO_2-emissions, carbon-footprint, methodology

1. BACKGROUND AND OBJECTIVE OF THE STUDY

At present considerable attention is being given to climate change and global warming. Global warming is the increase in the average temperature of the Earth's lower atmosphere air and oceans that has occurred since the mid-20th century and its projected continuation. Global surface temperature risen by 0.74 ± 0.18 °C between the start and the end of the 20th century. The Intergovernmental Panel on Climate Change (UN IPCC, 1998 and UN IPCC, 2007)) concludes that most of the observed temperature increases since the middle of the 20th century has been caused by growing concentrations of greenhouse gases resulting from human activity such as fossil fuel burning and deforestation.

Consequently, there is increasing pressure on governments and industries to come forward with (more) climate-friendly strategies. The recognition of this new challenge requires new approaches that include a reconsideration of existing production and consumption processes, new policy initiatives and instruments, new data, and new supportive research activities. Aberdeen Group (Shecterle, 2008) shows in their research on the Supply Chain Executive's Strategic Agenda 2008 that the recent interest in green supply chain initiatives is robust and growing. Their study explored the main green drivers among 400 companies, and has identified specific areas of opportunity in each individual company in relation to energy usage reduction, supply chain network design and logistics optimization, and green supplier initiatives. All these elements effect the carbon-footprint of a company.

Policy initiatives to reduce CO2-emissions became a policy priority from the mid-1990s when we observe an acceleration in new policy initiatives, e.g. international arrangements under the supervision of the United Nations, such as the Kyoto Agreement (UN IPCC, 1998); supra-national agreements, such as the Biomass Action plan by the European Commission (CEC, 2005; and, for an extended inventory of European initiatives, see Geerlings and Sluis-van Meijeren., 2008) and multilateral agreements, such as the Clear Skies and Global Climate Change Initiative initiated by the Bush Administration in 2002 (US National Oceanic and Atmospheric Administration, 2002; U.S. Environmental Protection Agency, 2005).
At the same time there are numerous policy initiatives on the national level dealing with the stabilization and reduction of CO2-emissions and other greenhouse gases, mostly addressed in national policy plans.

Transport systems have significant impacts on climate change, accounting for between 20 and 25 per cent of world energy consumption and CO2-emissions (World Energy Council, 2007). Greenhouse gas emissions from transport are increasing at a faster rate than any other energy using sector (UN IPCC, 2007). In particular, the container sector is currently the fastest growing industry. Over the last years container handling has experienced an explosive growth in the Netherlands. Due to the rapidly growing flow of containers from Asia, mainly from China, and the development of a new port extension in the Rotterdam area called Maasvlakte 2, it is expected that this growth will accelerate, as it is expected that the number of container handlings will rise from 11 million per year in 2008 to 33 million per year in 2033. This growth will account for a significant increase in the contribution of CO2-emissions caused by container handling both for deepsea terminals as well as hinterland inland terminals.

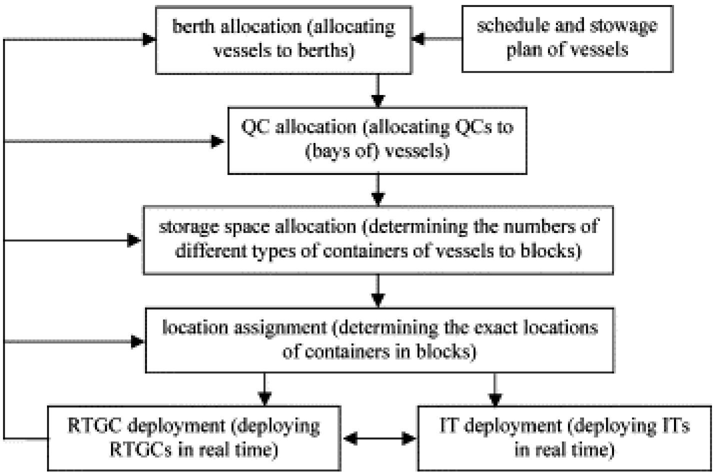
Analysing the policies announced both at national and regional (RCI) level; we observe a lack of: a clear plan, related instruments, and actions that focus on the reduction of the CO2-

emissions of this sector. A study by van der Voet (2008) specifically looked at the CO2-emissions caused by containers at the port and the possible solutions to reduce proportionate the contribution to CO2 reduction. Still there is a limited understanding of the CO2 contribution of this sector and a lack of proposed policies which might reduce the CO2-emissions in this sector. However, there is a strong pressure on the sector to become (more) sustainable. For both policy makers and the terminals it is therefore important as a first step to understand the total quantity of CO2-emissions of the different terminals, at the managerial level.

The main purpose of this article is to present a quick bottom-up methodology to analyse the CO2-emissions from container terminals in the Netherlands. The study provides insight into the processes of container handling and container transshipment at the terminals and the contribution of these processes to the CO2-emissions. On the bases of these insights and the identification of potential solutions to reduce CO2 at the terminals, policy proposals will be made for the operators of existing terminals and for governments

2. RESEARCH AND METHODOLOGY

There is extensive research related to decision making in container terminals. As Murty et al. (2005) stated in their work, all the decisions to be made at terminals are related to the berth allocation of vessels. Given the multi-criteria nature, the complexity of operations, and the size of the entire operations management problem, it is impossible to make an optimal decision that will be able to achieve the overall objectives. According to these authors the problems can be structured in a hierarchical structure, as can be seen in Figure 1.



