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DETERMINATION OF ENVIRONMENTAL FOOTPRINT OF INLAND CONTAINER TERMINALS

Janez Merlak[1], Aleš Groznik[2], Fouad Al-Mansour[3]*
[1]Univerza v Ljubljani, Fakulteta za pomorstvo in promet, Portorož, Slovenia
[2] Univerza v Ljubljani, Faculty of Economics, Ljubljana, Slovenia
[3]Jozef Stefan Institute, Ljubljana, Slovenia

The global warming is forcing us to assess the specific environmental impact of all our industrial activities without which we could not imagine our existence anymore. Energy and heat production, industrial production of all kind, agriculture, forestry and other land use, transportation, construction industry and other energy processing and refining and transport of fuel. Among stated sources of global Greenhouse Gas Emissions, transportation alone brings a share of 14%, studies show. Due to globalization of the international trade we are not able to avoid the massive movements of raw materials on one side and finished products on the other. Thus the Transportation Industry becomes a major factor in production cycle of the majority of products. Transportation modes available today have all the same task, to bring the goods from shipper to consignee as fast and as cheap as possible. Transportation mode selected, isn't necessarily the environmental friendly mode, but only the "best value for money" for the stakeholders. To stimulate the use of environmental friendlier transportation modes,a proper comparison between modes is required.The standard EN16258 provides methodology for calculating Green-House-Gas Emissions during transportation for all transport modes, but there are some grey areas in logistic chains. In Combined transport, where Rail and Road Transportationsare combined, there is a whole segment of activities,needed to shift from one mode to another, where emissions take place and have to be accounted for.

Key words: Container terminal environmental impact, CO2 emissions in intermodal logistic chain, Cointainer Terminal Emission Estimation Model

INTRODUCTION

The global playground of transport industry is changing all the time. The big players in logistics, major container shipping lines, are trying to control the entire logistic chains, from source to sink, generating as much profit as possible. When selecting a transportation mode on the continent, time and money savings would often prevail.

The specialized companies such as Combined Transport Operators are striving to shift cargo off the roads to the rail on the major portion of continental routes and use road for the first- and last-mile delivery. These effortsdiminish emissionsand road congestions with high external costs, on the entire continental Route.

In combined transport the transhipment points, so called container terminals, play a crucial role. The study is focusing on the activities and related emissions of Container Terminals in order to enable comparison between pure road and the combined transport. To estimate emissions of a combined transport and compare it to road transport one needs to estimate specific emissions of a single intermodal loading unit on its intra-continental journey(EU, 2019),(Martinez, Kauppila, & Castaing, 2014), (Schmied, Knörr, Friedl, & Hepburn, 2012).

Combined transport(UIC-ETF, 2019) uses the economy of scale on the railway part of the transport chain. The trains connecting the container terminals have capacity between 80 –108 TEUs per train, depending on the route and the continent. The emissions per ILU can be reduced up to 50% in comparison with the road transport, when Combined Transport (CT) is used(UIRR, International Union of Combined Road-Rail, 2003). But, one has to take into account some additional costs and time losses in container terminals. Some emissions are caused there, which need to be attached on the combined transport chain as a whole and be properly evaluated per each unit.The main energy consumers in the terminal are shown in a Figure 1.

There is a large potential to reduce the emissions within the terminal itself (Geerlings & Van Duin, 2011) as there is potential in port areas, regarding ships (Winnes, Linda, & Erik, 2015), on the road, regarding vehicles manufacturing provisions and test demands(Pavlovic, Marotta, & Biagio, 2016), (Fontaras, et al., 2016).There are possibilities to diminish emissions by changing the transportation habits in industrial sectors. (Bonilla, Keller, & Schmiele, 2014).

More and more products are getting containerized, thus enabling decision makers to select different modes of continental transportation.

The paper is addressing the methodology for assessment of emissions per single ILU to enable the complete calculation of the ILU's traveling through the continent, using combined transport and consequently, the container terminals.

**Pot pomorščakov 4, 6320 Portorož, Slovenia, janez.merlak@adriakombi.si*

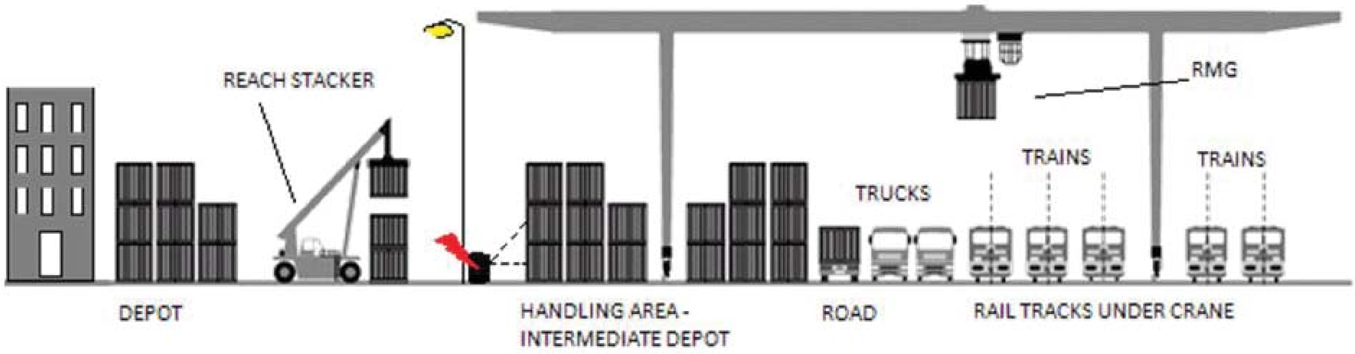

Figure 1: Container terminal energy users

In addition, when analysing specific emissions per process, one can get ideas for specific improvements that would lead to lower emissions in the terminal areas, by applying even some smaller corrections in operations and processes.

