ISSN 2229-5518

Methodology for Estimation and Calculation of the CO2 Emissions in Container Terminals

Janez Merlak[a], Aleš Groznik[b],

[a]Faculty of Maritime Studies, University of Ljubljana

[b]Faculty of Economics, University of Ljubljana

ISSN 2229-5518

Abstract

Combined transport consists of the rail and road part of the shipping journey. In general, a combined emission footprint has a more favorable outcome for the environment than road transport alone. However, combined transport includes not only rail transport and road haulage but also transshipment in container terminals. These are the nodes where the mode of transport changes during the shipping journey. In addition to handling, many other processes take place within the container terminal. These facilities are energy consumers and, as such, must be included in the calculation of the emission footprint for the entire transport chain. Every segment of the journey must be scrutinized. Calculation methods for transportation are prescribed in the Standard EN 16258. Calculation methods for handling and other terminal processes are not currently included.
If transport policymakers aim to promote sustainable modes of transportation, they need the tools to calculate and compare all the emissions caused by different transport chains.
This paper aims to show an empirical and also analytical approach to calculating the emissions restricted to container terminal processes that do not occur in road transportation alone. In this way, a comparison of different modes of transportation in regard to CO2e emissions can be supported.

***Keywords*: Container terminal carbon footprint, CO_2 footprint share of the terminal within the entire logistic chain, model for estimations**

---

1. Objective of the Study

The transport industry recognises its share in the overall CO2e emissions of the current environment. Globalization, and the fact that commodities are produced far from the end markets where they are being consumed, and in many cases distant from the raw materials needed for production, puts transportation in the position of becoming a very important factor regarding its share of product cost, its availability and the environmental impact of those products.

To enable the assesment of emissions within the logistic chains can help the transportation sector to choose from the various possibilities to transport the Intermodal Transport Units (ITUs). Data collection about the emissions from the various sources, such as terminals, railway stations, ports etc., is a very challenging and time-consuming task. While proper assessment is in place, any assessment of the data requires the processes to be well known. This study offers a process review and assessment model for the carbon footprint of container terminals as a link between different modes of transportation.

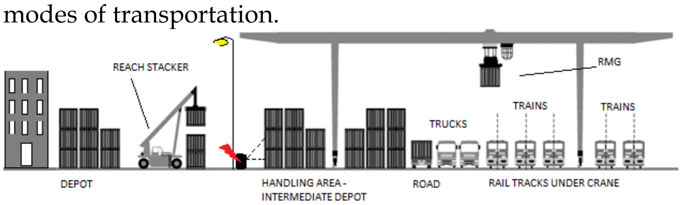

Figure 1: Schematic showing major energy consumers in a container terminal

The paper aims to enable a comparison between the existing modes of transportation within continents, where road as well as rail transport possibilities exist. Let us assume that commodities are produced in the Far East, in Asian Countries, put into maritime shipping containers and shipped to a consignee in Central Europe. The container unit needs to travel by sea to the European Continent and from its European arrival port it then proceeds to the final destination, a warehouse somewhere in Central Europe. The first part of the journey, the sea carriage, is exactly the same, no matter how the container is later transferred over the continent. In the second part, a continental journey that follows the sea carriage must be decided upon. There are two options for continuing the continental journey from the port to the final inland destination.

Option one:

Using a truck from the port terminal to the final destination and back to port or to the drop-off point assigned by the sea carrier.

Option two:

Using an Intermodal train to the nearest terminal to the destination and the last mile per truck and back the same way or to the drop-off point assigned by the sea carrier.

The mileage may differ but not significantly. There may exist significant differences in lead-time, flexibility and cost. What about the environmental footprint? Huge differences may exist.

Regarding the scope of this paper one could neglect the journey from the Far East to the container yard at the European destination Port, for example. A maritime journey is inevitable. We are interested about the emissions from the continental part of journey, referred to as the second part.

2. Literature Review

Literature related to the container terminal issues follows several trajectories. There are many studies that describe models for optimizing the processes within container terminals. Such optimizations do lead to emission reduction. Other studies suggest an effective terminal

layout for smooth running operations also have a positive impact. We would like to show any correlation between a terminal's properties and the environmental impact of a single unit being processed through that terminal. What are the actual drivers for terminal operators?
However, it is very hard to find a model for estimating energy consumption or even CO2e emissions for terminals which are, or which are to be included, in the chain of combined transport. By tracking the CO2e footprint of a single intermodal unit going through a combined transport system, there are some grey areas in the chain, where the estimation of CO2e emissions is not so straightforward. The proposed model aims to demonstrate how to (best) estimate energy consumption inside the terminals and thus calculate the environmental impact of the entire intermodal chain.