Note: QC = Quay Cranes, RTGC = Rail (Mounted or Electrical Overhead) Travelling Gantry Cranes
Figure 1 – Hierarchical structure of operational decisions in a container terminal (Source: Murty et al., 2005.)

For each of these fields, dedicated modelling approaches can be identified. In general, two types of approaches can be distinguished: analytical and simulation. Applying the analytical approach, mostly the problem needs to be simplified to be able to formulate a mathematical model. Often the hierarchical approach is used to break the problem into sub-problems and solve each as an optimization problem (see for example, Kim and Bae, 1998; Taleb-Ibrami et

al., 1993; Castilho and Daganzo, 1993; Roux, 1996). To cope with the complexity of the terminal operations, simulation models are used to evaluate the performances. The disadvantage of simulation is time needed for building a detailed and validated model and the costs of creating a working model (see, for instance, Liu et al., 2002; Saanen, 2004; Rijsenbrij and Saanen, 2007).
Both these approaches are being developed and applied by container terminal experts who are often characterized by a strong mathematical background. However, in our paper we will focus on the policy makers and therefore the applied methodology needs to be very simple and interpretable. In this respect, we have been able to develop a simple model which can provide for understandable, reliable predictions of CO_2-emissions and energy-consumption at terminals.
The audience of Hickman and Banister (2007) are also policy makers who want to look at a future horizon of 20 years regarding transport and $C0_2$-emissions. Their backcasting method can be a helpful for policy makers who wish to reduce the CO_2-emissions to a certain desired levels. However, their method does not explain how realistic the paths to these wanted emission-levels are, and how likely it is this can be achieved. Like other studies, such as Liao et al. (2009) and Notteboom and Verminnen (2009), they do not calculate the environmental performance of the transshipment activities, but they focus only on the environmental performance of the individual transport modes. In this paper we have made a start to develop a new bottum-up methodology to estimate the environmental performance of different terminal configurations. As Ariztegui et al. (2004) make clear, one has to tackle several problems to collect real data regarding the (terminal) traffic at different hours and days, to accurately estimate the emissions, to estimate the composition of the fleet, and to estimate the mileage driven by the fleet. In the new modelling approach we present in this paper, the detailed data needed to calculate the carbon-footprint, will be estimated in such a way that environmental footprints easily can be obtained from terminal operations.

This study is therefore based on a a quantitative analysis of the impact of terminal processes and the related CO_2-emissions. The CO_2-emissions are a direct consequence of the burning of fossil fuels to generate the energy needed to operate terminal processes. The transshipment of containers takes place with the different types of equipment that are used by the terminals. The type of equipment and the use of this equipment determine the energy consumption, and consequently the amount of CO_2-emissions. For this study, an emission model is developed to provide insight into the energy of the terminal processes. The emissions derived from the transshipment processes can be directly measured via the emissions of the equipment used (measured by the amount exhaust produced by the equipment). A second possibility is the indirect determination of emissions by measuring the amount of fuel needed for the processes. The quantity of fuel directly determines the emissions, which is different for different energy sources: for example, the burning of a litre of diesel produces around 2.65 kg of CO_2 (based on the calorific value of diesel with a density of 0.835 kg/dm^3 (ECN, 2008)). Hence, understanding the energy consumption indirectly provides a picture of CO_2-emissions, and it is this method of measurement which is used in this study.

This study builds on research by Medin and Mo (2006), van Zeebroeck (2005) and Oonk (2006). Medin and Mo were involved in a research project dealing with air pollution by road transport to and from the Port of Gothenburg. They developed a method based on a methodology and procedure which are presently used by the Swedish authorities 'Network for Transport and the Environment' (www.ntm.a.se). This authority collects data on emissions from freight transport in Sweden, whereby the data are calculated according to a number of steps. Medin and Mo have calculated the emissions from road transport according to these steps. On the basis of a selection of relevant vehicles, the type of fuel and fuel consumption and the vehicle performance (energy use and emissions) are calculated. By using a GIS-system for several transport routes, distances are determined, and hence the emissions can be calculated (based on vehicle performance and distance).

The same approach was used in a research project by Transport & Mobility Leuven (van Zeebroeck, 2005). The applied methodology was used in a project that concentrated on the emissions from "non-road mobile vehicle"'. The methodology was based on inputs from several research projects dealing with emissions:

- EPA NON-ROAD USA (US EPA, 2004);
- PROMIN Netherlands (Bouwman, 1996);
- TREMOD MM Germany (Lambrecht, 2004);
- EGTEI UN-ECE (CITEPA, 2003); and
- EMEP / CORINAIR Handbook (Samaras, 1996).

None of the above-mentioned authors (who each chose their own perspective inspired by specific conditions and situations) have explicitly addressed the CO_2-emissions in relation to climate change. But they all have in common a modelling paradigm which uses activity-based emission modelling (Beckx et al., 2009). We developed our methodology by combining these different efforts. This has resulted in a new combined and more generic model. This model includes a bottom-up calculation of the amount of work supplied by equipment, not using the amount of fuel as input, but as the result of the model. Oonk (2006) also uses a similar method in a study by the Dutch research institute TNO to assess the emission of harmful gases by terminal operator ECT (European Combined Terminals) at the Delta terminal on the Maasvlakte. This includes a study of the environmental performance of an automated terminal, called the Delta terminal, compared with a more traditional manned terminal. Different from the study of Oonk (2006), we use (the macro level data such as) the number of transshipments at the terminal and the deployment of various types of equipment, each with a different energy-consumption pattern. The overall environmental performance can be calculated on the basis of average distances, coupled with standard routes and average energy consumption

3. THE MODEL

Current emissions caused by the transshipments at container terminals are mapped using an emission model (per terminal). Since CO_2-emissions are the direct consequence of energy used by the transshipment process, it is important to obtain an idea of the factors in the transshipment processes that consume energy. These factors include the equipment used by each sub-process, the energy-consumption pattern of various types of equipment, the deployment of the equipment in each sub-process, and the average distance within a sub-process. The calculation of the emissions follows a number of assumptions resulting from a study by Oonk (2006).

