Journal of Civil & Environmental Engineering

Merlak et al., J Civil Environ Eng 2017, 7:4
DOI: 10.4172/2165-784X.1000278

Perspective Open Access

Methodology of Calculation of the Carbon Footprint of Container Terminals as a Link in the Logistics Chain

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Abstract

To minimize administration efforts and to base all energy consumption and greenhouse gas emissions recording on the same consistent operational database, an integrated approach to manage energy and capture carbon footprint in one management system is recommended. Measuring and reporting terminal GHG-emissions currently is not mandatory but recommended in the view of already existing and upcoming new carbon dioxide reporting standards. Some terminals have already developed systems to monitor emissions for internal use.

Mandatory carbon footprint reporting is expected for the near future, which must be based on comparable conditions and methodologies. Pre-competitive co-operation and exchange of ideas therefore is essential. Workload on container terminals is very high, so additional burdens from carbon footprint management system must be kept at a minimum.

This article explains the methodology of calculation of the carbon footprint of container terminals as a link in the logistics chain.

Keywords: Container terminals; Carbon footprint; Logistics chain

Introduction

The container terminals are responsible for significant energy consumption and consequently the greenhouse gas emissions [1]. The calculations of CO_2 equivalent emissions for transport chains usually don't include the emissions caused by terminals, transshipment docs, cargo stations, warehouses, etc. Therefore, we are missing a share of emissions in intermodal or combined transport chains. We are able to calculate the first mile road section [2,3], the rail section [4] and the last mile road section very accurately but we neglect the services performed in the terminals. It is not only the lifting by cranes [5], there are more processes going on which need to be taken into account. This makes things much more complicated. To calculate emissions of a combined transport chain one would need to know what the carbon footprints of respective terminals are. How to obtain all necessary data to do the calculation? It is obvious: this is one of the parameters of each container terminal. They know exactly how much energy they have consumed and how much intermodal transport units they've handled in a year. It should be published by the terminal operator in their price list of services or similar terminal publication. The yearly average of kilograms of CO2 emissions/unit should be published or communicated to the clients of the respective terminal. Calculating all other KPIs, the terminal operator should add the calculation of Carbon footprint per each unit.

Why is it so important to set things in proper order regarding emissions in intermodal transport chain? The global freight transport demand is growing and thus also the continental haulage [6,7]. The transportation impact on the environment and on the transport infrastructure networks of continents as well. There are calculations and studies [8, 9] that clearly show that using the railway on the longer leg of the journey bring us savings in emissions compared to road transportation. It is also helping to increase population mobility as it relieves the congested roads.

We need to know what exactly these savings are like. To be able to promote a transport mode, we need to understand it well and present all its strengths and weaknesses.

Objective of the study

The Carbon footprint is causing the climate change and all industries are trying to diminish the emissions [9]. The overall statistical data show that almost every industry has succeeded to show some results in that respect, except the transportation industry. The CO_2 emissions in transport are still growing as the sector itself is growing every year. The task of the transport professionals is to find ways of sustainable transportation modes to help the environment. To be able to do that, the carbon footprint has to be measured in all transport modes and compared to each other [10]. The comparison, besides showing the most sustainable mode of transport, often initiates efforts for reduction of current emissions.

Continental Container Terminals

The nodes where different transport modes meet and exchange the cargo units are Container terminals. It is obvious that we need to know the emissions caused by them [11]. There are different types of Container terminals [12]. They can be divided to unimodal, bimodal, trimodal terminals, depending on of how many transport modes they serve. Another division is by the geographical position where we can find seaports with container terminals, continental river terminals, rail terminals and different combinations of such. They can differ according to their role or purpose in the transport chains. Some of them are starting, ending terminals, others can be gateway terminals. Ownership defines their status, which is to be considered as private or public terminal, and last but not least they differ according to the equipment they use. Every terminal should be studied and observed individually as the combinations can give us a lot of variations, but they all have the common task to tranship the intermodal loading units between different means of transportation [5]. This study is limited to the continental intermodal transportation as obviously an alternative to

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Received June 28, 2017; **Accepted** August 03, 2017; **Published** August 09, 2017