BACKGROUND

The European Standard EN 16258(EU, 2019) describes the calculation methodologyfor CO2e emission assessment in transportation. But, there are some gaps in the standard, which need to be covered as well (Kellner, 2016). The procedures within the closed areas, such as a continental container terminal, need a detailed approach. There are many papers written about the container terminals in the ports around the world(Koster, Balk, & Nus, 2009)(Wen-Kai, 2013),(Venkatasubbaiah, Narayanaa Rao, Malleswara Rao, & Challa, 2017), (Sim, 2018). It is very clear to everybody that the entire transport chain emissions needto be covered. Intermodal transport chain or combined transport chain require the transhipment in container terminals, so the emission calculation has to include these nodes as well.

INLAND CONTAINER TERMINALS

The Inland Container Terminal network,(Roso, Woxenius, & Lumsden, 2009),(Geerlings & Van Duin, 2011), (Ketelaer, Kashub, Jochem, & Fichtner, 2014),(Palmer, Mortimer, Greening, Piecyk, & Dadhich, 2017), (Hjortnaes, Wiegmans, Negenborn, Zuidwijk, & Klijnhout, 2017), (Teye, Bell, & Bliemer, 2018), is essential for a flexible and reliable combined transport services within the continent. They are generally used for the following purposes:

- Vertical Transhipment Wagon-Truck or vice versa (first- or last-mile haulage)
- Vertical Transhipment Wagon-Wagon (switching from one to another intermodal train line)
- Intermediate depositing (waiting for successive carrier)
- Depositing of empty ILUs, waiting for continental/intercontinental export cargo
- Customs, inspections, repairs etc.

Adding the auxiliary services to above, we get the complete number of energy users (consumers) in the terminal area. However, this is still far from everything that combined transport adds to CO2e emissions.In road transportation on continental routes, where the terminals are avoided completely, such emissions don't take place at all. Therefore, one has to include these emissions in calculation of a combined transport route and only than it can be compared with pure road-transportation route to see the benefits in emissions. As previously mentioned, every inland container terminal needs certain external processes that are vital for its operations. The external train shunting processes and trucks in cues at the terminal gateshave to be included in the emission source.

Inland Container Terminal Operations

Inland Container Terminal needs external service providers in order to operate as well as the proper equipment and resources to perform the transhipment services in due time. Stopping at an inland container terminal is often seen as a disturbance in the transport chain, by the client. Therefore it is essential that the performance of the terminal is at the very highest level. The proper organization of processes is essential. The terminal must be well connected to transport infrastructure of the modes it is supposed to serve (rail station, highway connection, inland waterway port, sea port, industrial rail sidings, etc.). A good connection is much more than only physical infrastructure link.It includes also the service providers, operating on these links. They have to perform with excellence and according to general plan, made together with the container terminal operator. Hereafter, the specific services are explained in detail to get an insight of the CO2 emission agents of an Inland Container Terminal Operation.

Intermodal Train Shunting

To cope with the gap between railway main lines and terminal area it is necessary to engage the shunting service. Usually it happens at lower speed from 15 up to 30 kilometres per hour.

One needs to calculate the consumption of energy, used for movements of the train between the main line railway station and the terminal.

Shunting, using an electric driven Locomotive. To calculate the emissions caused by production of electric power, we need to know the energy consumption of the engine to calculate emissions:

$$E_e = t{*}C_e{*}f_e \quad (1)$$

E_e - emissions caused by electrical shunting or line engine,

t - time of operation,

C_e - nominal engine power,

f_e - respective factor of electricity production for respective country (see Table 1)The additional parameter is a number of TEU on the train. This is to be calculated with statistical average of utilisation rate of the intermodal trains on certain lines throughout the year.

$p(k)$ - probability of expected number of ILUs(k)

 - Usual number of ILUs on train, recorded by terminal operator

$$p(x = k) = \lambda^k/k! * e^{-\lambda} \quad (2)$$

Rail Traction of intermodal trains, using a catenary energy, has a country specific impact on environment as it depends on the electricity production mix of respective countries. The average of 27 EU member countries rail catenary emission factor and public grid emission factor are used in calculations(Schmied, Knörr, Friedl, & Hepburn, 2012).