3.1 Input variables

The aim of this research is to obtain a quick understanding of the CO_2-emissions of a container terminal at a high level. For a quick understanding, it is important that appropriate data is freely available and easy to obtain. Therefore the following data is needed as input for the calculation of emissions:

- *The overall transshipment performance by means of the total container throughput at a terminal in one year*
  Yearly reports of container terminals are easy to obtain. In the model the overall transshipment performance expressed in containers is dealt with, or, if it is not expressed in TEUs, making a recalculation to estimate the number of containers based on the 40ft and 45ft containers. [1]

- *Modal split: the breakdown of the transshipment to the various forms of pre-and post –transport*
  The modal split is important for its share in total container throughput to the various modalities. For each type of modality the handling processes and routes of the containers are different (see also next point).

- *Terminal configuration: deployment of equipment per sub-process*
  The various transshipment processes at the terminal can vary by each type of modality. The way the processes are laid out, what type of equipment is used, and to what modalities is transhipped made, all form the terminal configuration. The container terminals use the following equipment (Oonk, 2006):

  - *Quay cranes (QCs)* are used to (un)load different types of ships. These electric cranes pick up a container directly on a tractor or automatic guided vehicle, or make the container ready for subsequent transfer to a straddle carrier.
  - *Barge cranes (BCs)* have a smaller 'reach' (range) than the above mentioned quay cranes and are suitable for (un)loading barges.
  - *Rail cranes (RCs) or gantry cranes,* can run over one or more rail-tracks. The gantry cranes can directly transfer containers at a terminal, or this can be done by a Multi-tractor trailer system next to the track.
  - *Automated Stacking Cranes (ASCs)* are unmanned-cranes that put a container into the stacking area or pick up a container from the stacking area at an AGV (see below) or prepare them for a straddle-carrier. ASCs are electrically-driven.

[1] One EU is a 20 ft equivalent unit. So a 40 and 45ft container is corrected for the lifting the weight.

- *Rail-mounted Stacking Cranes (RSCs) or gantry cranes, are* placed on rails and can move around on or off the stack to pick up or position containers.
- *Automated guided vehicles (AGVs)* are designed for the horizontal transport terminals. AGVs are unmanned vehicles and have been seen at terminals since the 1990s. Currently, most AGVs are diesel-powered hydraulic-driven.
- *ReachStackers (RS)* are the most flexible handling solutions since they are able to transport a container in short distances very quickly and pile them in various rows depending on its access.

- *Terminal layout: average distances of equipment to sub-processes*

  The energy-consumption of the equipment also depends on the distances travelled to and from the various sub-processes. The layout of the container terminal will determine these distances. Each terminal has its own design and related distances between the various locations within the terminal. The energy consumption is calculated using an average distance by type of equipment, per modality. Distances between stacks, quays, gates, etc. are derived from satellite photos (Google-Earth ©). The distance calculation is based on the Manhattan-distance-metric system. Figures 2a and 2b show an example of a distance calculation at the APM terminal on the Maasvlakte.

Figure 2a - Areal photograph of the APM terminal (Source: Google Earth©.)

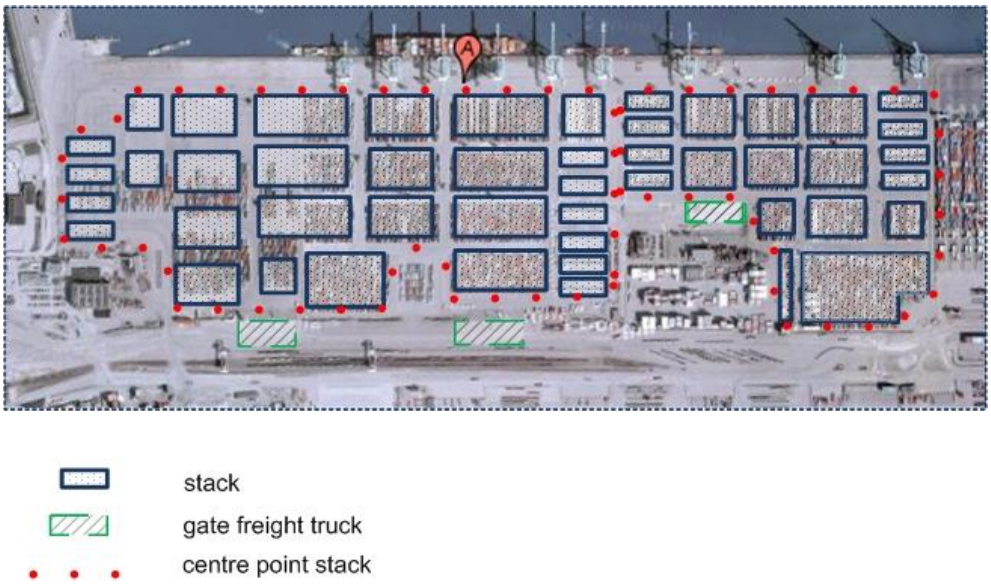


Figure 2b - Distance calculation APM-terminal (Source: van der Voet, 2008.)