Citation: Merlak J, Groznik A, Al-Mansour F (2017) Methodology of Calculation of the Carbon Footprint of Container Terminals as a Link in the Logistics Chain. J Civil Environ Eng 7: 278. doi: 10.4172/2165-784X.1000278

Conversion factors for energy consumption [MJ]			
Fuel type	**Units**	**TTW[1]**	**WTW[2]**
Diesel	MJ/l	35.9	42.7
Diesel D5 (5 vol% of BioDiesel)	MJ/l	35.7	44
Liquified Natural Gas (LNG)	MJ/kg	45.1	44.4
Petrol Gas (LPG)	MJ/l	25.3	50.5
Electric Traction EU27	MJ/kWh	3.6	10.8
electric energy EU27	MJ/kWh	3.6	10.2

[1]TTW: tank-to-wheel
[2]WTW: well-to-wheel
Source: Extracted from EN16258:2012

Table 1: Conversion factors for energy consumption.

Conversion Factors for CO_2e emissions [kg]			
Fuel type	**Units**	**TTW[1]**	**WTW[2]**
Diesel	kg/l	2.67	3.24
Diesel D5 (5vol% of BioDiesel)	kg/l	2.54	3.17
Liquified Natural Gas (LNG)	kg/kg	2.68	3.7
Petrol Gas (LPG)	kg/l	1.7	1.9
Electric Traction EU27	kg/kWh	0	0.468
electric energy EU27	kg/kWh	0	0.424

[1]TTW: tank-to-wheel;
[2]WTW: well-to-wheel
Source: Extracted from EN16258:2012

Table 2: Conversion factors for CO_{2e} emissions.

sea shipping is not available. Thus, in this study, the terminal emissions alongside vessels and operations for berthing unloading and loading the vessels in seaports are not observed, as these would have happened in any case, prior to mount a continental carrier. Each terminal operator knows his assets and energy consumption and he ought to provide the information about emissions per loading unit to its clients. The clients are organizers of intermodal or combined transport chain and are the ones who are providing the environmental footprint for the entire transport chain [13-15]. Thus, we get the information needed for comparisons between modes or between routes of transportation.

Calculation Factors

To be able to calculate the emissions, we need to set the conversion factors [2] for different power systems that are used for the operations. There are some selected energy sources and the conversion factors, extracted from the standard EN 16258-2012 (Tables 1 and 2).

When calculating emissions for rail tractions and terminals by using the electrical equipment it is important to consider the energy mix for production of electricity for each country respectively [16]. There are values for EU27 (before Croatian admition and the Brexit), for electrical grid of each member state and the catenary power in railway network (Table 3).

The terminals can obtain with not much efforts information about consumption of the electrical equipment in kWh, which they need to multiply with the energy-mix factor for the respective country.

Operational processes

Operational processes are listed and studied in logical bundles. Each process is defined by its KPIs and can be monitored and measured accordingly. It is essential for every terminal operator to manage these KPIs, which lead to improvement in efficiency and profitability.

Rail shunting, outside the terminal

Rail shunting, outside the terminal is a process for getting the trains from or toward the nearest main line stations where the container terminals lie. This is so-called first or last rail-mile, respectively. This shunting can be made by electric (where there is a catenary available) or diesel engines [17]. Should the terminal lie alongside the main lien and have catenary right to the entrance, even the line engine could provide the delivery. However, in any case the emissions have to be calculated as in case that the terminal wouldn't be used, there would not be any last-mile or first-mile process, respectively [18-20].

Electric shunting: Using an electric locomotive, one has to calculate the emissions caused by production of electric power; hence we need to know the consumption of the engine to calculate emissions:

$$Ee = t.Ce.fe$$

Where *Ee* stands for emissions, caused by electro engine, t stands for s time of operation, Ce for nominal power of engine (The electric meter directly after the locomotive pantograph is not yet mandatory, but the legislation goes in the direction of regulating it), and fe stands for the conversion factor for catenary electricity production mix for respective country.

Diesel shunting: Diesel engine consumes diesel fuel and directly produces emissions of the greenhouse gases. The calculation:

$$Ed = t.pd.fd$$

Where Ed stands for emissions, Pd is diesel consumption per hour and fd is conversion factor for diesel fuel.

