ESTIMATING CO_2 FOOTPRINTS OF CONTAINER TERMINAL PORT-OPERATIONS

J.H.R. VAN DUIN[1] & H. GEERLINGS[2]
[1]Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands.
[2]Department of Public Administration/Erasmus Smart Port, Erasmus University Rotterdam, Rotterdam, The Netherlands.

ABSTRACT

At present there is increasing pressure on governments and industries to come forward with initiatives to reduce CO_2 emissions. This is particularly relevant for the transport sector, as the share of transportation is still increasing, while other sectors are reducing their CO_2 footprints.

The main purpose of this paper is to present a methodology to analyze the CO_2 emissions from container terminals and gain a better understanding of the CO_2 emissions by container terminals in port areas. With a better understanding of the CO_2 emissions, more effective solutions to reduce CO_2 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 CO_2 emissions (or carbon footprint) of the container terminals. The model was validated by application on 95% of all sea and inland container terminals in the Netherlands.

Keywords: carbon footprint, CO_2 emissions, container terminal, modeling.

1 INTRODUCTION

In the mid-1990s we observed a first recognition of policy initiatives reducing CO_2 emissions. From that moment on there is an acceleration in new policy initiatives, e.g. international arrangements under the supervision of the United Nations, such as the Kyoto Agreement [1]; supra-national agreements, such as the Biomass Action plan by the European Commission ([2]; and, see for an extended inventory of European initiatives [3]) and multilateral agreements, such as the Clear Skies and Global Climate Change Initiative initiated by the Bush Administration in 2002 [4, 5].

At the same time there are numerous policy initiatives on the national level dealing with the stabilization and reduction of CO_2 emissions and other greenhouse gases, mostly addressed in national policy plans. Consequently, there is increasing pressure on industries as well 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 [6] showed 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 affect the carbon footprint of a company.

From a sectoral perspective it is noted that transport systems have significant impacts on climate change, accounting for 20–25% of world energy consumption and CO_2 emissions [7]. Greenhouse gas emissions from transport are increasing at a faster rate than any other energy-using sector [8]. In particular, the container sector is currently the fastest growing industry (despite the last two crises years). Especially in the Netherlands over the last 10 years, container handling has experienced an explosive growth. 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

ISSN: 1743-7601 (paper format), ISSN: 1743-761X (online), http://journals.witpress.com
DOI: 10.2495/SDP-V6-N4-459-473

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 CO_2 emissions caused by container handling both for deep-sea as well as hinterland inland terminals.

Analyzing the policies announced both at national and regional level [9] we observe a lack of a clear plan, related instruments, and actions that focus on the reduction of the CO_2 emissions of this sector. There is a serious knowledge gap since there is almost no understanding and knowledge of the CO_2 production of this sector. Especially terminal operators do not have any idea how to perform a CO_2 footprint. Therefore, for policymakers it is even more difficult to address proper policies which might reduce the CO_2 emissions since they don't know what the most polluting factors in this sector are. However, there is a strong pressure on the sector to become (more) sustainable. As a first step, both for policy makers and terminal operators, it is therefore important to understand the total quantity of CO_2 emissions of the different terminal configurations, at the managerial/policy level.

Therefore, in this paper the research goal is how to develop a methodology that can predict the total CO_2 emissions at terminals. This article presents a quick bottom-up methodology to estimate the CO_2 emissions from container port terminals based on fuel and energy consumption. The study provides insight into the processes of container handling and container transshipment at the terminals and calculates the contribution of these processes to the CO_2 emissions. The estimates are validated for sea and inland container terminals in the Netherlands. On the basis of these insights and the identification of potential solutions to reduce CO_2 at the terminals, policy proposals can be made for the terminal operators and governments.

2 LITERATURE OVERVIEW

There is extensive research related to decision making in container terminals. As Murty *et al.* [10] stated in their work, all the decisions to be made at terminals are related to the berth allocation of vessels. No contributions can be found with respect to the emissions of terminals. Considering our audience of policymakers and terminal managers, our methodology should provide good estimates of the emissions and the applied methodology, as a consequence, needs to be very simple and interpretable instead of a methodology based on difficult mathematical equations. 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.

