CONTAINER BASED CALCULATION OF GREENHOUSE GAS EMISSION – A METHOD TO DETERMINE EMISSIONS OF CONTAINER HANDLINGS IN CONTAINER TERMINALS

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ABSTRACT

The container transport is the key factor for globalized markets. Due to this the shipping volume in the past 20 years grew by the factor of 5. Based on this, container terminals are very important transshipment facilities in global transport chains with a high amount of annual throughput and greenhouse gas (GHG) emissions. The transport sector is responsible for a large proportion of GHG emissions. An increase of traffic and GHG emissions for any transport mode is estimated. However, emissions are caused by transport modes and transshipment facilities and have to be reduced for both.
State of the Art methods of determining transportation caused emissions consider only transportation modes. Emissions in transshipment facilities were currently rarely applied. However, for calculating emissions along the entire transport chain, the emissions from transshipment facilities have to be taken into account. Furthermore the reduction of greenhouse gases is significant for both the terminal itself and for the entire transport chain.
Derived from existing standards for calculation of GHG emission a calculation tool for container terminals has been developed. Based on the energy consumption of the handling equipment and storage facilities the tool calculates the overall emissions in terminals. Furthermore, these emissions are allocated to loading units by using overall handling data and handling factors. The developed tool can be adapted to any multimodal container terminal. The calculated results of the tool include total emissions and the allocation of emissions on loading units.

Keywords: Logistics, intermodal freight transport, container terminal, greenhouse gas emission

INTRODUCTION

The transport sector contributes significantly to GHG emissions all over the world. Moreover forecasts emphasize an increase of freight traffic. This trend occurs internationally and leads also to increased GHG emissions. (Clausen 2011) The large increase is not only caused by the transport modes but also by transshipment facilities.
There exist different methods to determine GHG emissions. One method is the draft standard prEN 16258:2011. This standard will be published in December 2012 by the European Committee for Standardisation (CEN). Like other methods prEN 16258:2011 account transport routes for the calculation only. This consideration is not sufficient if an overall calculation is required. This means that the whole transport chain including transportation routes as well as transshipment facilities need to be taken into account. Based on the fact that many goods are transported in standardized loading units the container terminal is likely to be one of the most relevant transshipment points. In order to reduce GHG emissions in container terminals as well as for the transport chains, emissions have to be identified regarding their origin and their amount.
This paper shows the development of a method to determine the GHG emissions in container terminals and analyzes a typical inland port container terminal in Germany. As a result the GHG emissions of the terminal are evaluated, both overall and allocated to loading units.

DETERMINE EMISSIONS IN CONTAINERTERMINALS

In container terminals GHG emissions occur in many areas (figure 1). At first emissions occur from using transport and handling equipment for containers. Therefore fuel and electricity are needed. At second emissions occur from stowing goods. Electrical connections for refrigerated containers and tempered stocks for warming or cooling goods require electricity and coolant. Especially the cooling fluid causes a high amount of GHG emissions. Moreover GHG are emitted by the operation of buildings as they need to be heated in cold weather periods and consume electricity. Another emission driver is the area lightening of the terminal. In particular the crane lamps need a lot of electricity.

