Green logistics and transportation: the estimation of GHG emissions and energy consumptions in an industrial case

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1. Introduction

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally-binding global climate treaty, which aims to reduce carbon output "as soon as possible". The achievement of this ambitious goal will require the parallel implementation of many actions to reduce global greenhouse gas (GHG) emissions and increase energy efficiency. A large portion of GHG emissions, which actually increased in the last decade (IPPC, 2014a; Greene and Shafer, 2003; EUROSTAT, 2007; WEC, 2011), are caused by the transportation sector. Road freight transport system is responsible for the most part of transportation energy (IPPC, 2014b). Although improvements in fuel efficiency, vehicle design, and engine performance (ICCT, 2013) have helped reduce the overall environmental impact of trucks, new technologies alone are not yet sufficient to achieve the targeted improvements in road-freight transport. Chapman (2007), in reviewing the impact of various freight transport modes, underlined the importance of both technological and behavioural changes on the reduction of GHG emissions. For example, environmental benefits for road transport can be achieved by improved utilization of the vehicle fleet (Saetta et al., 2015), more complete vehicle loading (McKinnon, 1999), and a reduction of empty trips.

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Railway transportation is a better option than road transportation, especially for long distances, because it can reduce both GHG emissions and energy consumption. Railway CO2 emissions can be reduced to a minimum, when energy stems from non–fossil fuel sources, such as nuclear or renewable. Electricity used by railways in Europe is produced with an average of 30% from renewable sources (UIC, 2011). Still, a relevant part of the railways traffic run nowadays using diesel fuel. In the European Union in 2011, for example, the percentage was 14% (UIC, 2013). To make trains attractive and viable, however, the rail service must be fully integrated with other transport modes.

Although sea transport is very environmentally friendly and is the dominant transport mode for overseas freight, it is minor than on land transportation for short and medium distance.

Supply chain managers make every day important decisions about transportation systems. With the Sustainable Supply Chain Management (SSCM) (or Green Logistics) companies give their relevant contribution to the Sustainability by including the ecological impact in every decision processes. SSCM requires methodologies that are a good trade-off “between accuracy and simplicity” (Kellner, 2016), also concerning the transportation activities.

Various methods, tools, and methodologies exist to compute CO2 (COFRET, 2011), with the aim of developing best practices for the transportation efficiency within the supply chain.

In 2011, the European Committee for Standardization (CEN) published the European norm EN 16258: “Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).” (EN 16258, 2012). This norm specifically targets transportation supply chains (Davydenko et al., 2014). Many organizations also provide emissions calculation tools and services, for example, Clean Cargo Working Group and EcoTransIT (IFEU Heidelberg, Öko-Institut, IVE & RMCON, 2011).

Despite the importance of studying this norm in real applications (to support industry in pursuing sustainability), the literature lacks case studies about the EN 16258 in manufacturing companies for scrutiny. Therefore, in this paper, an EN 16258 based tool and the EcoTransIT tool are applied to the shipments of a stainless steel manufacturing company. In particular, the case study treats GHG emissions and energy consumption during transportation, an aspect often neglected in the iron and steel industry - the largest industrial source of CO_2 emissions (Carpenter, 2012). The study provides a general evaluation of the company’s transportation operations that includes average data about transport activities. Such evaluations can help companies with preliminary planning of their transport activities, before knowing the specific logistics operator and fuel consumption data. The energy consumption and GHG emissions of the current shipments are compared to those obtained with a different mode of transport.

The objective of the paper is to evaluate different calculation instruments and choose the mode of transport that minimizes energy consumption and GHG emissions. An EN 16258-based tool developed specifically for the case considered is compared with one commercially available tool. In Section 2 and 3 the two tools are described. A real world case study on an Italian steel company is analysed in section 4. Finally, the conclusions are drawn in section 5.

2. The EN 16258 based tool

Several standards deal with the calculation of greenhouse gas emissions in freight transports (e.g., ISO 14064-1: 2006, GHG Protocol: 2004, ISO 14040: 2006, and PAS 2050: 2011). None of these provides specific rules, however, and the actual implementation is thus subject to interpretation. This hampers comparisons outside company boundaries and investigations about unfavourable results to be improved. To avoid these problems and to ease company emission calculations, a first draft of the EN 16258 was issued in 2011. As implied by its title, “Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)”, this draft provides a detailed framework for companies to assess the environmental impact (i.e., energy consumption and GHG emissions) of their transport processes. It offers a standardized method that permits repeated calculations over time, and thus makes it possible to document improvements. The results can also be used to identify weaknesses in the processes and direct financial resources toward their optimization. After some adjustments, EN 16258 was finally released in 2013, and an increasing number of companies making use of it, either due to legislation or because their customers are requesting it. In France, for instance, freight carriers are required to provide information about the carbon dioxide emissions (but not GHG emissions) related to their shipments using a standard similar to EN 16258 (MEDDE, 2012).