In literature the next contributions can be found related to transport and environmental performance. The audience of Hickman and Banister [11] consists of policy makers who want to look at a future horizon of 20 years regarding transport and CO_2 emissions. Their back-casting method can be helpful for policy makers who wish to reduce the CO_2 emissions to a certain desired level. However, their method does not explain how realistic the paths to these wanted emission levels are, and how likely it is that this can be achieved. Like other studies, such as Liao *et al.* [12], Lodewijks and Wellink [13], and Notteboom and Verminnen [14], 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 bottom-up methodology to estimate the environmental performance of different terminal configurations. As Ariztegui *et al.* [15] makes 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. The new model presented here will be estimated in such a way that environmental footprints easily can be obtained from terminal operations.

This study builds on research by Medin and Mo [16], van Zeebroeck [17], and Oonk [18]. Medin and Mo [16] have calculated the emissions from road transport on the basis of a selection of relevant vehicles, the type of fuel and fuel consumption. 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 [17]. The applied methodology was used in a project that concentrated on the emissions from 'non-road mobile vehicle'.

Most of these research contributions share the same modeling paradigm based on activity-based emission modeling [19]. We have applied this modeling paradigm to develop a methodology for the calculation of emissions caused by the container terminals, i.e. terminal-equipment. 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 [18] 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 [18], which can be seen as an advantage, our model uses 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, coupled with standard routes with average distances, and average energy consumption (see Fig. 1). A disadvantage of the model could be too rough estimates of the energy consumptions and related environmental performance. However, the quality of the estimations by our methodology will be validated on the real energy consumption figures of the selected terminals.

This study is therefore based on a quantitative analysis of the energy consumption of terminal processes and the related CO_2 emissions. The CO_2 emissions are a direct consequence of the burning

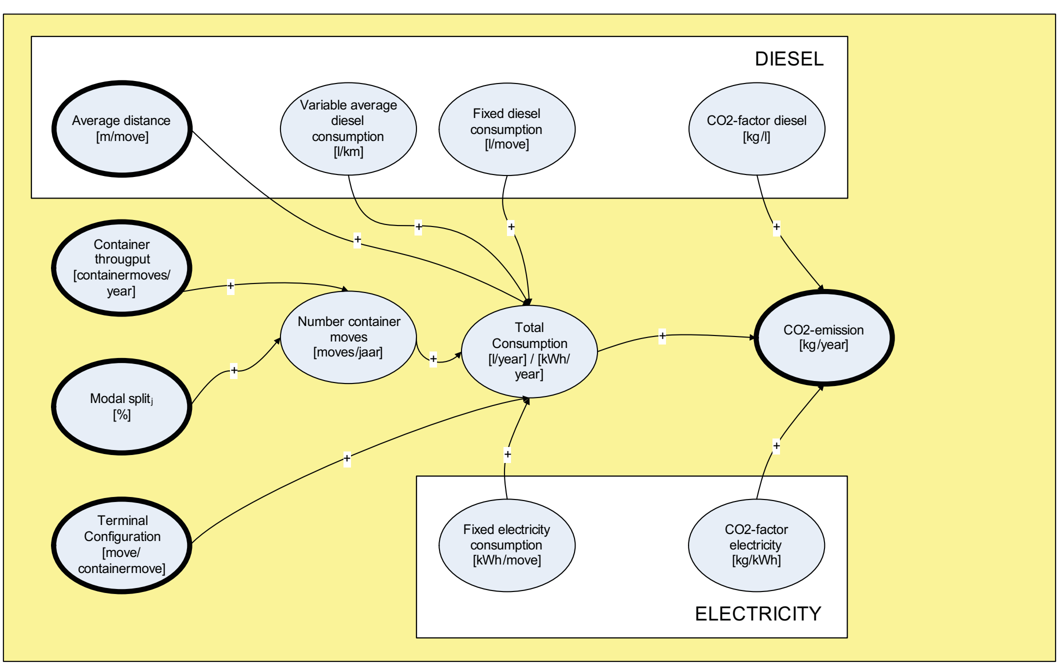

Figure 1: The conceptual model for calculating CO_2 emissions at terminals.