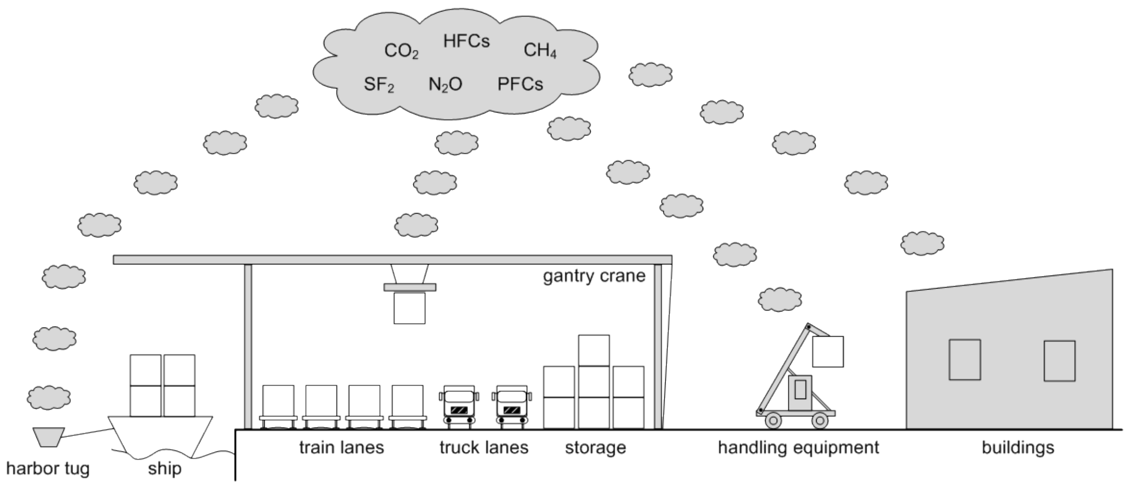

Figure 1: Emissions in a container terminal

Beside CO_2 other natural and anthropogenic gases contribute significantly to GHG emissions. The natural gases existing in the atmosphere are ozone (O_3), nitrous oxide (N_2O) and methane (CH_4). Anthropogenic GHG include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_2). There is the opportunity to record CO_2 only or to record other GHG as well. (Kranke 2011)
Following the Kyoto protocol the developed method record next to CO_2 also CH_4, N_2O, HFCs, PFCs and SF_2. All these GHG are listed together as CO_2 equivalent emissions, short CO_2e emissions. (United Nations 1997) The results of the developed method show the measured CO_2 emissions separately so that the part of CO_2 emissions, which is contained in the CO_2e emissions can be recognised immediately.
Furthermore the results also present energy consumption. It shows the WTW[1] (Well-to-Wheel) energy consumption and emissions as well as TTW[2] (Tank-to-Wheel) energy consumption and emissions according to the draft standard prEN 16258:2011.
All in all six result values are calculated that can be distinguished in TTW/direct energy consumption, CO_2e emissions and CO_2 emissions as well as WTW/total energy consumption, CO_2e emissions and CO_2 emissions.
For the calculation of energy consumption und emissions two different methods can be used. One method is based on consumption the other is based on distance. For the consumption based approach information about annual consumption of fuel or energy are needed. Whereas in the distance based approach information about the weight of the shipment, the traveled distance or the ton-kilometer are necessary. The developed calculation tool refers to the method based on consumption. Concerning the practicability this method is more precise compared to the other method that is based on distance. In addition to that the terminal operators cannot provide all essential dates that are necessary to use the method of distance.

System Boundaries

In order to define system boundaries it is important to point out whether the emissions are caused by in-house actions or external actions. In-house emissions can be influenced directly and therefore they have to be included in the GHG balance. In contrast to this, emissions caused by external actions are difficult to determine. Hence, they are excluded from the calculation except in some special cases like using a shunting locomotive, which is in possession of the port. In this way doublecountings can be avoided. Doublecountings are all emissions, which are assigned to two different GHG balances. As a consequence they are recoded twice, but each type of emissions should be allocated appropriate to its source and should not be counted twice. The results of the GHG balance would be distorted and might lead to a bad interpretation.
Vehicles as trucks, trains and ships operate in container terminals to handle loading units. Thereby they produce emissions.

[1] WTW: all emissions and consumptions, which arise directly and indirectly. That means that all losses of the pre-chain are included.

[2] TTW: all emissions and consumptions, which directly arise by the vehicle use.

The truck moves in the terminal area to carry out loading and unloading processes. Therefore the truck is considered as an external factor and the truck emissions are not included in the GHG balance of the terminal. At this point it becomes clear, that a differentiation between in-house and external actions make sense. In some cases it occurs that the company which is responsible for the transportation, records already itself the emissions for a completely truck tour. If the emissions are calculated in the terminals GHG balance too, they are counted twice. This doublecounting should be avoided.

The train enters the system either with the main-line locomotive or a shunting locomotive. Using a shunting locomotive, the train is decoupled from the main-line locomotive outside of the terminals. Further shunting activities are made with the help of the shunting locomotive. After finishing the handling processes, the train is going to be shunted in the siding outside the terminal. After coupling the train with the main-line locomotive the train leaves the system. In case that the locomotive drives the train into the terminal the emissions are not considered, as the locomotive is seen as an external factor. Using the shunting locomotive makes a further differentiation necessary. If the shunting locomotive is in-house and belongs to the terminal total emissions have to be included in the balance. Is the shunting locomotive in possession of the port it can be seen as external. As the port locomotive only operates for companies located at the port the emissions have to be distributed to the different companies on a pro rata basis.