The volumes relative emissions would be calculated:

$$E = \frac{\Sigma E}{ITU}$$

Rail shunting, inside the terminal

Rail shunting, inside the terminal is a process of positioning and/or moving the train sets underneath the crane lanes or into the transhipment positions. This is done normally (or lately also battery-driven locomotive) by the diesel shunting locomotive which can be

Tank-to-wheel EU State	Rail Traction Energy [MJ/kWh]	Catenary CO_2e [kg/kWh]	Public electricity Energy [MJ/kWh]	Supply grid[3] CO_2e [kg/kWh]
EU - 27	10.8	0.468	10.2	0.424
Austria	4.5	0.119	6.8	0.21
Belgium	13.5	0.393	12.4	0.219
Bulgaria	12.3	0.66	10.5	0.538
Czech	11.2	0.661	11.2	0.681
Danmark	6.2	0.433	10.9	0.471
Estonia	13.8	1.208	9.7	1.012
Finland	9.9	0.48	10.3	0.295
France	13.2	0.077	13.5	0.072
Greece	16	1.004	9.1	0.801
Ireland	11.9	0.779	7.5	0.526
Italy	9.6	0.749	8.4	0.463
Latvia	5.1	0.16	5.8	0.181
Lithuania	11.9	0.108	7.4	0.39
Hungary	14.5	0.637	13.1	0.481
Germany	10.8	0.574	9.7	0.583
Netherlands	8.8	0.497	9.2	0.46
Poland	12.5	1.085	10.6	1.005
Portugal	8.9	0.544	7.8	0.399
Romania	9.4	0.556	8.9	0.495
Slovakia	12.1	0.199	10.5	0.37
Slovenia	11.7	0.686	9.4	0.405
Spain	9.2	0.425	8.3	0.363
Sweden	3.8	0.004	8.7	0.058
United Kingdom	10.7	0.621	9.5	0.488

[3]Public electricity supply grid: including all losses in electricity grid.

Table 3: Calculation of emissions.

asset of the terminal or in domain of nearby railway station [21]. Hence, the calculation must include the energy consumed even outside of the perimeter if the shunting engine comes from the nearby railway station. The calculation is the same as with diesel shunting out of the terminal or else (if the terminal is equipped with such) battery driven shunting engine.

Again, the calculation would be:

$$Ed = t.pd.fd$$

Shunting engine fuelling: One has to have in mind also the location of the refuelling station as it can be often quite far away from terminal location. This is meant for diesel engines as they have to travel to the fuelling station to re-fuel.

Vertical manipulations

Vertical manipulations are basically the lifts done in order to take ITU[1]s off and on the specific train, truck or ground. These are performed normally with the terminal equipment such as reach stackers, container forklifts, and gantry cranes, RMG or RTG. Since the ITUs can weigh up to 30 tones, this equipment has to be approved and well maintained and tested [22]. It is important that one calculates all the lifts, not only the ones that have been invoiced. There is a significant portion of dead-lifts that are done to get a specific ITU out from the block. Of course, the share of non-payed manipulations varies from terminal to terminal as it depends on organization of the terminal and also on type or purpose of the terminal. The calculations have to be done for diesel and electricity consumption respectively and divided by number of units handled in certain period of time, using of course the respective factor, to get the emissions.

Weighting of ITUs

Weighting of ITUs has become mandatory for maritime transport as in July 1st of 2016 the amendment of SOLAS convention demands the shipper to communicate the VGM to the port terminal, prior its physical arrival to the Seaport in outbound direction. However, there is also a calculation method to define VGM available and no weighting of entire container would be necessary.

Here the energy consumption for manipulations with ITU for the purpose of weighing has to be considered.

Terminal internal non-rail transport

Terminal internal non-rail transport consists of movements of the ITU[1]s with the trucks, mafis, AGV[2]s, reach stackers, container forklifts etc. This is depending of the work organization, equipment in the terminal and also of the layout of the same. The calculations have to be made for every equipment segment with the same or similar fuel and energy consumption.

For each vehicle, the consumption per hour has to be collected and calculated with the same formula as above.

Terminal internal transport of external trucks

Terminal internal transport of external trucks is a path of external

[1] ITU: Intermodal Transport Unit e.g., 20', 40' Maritime container, Swap-body, Semi-trailer, etc.; any transport unit, fitted with standardized fittings to enable vertical manipulation with terminal equipment.