In this situation, the average distance for a straddle carrier (SC) is determined between the stack and the trucking gates. At the terminal there are three gates. For the distance calculation from the gates, the distance in two directions between the gate and the centre point of the stack (or buffer zones) are determined. In this way each type of equipment has its own average distance, depending on the sub-process.

Regarding the number of movements, it should be mentioned that a distinction should be made between a “container-move” and a “ride”. A “container-move” is a movement in which only one container is moved. A “ride” is a motion of an SC, a crane or another type of equipment, which may be assigned to one or more containers.
Electrical equipment, which is often static, is assigned with a fixed consumption per ride. For diesel-powered equipment the distance is adjusted using a variable consumption depending on the distance and a fixed consumption per ride for lifting operations (for example, by SCs).

Table 1 - Energy consumption per type of equipment

Energy	Type of equipment	Fixed consumption per containermove	Variable consumption	Terminals	Source
ELECTRIC	QC: Quay Crane	6.00 kWh		ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP	(TNO, 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.

The energy consumption patterns by the various types of equipment are shown in Table 1. In addition to the emissions of the two different energy sources in the investigation (electricity and diesel), some other assumptions are made. In our research a diesel emission factor of 2.65 kg of CO_2 emissions per litre is applied. This value is based on the calorific value (42.9 MJ / kg) and emission factor (74.3 kg / GJ) of diesel (ECN, 2008) combined with a density at

150C of 0835 kg/dm^3. For the emission of electricity, an assumption is made of 0.52 kg of CO_2 emissions per kWh. This value is based on an average provided by some Dutch energy-suppliers (Groot, 2004).

3.2 Formalisation

Finally, the total CO_2-emissions of 'Terminal x' can be calculated as the total sum of emissions provided by combinations of various types of equipment (i) and their contribution to the sub-processes to tranship them to another modality (j). This leads to the next formula (1):

$$W_X = \sum_{i=1}^{11} \sum_{j=1}^{5} \left(\left(v_{i,j} \times f_D \right) + \left(P_{i,j} \times f_E \right) \right), \tag{1}$$

where:

W_x = Total weight of CO_2-emission produced at terminal x
$V_{i,j}$ = Yearly consumption of diesel in litres with equipment *i* to modality *j*
f_D = Emission factor in kilogrammes of CO_2-emission per lit diesel (= 2.65)
$P_{i,j}$ = Yearly power consumption of electricity in kWh for equipment *i* to modality *j*
F_E = Emission factor in kilogrammes of CO_2-emission per kWh (= 0.52),

combined with:

$$V_{i,j} = n_{i,j} * (C_{i,j} + c_{i,j} \bar{X}_{i,j}) \qquad \forall i, j \in T \tag{2}$$
$$P_{i,j} = n_{i,j} * (p_{i,j}) \qquad \forall i, j \in T \tag{3}$$

where:

$n_{i,j}$ = Number of rides with equipment i to modality *j*
$C_{i,j}$ = Fixed usage (for example lifting operations) per ride in litres
$c_{i,j}$ = Variable usage per km in litres (see Table 1)
$\bar{X}_{i,j}$ = Distance travelled according Manhattan-metric for equipment *i* to modality *j*
$p_{i,j}$ = Fixed usage per ride in KWh Table 1 for equipment *i* to modality *j*

Next, Table 2 shows an overview of possible combinations with different types of equipment (i) and the modalities (destinations) (j):

Table 2 - Types of equipment and transport modes at a terminal

i	i (Equipment)	j	j (mode)
1	Quay Crane (QC)	1	Inland shipping
2	Barge Crane (BC)	2	Road
3	Rail Crane (RC)	3	Rail
4	Automated Stacking Crane (ASC)	4	Shortsea
5	Rail-Mounted Stacking Crane (RSC)	5	Inter-terminal transport
6	Platform (P)		
7	Automated Guided Vehicle (AGV)		
8	Straddle Carrier (SC)		
9	Terminal Truck (TT)		
10	Multi-Trailer System (MTS)		
11	Reach Stacker (RS)		

4. APPLICATION OF THE MODEL

The selected terminals for our validation are: the Delta, Home and Hanno terminals of ECT, the APM terminal, the Rotterdam Shortsea Terminal (RST) and the Uniport Multipurpose Terminal (UNIPORT) in the Rotterdam region and three inland terminals Bossche Container Terminal (BCT), Container Terminal Nijmegen (CTN) and Wanssum Intermodal Terminal (WIT). The selection of the terminals was based on their voluntariness to provide us the necessary data to validate our model. The ECT Delta terminal and the APM terminal are the biggest terminals with a maximum load water-line of 16.60 meters and a total surface of 350 hectares. Both terminals can receive the large container-vessels up to 10,000 TEU, in future up to 12,000 TEU. The location of the terminals is close to the North Sea. The other Rotterdam terminals (ECT Home, ECT Hanno, Uniport and RST) are located in the Eem-Waalhaven area, which is 25 kilometres inland with a total surface of 157 hectares. These terminals can and have on average a maximum load water-line of 14 meters and can handle vessels up to 5500 TEU. The Hanno terminal is mainly used to educate employees for crane-drivers and straddle-carrier drivers. The other three containers are inland terminals owned the BCTN-group can handle all seizes inland vessels. The surface of each terminal varies from 3 – 4.5 hectares.
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Table 3 - Overview of selected terminals and their volumes

Terminal	Transshipment Volumes (TEU)
ECT Delta	4,260,000 (2006)
APM	2,200,000 (2006)
ECT Home	1.000.000 (2006)
UNIPORT	380,000 (2006)
RST	1,150,000 (2006)
ECT Hanno	50,000 (2006)
BCT	236,628 (2007)
CTN	169,019 (2007)
WIT	185,292 (2007)

The use of the model will first be illustrated in detail by using the case Delta terminal, and thereafter, all results obtained with the presented model will be explained in general.