The ship reaches the system as soon as it has berthed at the quay wall and leaves the system by departing from the quay wall. The quay wall is a point where ships can only be loaded and unloaded and do not cause any emissions. This makes a consideration in the balance unnecessary. In case that the ship needs a harbor tug for berthing, the emissions have to be considered only partly, like the emissions of the port locomotive.

Cranes and industrial trucks are in possession of the terminal and belong consequently to the terminal-own equipment. The emission values of this equipment need be included completely in the calculation. Again it is relevant to measure the consumptions as far as possible.

Allocation parameter

In the following the loading unit is chosen as an allocation parameter as it is an appropriate unit for a container terminal. A separation between container, swap body and semitrailer might be useful if the terminal has differentiated handling data.

The handling factor shows, how often a loading unit is moved in a terminal. A so called indirect transshipment occurs when containers are moved many times within one transshipment process. Furthermore, a distinction is made between full, empty and refrigerated containers. Concerning refrigerated containers a handling factor of two is acceptable as it usually changes its position twice (handling from originating transport mode to stowage location with cooling unit and from there to the terminating transport mode). Handing factors of full and empty containers are often larger than two. Furthermore empty Containers are moved more often than full containers. Semitrailers and swap bodies are usually handled directly so that a handling factor of one can be accepted. An indirect handling causes more emissions than a direct handling, because the loading unit is moved

more often in the terminal by the handling equipment and industrial trucks. This fact need to be considered as well.
Some loading units are only moved with certain handling equipment. It is appropriate to assign the emissions - caused by certain handling equipment – to the related loading units which were actually used by this equipment. For example semitrailers are handled to 90 percent with the crane and to 10 percent with the reach stacker. That means that emissions and consumptions are allocated to the semitrailer in this proportion. The same applies for refrigerated containers so that emissions and consumptions that occur from the storage of refrigerated containers are attributed to the refrigerated containers only. However such emission allocations can just be made if detailed handling dates are available. An exact allocation of emissions and consumptions is advisable, as results become more precise.

GREENHOUSEGAS CALCULATION TOOL

The software application Microsoft Office Excel is used as a basis for the tool. The tool gives terminal operators the opportunity to determine the emissions and consumptions of their terminal on their own. Therefore you only need to enter required data to a calculation tool which leads the user step by step through the program. This makes the usage of the tool very simple. Moreover the tool provides explanations for every step. Pages for data entry, the presentation of results and the allocation represent the main parts of the tool.

Data entry

In the first step the user is asked to enter relevant data of the container terminal. Firstly the user has to enter dates of consumptions from all handling equipment, industrial trucks and sources of electricity, coldness or heat. It is of major significance that the consumption data of every element on the terminal is required. In the section “System boundaries” is explained which elements belong to the terminal.
The more accurate the values are the more precise the calculation of GHG emissions can be made. According to the draft standard prEN 16258:2011 individual measured values is given the first priority. This rule is extended on consumption caused by transport and transshipment processes or by cooling and warming mediums. Typical average values or realistic estimations have second priority while the last priority is given to default values. Here established data sources, like EcoTransIT World, TREMOD or HBEFA can be used. If there is no consumption data for handling equipment and industrial trucks available the data can be calculated on the basis of operating hours and the average consumption per hour. Therefore the tool is equipped with a special calculator. Apart from information about consumption data the user always needs to specify the source of the data as additional information.
In the second step the user is asked to give specific data information about loading units. The tool needs to know the overall number of loading units being handled by the terminal in one year. Furthermore the percentage distribution of loading units whether there are full containers, empty containers, refrigerated containers, semitrailers and swap bodies is important. The user must indicate the handling factor for every special loading unit.

The third step of the data entry is optional. The user must enter data to an additional data table in case he has information about the handling of certain loading units. The user has to indicate if a loading unit is only moved with certain handling equipment and industrial trucks. All in all it is recommendable to enter data precise and conscientiously.