Shunting with a diesel driven Locomotive. Diesel consumption is calculated with the following formula:

$$E_d = t{*}C_d{*}f_d \quad (3)$$

E_d - emission

t - time of operation

C_d - Diesel fuel consumption per hour

f_d - factor of well-to-wheel (WTW)

The emission conversion factorsare calculated according to standard EN 16258 and shown in the Table 2.

The emissions per single ILU are expressed with the following formula:

$$E = \sum e / ILU \quad (4)$$

e - partial emissions per process,

ILU - number of units on the train (estimation)

E - total emissions per ILU.

Inland Container Terminal Internal shunting

To put the intermodal train into the position for handling, the internal (terminal) shunting takes place. Train has to be positioned underneath the cranes, near the platform which is used to manipulate with the ILUs. This shunting might be a part of external shunting procedure or completely separate and independent, done by the terminal operator. Usually the internal engines are not taking energy from the rail catenary but are autonomous with diesel or even battery power packs. The calculation is similar to external shunting, but the power/consumption parameters have to be used for such specific engine.

$$E_d = t{*}P_d{*}f_d \quad (5)$$

It is important to note here, that when terminal operator owns its own internal shunting engine, this must be maintained and refueled regularly. In many cases the fueling stations are outside of the terminal and the engine consumes additional energy to go to refueling station periodically. The calculation of refueling-related emissions must be done on weekly or even yearly set of data, to get approximation of the emissions per each ILU.

Vertical manipulations

A heavy duty lifting equipment is usually found inside Container Terminal areas. In some of the terminals they use state of the art, modern equipment, the others may use 30 year old machines, which are maintained regularly and are coping with the demands. The terminal operator decides which equipment to purchase, based on analysis of daily operations and market demands. The main objective is to lift heavy burden quickly, efficiently and safely. Since they have all the historical data of terminal visits, they can easily estimate how many machines and what kind of equipment they need.

The emission calculation is similarly done by specific energy consumption of the equipment and the time it is in use. The energy consumption and hours of usage are well known to the terminal operator, one only needs to include the appropriate WTW Conversion Factors from tables 1 and 2.

Non-rail internal movements of ILUs

There are several horizontal moves of each ILU internally to be performed. Whether it is movement to or from depo to or from manipulation rail tracks to make space necessary for manipulations, or it is simply movement of the lifting equipment from one part of the train or terminal to another. These movements use energy and thus produce certain amount of emissions. Here the estimation is based on the terminal layout and its size.

Table 1: Factors for 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
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
Denmark	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
1) including losses in network				

External trucks performing internal movements of ILUs

To perform the vertical lift on/off, the external truck must be positioned to the proper micro location where the terminal operator has planned to perform the lifting operation. The external truck, visiting container terminal does not end the journey at the terminal gate, but drives inside terminal area as well. This happens at a very low speed 15-20 km/h. The energy consumed is equivalent of time spent with the engine running.

Electricity consumption

Every Container Terminal's consumption of electrical energy is based on number and type of equipment and appliances and the equipment's specific energy consumption rate. Certain parameters, such as size of the main building (heating, operating costs, etc.), number of terminal staff (work place appliances) and terminal area size (illumination, security devices, etc.) are decisive for total energy consumption. The research of 50 terminal sites in Europe showed that every terminal operator is well aware of the electric energy consumption as it is cost-related and they are all striving to minimize it.

Table 2: Conversion factors for emissions in kilograms of CO2e, (source: Guide on Calculating GHG emissions for freight forwarding and logistics services; CLECAT)

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

Ancillary activities' energy consumption

In daily operation of a container terminal, there are many irregularities that may occur. Such events call for ancilliary services. These are:

- Quick repairs of containers
- Small repairs on wagons
- Emergency shunting
- Stripping or stuffing of the ILU for safety or inspection reasons
- etc.

These services are, normally, all recorded and presented yearly, so the calculation of these specific emissions have to be calculated with yearly energy consumption divided to all ILUs processed in the respective terminal.

Emissions of external trucks, waiting at the gate

In the Combined Transport, road trucks are not excluded from the logistic chain. They are an equal partner to rail and very important to the entire transport chain. They are essential to perform first-mile and last-mile deliveries of intermodal loading units and thus completing the combined transport chain. One intermodal train equals in average 40-50 truck-loads. At arrival of a train to the terminal, the operator has the task to offload the complete train and serve all trucks that have arrived to pick up the unit or delivered a unit or even both. Normally this would lead to rush hours, peaks in demand of service, congestions. Terminal Operators are trying to plan and schedule the trucks to eliminate waiting times at the gate of the terminal. However, the reality shows that there are peaks and downs in service demand, therefore a stochastic system.

The peaks are accumulated at the end of the delivery time window (just before closing for a certain train) and at the beginning of the "ready for pick-up" time window, scheduled by the terminal operator. The busiest terminals have up to 50 trains per day but not all ILUs get loaded onto trucks. A lot of them are transshipped to another train. In any case, there are unavoidable minor congestions which can get bigger in case of other irregularities, such as train delays, road blockages, RMG, RTG or RS malfunction, etc.