3. Continental Container Terminals

Intermodal Transport Unit travels from origin to destination and during the journey changes modes of transport. The points where the transport mode is changed is called Container or Transshipment Terminal. Many authors agree on the need to identify emissions from container terminal activities (Geerlings & Van Duin, 2011; Palmer, Mortimer, Greening, Piecyk, & Dadhich, 2017; Ketelaer, Kashub, Jochem, & Fichtner, 2014). The purpose of this study is to show all energy consumption within the transport chain of the continental intermodal transportation, including all the continental terminals that are being visited.
Each terminal operator ought to provide information about the emissions per loading unit to its clients. The clients are operators of intermodal or combined transport chains and they are the ones that ought to provide an environmental footprint for the entire transport chain. In this way, it is possible to obtain the information needed for comparison. However, modelling these processes can help us to provide estimations, instead of collecting this information from each terminal operator, which would be a rather lengthy and challenging task.

3.1. Operational processes

For the analisys, the different processes in the operations have been determined. Certain KPIs are established by the terminal operators for each important process in order to monitore and measure them accordingly. They use them for constant improvements in their operations. As for the purpose of calculating the environmental footprint of a Combined Transport Chain, the energy consumption in performing these processes has to be estimated in order to calculate the emissions of the entire chain.

3.1.1. Rail shunting, outside the terminal

Rail shunting of a train is needed to approach the manipulative tracks of a terminal from the railway station or in the oposite direction when leaving the terminal area. These are the so-called first- or last rail-miles, respectively. The processes are done with low speed (15-30 km/h max) and the energy consumption can be estimated and through that the emissions caused by this operations. To get the emission value per single unit, we have to consider the utilisation rate of train capacity which gives us number of units being shunted.
Electric shunting. To calculate the emissions caused by production of electric power, we need to know the energy consumption of the engine to calculate emissions:
$Ee = t.Ce.fe$ (1)
Ee stands for emissions, caused by electro engine, t stands for time of operation, Ce for nominal engine Power and fe for respective factor of electricity production for each country (see Table 1) and is calculated by duration of the train journey. The input parameters are the distance and number of trains per year. To estimate number of units per train we can use Poisson Distribution, where p(k) is the probability of expected number of units (k) on the train
$p(x = k) = \frac{\lambda^k}{k!} e^{-\lambda}$ (2)
The energy consumption gives us the input to read a value for the electric energy production mix from the table for each country where transshipment takes place.

Table 1: Factors for calculating energy consumption and GHG emissions for rail traction current and power from the national grid (Source: Guide on Calculating GHG emissions for freight forwarding and logistics services; CLECAT, Eco TransIT 2010, GEMIS 4.8)

State	Rail Traction Catenary		Electricity from the public grid of the Country	
Well-to-wheels	Energy [MJ/kWh]	CO2e [kg/kWh]	Energy [MJ/kWh]	CO2e [kg/kWh]
EU - 27	10.8	0.468	10.2	0.424
AT	4.5	0.119	6.8	0.21
B	13.5	0.393	12.4	0.219
BUL	12.3	0.66	10.5	0.538
CZ	11.2	0.661	11.2	0.681
DK	6.2	0.433	10.9	0.471
EST	13.8	1.208	9.7	1.012
FIN	9.9	0.48	10.3	0.295
F	13.2	0.077	13.5	0.072
GR	16	1.004	9.1	0.801
IRL	11.9	0.779	7.5	0.526
IT	9.6	0.749	8.4	0.463
LAT	5.1	0.16	5.8	0.181
LT	11.9	0.108	7.4	0.39
HU	14.5	0.637	13.1	0.481
DE	10.8	0.574	9.7	0.583
NL	8.8	0.497	9.2	0.46
PL	12.5	1.085	10.6	1.005
P	8.9	0.544	7.8	0.399
RO	9.4	0.556	8.9	0.495
SK	12.1	0.199	10.5	0.37
SLO	11.7	0.686	9.4	0.405
ES	9.2	0.425	8.3	0.363
S	3.8	0.004	8.7	0.058
GB	10.7	0.621	9.5	0.488

[1)] including losses in network

Diesel shunting. Diesel – Hydraulic shunting engines consume diesel fuel and thus directly produce emissions of the greenhouse gases.

$$Ed = t.Cd.fd \quad (3)$$

Where Ed represents emissions, t stands for time of operation, Cd for consumption of diesel fuel per hour and fd stands for the factor of well-to-wheel (WTW) emissions according to Table 2.

Conversion Factors for emissions in standardized unit CO2e [kg]			
	Units	direct (TTW)	Sum (WTW)
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
Aviation Kerosene	kg/kg	3.18	3.88
Heavy Oil (HFO)	kg/kg	3.15	3.41
Maritime Diesel Fuel (MDO)	kg/kg	3.24	3.92
Electric Traction EU27	kg/kWh	0	0.468
Electric energy EU27	kg/kWh	0	0.424

Table 2: Conversion factors for emissions in kilograms of CO_2e, (source: Guide on Calculating GHG emissions for freight forwarding and logistics services; CLECAT)

The volumes of relative emissions per single Intermodal Transport Unit would be calculated as:

$$E = \frac{\sum e}{ITU} \quad (4)$$

Where e stands for partial emissions per process, ITU is number of units in monitored periode and E total emissions per Intermodal transport unit.