Results

As soon as all data is entered the results can be shown immediately. The results are based on conversion factors, which originate from established data sources. The tool uses the conversion factors calculated by Kranke 2011, whose calculation is based on values out of data sources established all over Europe.
The calculation method of the tool is divided in a handling and transport part, a stowage part and a part called buildings and others. In order to identify the main emission drivers it is important to determine energy consumption and the emissions of every single element of the terminal. This is the only possible way to achieve emission reduction potential.
In substance the calculation works as follows: the consumption data of one year has to be multiplied with the relating TTW/direct or WTW/total conversion factors.
The tool provides suitable calculations so that the energy type matches the relating conversion factor. The results are presented in a detailed table, which provides TTW/direct and WTW/total energy consumption, CO_2 and CO_2e emissions. Additionally a synoptic table represents energy consumption and emissions classified according to the different terminal sections and the total energy consumption and the terminal emissions. The energy consumption and emissions are displayed in a bar chart illustrating the emissions in proportion to the terminal sections as well as the total sum of energy consumption and emissions expressed as a percentage. In this way the user can identify quickly and efficiently emission driving parts in the terminal. Further diagrams show the distribution for handling equipment, industrial trucks and buildings.

Allocation

The tool allocates energy consumption and emissions to single loading units. The user also gains an impression how the energy consumptions and emissions are distributed. Some positions can be allocated to any loading unit others need to be allocated partly to a specific loading unit. How the distribution on loading units is performed depends on the data entered by the user and varied in each case.
If the user has entered specific data in step three of the data entry the allocation on handling equipment and industrial trucks will be made proportionately. Otherwise only the handling factors are considered for allocating the transshipment. Energy consumption and emissions are distributed to every loading unit. Elements used for the storage of refrigerated containers are always assigned to refrigerated containers proportionately. The entire energy consumption and the entire emissions of all other parts of the terminal like external equipment of the harbor, stowage and buildings are distributed to all the loading units. A summary of the distribution can be found in a special table in the tool.

Another table gives detailed values regarding the allocation of the several parts of the terminal to the loading units. Depending on whether the user entered detailed data in step three of the data entry, the table might contain different ways of calculation. In general a detailed data entry and therefore a proportionately distribution leads to more detailed results.
Closing this part of the tool a last table summarizes the energy consumption and emissions for each loading unit. The recorded values in this last table are useful for a comparison of different terminals with regard to environmental impact.

EXAMPLE AND RESULTS

As an example a fictitious container terminal is considered. The terminal is a typical inland port container terminal. It is equipped with two rail-bound gantry cranes, two reach stackers, one container stacker and two empty container stackers for cargo handling. There are 12 connections to handle the storing process of refrigerated containers. Trains are shunted in the terminal by a diesel-driven harbor locomotive on the last mile. Furthermore the terminal is equipped with an office building covering an area of $440m^2$ and a hall for package with the measures of 60 x 24 x 7,5 meters. To provide lighting 16 crane lamps and 33 floodlight lamps are installed all over the terminal. The operating time of the terminal is five days a week whereas there are no working hours at nighttime.
In order to get realistic data five container terminals corresponding to the above-described construction were interviewed. It turned out that no terminal operator was able to state all information completely. Because of this the mean results of the interviews are used for the calculation. So the data is based on estimate values derived of the reality. The first three figures show the first three steps of the data entry. Figure 2 presents the energy consumption of every element of the terminal. Out of a drop down menu an area as well as an energy type have to be chosen for each element. Subsequently the user must enter the annual consumption in the displayed unit. Furthermore the user has to specify how the consumption was determined.

area	element	form of energy	consumption per year	unit	consumption determination
buildings	lighting package hall	electricity	9,651	kWh	estimation
buildings	dark radiator package hall	natural gas (heating value)	274,428	kWh	estimation
buildings	electricity office building	electricity	70,840	kWh	estimation
buildings	heating office building	natural gas (heating value)	32,560	kWh	estimation
others	area floodlight	electricity	85,800	kWh	estimation
others	cran lighting	electricity	20,800	kWh	estimation
external subsidies	port locomotive	diesel	7,084	l	estimation
storage of refrigerated containers	connection refrigerated containers	electricity	204,600	kWh	estimation
handling equipment and industrial trucks	empty container stacker 2	biodiesel 6.2 %	28,125	l	estimation
handling equipment and industrial trucks	empty container stacker 1	diesel	31,500	l	estimation
handling equipment and industrial trucks	container stacker	diesel	30,400	l	estimation
handling equipment and industrial trucks	reach stacker 2	biodiesel 6.2 %	32,120	l	estimation
handling equipment and industrial trucks	reach stacker 1	diesel	45,360	l	estimation
handling equipment and industrial trucks	gantry crane 2	electricity	500,000	kWh	estimation
handling equipment and industrial trucks	gantry crane 1	electricity	600,000	kWh	estimation