In order to compare the GHG emissions and energy consumption of different modes of transport, both tank-to-wheel (TTW) and well-to-wheel (WTW) values are usually evaluated (see Figure 1). The WTW approach is commonly used to compare alternative fuels (Wang et al., 2012) or different kinds of fossil fuels (Rahman et al., 2015). TTW emissions result from consumption of fuel during transport; WTW emissions are the sum of TTW emissions and well-to-tank emissions (WTT), which result from the production and distribution of a unit of fuel (or electricity). WTW emissions are used for the GHG emissions comparison of different transport solutions.

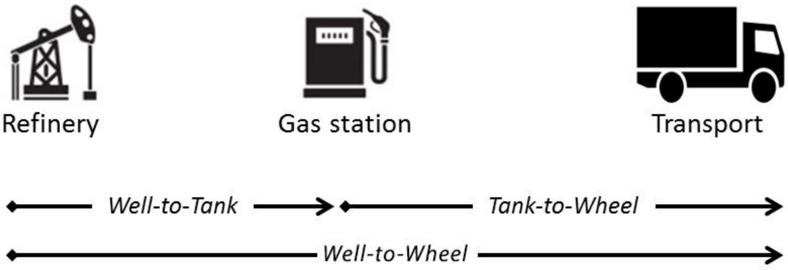


Figure 1. **Visualizing WTT, TTW and WTW.**

To calculate the energy consumption and GHG emissions for a given transport service, 3 main tasks must be carried out. In task 1,one must identify the various stages (called legs) of a transport service. Legs can usually be determined by locating the transshipment points, that is, the points where the good changes vehicles. Second, the energy consumption and GHG emissions must be calculated for each leg. Third, the results for each leg must be added up to obtain the final total values for the whole transport service.

Task 2 consists of four sub-tasks. First a so-called vehicle operating system (VOS) is identified for each leg. The VOS is the complete journey made by a vehicle being used to transport the good. The starting point of a VOS is not where the good starts its journey, but rather where the vehicle starts its journey - although these could conceivably be the same. The same holds true for the end of the VOS. The good might not stay on the vehicle until the end of the vehicle’s journey. In this case, the leg would only be a portion of the VOS. Second, after VOS has been defined, its fuel consumption is assessed, either based on real values via telemetry data or, if that is not possible (e.g., because subcontractors are used), by using default values. Third, VOS energy consumption and emissions levels can be calculated using special conversion factors. Fourth, a portion of the total energy consumption and GHG emissions is allocated to the good, typically using ton-kilometer (tkm) as a transport performance measure.

Figure 2 shows the three levels that need to be considered and their relation to each other. Level 1 depicts the transport service as a whole, from points A to D. Level 2 shows the three legs with their respective vehicles. Level 3 illustrates the VOSs, which typically account for more than the corresponding component.

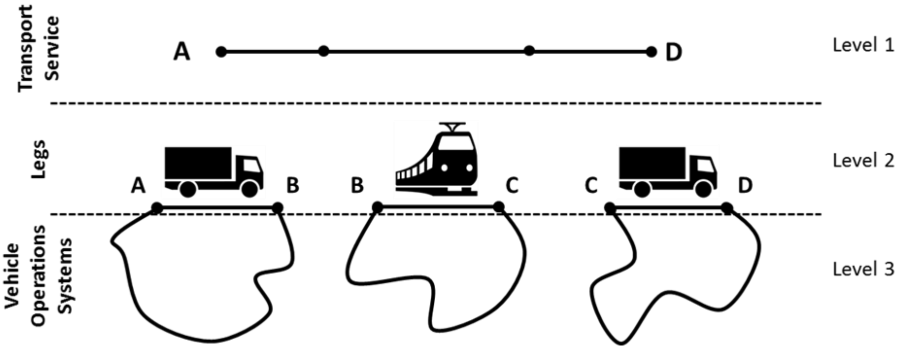


Figure 2. The hierarchy of a transport service according to EN 16258.