4.1 Case of the Delta terminal

The Delta terminal is currently the largest and most automated container terminal in the Port of Rotterdam. The terminal is characterized by the fully-automated handling of containers from sea by means of the use of AGVs and ASCs. The landward-side processes are still mainly driven by people. The terminal covers an area of 293 hectares and has an annual cargo of 4.5 million TEUs. In 2006 the Delta terminal achieved a throughput of around 4.3 million TEUs. Of these, 3,096,129 were destined for or, originating from the hinterland with the following breakdown on the modalities:

• Road 49%
• Inland 34%
• Rail 17%

In Figure 3 below is a satellite-view of the Delta terminal (light part) is shown.

Figure 3 - Aerial photograph of the ECT Delta terminal (Source: Google Earth©)

The terminal configuration describes the establishment of the various sub-processes. The pivot of the sub-processes is the stack. Depending on the modality, the use of terminal equipment varies. At the Delta terminal, the following sub-processes can be distinguished:

• Throughput from the sea to stack, vice versa: QC> AGV> ASC;
• Transshipment of inland waterways to stack, vice versa: QC> AGV> ASC
  or BC> MTS> SC> ASC;
• Throughput on the way to stack, vice versa: SC> ASC;
• Transshipment of rail to stack, vice versa: RC> MTS> SC> ASC;
• Inter-terminal transport (Stack - Stack): (ASC> SC>) MTS> SC> ASC.

The deployment of equipment has already been provided in the investigation of Oonk (2006) and can follow a matrix display (see Table 4). The matrix clarifies what the contribution of each type of equipment is per container-move. A '1' means that this type of equipment is fully-used for each container-move; and a '0.2' means that this type of equipment is used only once per (on average) 5 container-moves. What is also important for the determination of emissions is the average distances covered by the various types of equipment. For the Delta terminal, these average distances are known from the investigation by Oonk (2006). These have been incorporated into our study.

Table 4 - Equipment contribution per type of modality

	SEA	BARGE	ROAD	RAIL	ITT
QC	1	0.71	0	0	0
BC	0	0.29	0	0	0
	0	0	0	1	0
ASC	1	0	1	1	1
RSC	0	0	0	0	0
P	0	0	0	0	0
AGV	1	0.71	0	0	0
SC	0	0.29	1	1	0.9
TT	0.02	0.01	0	0.02	0.1
MTS	0	0.06	0	0.2	0.18
RS	0.02	0.01	0.02	0.02	0.1

Note: an explanation of the abbreviations, see Table 2

The emission results can be found in Figures 4a and 4b below. In addition, the actual consumption of the terminal in 2006 and the observed differences in energy consumption of the model are compared with the actual energy consumption of the terminal (really measured in practice!) in Table 5.

Table 5 - Energy consumption estimated by the model (= result) versus actual performance (= provided by the terminal)

	Estimates	Real consumption	Difference
Diesel	15,005,338 litres	17,654,322 litres	-15.0 %
Electricity	45,503,821 kWh	47,142,857 kWh	- 3.5 %

The deviations of 15 and 3.5 per cent are relatively small in the context of the investigation, and this, combined with the easiness of methodology, indicates that the model and the related methodology model provide acceptable estimates.
The total energy consumption produced CO_2-emissions of 63.43 tonnes per year. Conversion to TEUs for 40ft and 45 ft containers implies, respectively, 24.55 and 14.88 kg per kg move. The emissions per type of equipment and the total sums of the equipment used by modality are shown in Figures 4a and Figure 4b. The annual emissions are shown in blue, indicating the proportion of the total emissions of the terminal. The emissions per container are shown in red.

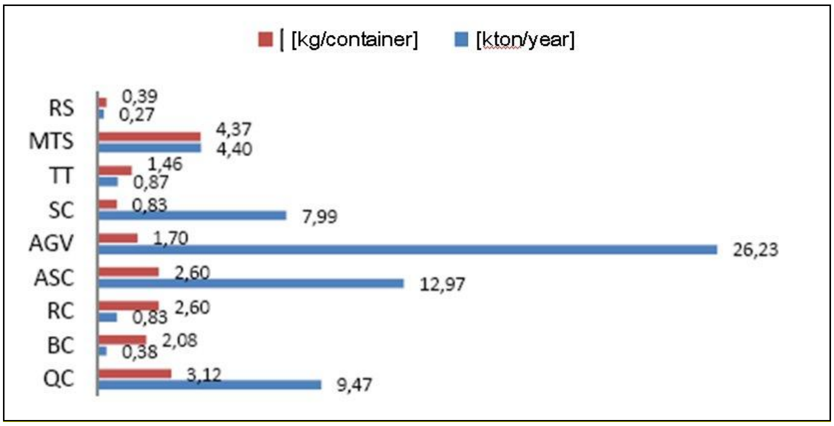

Figure 4 a - CO_2-emissions per type of equipment

Figure 4a clearly shows clearly that the AGV is the most energy-consuming of the Delta-terminal.