3.1.2. Rail shunting, within the terminal

Rail shunting inside the terminal perimeter is needed for positioning the train sets beneath the crane lanes or into vertical manipulation transshipment positions. Ususlly done by the diesel-hydraulic shunting machines (or more recently also by battery-driven shunting locomotive), which can be an asset of the terminal or part of the fleet of a nearby railway station. Hence, the calculation must include the energy consumed even outside of the terminal perimeter if the shunting engine comes from a nearby railway station. The calculation is the same as with diesel shunting out of the terminal, or different if terminal uses battery driven shunting engine by help of Table 2, one needs to calculate kWh and use also the Table 1.

Again, the calculation would be:

$$Ed = t.Pd.fd \quad (5)$$

Shunting engine fuelling. It is important to mind the location of the refuelling station as it can be often quite far away from terminal location. This is a (an additional) consideration for diesel engines, as they have to travel to the fuelling station to re-fuel from time to time. The distance from starting point to the fuelling station and frequency of fuelling operations have to be taken into consideration. This only applies to the terminal operators themselves, should they want to calculate their own footprint.

This calculation may be ignored as the majority of the terminals that own shunting engines are also equipped with the fuelling station, or have fuel delivered to the site and only a few engine movements are recorded for this purpose.

3.1.3. Crane Manipulations of ITU[1]s

Those are basically the lifts done in order to transfer ITUs off and on the train, truck or terminal ground. These are performed with the terminal equipment – container cranes, such as reach stackers, container forklifts, gantry cranes, RMG or RTG. Since ITUs can weigh up to 30 tons, this equipment has to be compliant with technical requirements and regulations. Not all lifts performed are charged to the terminal clients and those are normally not in annual reports. The share of non-paid payload manipulations varies from terminal to terminal as it depends on organization and layout of the terminal and also on type or purpose of the terminal. A Poisson Distribution may be used to calculate the probabilities for number of lifts per train and thus to estimate the energy consumption per train. A study of many different terminals indicates that two lifts for each intermodal transport unit on arrival at the terminal, and two lifts when departing the terminal should be calculated. When transshipment from train to train is performed, again one has to calculate two lifts per each unit (arriving and departing the terminal). The estimation of number of containers per train is also done by Poisson Distribution.

$$p(x = k) = \frac{\lambda^k}{k!} e^{-\lambda} \quad (6)$$

3.1.4. Terminal internal transportation of ITUs, not rail

Iternal transportation of ITU by trucks, mafis, reach stackers, container forklifts are dependent on the organization, layout and machinery available at the terminal. Calculations are required for every equipment segment with the same or similar fuel and energy consumption. For each equipment the consumption per hour is to be collated and calculated with above formula.

3.1.5. Terminal internal transportation of ITUs with external trucks

is the trip needed by an external truck to move an ITU, inside the terminal, beneath or beside the position for manipulation, for the terminal equipment to undertake the lift. Here we should only estimate the energy consumption.

3.1.6. Consumption of electricity of a terminal

This is basically the consumption of all electrical equipment and appliances installed at the terminal, including RMGs, e-RTGs, power-docks, battery chargers, lighting, heating, appliances in the office facilities etc. Every terminal operator is well aware of such consumption through the electricity bills they are paying. Electricity consumption per unit is obtained by dividing the total amount by the number of ITUs that come in and out the terminal. It is then possible to calculate the emissions based on the energy mix of the electricity supply grid for that respective country.

3.1.7. Energy consumption for auxiliary activities

Energy consumption for auxiliary activities, where these are represented by: emergency shunting, removal of technically non-compiant wagons, resetting of wagon sets, small repairs on wagons, etc., amongst others. All these actions require that a shunting engine be able to operate inside the terminal, so either diesel engine or battery-driven engine. The calculation is similar to the operations for shunting, internal trucking, etc.

3.1.8. Energy consumption of trucks, waiting to be served

Trucks, delivering or picking up the ITUs, which are waiting outside or inside the terminal perimeter to get served, would not normally be considered in terminal emission calculations. Terminal operators usually don’t measure these emissions as they are not happening within the terminal’s processes. But it is important to include waiting trucks into the emission calculations of a terminal as these emissions would not be emited if it wouldn’t be for the sake of wating for the terminal services. The calculation method is to measure diesel consumption per hour as the input for calculating emissions.

Trucks call the terminal within the delivery time-window, usually planned by the terminal operator. However, historical records show peaks and troughs for certain times of the day or week etc. Here, a stochastic model is assumed. The probability of multiple truck calls increases as the cut-off time for specific trains or the time of arrival of a train approaches, and decreases when there are only few or no trains inside. It is only natural that the truck drivers strive to arrive to the terminal very early, as soon as the ITUs from the arriving train are released for collection, making last mile delivery, wait for stripping of the unit and returning back to the terminal just in time to catch the outgoing train with the empty ITU.