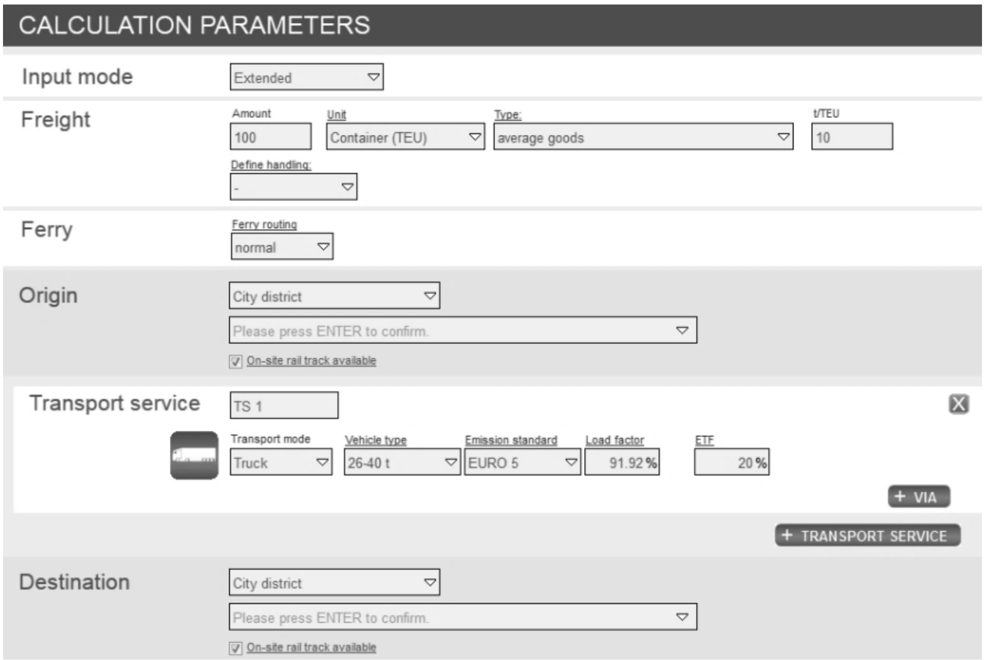
Ideally, the values used to calculate fuel consumption and freight quantities are specific measurements. However, this is only possible if a company has direct control over the VOS and possesses the technical capabilities to collect the data. If it is not possible to obtain such information, vehicle or route-specific average data can be used. The information required here might be obtained from the accounting department. For instance, annual values for fuel consumption and load capacity may be based on bills or customer orders. If no values for particular vehicles exist, it may still be possible to estimate numbers for an entire fleet.

The values described above (specific measurements, vehicle averages, fleet totals) would normally be collected and supplied by logistics operators. Manufacturing companies, as the one considered in this case study, do not have these detailed data, but would be interested in their transportation emissions. Therefore, default values are used instead, based on scientific databases, which allow for a reasonable approximation ex ante. The fuel consumption, the conversion factors for energy consumption and the GHG emissions used to calculate total energy consumption and total GHG emissions are shown in the Appendix (Table A and Table B: EN 16258; EcoTransIT: Ecological Transport Information tool, IFEU, 2011; MIT, 2011). In particular, the Italian values for energy efficiency and emission factors of the electricity supply for railway transport are used (38% electric efficiency and 0.64 kg CO2/kWh emission factor).

3. Tools for energy consumption and GHG estimations: EcoTransIT

Several commercial calculation tools can support companies in applying EN 16258, for example Map&Guide, VERSIT+ and LogEC. The tool used in this paper, EcoTransIT (www.ecotransit.org), allows one to analyse all modes of transport and is available as a free web application. It calculates GHG emissions and energy consumption according to the latest national policies and is also compliant with EN 16258 (EcoTransIT, 2014). One useful feature is that it integrates street, rail, waterway, and airport locations, which allows the user to model intermodal transport. Based on the origin and destination of the transport service, the software searches for a suitable route. Although the user can neither change the route nor specify route-selection criteria (e.g. fastest or shortest) when using the software on the website, it is possible to customize the transport service (e.g. load factor, empty trip factor and type of goods). One disadvantage for scientific use is that the software on the website does not permit a series of calculations to be made. Instead, each trip must be entered by hand - a time consuming task. Nor are intermediate results stored, which means that the user must add them up on his or her own. Nevertheless, the free access is an advantage for the case study described in this paper since it allows anyone to replicate and validate it.