Empiricalmethod

To calculate the emissions of CO2e in a combined transport chain, one has to add to described calculation for rail transport, according to EN 16258, the emissions taking place in connection to Container Terminal. Empirical approach demands one to retrieve large amount of information from the terminal operator and sum up all particular emissions. The Figure 3 is showing all emission sources that need to be addressed in the calculation process.

$$E_{sum} = \sum_{k=1}^{p} CO2_{eij} \quad (6)$$

Calculation is shown in (6) and represented by *Esum*. The empirical method is in fact very time consuming and is to be used when one needs to optimize the terminal operations rather than when calculating the emissions for reporting or comparison purposes. The detailed analysis per each process can help find the best way of optimizing the processes and save costs, as the emissions are always related to energy consumption.

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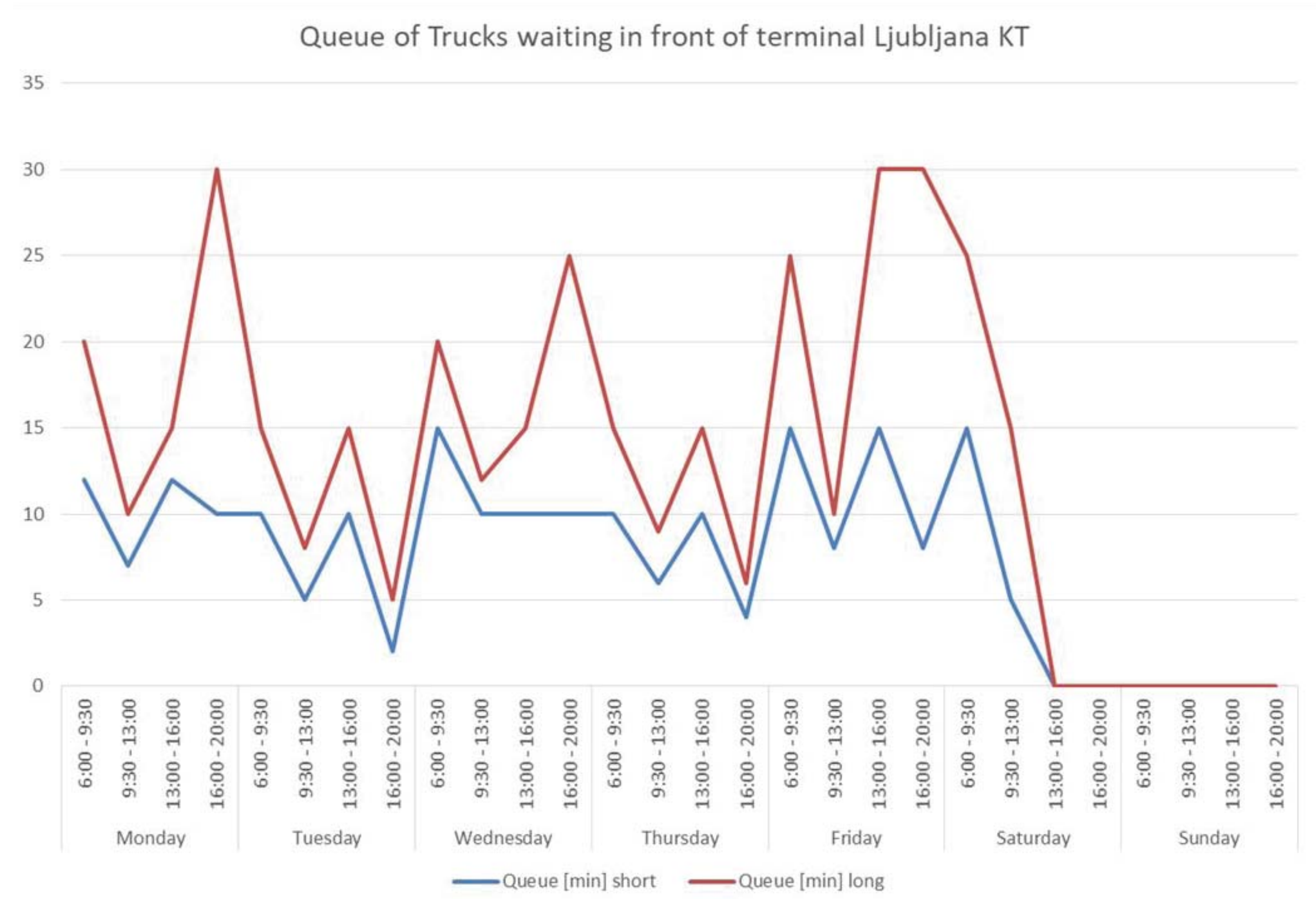

Figure 2: anexample of max and min queuing times over an average week at Ljubljana Container Terminal

Source: Author

Estimation Calculation model

The specific terminal-related emissions (or energy consumption) can be estimated if one knows the processes and holds certain information necessary to do the numerous assumptions.

It is important to know how much CO2e emissions we are producing in a transport chain, but this information is not (yet) crucial for the transport itselfand for the respective carrier. It is crucial for the environment at a global scale. The methodology, therefore, has to be simple, easy to use, fair and clear. The calculation result is to be added to the intermodal train calculation, described by EN16258 and the combined transport chain is thus complete. Not only that the emissions will be properly calculated, it will enable the proper and fair comparison among the modes of transport, such as among road transport and combined transport.