[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 standard Terminal Equipment.

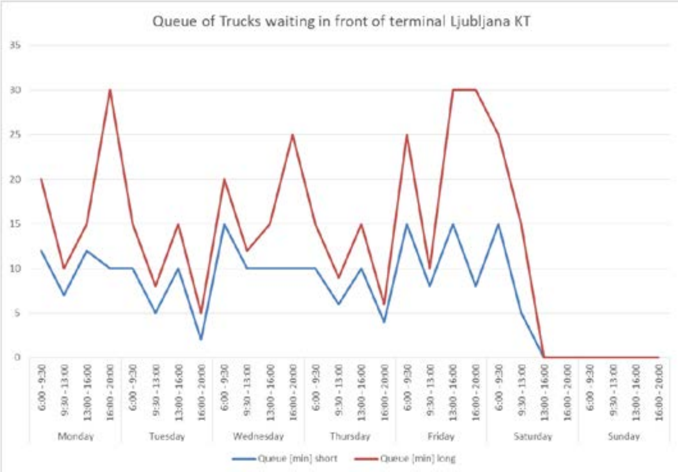

Figure 2: Measured max and min queuing times over an average week at Ljubljana Container Terminal
Source: Author

To calculate the probability of trucks waiting when calling the terminal, a Poisson Distribution can once again be used to estimate the queuing and the probable emissions, or, if possible, to measure the actual queuing time with truck engines running in idle. An appropriate estimation would be derived from the assumption that no terminal can afford lengthy queues in front of the gate or longer retention of trucks. Therefore a common acceptable waiting time for service can be estimated as being between 10 and 15 minutes in 90% of the cases.

3.2. Empirical Calculation model

The complete calculation is to be done by following the process flow chart to calculate the specific emissions. If any of processes do not appear at the certain terminal, they are simply omitted from the calculation. Should there be any extra terminal process not mentioned in the model, these can be added at the end. The model can serve as a check-list to consider all possible processes with influence over CO2e emissions.

Figure 3 summarises the identified processes that should be considered for specific terminals and ignore the ones that are not relevant. An estimation of the CO2e footprint of that terminal can be obtained from the total.

The major problem of the model is the consistency and correctness of data collected from respective terminals and other stakeholders.

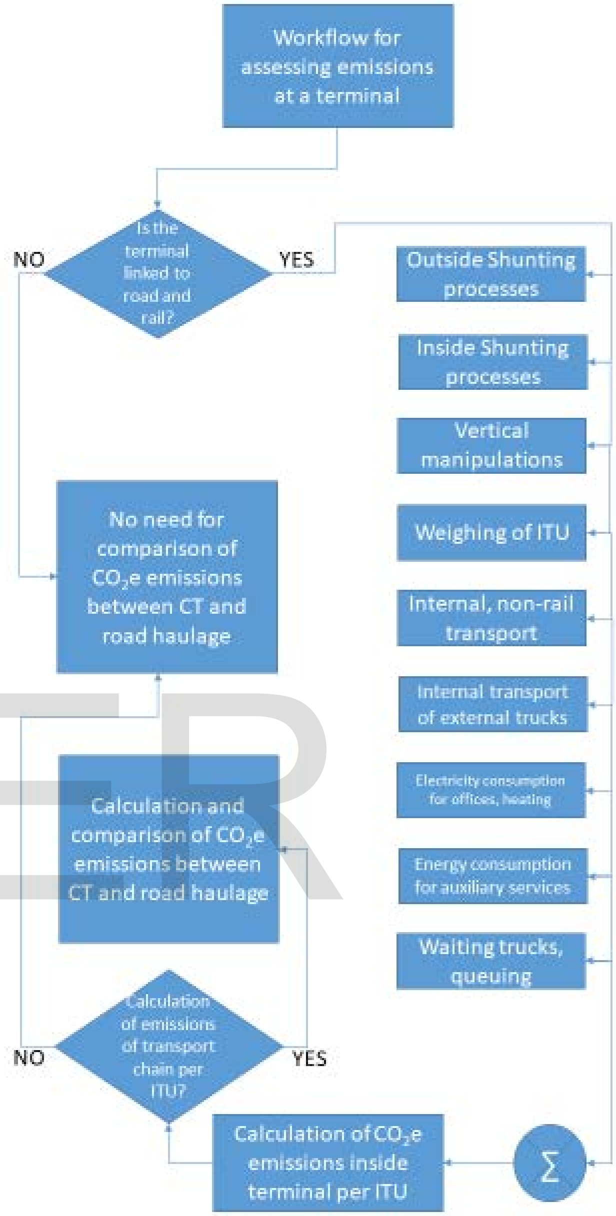

Figure 3: Model for calculating the terminal footprint

$$E_{sum} = \sum_{k=1}^{p} CO2e_{ij} \quad (6)$$

The resulting total for emissions of CO2e within the chain of processes is shown as (7) Esum.