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. The quantity of fuel directly determines the emissions, which is different for different energy sources: for example, the burning of a liter 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) [20].

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 processes, 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.

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 macro 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 (see Fig. 1):

- *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 40 ft and 45 ft containers.
- *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 are transshipped, are all part of the terminal configuration. Container terminals can use the following equipment [18]:
  - *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.

- ○ *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.
- ○ *Reach Stackers (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. Figure 2 shows an example of a distance calculation at the APM terminal on the Maasvlakte.

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 center 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

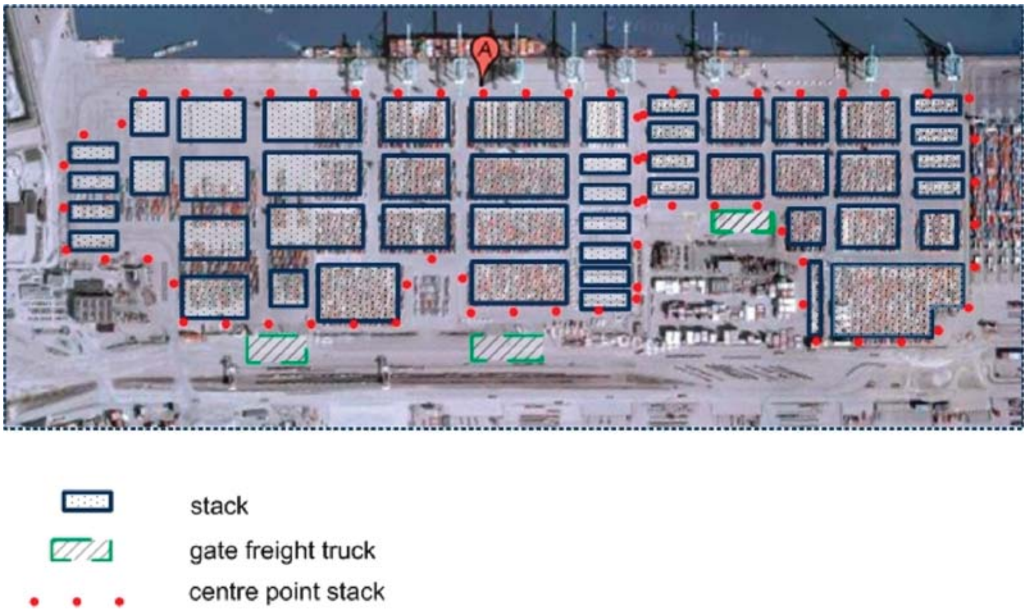

Figure 2: Distance calculation APM-terminal. Source [21].

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).

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 liter is applied. This value is based on the calorific value (42.9 MJ/kg) and emission factor (74.3 kg/GJ) of diesel [20], combined with a density of 0.835 kg/dm^3 at a temperature 15°C. 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 Dutch energy suppliers [22].

Table 1: Energy consumption per type of equipment.

Energy	Type of equipment	Fixed consumption per container-move	Variable consumption	Terminals	Source
Electric	QC: Quay Crane	6.00 kWh		ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP	[18]
	BC: Barge Crane	4.00 kWh		ECT-D, APM, BCT, CTN, WIT	[18]
	RC: Rail Crane	5.00 kWh		ECT-D, APM	[18]
	ASC: Automated Stacking Crane	5.00 kWh		ECT-D	[18]
	RSC: Rail-mounted 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	[18]
	SC: Straddle Carrier	0.80 l	3.50 l/km	ECT-D, ECT-Ho, APM, RST	[18]
	TT: Terminal Tractors		4.00 l/km	ECT-D, ECT-Ho, ECT-Ha, RST, UNP	[18]
	MTS: Multi-trailer System		4.20 l/km	ECT-D, ECT-Ho, APM, UNP	[18]
	RS: Reach Stacker/Top Lifter		5.00 l/km	ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP, BCT, CTN, WIT	[18]