Train Shunting emissions

For estimation of the emissions caused by shunting engine moving an intermodal train in or out of the terminal from or to the main line station, we need to set a distance based table with precalculated values. It is not to difficult to obtain information about terminal's location and connections to main line. Emissions also depend on the type of engine used and total weight of the train, but above all it depends on utilisation of the trains capacity. The main station and terminal are lying in almost all the cases at the same altitude, so the shunting is purely horizontal. For the calculation of the values in the table, the average diesel fuel consumption or electric energy consumption are used. The emissions are calculated according to the rules of the standard EN 16258 (Kellner, 2016).

The calculated values show emissions per single TEU for respective distances and respective train utilisation rates in kilograms of CO2e. To calculate emissions per ILU, one needs to apply the conversion between actual type and length of ILU and TEU, which is rather trivial (for example one 40 feet ISO container equals 2 TEUs, and so on).

ILU handling emissions

Calculation of CO2e emissions per each lift is a very difficult task to perform. We have to know how many manipulations per each unit is done in a terminal, what is the average weight of the unit, what kind of lifting equipment is used and what is the actual handling speed.

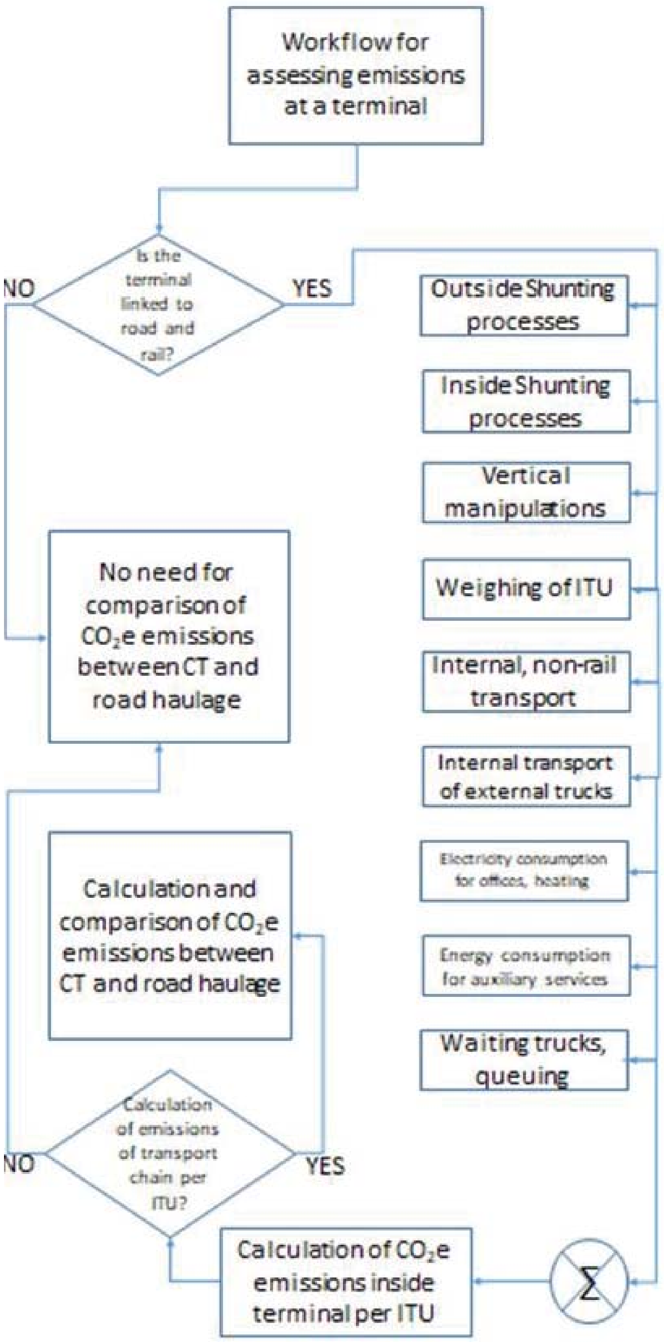

Figure 3: Flowchartfor calculation

Very important factors are also the driving habits of crane drivers. The driving mode has a big impact on energy consumption, hence the emissions. Since there are so many parameters, the average values need to be set, to show the average emissions of handling ILUs. For each stop over at a terminal, one shall calculate 2 lifts in average for each ILU. The average weight per ILU in continental combined transport is 10 tons of cargo per TEU (UIC-ETF, 2019) considering also cases of empty returns to place of origin.

Data from 43 terminals in European continent show that the energy per lift is calculated in the price for manipulation. The study, ordered by the Economic Commission of Latin America and Caribbean – ECLAC and conducted by (Greene & Lewis, 2016) included 41 maritime container terminals around the world on emissions, produced per each container moved. The result was an average value of 29.8 kg CO2e per each container.

Within this research, conducted on 43 European terminals, an average service price in amount of 26.35€ per each lift performed, has been determined. The price calculation can't be revealed in the paper, because of non-disclosure agreements, but in theTable 5 it is shown what percentage of the total price per lift, actually falls on the cost of energy consumed. From that end the emissions can be calculated.