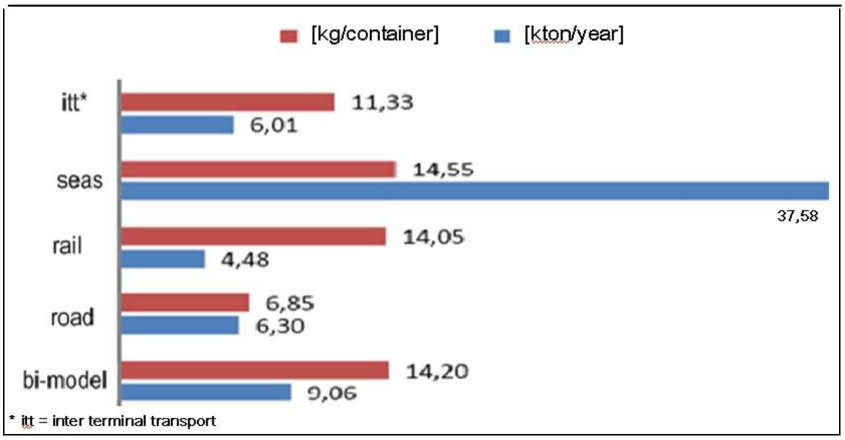

Figure 4 b - CO_2-emissions per mode

Because of the large volumes of sea transport we can also clearly observe in Figure 4b that the facilitating processes produce the largest weight of CO_2 (see 'seas' in Figure 4b).

4.2 Application of the model to all terminals

To validate our model the explained way of working in the case Delta terminal has been applied to all terminals. Our first modelling results shown in Table 6 indicate only limited deviations from the actual consumption of the terminals. This is a first encouraging indication for the possibility of a further application of the model in researching other ports and terminals.

Table 6 a and b - Energy consumption (6a=Diesel, 6b=Electricity) estimated by the model (= result) versus actual performance (= provided by the terminal)

	Terminal	Model Estimates			Real consumption			
		l/year	*l/TEU*	*l/cont*	*l/year*	*l/TEU*	*l/cont*	*difference %*
Diesel	ECT Delta	15,005,338	3.52	5.81	17,654,322	4.14	6.83	-15.0
	ECT Home	4,577,564	4.40	7.27	4,190,952	4.03	6.65	9.2
	ECT Hanno	324,718	5.62	9.28	684.000	11.84	19.54	-52.5
	APM	11,827,265	5.38	8.87	Unknown			
	RST	2,285,928	2.29	3.78	1.900.000	1.65	2.72	20.3
	UNIPORT	1,366,188	3.87	5.73	1.100.000	2.91	4.32	24.2
	BCT	90,222	0.38	0.58	99,788	0.42	0.64	-9.6
	CTN	69,099	0.41	0.69	61,429	0.36	0.61	12.5
	WIT	140,731	0.76	1.35	154,390	0.83	1.48	-8.8

	Terminal	Model Estimates			Real consumption			
		kWh/year	*kWh/TEU*	*kWh/cont*	*kWh/year*	*kWh/TEU*	*kWh/cont*	*difference %*
Electricity	ECT Delta	45.503,821	10.67	17.61	47,142,857	11.06	18.25	-3.5
	ECT Home	4.691,736	4.51	7.45	7,500,000	7.22	11.90	-37.4
	ECT Hanno	640,544	11.09	18.30	1,250,000	21.65	35.71	-48.8
	APM	10,489,636	4.77	7.87	Unknown			
	RST	9,498,600	8.24	13.59	11,000,000	9.54	15.74	-13.6
	UNIPORT	6,313,260	16.70	24.78	6,960,000	18.41	27.31	-9.3
	BCT	480,401	2.03	3.10	505,976	2.13	3.25	-4.7
	CTN	301,276	1.78	2.99	315,501	1.87	3.13	-4.5
	WIT	232,628	1.26	2.23	219,788	1.19	2.11	5.8

From the Tables 6a and 6b we can be observe that the model outcomes for the ECT Hanno differ significantly (-52.5% and 48.8%). The explanation for this difference can be found by the fact that this terminal is used as an educational terminal for cranes-drivers. This means that for this terminal, the energy consumption of the cranes does not represent the number of container moves, since the exercise-movements are not recorded.

By multiplying the consumption data with the emission factor for diesel and electricity, the total CO_2 production of a terminal will be known. For the selected terminals the total CO_2 production is around 157 kton. With respect to the sea container terminals one can see clearly that the RST produces a significant lower level of CO_2, both in diesel and electricity consumption. This can be explained while the terminal is relative new and it has a very compact design. The influence of the spatial design (the lay-out) can be clearly observed from the small inland barge terminals. The contribution of the driven kilometers by the fork trucks/ reach stackers (type Hyster H18), combined with inter terminals transport, are extremely less compared to the travelled distances at the large seaport-terminals.