[2] AGV: Automated Guided Vehicle

truck, bringing in an ITU underneath or beside the prescribed position for terminal to perform the lift. In some well-organized facilities, the external trucks with double-call[3] are often asked to perform inner-movement to position, where they are to be served by the crane operator. Here the terminal can or should only estimate the energy consumption. This is an average value. The terminal operator has to measure or estimate average path (from entrance of the terminal to the position under crane and back) for external trucks.

Electricity Consumption

Electricity consumption of the terminal is basically the consumption of all electrical appliances that are installed in the terminal, including portal cranes, RMGs, power-docks, battery chargers, lighting, heating, appliances in the office facilities etc. Every terminal operator is aware of the mentioned consumption as he pays the bills for electricity. Divided by the ITUs that come in and out the terminal, they get the electricity consumption per unit. Based on the energy mix of the electric power supply grid of respective country, it is possible to calculate the emissions.

Energy consumption for additional activities

It represent others shuntings i.e., additional shunting, exclusion of damaged wagons, resetting the wagon sets, small repairs of wagons, etc. All these actions require the shunting engine that is able to operate inside the terminal, so either diesel engine battery driven engine. The calculation is similar to the operations of shunting, internal trucking etc.

Energy consumption of the waiting trucks

Outside the terminal perimeter would normally not tackle the terminal itself, however if the terminal would not be used, these emissions would not occur. So, it is important to include the waiting trucks into the emission calculations [23]. The calculation method is to measure diesel consumption per hour that gives the input to calculate emissions.

Trucks call the terminal inside the time window, published by the same. However, the history shows that there are peaks and downs in the certain time of the day or week etc. We can assume that we are dealing with the stochastic model [24,25]. The probability of multiple truck calls gets higher when we are approaching the cut-off time for specific trains or the time of arrival of a train is approaching, and lowers when there is nothing urgent to be transhipped inside the terminal. It is only natural that the truck drivers are striving to call the terminal very early, as soon as the ITUs from the arriving train are released to pick them up, deliver over the last mile and return back to the terminal just in time to catch the outgoing train (Figure 1).

To calculate the probabilities of trucks calling the terminal one can use the Poisson distribution[4] to estimate the cueing and the probable emissions or if possible, to measure the actual cueing time with truck engines running in idle.

Probability to have exactly 6 calls in the interval of 30 minutes on Mondays is 7%. Whereas the probability to have between 3 and 6 calls would be 47% what we can calculate with discrete cumulative distribution function.

Equation 1: Poisson distribution; probability function.

$$p(x=k)\frac{\lambda^k}{k!}e^{-\lambda}$$

[3] Double-call: A truck bringing an ITU to the terminal for drop-off and picking another ITU within the same call to the terminal

[4]Poisson process; equation: $p(x=k)\frac{\lambda^k}{k!}e^{-\lambda}$, where k is expected number of events, λ is average number of events on the selected time interval.