3.3. Estimation Calculation model

Unfortunately, the values required to calculate actual CO2e emissions are very hard to obtain from the terminal operator. Some terminal operators might share this information, others not. Some operators provide accurate values; others might communicate misleading numbers. Therefore, there is an option to use an estimation model suited to every continental terminal in general. All emission calculations are based on certain assumptions, but that is also the case with estimating emissions in pure road transportation, so it would be appropriate to do the same with the terminal processes. Once the processes taking place inside the terminal and the emissions caused by the terminal operations and procedures are understood, it is possible to make certain estimations on which to build a model for emission calculations. These should be simple to use and should improve intermodal or combined transport CO2e emission calculations significantly, since calculations of the transport chains in this segment are not currently included in Standard EN16258.

The processes that occur during transshipment operations, taking place whenever the transport changes modality or simply switches from one transport leg to the next one, have been identified.

3.3.1. Calculation of shunting emissions estimation

To calculate the estimated CO2e emission per transport unit in the shunting process, Table 3 indicates values for shunting by diesel traction and, similarly, Table 4 for by electric locomotive engines. Thus the value of CO2e emissions per single unit can be obtained. The model uses train utilisation rates from 50% to 100%. Maximum utilisation envisages 82 TEUs per train, taken into consideration that most of continental terminals in EU are built to accept trains of 550m length without the engine. The model was built on this assumption, but can be easyly modified if the train capacities change in the future. Utilisation values under 50% are not included in the tables as trains with such low utilisation rates are not considered sustainable and thus rather rare. The distance of the terminal manipulation tracks from the main station should also be considered, where a line engine is replaced by a shunting locomotive. For line engines that deliver their cargo beneath the cranes, calculations are based on Table 4. The CO2e emission for an engine that is shunting an intermodal train is estimated as 3.24 kg per liter of diesel fuel consumed, and as 0.468 kg per kWh used, when catenary electric traction is being used for shunting. Both tables include the calculations for various distances, where the distance between a main-line station to its respective terminal must be considered. The values in the tables show emissions per single Intermodal Transport Unit.

CO_2e	Distance [km]			WTW	3,24kg CO_2e/l Diesel
utillisation rate	1km	2km	3km	4km	5km
50%	0.1106	0.2213	0.3319	0.4425	0.5532
55%	0.1008	0.2016	0.3024	0.4032	0.5040
60%	0.0926	0.1851	0.2777	0.3703	0.4629
65%	0.0856	0.1712	0.2568	0.3423	0.4279
70%	0.0796	0.1592	0.2387	0.3183	0.3979
75%	0.0744	0.1487	0.2231	0.2974	0.3718
80%	0.0698	0.1396	0.2094	0.2791	0.3489
85%	0.0657	0.1315	0.1972	0.2630	0.3287
90%	0.0621	0.1243	0.1864	0.2485	0.3107
95%	0.0589	0.1178	0.1767	0.2356	0.2945
100%	0.0553	0.1106	0.1660	0.2213	0.2766

Table 3: Emissions of CO2e [kg] per TEU by diesel shunting

The WTW calculation method for CO2e emissions is used in both tables.

CO2e	Distance [km]			WTW	0.468 kg CO_2e /kWh
Utillisation rate	1km	2km	3km	4km	5km
50%	0.0925	0.1849	0.2774	0.3698	0.4623
55%	0.0842	0.1685	0.2527	0.3370	0.4212
60%	0.0774	0.1547	0.2321	0.3095	0.3868
65%	0.0715	0.1430	0.2146	0.2861	0.3576
70%	0.0665	0.1330	0.1995	0.2660	0.3325
75%	0.0621	0.1243	0.1864	0.2486	0.3107
80%	0.0583	0.1166	0.1750	0.2333	0.2916
85%	0.0549	0.1099	0.1648	0.2198	0.2747
90%	0.0519	0.1039	0.1558	0.2077	0.2596
95%	0.0492	0.0985	0.1477	0.1969	0.2462
100%	0.0462	0.0925	0.1387	0.1849	0.2311

Table 4: Emissions of CO2e [kg] per TEU by e-locomotive shunting

The calculated values show emissions per single TEU for respective distances and respective train utilisation rates in kilograms of CO2e.

3.3.2. Calculation of ITU lifting or ITU handling emission estimations

Shunting emissions are added to the estimated emissions per lift per unit. Each unit is handled at least twice on average. The first lifting is removal from the train and the second is placing it on a truck chassis or onto another train leaving the terminal. Despite the fact that terminal operators strive to achieve as many direct manipulations as possible (only one lift per unit) it is almost impossible to set the timing such that a lifted unit the air can be immediately lowered onto the next carrier for on-going transport or, the so-called, next leg of transportation. Therefore an average number of handlings of 2 per each unit is assumed. The table shows the terminals all over EU and the cost per single manipulation being charged. The (most) important figure in handling is gross weight of ITUs. To compare emissions throughout a journey a representative weight value for ITU or the cargo space of a truck is required. A weight of 24,000 kgs of cargo will be used in calculations. An ITU tare weight of 2,100 kgs is added to calculate for energy consumption from handling.