Table 7 - Yearly CO_2 production per terminal

Terminal	CO_2 Kton/year (actual)	CO_2 Kton/year (model)	CO_2 kg/TEU based on diesel	CO_2 kg/TEU based on electricity
ECT Delta	71.3	63.4	9.33	14.88
ECT Home	15	14.6	11.67	14.02
ECT Hanno	11.9	24.6	14.90	20.67
APM		35.9	14.03	16.34
RST	10.9	10.7	5.25	9.54
UNIPORT	6.9	6.5	9.58	18.26
BCT	0.53	0.52	1.1	1.1
CTN	0.33	0.32	1.0	1.0
WIT	0.46	0.52	2.2	0.7

To validate the model, some statistical testing has been carried out to check the correlations between our inputs, the moves of the terminal equipment and the variables to be explained: the diesel consumption and the electricity consumption. Due to the limited number of observations (n=9) no hard conclusions can be drawn; however they can indicated whether the modelling formulations are based on correct assumptions. With the statistical testing, the discussion that the model might lucky predict well is no longer valid and it proves that our approach is based on a set of well selected and highly significant indicators.

Table 8 - Correlation testing Electricity and Diesel

	Usage (terminal)	QCmoves	BCmoves	RCmoves	ASCmoves	RSCmoves	Pmoves
Sig. (1-tailed)	0.0000	0.000	0.060	0.000	0.000	0.494	0.459
	Usage (terminal)	**AGVkms**	**SCkms**	**TTkms**	**MTSkms**	**RSkms**	
Pearson Correlation	1.0000 Diesel	0.973	0.628	0.100	0.964	0.078	
Sig. (1-tailed)	0.0000	0.000	0.048	0.407	0.000	0.428	
N	9	9	9	9	9	9	9

Table 8 contains the correlations between the dependent variable usage terminal. As can be observed QCmoves, BCmoves, RCmoves en ASCmoves have a strong correlations with the dependent variable: Usage Electricity, showing a significance at a 5 percent significance-level. The variables RSCmoves en Pmoves show very little correlationship and both show no significance. The variables AGVmoves, AGVkms, SCmoves, SCkms en RSkms have also strong correlation with the dependent variable diesel usage. They all show a significant correlationship. However the variables TTkms en RSkms have little correlationship and show no signficant results. With respect to non significant variables it seems very logical since their contributions are relative small (varies from 0.05 - 0.1) with respect to the large container volumes handled by other equipments. Regressions analysis has been applied on the data, however the statistical analysis gave similar insights with respect to the Spearman-correlation-tests.

5. POLICY IMPLICATIONS

From a theoretical perspective, the CO_2-emissions of container terminals can be addressed in three different ways:

- By reducing the impact of specific modes through technological means, e.g. vehicle design, hybrid vehicles, engine technology, improved energy efficiency, etc.
- By shifting to less damaging modes of transport or forms of behaviour, e.g. alternative fuels, driving stile, etc.
- By reducing the total amount of transport undertaken, e.g. optimal terminal layout and organisational measures.

The most effective measure for CO_2 reduction is undoubtedly the adaptation of the terminal layout, as clearly is shown in the examples of the Rotterdam Shortsea terminal (RST) and the inland terminals CTN, BCT and WIT. This would make it possible to reduce the CO2-emissions of the current terminals by nearly 70 per cent. However, this measure is by far, the most costly option if changes in the spatial design will be implemented and the implications in terms of operation performances and terminal configurations will also be significant. An application of this measure to the current terminals is therefore, in the short term, probably not realistic.

The other two policy proposals to reduce CO_2-emissions from the existing terminals may be simpler, but their impacts are far less.

The first perspective is the establishment of policies which aim at replacing obsolete equipment by new (state-of-the-art) equipment, which can achieve a 20 per cent reduction in CO_2-emissions if all diesel-powered equipment is replaced by equipment that operates 20 per cent more efficiency. This policy is applied at the new Euromax terminal of ECT, where all new equipment is diesel-electric according to the latest state-of-the-art and that can in the future transformed towards hydrogen as energy sources. This is the inspiration for a replacement schedule on the other terminals as well that are present in operation.

The second perspective is the shift to less damaging modes of transport or alternative fuels, etc. Extensive research has been done by the terminal operators and the Rotterdam municipality (in the context of RCI) after the opportunities offered by renewable energy, such as wind and solar energy or by means biomass. None of these options are at this moment feasible, due to a wide variety of barriers varying from financial and economic barriers to institutional, political or legislative barriers. A significant effect can be achieved by the measure of mixing 30 per cent bio fuels with the presently used diesel. This results in a reduction of CO_2-emissions by between 13 and 26 per cent per terminal and a reduction of the emissions of the whole container sector by 21 per cent. When 30 per cent of the diesel is composed of blended bio fuel, then the CO_2 levels by using diesel are also 30 per cent lower per litre of fuel consumed. In that model, this can easily be simulated by adjusting the CO_2-factor for diesel from 2.65 to 1.86 kg/l. Table 9 shows what causes these differences in the total emissions of CO_2 from the various container terminals. The calculations for the inland terminals are omitted since their CO_2 productions are negligible small (*see Table 7*). A blend of 30 per cent with the diesel ensures that the terminals have an emission reduction ranging from 4.5 to 8.6 per cent. If this measure is taken, then the APM terminal, which mainly uses diesel-powered straddle carriers, would have a greater reduction in emissions than, for example, the Uniport terminal where the share of electrical equipment is significantly higher in the total throughput. The latter measure is the most obvious and easiest to implement since its implementation is already underway for road. Table 9 below shows the current emissions of CO_2 and the situation in the year 2025 after the implementation of the proposed measures.