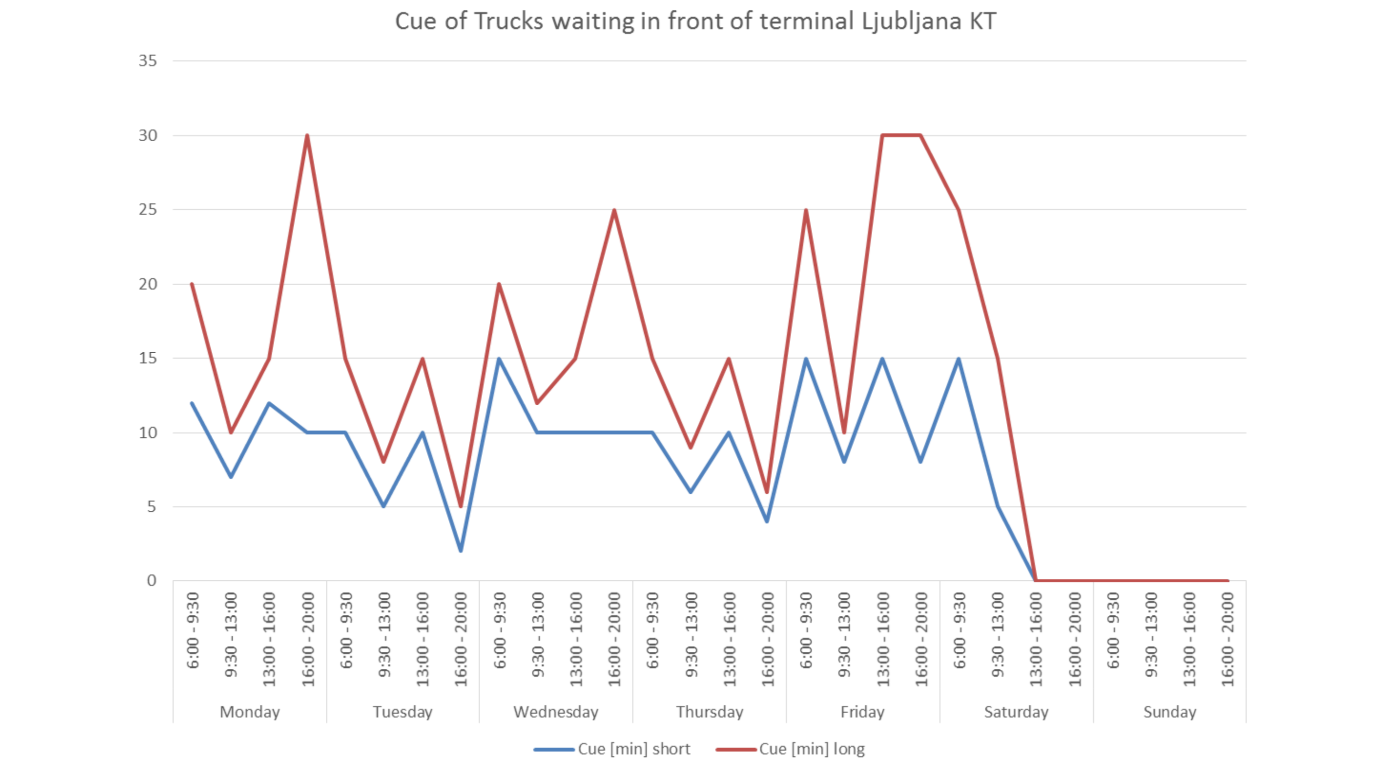

Figure 1: Measured max and min cueing times over an average week in Ljubljana container terminal. (Source: Author).

Equation 2: Poisson distribution, Cumulative distribution function.

$$Sum\ p(x=k)=\sum_{i=0}^{k}\frac{\lambda^i}{i!}e^{-\lambda}$$

$k \geq 0$

The calculation of the probability of cueing might get important if the terminal operator would like to regulate the number of truck calls within time interval to optimize resources and thus save on emissions which he cannot measure directly due to missing readings on diesel consumption of the trucks in cue.

Energy consumption for any auxiliary processes

It is to be measured as well, given there are any processes that haven't been mentioned above, but they would exist in certain facilities and they consume energy. These processes can be identified as the repair service for intermodal transport units, cleaning facilities, stripping, stuffing etc.

Conclusion

The operations described in this paper are the crucial ones for performance of each and every terminal. Some operations might not exist in specific terminals, but every terminal should have at least few processes which can be identified as compliant with the paper. Every terminal operator is striving to improve the performance and to cut costs and is therefore forced to monitor all processes in the terminal and energy consumption [26]. One could calculate total energy consumption in one-step indeed, regardless what consumption is there within the different processes, but it is advisable to do it separately as it gives the opportunity to compare and improve certain processes with better equipment, better energy utilisation, change of MO[5], or using of alternative processes [5].

The monitoring that would burden the terminal operator is therefore not necessary, one only needs to calculate emissions, based on energy consumption within the stated processes per intermodal transport unit and report it to the terminal users who are responsible to calculate the emissions on entire transport chain [27]. The data is all there and is being measured constantly or annually. They only need to collect it and use it for calculations.

What is the motive behind this requirement? Is it to show that intermodal transport chain pollutes more than stated today? No, absolutely not. The author wants to lay all cards on the table and compare the emissions with pure road transport to show that there still are significant savings in emissions by using combined transport.

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[5] Modus Operandi, Lat.-a particular way or method of doing something.