Figure 2: Data entry step one based on valuations

Figure 3 shows the data entry in step two where information about transshipped containers and suitable handling factors is required. In the fictitious terminal in total 230.000 loading units are transshipped per year in total. In the last year no semitrailers and only one percent of refrigerated containers have been transshipped.

transshipped loading units (LU)				handling factor
	per year	230000	LU	
of that:	semitrailer	0	%	1
	swap bodies	10	%	1
	full containers	48	%	2.5
	empty containers	41	%	3.5
	refrigerated containers	1	%	2
		100	%	

Figure 3: Data entry step two based on valuations

Step three of the data entry is shown in figure 4. This step is optional and terminal operators should only use it if the required data are actually available. In the example the following values are estimated. Full containers for example are moved by gantry crane one by 45 percent, by gantry crane two by 40 percent and by the reach stacker one and two and the container stacker in each case by 5 percent.

handling equipment and industrial trucks	semitrailer	swap bodies	full containers	empty containers	refrigerated containers
sum in percent	0	100	100	100	100
empty container stacker 2	0	0	0	15	0
empty container stacker 1	0	0	0	20	0
container stacker	0	15	5	15	5
reach stacker 2	0	25	5	0	5
reach stacker 1	0	30	5	0	5
gantry crane 2	0	15	40	20	40
gantry crane 1	0	15	45	30	45

Figure 4: Data entry step three based on valuations

As soon as all dates are entered the results can be request on the next pages. Figure 5 shows a detailed table of the energy consumption and emissions of each element of the terminal. The table points out that the energy consumption of the gantry cranes is noticeable high. As the cranes are powered by electrical energy there are no direct CO_2 and CO_2e emissions. The total CO_2 and CO_2e emissions are however in contrast to the other emissions really high. This first overview allows to conclude that the gantry cranes belong to the strong emission drivers at terminals.

area	element	consumption per year	unit	form of energy	energy (direct/TTW) in MJ	energy (total/WTW) in MJ	CO_2 (direct/TTW) in kg CO_2	CO_2 (total/WTW) in kg CO_2	CO_2e (direct/TTW) in kg CO_2e	CO_2e (total/WTW) in kg CO_2e
handling equipment and industrial trucks	empty container stacker 2	28,125.00	l	biodiesel 6.3%	1,004,062.50	1,164,375.00	69,468.75	78,750.00	70,312.50	82,125.00
	empty container stacker 1	31,500.00	l	diesel	1,130,850.00	1,294,650.00	83,475.00	92,925.00	84,420.00	94,815.00
	container stacker	30,400.00	l	diesel	1,091,360.00	1,249,440.00	80,560.00	89,680.00	81,472.00	91,504.00
	reach stacker 2	32,120.00	l	biodiesel 6.3%	1,146,684.00	1,329,768.00	79,336.40	89,936.00	80,300.00	93,790.40
	reach stacker 1	45,360.00	l	diesel	1,628,424.00	1,864,296.00	120,204.00	133,812.00	121,564.80	136,533.60
	gantry crane 2	500,000.00	kWh	electricity	1,800,000.00	5,000,000.00	0.00	282,000.00	0.00	294,500.00
	gantry crane 1	600,000.00	kWh	electricity	2,160,000.00	6,000,000.00	0.00	338,400.00	0.00	353,400.00
external subsidies	port locomotive	7,084.00	l	diesel	254,315.60	291,152.40	18,772.60	20,897.80	18,985.12	21,322.84
buldings	lighting package hall	9,651.00	kWh	electricity	34,743.60	96,510.00	0.00	5,443.16	0.00	5,684.44
	dark radiator package hall	274,428.00	kWh	EGHW	987,940.80	1,130,643.36	55,160.03	61,197.44	55,434.46	68,332.57
	electricity office building	70,840.00	kWh	electricity	255,024.00	708,400.00	0.00	39,953.76	0.00	41,724.76
	heating office building	32,560.00	kWh	EGHW	117,216.00	134,147.20	6,544.56	7,260.88	6,577.12	8,107.44
storage of refrigerated containers	connection refrigerated containers	204,600.00	kWh	electricity	736,560.00	2,046,000.00	0.00	115,394.40	0.00	120,509.40
others	area floodlight	85,800.00	kWh	electricity	308,880.00	858,000.00	0.00	48,391.20	0.00	50,536.20
	cran lighting	20,800.00	kWh	electricity	74,880.00	208,000.00	0.00	11,731.20	0.00	12,251.20