Under assumption thatevery ILU, as an container in a maritime container terminal,has to be lifted at least three to four times while inside a terminal,the emissions value approaches the 29.8 kg/ILU,as shownin the ECLAC study(Greene & Lewis, 2016).

The price includes the cost of all necessary movements of a single unit inside the terminal (off-lift, on-lift, bringing to depo, on-lift, etc.). It is also a market oriented price, as terminals are competing to each other, where the density of terminals in an industrial area is higher. The clients of the terminals, such as big combined transport operators, carriers and forwarders are also setting the prices and keeping them limited,since they are using terminals all over the continent as a benchmark.

The emissions caused by lifts with terminal equipment can be extrapolated from the data, collected by measurements and observations in the terminals as well. The emissions depend on several factors:

- Equipment type
- Equipment age
- Nominal power
- Source of energy
- Driver's driving and operating mode
- Other, terminal specific factors

The Table 6shows the extrapolated values from the data, provided by terminal operators. The average values of emissions are calculated for two most common types of terminal equipment. No other processes than lifts alone are calculated in the following table.

Emissions of internal horizontal moves

Inside the terminal,ILUs need to be displaced or moved to other location than that of actual vertical manipulation. Such locations are empty unit's depo or intermediate stock for units that are planned to be picked up by external trucks or re-shipped by trains at a later time. The emissions are mostly depending on the layout and size of the terminal manipulating area.

To calculate that, one can take the average values for truck running with low speed along the length of manipulation rail-tracks, multiplied by two and use the diesel conversion, WTW factor, as in equationE [kg]= (C[l] 2l[m])/(100.000[m]) 3.24[kg/l] (7).

Table 3: Emissions in kg of CO2e per TEU

Diesel Shunting	Distance [km]		WTW	Diesel	
Train occupancy rate	1km	2km	3km	4km	5km
50%	0.07007	0.14014	0.21020	0.28027	0.35034
55%	0.06384	0.12768	0.19152	0.25536	0.31920
60%	0.05863	0.11726	0.17589	0.23451	0.29314
65%	0.05420	0.10841	0.16261	0.21682	0.27102
70%	0.05040	0.10080	0.15120	0.20160	0.25200
75%	0.04710	0.09419	0.14129	0.18838	0.23548
80%	0.04420	0.08839	0.13259	0.17679	0.22098
85%	0.04163	0.08327	0.12490	0.16654	0.20817
90%	0.03935	0.07871	0.11806	0.15741	0.19677
95%	0.03731	0.07462	0.11193	0.14924	0.18655
100%	0.03503	0.07007	0.10510	0.14014	0.17517

**Constant: 3,24kg of CO2e per 1 l of Diesel fuel burned*

Table 4: Emissions in kg of CO2e per TEU

eLok shunting	Distance [km]		WTW	0.468 kg CO2e/kWh	
Train occupancy rate	1km	2km	3km	4km	5km
50%	0.0002	0.0004	0.0006	0.0008	0.0010
55%	0.0002	0.0004	0.0006	0.0008	0.0010
60%	0.0002	0.0003	0.0005	0.0007	0.0009
65%	0.0002	0.0003	0.0005	0.0006	0.0008
70%	0.0002	0.0003	0.0005	0.0006	0.0008
75%	0.0001	0.0003	0.0004	0.0006	0.0007
80%	0.0001	0.0003	0.0004	0.0005	0.0007
85%	0.0001	0.0002	0.0004	0.0005	0.0006
90%	0.0001	0.0002	0.0004	0.0005	0.0006
95%	0.0001	0.0002	0.0003	0.0004	0.0006
100%	0.0001	0.0002	0.0003	0.0004	0.0005

**Constant: 0.468 kg of CO2e per 1 kWh used*

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

1 Handling	Avg. price		Share of energy cost[%]	Emissions	
Diesel (Reachstacker)	26.35	€	8%	7.47	kg CO2e
Electricity (RMG)	26.35	€	13%	7.72	kg CO2e

Table 6: Average consumption of terminal equipment

	Avg. consumption	Units	Emissions	Units
Diesel	1.44	litres	4.66	kg CO2e
Electricity	6.09	kWh	2.85	kg CO2e

In such case one never calculates less emission than could actually occur.

E [kg]= (C[l] 2l[m])/(100.000[m]) 3.24[kg/l] (7)

E - emission

C - average diesel consumption in litres per 100 kilometres

l - length of the manipulation rail-tracks

Emissionsof external trucks

The emissions of external trucks which are waiting outside the gate to be let inside the terminal to drop-off or pick-up the ILU are usually not being monitored in sense of emissions. They are considered as outside of the scope of the terminal emissions. But, if the transport of an ILU would be done by road only, the trucks would not wait at the terminal gate and these emissions wouldn't exist at all. Therefore, it is essential to include them in combined transport chain, even if there is no direct link to energy consumption of the respective container terminal. Calculation of the emissions with consumption C in litres per hour and with the 0.9 probability that the visitors spend 10 minutes waiting for service.