Benchmarking in the ITU handling field is essential and it is assumed that values from terminal to terminal are relatively consistent and do not make a significant difference to a single unit's long distance transport chain. Using new and more sustainable equipment, moderate driving habits for forklift and reach stacker drivers and employing battery driven or hybrid equipment, makes a difference where large numbers of units are handled in given terminal – the savings can be significant.

	avg.consumption	units	emissions	units
diesel	1.44	litres	4.66	kg CO2e
electricity	6.09	kWh	2.85	kg CO2e

In 2015 the Economic Commission of Latin America and Caribbean (ECLAC) (Greene & Lewis, 2016) conducted a study for 41 maritime container terminals around the world on emissions produced per ITU moved. The study came up with the value of 29.8 kg CO2e/ITU. This benchmark will be used to compare the average emissions between inland intermodal terminals and maritime container terminals.

To properly estimate the emissions during actual lift-on or lift-off, the energy consumed for this operation should be estimated. There are several approaches. The most convenient approach is through the price of handling. According to research conducted at many European Terminals, the share of energy in respective pricing per single handling is, on average 8% of the handling price for a diesel reach stacker, and in average 13% for electric RMGs. The amount of energy consumption and thus CO2 emission potential per single operation can be calculated out of these values. Of course, the handling prices are discretely shared and may not be revealed. Prices of energy differ per country and are subject to change and the prices of handling in the terminals follow in proportion, but are generally set for the calendar year. To calculate the emission estimation per handling a simple formula for diesel is taken from Table 2, where each litre of diesel fuel burned contributes with 3.24 kg of CO2e; similarly for Table 1 where each kWh of electricity consumed from of grid in EU contributes to an emission of 0.424 kg of CO2e. The average price of a single handling in 43 monitored open-access Inland Intermodal Terminals in Europe results in 26.35 € per handling per unit. Calculating emissions from the cost per single handling is relatively trivial. Table 5 shows the calculated values of emissions built into the handling price by terminal operators. The share of energy cost within the handling price is shown in the table. Handling prices also reflect trends in the transport industry, fuel and energy costs. Benchmarking is common practice in the field so handling fees are very similar all over the continent. The same handling equipment, or very similar, is used across Europe. Differences are attributed to terminal layout and process organization.

1 Handling	Avg. price		share [%]	emissions	
Diesel (Reachstacker)	26.35	€	8%	*7.47*	kg CO2e
Electricity (RMG)	26.35	€	13%	*7.72*	kg CO2e

Table 5: Share of energy consumption in handling price derived as value of emissions

Assuming that every Intermodal Transport Unit has to be handled four times while inside a terminal, we arrive at the value of 29.8 kg/ITU, similar to the ECLAC study. The share of energy cost that is represented in the price indicates that it most likely includes all foreseen movements in the terminal such as inside moves of units to blocks, segregation at the terminal, additional handling, etc.

The other approach is to measure the energy consumption directly from the equipment. It depends of the build year, type, nominal power, driver etc. In Table 6 only average emissions for single handling are calculated. These values reflect handling and do not include any emissions of other processes inside terminal.

Table 6: Average consumption of reach stackers and RMGs. reported by TOs per handled unit and emission values

3.3.3. Calculation of terminal inner trucking emissions estimation

Total operational emissions must include estimates of those generated by inside trucking or manipulation shipping containers. As explained in the previous subsection, the handling prices set by the terminal operators already predict the movements within the terminal perimeter. These, however, depend on the size and type of the terminal, as well as on its organization. The length of tracks, multiplied by two, should provide a realistic distance for calculations involving truck journeys within the terminal. The calculation works with estimated diesel consumption per 100 km. Track lengths are between 250 m – 750 m, where lowest and highest values are quite rare. Most terminals work with distances between 550-600 m of manipulation rail tracks; 750 m for newly built terminals.

The calculation with $E\ [kg] = \frac{C[l]2l[km]}{100\ [km]} . 3.24\ [kg/l]$ [8] with l being the length of manipulative rail tracks in km. C the average diesel consumption [l] per 100 km and factor 3.24 kg of CO2e per each litre of diesel fuel burned. Average consumption is estimated based on the engine type, year of build, driving style, etc.