Figure 5: Energy consumption, CO_2 and CO_2e emission (TTW/direct and WTW/total)

Figure 6 shows the summarized results classified according to different areas. A table reflects each value of the areas in total. The according diagram represents the energy consumption and emissions in the form of bar charts so that the user sees immediately which of the areas causes high emissions at a glance. It becomes evident that most emissions are caused by handling equipment and industrial trucks.

areas	energy (direct/TTW) in MJ	energy (total/WTW) in MJ	CO_2 (direct/TTW) in kg CO_2	CO_2 (total/WTW) in kg CO_2	CO_2e (direct/TTW) in kg CO_2e	CO_2e (total/WTW) in kg CO_2e
handling equipment and industrial trucks	9,961,380.50	17,902,529.00	433,044.15	1,105,503.00	438,069.30	1,146,668.00
external subsidies	254,315.60	291,152.40	18,772.60	20,897.80	18,985.12	21,322.84
storage	0.00	0.00	0.00	0.00	0.00	0.00
storage refrigerated containers	736,560.00	2,046,000.00	0.00	115,394.40	0.00	120,509.40
buildings	1,394,924.40	2,069,700.56	61,704.59	113,855.25	62,011.58	123,849.21
others	383,760.00	1,066,000.00	0.00	60,122.40	0.00	62,787.40
sum	**12,730,940.50**	**23,375,381.96**	**513,521.34**	**1,415,772.85**	**519,066.00**	**1,475,136.85**