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

Emissions of support services

The support and ancillary services include the lightning of the terminal area, operation of offices, information and security system operation, administration, etc. These values are dependent on the general properties of a terminal, such as:

- Terminal size (m^2)
- Terminal annual throughput (TEU/year)
- Size of the office building

This information is widely accessible from different sources. National catalogue of railway infrastructure, the national list of logistic centres, or internationally it is accessible on the various Internet sites. For European terminals, the general data is obtainable at AGORA terminal site (KombiConsult, 2018).

The Table 7 shows the pre-calculated values of ILU emissions caused by the energy consumption of supporting services according to size of facilities and with respect of yearly throughput of TEUs in the terminal.

Table 7: Kg of CO2e emissions per ILU for supporting services

Number of boxes p.a.	Lightning 100.000 m^2	Lightning 200.000 m^2	Office area up to 500 m^2
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

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Table 8: information to be fed to the emission calculation tool

No.	Question	Input	Units	Source of information	Availability	Information accuracy
1	Average yearly throughput of departing terminal	int	TEU	Agora	good	fair
2	container yard capacity of departing terminal	int	TEU	Agora	good	fair
3	Average yearly throughput of destination terminal	int	TEU	Agora	good	fair
4	container yard capacity of destination terminal	int	TEU	Agora	good	fair
5	Average utilisation of train connecting two terminals	int	%	CT operator or Terminal operator(s)		
	optional	subjective				
6	weight of the cargo	float	kg	shipper	excellent	perfect
7	rail distance between two terminals	float	km	GIS	excellent	perfect
8	first-mile rail leg (departing terminal-railway station)	float	km	GIS	excellent	perfect
9	last-mile rail leg (railway sta-tion - arriving terminal)	float	km	GIS	excellent	perfect
10	first-mile road leg (shipper's warehouse-departing terminal)	float	km	GIS	excellent	perfect
11	last-mile road leg (arriving terminal-c/nee's warehouse)	float	km	GIS	excellent	perfect
12	*Pure road transport distance from POL to POD	float	km	GIS	excellent	perfect

**Additional information serves to compare the road vs combined transport CO2e emissions*

Calculation

The calculation tool is fairly easy to prepare, by using the tables 1 to 7. There are only 11 questions to answer, to get a result. The questions are not complex and the information needed is almost always available. If one decides to answer one additional request of the tool, one can get a valuable comparison of road and combined transport on the same relation. The information to be fed to the calculation tool is shown in Table 8. The questions are strait forward and the input is clear and easy to obtain. The only possibly questionable answer is under sequence number 5, as it is depending on the operator's subjective assessment and might be misleading to certain extent.

Required Information to enable calculation of emission on entire combined transport chain.

The comparison by the growing distance between place of loading (POL) and place of discharge (POD) show the savings if the decision maker would select combined transport over pure road transportation. Calculations conducted inPython 3.7, code written by authors. (System: 64 Bit OS, Processor; Intel® CORE™ i7-5600U CPU@ 2.60GHz 2.59 GHz, RAM 8.00 GB).

The chart in Figure 1 is showing the difference between combined transport, inclusive terminals, first- and last-miles and between pure road transportation, in kilograms of CO2e. The road calculation is done for the distance from POL to POD respectively. The Combined transport route includes rail distance covered by train and the road distances for first-mile and last-mile deliveries per truck.

From the chart above one can read that short rail distances do not bring any emission savings. The routes, where combined transport uses gateway terminals and ILUs switchtrains, the difference in emission is lower as one has to calculate the emissions inside gateway-terminals as well. The direct CT routes (from A to B) bring more savings.