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

3.2 Formalization

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 transship them to another modality (j). This leads to eqn (1):

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

where:

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

combined with:

$$V_{i,j} = n_{i,j} * (C_{i,j} + c_{i,j} \bar{X}_{i,j}) \ \forall^{i,j} \in T \quad (2)$$

$$P_{i,j} = n_{i,j} * (p_{i,j}) \ \forall^{i,j} \in T \quad (3)$$

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 liters
$c_{i,j}$ = Variable usage per km in liters (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

To validate the model the next 12 terminals have been selected: the Delta, Home and Hanno terminals of ECT, the APM terminal, the Rotterdam Short sea 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 willingness 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 other Rotterdam terminals (ECT Home, ECT Hanno, Uniports and RST) are located in the Eem-Waalhaven area, which is 25 km inland with a total surface of 157 hectares. These terminals 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 by the BCTN group can handle all seizes inland vessels. The surface of each terminal varies from 3 to 4.5 hectares.

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

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)

Figure 3: Aerial photograph of the ECT Delta terminal. Source: Google Earth©.

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
RC	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 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 [18] 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 [18]. These have been incorporated into our study.

The emission results can be found in Figs. 4a and b 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.

The deviations of 15% and 3.5% are relatively small in the context of the investigation, and this, combined with the easiness of methodology (usage of macro data), 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 45ft containers implies, respectively, 24.55 kg 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 Figs. 4a and b. 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 4a clearly shows that the AGV is the most energy consuming of the Delta terminal. Because of the large volumes of sea transport, we can also clearly observe in Fig. 4b the facilitating processes produce the largest weight of CO_2 (see *‘seas’ in* Fig. 4b).

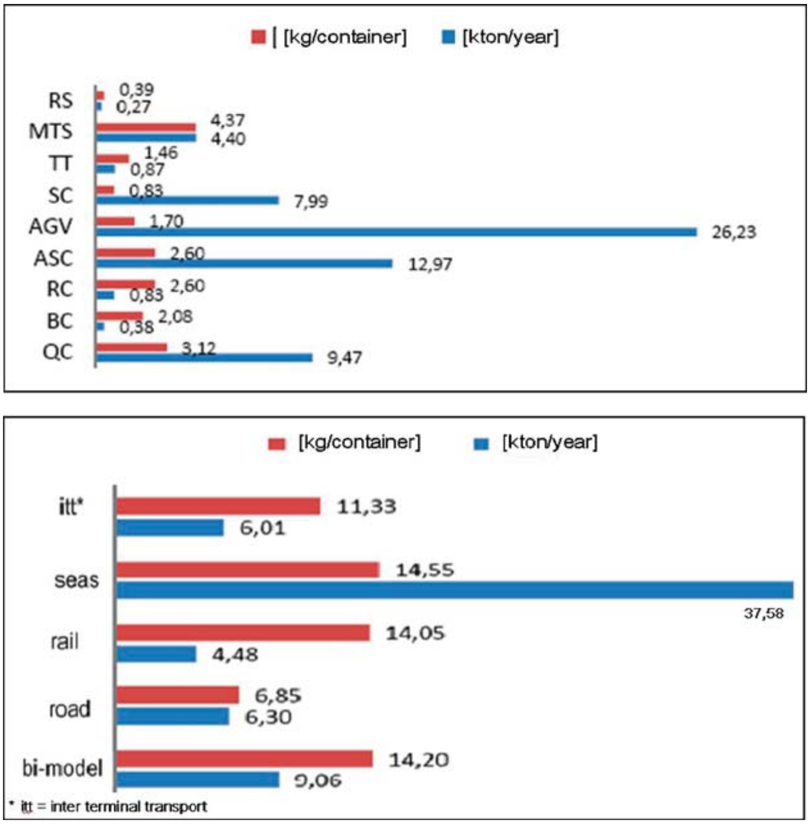

Figure 4 (a): CO_2 emissions per type of equipment. (b): CO_2 emissions per transport mode.