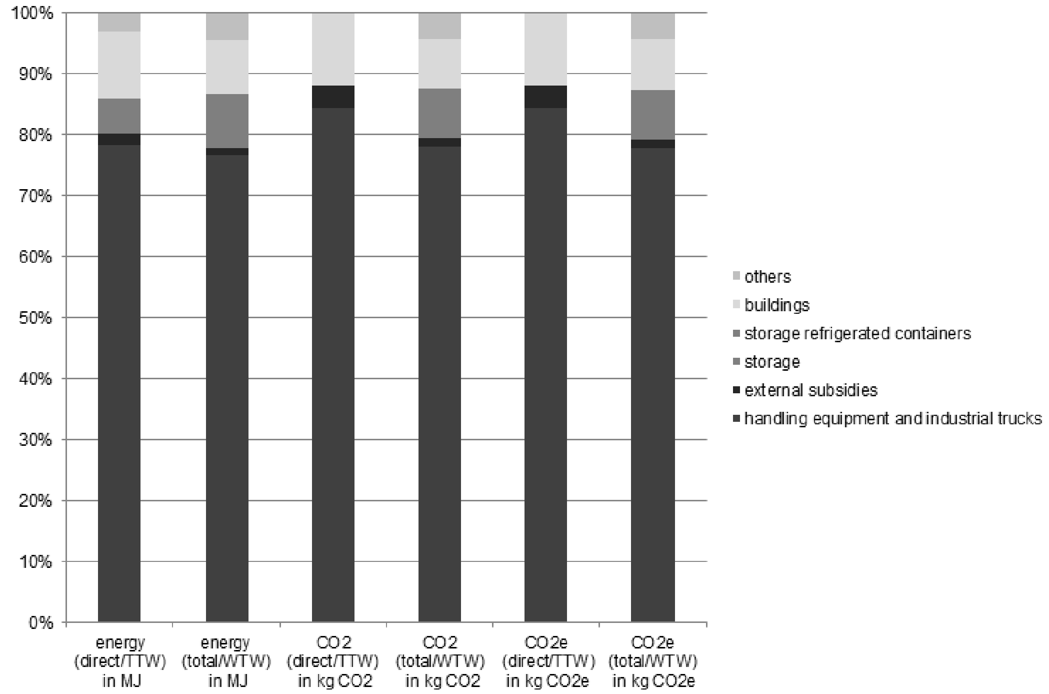

Figure 6: Results summarized in areas

The next part of the tool is the allocation area shown in figure 7 where emissions and energy consumption are distributed to different loading units. The first part of the table provides information of how the emissions and energy consumption are allocated. The second part of the table shows the allocation results for each single loading unit. Handling refrigerated containers causes the most emissions in total as the electrical connections need a lot of electricity. In contrast to refrigerated containers the emissions and energy consumption of the other containers is much lower.

distribution of energy and emissions	distribution
external subsidies, storage (except connection of refrigerated containers), buildungs, others	all LU
handling equipment and industrial trucks	pro rata
storage of refrigerated containers	pro rata

	energy (TTW/direct) in MJ	energy (WTW/total) in MJ	CO_2 (TTW/dicekt) in kg CO_2	CO_2 (WTW/total) in kg CO_2	CO_2e (TTW/direct) in kg CO_2e	CO_2e (WTW/total) in kg CO_2e
semitrailer	nonexisting	nonexisting	nonexisting	nonexisting	nonexisting	nonexisting
swap bodies	52.0193579	69.28835329	3.255970911	4.557512705	3.291955799	4.726365845
full containers	48.37762083	93.79646097	1.71948789	5.5985252	1.737665006	5.841997954
empty containers	56.88192053	97.57350317	2.603157284	6.010471224	2.631532333	6.254499123
refrigerated containers	360.713401	967.5822583	1.445570476	54.81975533	1.460563914	57.24982397

Figure 7: Allocation on loading units

The question rises how best to reduce and avoid energy consumption and emissions. Considering the gantry cranes the easiest way is to use electricity from renewable energy sources. Depending on the age of the system it is possible to avoid emissions in total or at least up to 50 percent. Furthermore special software tools could optimize the sequence of container handling so that less energy would be needed. Another opportunity of how to decrease the consumption lies in special training courses for crane drivers as a correct use of the crane might also reduce the energy consumption.
Finally a comparative calculation is made to classify the values of the results. Therefore a long and a short distance are considered. Within the long distance a forty-foot container is transported from Rio de Janeiro (Brazil) to Dortmund (Germany). The transport takes place between the transshipment points Rio de Janeiro, Hamburg and Dortmund. The transport causes about 5,150 kg of CO_2e in total and each transshipment causes about 6 kg of CO_2e in total. This means that each transshipment contributes to 0.1 percent to the whole emissions which doesn't seem to be a lot.
Within the short distance the same container is transported from Hamburg to Munich. The first option is a transport that directly goes by truck. The tour causes about 1,252 kg of CO_2e in total. Considering the second option the container is transported in combined transport by train and by truck in a pre- and on-carriage. Thereby the transport causes about 592 kg of CO_2e in total and the handling causes about 12 kg of CO_2e. This results in a total sum of 604 kg of CO_2e emissions. As you can see the direct transport of option one causes twice as much emission as the combined transport of option two including two handlings. Considering the combined transport two percent of the caused emissions concern the transshipment process.

CONCLUSIONS

The developed calculation tool gives terminal operators the opportunity to calculate energy consumption and emissions on their own. The tool guides the user in a few steps with clear instructions of the data entry and the use of the tool to the desired result. On the one hand emissions and energy consumptions divided by the elements of the terminal are disclosed. On the other hand the allocation on loading units used in the container terminal is taken place, so that a statement of how many CO_2 is caused by the handling of one single loading unit can be made. On basis of this information a comparison between different terminals is possible.
If terminal operators have an interest in using the tool the necessary input data needs to be determined properly. This is the only way to ensure high quality results and a clear identification of strong emission drivers. Subsequently general and specific measures for avoiding and reducing emissions can be developed.
Furthermore an annual determination of emissions is inevitable as this is the only way to check whether the chosen measures result in genuine improvements.
Regarding to the comparative calculation it can be concluded that transshipments within short distances have a greater significance than transhipments within long distances.

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