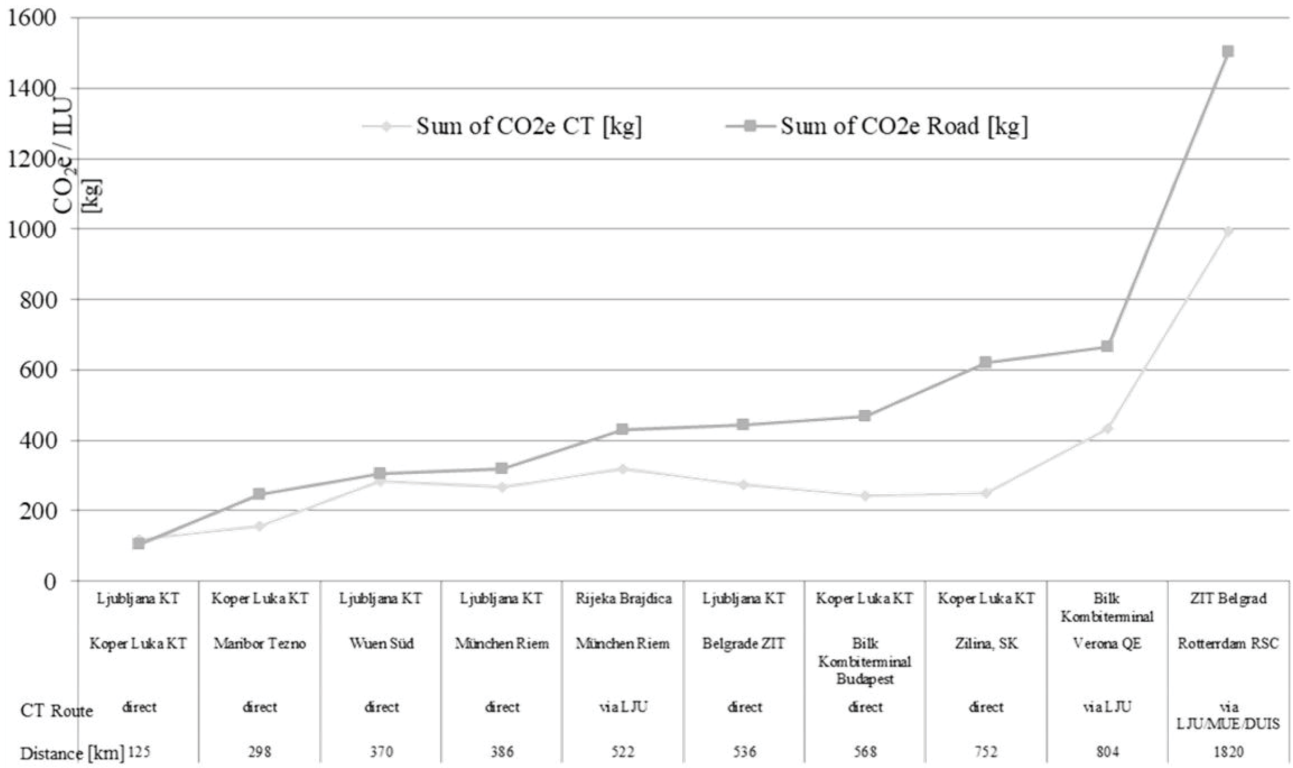

Figure 4: Chart with CO2e emission values per ILU for Combined Transport (CT) and Road transport (Road)

The Figure 5 shows calculated values in correlation with distance, routing and also, very important, train occupancy rate, therefore the gap in emission between road and Combined Transport is not linearly increasing with growing distance.

CONCLUSIONS

The methodology for estimation of energy consumption and respective emissions, taking place inside a closed system of a container terminal, enables logistic providers to calculate the emissions on the entire logistic chain using combined transport services on a part of this chain.

Other than pure road transportation over the continents, the terrestrial logistic chain emissions were not defined entirely. With grey areas (Kellner, 2016) in the calculations, defined by a standard EN 16258, the reporting, optimization efforts, comparison and improvement of the footprint, is not exact and not entirely correct. The purpose of calculation of CO2e emissions is only to distinguish among transportation options in aspect of environmental sustainability.

POL	departure terminal	CT route	combined transport distan	CO2e emissic
Količevo, Domžale	Ljubljana KT	direct	186	117,47
Port Koper	Koper Luka KT	direct	376	155,94
Yulon,Letališka, Ljubljana	Ljubljana kt	direct	480	283,25
TKK Srpenica	Ljubljana KT	direct	489	266,45
Rijeka port	Rijeka Brajdica	via LJU	568	319,82
Ljubljana, Brnčičeva 51, Črnuče	Ljubljana KT	direct	584	274,94
Koper	Koper Luka KT	direct	731	242,36
Koper Port	Koper Luka KT	direct	823	250,12
Budapest, center	Bilk Kombiterminal	via LJU	886	434,15
Belgrade	ZIT Belgrad	via LJU/MUE/DUIS	2009	993,57

Figure 5: Table of random freight transport connections served by CT and by road

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There is no other purpose until the day the governments decide to collect the money from polluters respectively.

The terminal Operators are cost driven and they are striving to be as efficient as possible. Therefore, the possible deviations in emission stay inside a reasonable frame (Martinez, Kauppila, & Castaing, 2014). The dynamics of demand for services is met by extending working hours, hiring additional work force, and with purchase of new handling equipment and thus keeping the energy consumption per ILU at an even level.

The standard calculation error of calculated values of this paper isn't in any way higher than usual errors on the road emission calculations are, when the irregularities, stop-overs, congestions and big external costs, caused by the road freight transport, are not taken under consideration for Road Transport Emission Calculation(Kellner, 2016)(Schmied, Knörr, Friedl, & Hepburn, 2012).

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Road route	road distance [k	CO2e emissions	arrival terminal	POD
direct	125	103,28	Koper Luka KT	Port Koper
direct	298	246,21	Maribor Tezno	MORZ, PUNTIGAMER STRASSE 61, 8041 GRAZ
direct	370	305,69	Wuen Süd	Wien Kledering
direct	386	318,91	München Riem	Munchen, city center
direct	522	431,28	München Riem	München, center
direct	536	442,84	Belgrade ZIT	Belgrade 3-jump, Pančevo
direct	568	469,28	Bilk Kombiterminal Budapest	Vaci Ut., Budapest
direct	752	621,3	Zilina, SK	KMS, zilina
direct	804	664,26	Verona QE	Verona, center
direct	1820	1503,68	Rotterrdam RSC	Rott port

Figure 5: Table of random freight transport connections served by CT and by road

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