ISSN 2229-5518

$$E\ [kg] = \frac{C[l]2l[km]}{100\ [km]}.3.24\ [\mathrm{kg/l}]\quad [7]$$

3.3.4. Calculation of visiting truck emission estimation

Trucks waiting to enter the terminal with their engines running are also emission sources. These emissions can be considered as external intermodal transport chain costs but never the less apply to the overall contribution of CO2e. In equation [9], where t is time, C consumption of litres of diesel per time unit, the right side of Poisson distribution functions to return the probability of visit with waiting time t, where λ stands for actual t=10 min visits on a monitored time interval.

$$E\ [kg] = 3.24 \left[\frac{kg}{l}\right] C \left[\frac{l}{60min}\right].\left[\frac{\lambda^t}{t!}e^{-\lambda}\right]\quad [\text{Error! Bookmark not defined.}]$$

Drivers, who keep their engines running while waiting for admission and service, would therefore cause between 1.6 and 2 kgs of CO2e per truck with EURO 6 diesel engine.

3.3.5. Calculation of terminal supporting services emission estimation

Last but not least are the emissions from facility operations, including support staff and services, which must be added to the total value. Here we estimate the emissions caused by terminal lighting and offices, heating, office appliances, information and security systems, etc. The values are rather small per handled unit but they must also be considered. For that purpose Table 7 is represents calculated kilogram values for CO2e emissions per unit, taking into account the average size of the facility and average energy consumption.

Number of boxes p.a.	Lightning 100.000 sq m	lightning 200.000 sq m	Office area of 500 sq m
50.000	0.8484	1.6967	0.7738
60.000	0.7070	1.4139	0.6448
70.000	0.6060	1.2119	0.5527
80.000	0.5302	1.0605	0.4836
90.000	0.4713	0.9426	0.4299
100.000	0.4242	0.8484	0.3869
150.000	0.2828	0.5656	0.2579
200.000	0.2121	0.4242	0.1934
300.000	0.1414	0.2828	0.1290
400.000	0.1060	0.2121	0.0967
500.000	0.0848	0.1697	0.0774

Table 7: Kilograms of CO2e emissions per single unit for supporting services in the facility

To build a tool for calculations, certain input has to be assured. The following parameters need to be included Code 1: Input Parameters required to calculate CO2e. General data about terminals can be obtained from different sources. In Europe, an internet site of AGORA Terminals (KombiConsult, 2018) exists. The sources of data are terminal operators, intermodal operators, seaports, inland waterway ports or regional governments to whom the terminals belong. etc.

3.3.6. Calculation of emissions

To estimate the emissions for the container terminals on each end of the journey and the journey itself, one could use the tool presented on the following pages. Providing the required information, the estimated values can be calculated by the algorithm which contains calculations explained in prior chapters. The code is pritten in Python 3.7 and calculates the result, based on the input according to the course of journey.

```
T1=input('What is the name of departing terminal? ')
T1n=input('What is the average yearly throughput of '+str(T1)+ '. in TEUs? ')
T1Cap=input('What is '+str(T1)+ ' container yard capacity in sq meters? ')
T2=input('What is the name of destination terminal? ')
T2n=input('What is the average yearly throughput of '+str(T2)+ '. in TEUs? ')
T2Cap=input('What is '+str(T2)+ ' container yard capacity in sq meters? ')
UT=input('What is the utilisation rate of the train in %? ')
ITU=input('Weight of the cargo within an ITU. in kgs? ')
RA=input('What is km distance by rail between departing and destination terminal? ')
Shunt1=input('What is the distance between main rail station and '+str(T1)+' in km? ' )
Shunt2=input('What is the distance between main rail station and '+str(T2)+' in km? ' )
T1fm=input('How many km for the first-mile delivery of ITU? (Insert 0. if none) ')
T2lm=input('How many km for the last-mile delivery of ITU? (Insert 0. if none) ')
RO=input('Road distance from POL to POD in km? (If unknown. enter 0 and the module will sum up rail kilometers and two trucking legs to compare!) ')
```

Code 1: Input Parameters required to calculate CO2e

The result for a representative journey is shown in the following text.

What is the name of departing terminal? TERMINAL 1
What is the average yearly throughput of TERMINAL 1. in TEUs? 22000
What is TERMINAL 1 container yard capacity in sq meters? 21500
What is the name of destination terminal? TERMINAL 2
What is the average yearly throughput of TERMINAL 2. in TEUs? 240000
What is TERMINAL 2 container yard capacity in sq meters? 60000
What is the utilisation rate of the train in %? 69
What is the weight of the cargo within an ITU. in kgs? 24000
What is km distance by rail between departing and destination terminal? 429
What is the distance between main rail station and TERMINAL 1 in km? 2
What is the distance between main rail station and TERMINAL 2 in km? 4
How many km for the first-mile delivery of ITU? (Insert 0. if none) 25

```
How many km for the last-mile delivery of ITU? (Insert 0. if none) 22
What is the road distance from POL to POD in km? (If unknown. enter 0 and the module will sum up rail kilometres and two trucking legs to compare!) 412
____________________________________________________________________________________
** CO2e emission for pure rail transport between TERMINAL 1 and TERMINAL 2 is 164.35 kg.
** CO2e emission for diesel train shunting in both terminals is 2.32 kg.
** CO2e emission for handling at both terminals is 15.04 kg.
** CO2e emission for diesel inner trucking at both terminals is 2.18 kg.
** CO2e emission for waiting trucks at the gates of both terminals is 7.20 kg.
** CO2e emission of supporting services at both terminals is 1.89 kg.
** CO2e emission for first and last-mile trucking at both ends is 23.97 kg.
** Distance for intermodal calculation considered was 529 km.
** CO2e emissions for complete intermodal transport chain for the ITU. 24000 kg of cargo. between POL and POD is 216.95 kg.
** Calculation of the rail part in accordance with EU27 average WTW conversion factor.
------------------------------------------------------------------------------------------
* Distance for road calculation considered was 412 km.
* CO2e emissions for pure road transport of 24000 kg of cargo between POL and POD is 340.39 kg.
* Calculation of the road part in accordance with WTW conversion factor.
==============================================================================================
*** The emission saving made by selecting Intermodal Transport over Road Haulage is 124.00 kg CO2e per Unit. **
```