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

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

4.2 Application of the model to all terminals

To validate our model similar (to the 'Delta' case) modeling steps have carried out to the other terminals. Our first modeling 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.

From the Tables 6a and b we can 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 (see Table 7). For the selected terminals the total CO_2 production is around 157 kton. To have some reference, this share of CO_2 production represents around 2% of the whole CO_2 production freight transport caused by the transport modes road, rail and barge in the Netherlands (the calculations are based on the total km per transport mode [23] and the average emission in grams per kilometer transport mode [24]). With respect to the sea container terminals one can see clearly that the RST terminal produces a significant lower level of CO_2, both in diesel and electricity consumption per TEU. This can be explained while the terminal is relative new and it has a very compact design. The influence of the spatial design (the layout) 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.

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 indicate whether the modeling 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 contains the correlations between the dependent variable usage terminals. As can be observed, QCmoves, BCmoves, RCmoves en ASCmoves have a strong correlation with the dependent variable: usage Electricity, showing significance at a 5% significance level. The variables RSCmoves en Pmoves show very little correlation and both show no significance. The variables AGVmoves, AGV kms, SCmoves, SC kms en RS kms have also strong correlation with the dependent variable diesel usage. They all show a significant correlation. However, the variables TT kms en RSkms have little correlation and show no significant results. With respect to insignificant variables it seems very logical since their contributions are relative small (varies from 0.05–0.1) with respect

Table 6 (a+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

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	24.6	11.9	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

Continued

Table 7: *Continued*

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
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

Table 8: Correlation testing electricity and diesel.

	Usage terminal	QC moves	BC moves	RC moves	ASC moves	RSC moves	P moves
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

to the large container volumes handled by other equipment. Regressions analysis has been applied on the data; however, the statistical analysis gave similar insights with respect to the Spearman-correlation tests.

5 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 simple for different terminal configurations. To our opinion this is a first and promising step; however, the reliability of the model should be verified by further research on a larger sample of terminals. In practice, the number of deep-sea terminal operators is limited as we observe that this research covered already 95% 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 compared to the real 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 harbor wide CO_2 emissions by transshipment processes. From a policy perspective it seems to be an interesting policy option to stimulate the usage of biodiesels by mixing 30% biofuels with the presently used diesel. Application of our model shows a potential reduction of CO_2 emissions by between 13% and 26% per terminal and a reduction of the emissions of the whole container transshipment sector by 21%.

Furthermore, it is noticeable that the Rotterdam Short sea 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 (extra) 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 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.

In practice most terminals have shown a strong interest in this methodology since they are forced to provide insight in their CO_2 production by the local governments. For these companies application of the methodology had sufficient precision in estimating the overall CO_2 production at their terminals.

REFERENCES

[1] U.N. Intergovernmental Panel on Climate Change (1998). Kyoto protocol to the United Nations framework convention on climate change. Accessed April 4, 2007, from United Nations framework convention on climate change website, available at http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[2] Commission of the European Communities. *Biomass Action Plan COM*, **628**. Luxemburg: Office for Official Publications of the European Community, 2005.

[3] Geerlings, H. & Sluis-van Meijeren, M., The dominance of the Lisbon agreement as a barrier for an environmentally oriented transport policy in Europe; the gap between theory and implementation in policy integration. *European Transport/Transporti Europei*, **39(3)**, pp. 14–32, 2008.

[4] U.S. National Oceanic and Atmospheric Administration. Clear Skies & Global Climate Change Initiatives, Silver Spring, Maryland, 2002.

[5] U.S. Environmental Protection Agency (EPA). *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel*. 23 April 2008, United States Environmental Protection Agency, Washington, 2005.

[6] Shecterle, R., *The Supply Chain Executive's Strategic Agenda 2008: Managing Global Supply Chain Transformation*. Aberdeen Group, Boston, 2008.