Table 9 - Emissions of CO_2 after the implementation of policies

	Present (2006)	**Compact terminal**		**Fast replacement diesel equipment**		**30%blending with diesel**	
	Emission [ktonyear]	*Emission [ktonyear]*	*Difference compared to 2006*	*Emission [ktonyear]*	*Different compared to 2006*	*Emission [ktonyearr]*	*Difference compared to 2006*
Delta	71,30	23,81	-67%	55,47	-22%	57,35	-20%
Home	15,01	5,40	-64%	12,14	-19%	11,70	-22%
Hanno	1,20	0,26	-78%	1,03	-14%	0,94	-22%
APM	35,95	10,69	-70%	29,77	-17%	26,74	-26%
RST	10,76	5,99	-44%	9,79	-9%	9,25	-14%
Uniport	6,53	2,49	-62%	6,18	-5%	5,67	-13%
Total	*140,75*	*48,68*	*-65%*	*114,38*	*-19%*	*111,65*	*-21%*

These findings are the basis for clear recommendations for policies aimed at reducing CO_2-emissions at container terminals.

The associated results are described in the following three alternative policy proposals:

- *Construct compact terminals*.

The aim of compact terminals is to reduce the horizontal transporting terminals by repositioning the stacks directly at the quayside. Terminals should be designed in accordance with the principle of the Rotterdam Shortsea Terminal. This provides an energy conservation in the following transshipment process (and thus a reduction in CO_2- emissions) while also saving space. The disadvantage of this measure is that those terminals which require considerably more quay-length for export under this model cannot operate.

- *Fast replacement of (diesel-powered) terminal equipment*.

The aim of this policy is to increase the efficiency of the equipment of the terminals. By means of a subsidy, outdated diesel equipment replacement can be accelerated. The energy consumption of the diesel equipment then drops significantly and hence the related CO_2-emissions. The basis for the legitimacy of this measure is the assumption that the diesel equipment being used in the year 2025 will use 20 per cent less diesel on average, compared with the current use of diesel.

• *Blending biofuels*. This policy is directed towards the reduction of the emissions of diesel fuel. By blending biofuels with diesel, the emissions of diesel will be reduced, which means in particular that the CO_2 produced per litre of diesel used, will be reduced. The idea is that with an equal transshipment performance, CO_2 -emissions will fall by 30 per cent if a blending of 30 per cent biofuels with diesel is realised in 2025.
As can be observed in Table 9 each of these proposals will have their own clear effect on emissions of CO_2.

The potential of these measures, though not insubstantial, is likely to be eroded by a few years of further growth. For the longer term additional action will therefore be required. Technologically, the area of greatest potential is that of new fuels, with respects for biofuels, hydrogen, and various forms of electric power. But at the moment they are too expensive and not ready for the market.

6. CONCLUSIONS

The developed bottom-up methodology provides new opportunities for a relatively simple assessment of the CO_2-emissions per terminal, based on macro terminal data and can be adopted reasonably well and simply for different terminal configurations. This is a first and promising step, but the reliability of the model should be verified by further research on a larger sample of terminals, however the number of deep-sea terminal operators is limited as we observe that this research covered already 95 per cent of all the deep sea terminals in the Port of Rotterdam. Therefore it is important to note that the first estimates with the developed methodology provides reliable predictions for the total CO_2-production at terminals and the differences to the real consumption energy consumption data are within an acceptable range.

With respect to the mitigation of CO_2-emissions, the analysis of the emission model shows that, compared with the electrically powered equipment, the diesel-powered terminal equipment represents a large fraction of the total harbour wide CO_2-emissions by transshipment processes. Furthermore, it is noticeable that the Rotterdam Shortsea Terminal and the inland barge terminals emit considerably less CO_2-emissions per container handling. The main difference with the other terminals is the procedure; these terminals work on a principle whereby the stacks (locations where containers are stored temporarily) are positioned directly at the quayside. This method of unloading ensures that there is much less horizontal transport needed at the terminal, which ultimately, is more efficient. However one can imagine that the design of these terminals is only possible with less container volumes and steady arrival patterns of the vessels. Therefore the related policy alternative *‘Compact terminal’* can only be applied for new terminals (for instance, in the new Port extension area Maasvlakte 2). It is recommended that the layout of the terminal site and the energy consumption of equipment should be considered, when it comes to the design of new terminals. Further research into the precise costs and the technical and administrative consequences is also needed before implementing this measure.

For the existing container terminals, the alternatives of '*Fast replacement of diesel equipment*' and '*Blending sustainable biodiesel fuels*' can be easily implemented and will lead to significant decreases in CO_2-emissions. For the longer term additional action is required. The area of greatest potential is that of various forms of electric power, based on hydrogen, biomass, solar and wind. But at the moment renewable-derived electricity does not look of importance for the container terminals. It is recommended that further research should be conducted with these alternatives, especially with respect to the costs, technical and administrative consequences and the sustainable sensitivities such as food supply in developing countries and the Life Cycle Analysis (LCA)-impacts.

Are the terminal operators *'Penny wise, pound foolish'*? At the end of this paper one should keep in mind that the share of CO_2-emissions from the container transshipment in Rotterdam (140 Kton in 2006) is less than 1 per cent of total CO_2 emissions in the "World Capital of CO_2-free energy". It should be examined to what extent large investments in this sector, with that aim to realise a significant CO_2 reduction, are sensible. But as we see that all other sectors are able to reduce their carbon-footprint, this methodology can contribute to a new discussion, based of serious facts and figures.

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