Code 2: Result. based on the entered parameters. with calculated difference between the two modes of transportation

Code 2 shows the input of required data and the results provided by the module. At the end it calculates the savings of CO2e. If the rail component is too short, the module will show no savings and suggest that trucking be used all the way.

Using random numbers for inputs, with lower and upper limits rather than entering actual requested parameters, it is possible set multiple iterations and results for different combinations, such as terminal capacity, kilometre distances, first and last-mile options, etc. The tool calculates the CO2e savings for different combinations of parameters; it can derive the minimum and maximum emission savings for different combinations of terminals and transport modes.

4. Conclusions

The operations described in this paper are crucial for establishing the performance at each and every terminal. Some operations might not exist in specific terminals, but every terminal should, at minimum, have several processes that comply with the paper. Every terminal operator is striving to improve the performance and cut costs and is therefore forced to monitor all the above-mentioned processes. This is the main reason why process-driven emissions are actually very similar, even if the terminals differ by many parameters. It should be possible for terminal operators to calculate all energy consumption in one step, regardless of the consumption occurring within the different processes. However, 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 MO2, learning and assembling best-practices or suggestions for alternative processes.

On the other hand, intermodal operators who are trying to assess CO2e emissions for the whole chain, need a tool to estimate and calculate these values avoiding extensive calculation.

Terminal operators are keen to utilise their assets to their full extent. Hence, energy usage per unit handled in the terminal always remains within a certain reasonable frame (Martinez, Kauppila, & Castaing, 2014). The dynamic demand for manipulations is met by increasing resources and handling equipment or by extending working hours. For calculation purposes, these actions hardly influence average energy consumption, measured by the number of units handled in particular terminal.

Monitoring activities that would otherwise burden the terminal operator are, therefore, unnecessary. Emissions calculations based on energy consumption within the stated processes is the only data needed and subsequently reported to the terminal users responsible for calculating emissions for the entire transport chain. All data is available and continually or annually calculated. There is only the need to collect the information and use it in the calculations. The tools, similar to the code in this paper are able calculate the emissions estimation for each and every transport.

On behalf of all authors, the corresponding author states that there is no conflict of interest.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

5. References

Geerlings, H., & Van Duin, R. (2011, April 1). A new method for assessing CO2-emissions from container terminals: a promising approach applied in Rotterdam. *Journal of cleaner Production, Vol.19 (6)* (Apr 1, 2011).

Greene, S., & Lewis, A. (2016). *GLEC Framework for Logistics Emissions Methodologies.* Amsterdam: Smart Freight Centre 2016. GLEC Framework for Logistics Emissions Methodologies.

Ketelaer, T., Kashub, T., Jochem, P., & Fichtner, W. (2014). The potential of carbon dioxide emission reductions in German commercial transport by electric vehicles. *International Journal of Environmental Science & Technology (IJEST)*, 2169-2184.

KombiConsult. (2018). *AGORA*. Retrieved from Agora Terminals: http://www.intermodal-terminals.eu/database/

Martinez, L., Kauppila, J., & Castaing, M. (2014, December 1). International Freight and Related CO2 Emissions by 2050: A New Modelling Tool. *International Transport Forum.* Paris.

Palmer, A., Mortimer, P., Greening, P., Piecyk, M., & Dadhich, P. (2017). A cost and CO2 comparison of using trains and higher capacity trucks when UK FMCG companies

[2] Modus Operandi (abrev. MO), Lat. - a particular way or method of doing something.

ISSN 2229-5518

collaborate. *Transportation Research Part D: Transport and environment*, 94-107.

Siskos, P., Capros, P., & De Vita, A. (2015). CO 2 and energy efficiency car standards in the EU in the context of a decarbonisation strategy: A model-based policy assessment. *Energy Policy*, 22-34.

UIRR, International Union of Combined Road-Rail. (2003). *CO2 REDUCTION THROUGH COMBINED TRANSPORT.* Brussels: UIRR.