[7] World Energy Council (2007). Transport Technologies and Policy Scenarios. World Energy Council, available at http://www.worldenergy.org/publications/809.asp.

[8] UN-Intergovernmental Panel on Climate Change (2007). IPCC Fourth Assessment Report: Mitigation of Climate Change, Chapter 5, Transport and its Infrastructure. Intergovernmental Panel on Climate Change, available at http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter5.pdf.

[9] Rotterdam Climate Initiative (RCI), available at www.rotterdamclimateinitiative.nl/NL/Over_rci/Ambities/?cid = 25 or www.rotterdamclimateinitiative.nl.

[10] Murty, K.G. Liu, J., Wan, Y. & Linn, R., A decision support system for operations in a container terminal, *Decision Support Systems*, Elsevier, **39**, pp. 309–332, 2005. doi:http://dx.doi.org/10.1016/j.dss.2003.11.002

[11] Hickman, R. & Banister, D., Looking over the horizon: Transport and reduced CO2 emissions in the UK by 2030, *Transport Policy*, Elsevier, **14,** pp. 377–387, 2007. doi:http://dx.doi.org/10.1016/j.tranpol.2007.04.005

[12] Liao, C-H., Tseng, P-H. & Lu, C.S., Comparing carbon dioxide emissions of trucking and intermodal transport in Taiwan, *Transportation Research D*, Elsevier, **14**, pp. 493–496, 2009.

[13] Lodewijks, G. & Wellink, J.H., The environmental impact of transport systems, Proceedings of CHoPS_ICBMH, pp. 8–14, 2009.

[14] Notteboom, T.E. & Vernimmen, B., The effect of high fuel cost on liner service configuration in container shipping, *Journal of Transport Geography*, Elsevier, **17**, pp. 325–337, 2009. doi:http://dx.doi.org/10.1016/j.jtrangeo.2008.05.003
[15] Ariztegui, J., Casanova, J. & Valdes, M., A structured methodology to calculate traffic emissions inventories for city centres. *Science of the Total Environment*, **334–335**, Elsevier, pp. 101–109, 2004.
[16] Medin, E. & Mo, Z., Environmental performance calculations for the Port of Gothenburg, Emissions to the air from Road transports. Gothenburg: School of Business, Economics and Law, Gothenburg University, 2006.
[17] Zeebroeck, van. B., Emissies door niet voor de weg bestemde mobiele machines in het kader van internationale rapportering (in Dutch). (English translation: Emissions by non-road mobile machinery in the context of international reporting). Ministerie van Vlaamse Gemeenschap, Departement Leefmilieu en Infrastructuur, Brussels, 2005.
[18] Oonk, H., Emissions to air due to activities on container terminals and future developments as a result of autonomous developments and additional measures. Apeldoorn: TNO Built Environment and Geosciences TNO, 2006.
[19] Beckx, C., Panis, L.I., Vankerkom, J., Janssens, D., Wets, G. & Arentze, T., An integrated activity-based modelling framework to assess vehicle emissions: approach and application. *Environment and Planning B: Planning and Design*, Pion Ltd and its Licensors, **36**, pp. 1086 –1102, 2009.
[20] ECN. Energy in the Netherlands. Petten: ECN 2008, available at www.energie.nl/index2.html.
[21] Voet, M. van der., CO_2-emissions by container transshipment processes in the Rotterdam port. A method for CO_2-emissions from transshipment processes in the port of Rotterdam in identifying and impact of proposed policies and knowledge to make (in Dutch), Master's thesis, Delft University of Technology, 2008.
[22] Groot, M., Milieuprofiel of stroomaanbod in the Netherlands. CE, Delft, 2004.
[23] Noreland, J., Modal split in the inland transport of the EU, *Eurostat Statistics in focus*, **35**, ISSN 1977-0316, European Communities, Luxembourg, 2008.
[24] EEA, In Transport at a crossroads, Term 2008 indicators tracking transport and environment, EEA Report **NO3/2009**, ISSN 1725-9177, Copenhagen 2009.