When using the EcoTransIT tool, the user has more freedom to customize the transport process in terms of the freight and the vehicle (see Figure 3). For instance, it is possible to adjust both the type of good (heavy, average, and light) and its weight in terms of tons per TEU (Twenty Foot Equivalency Unit). The vehicle information can also be altered regarding the specific vehicle used (load capacity), load factor and empty trip factor. The latter two contain default values that can be changed if necessary. Emissions calculations are computed internally on the basis of specific emission data for each vehicle. Although the EcoTransIT software is convenient, since the user does not have to enter that much information, its results may not be as accurate as those obtained via the manual method, since it is not possible to model the exact VOS.



CALCULATION PARAMETERS

Input mode: Extended

Freight
Amount: 100
Unit: Container (TEU)
Type: average goods
t/TEU: 10
Define handling: -

Ferry
Ferry routing: normal

Origin
City district
Please press ENTER to confirm.
☑ On-site rail track available

Transport service: TS 1
Transport mode: Truck
Vehicle type: 26-40 t
Emission standard: EURO 5
Load factor: 91.92 %
ETF: 20 %

Destination
City district
Please press ENTER to confirm.
☑ On-site rail track available

Figure 3. The extended input interface for the EcoTransIT internet tool.

4. Industrial case study

The EN 16258 based tool and the EcoTransIT tool are applied to the real case study of an Italian steel metallurgy company. Special emphasis is put on the GHG emission calculation, rather than the user-friendliness of the EcoTransIT internet tool. Since the company's incoming goods are iron scraps and its outgoing good are coils, it uses different transport means. Because the analysis considers the incoming and the outgoing goods, it includes data of both the company, its customers and its suppliers.

The available data consists of the cities where the suppliers and customers are situated, the number of trips and the total quantity of goods transported. For confidentiality reasons, the locations and names of the cities are not shown. The objective is to determine the energy consumption and GHG emissions and then find a way to reduce them. Starting from the data for the currently used mode of transport, the study assesses alternative modes. For example, if the company currently sends a truck to city 1, the use of a diesel train and an electric train are assessed for the same trip.

In this case study, three scenarios are analysed, denoted by single trip, intermodal trip, and round trip. A single trip relates to a transport from a start point to an end point. For incoming goods, the single trip is from the supplier to the company; for outgoing goods, it is from the company to the customer. An intermodal trip involves a freight village, that is, a cluster of transport and logistics facilities co-located and coordinated for synergies (Higgins and Ferguson, 2011). Here, outgoing goods are sent to a freight village by trucks for cargo consolidation and then delivered to the customer by train. A round trip takes into account the return trips after deliveries from and to the company. When a train is used, the last mile deliveries are made by trucks. This final part of the trip is not included in the calculations, however. In each scenario, goods are transported by heavy goods trucks. Thus, it is not possible to evaluate alternative truck solutions, as done in Galos et al. (2015) and Rodrigues at al. (2015).

4.1 SINGLE TRIPS

Figures 4-6 show the results for the single trip scenario. First, the energy consumption Et and E_w (tank-to-wheel and well-to-wheel) and the GHG emissions G_t and G_w (tank-to-wheel and well-to-wheel) for the current input and output trips are calculated based on the available data for 2013 and the first quarter of 2014. Then, to compare different modes of transport with their differing travel distances - but still considering the same number of trips and the same cargo - the number of trucks and trains used to complete the shipments are updated. These results allow to calculate the fuel consumption F(VOS), along with E_t, E_w, G_t and G_w.

4.1.1 Incoming trips

An input trip is the trip from a supplier to the company. Seven suppliers, whose goods are all delivered by truck, are considered. Table 1 shows the available data: the road distances, the number of trips, the amount of cargo transported and the number of trucks. The VOS consists of the vehicle operation per delivery from the supplier to the company. The fuel consumption (F) is calculated for the current mode of transport. Then the new mode of transport (by train) is analysed. Here, the railway distances are measured and, considering the capacity of a train and the total load to be delivered, the number of trains used is calculated. Finally, the fuel consumption of diesel and electric trains is calculated, along with values of E_t, E_w, G_t and G_w (see Table C in the Appendix).

Destination	**Road Distance [km]**	**Railway Distance [km]**	**N. delivery**	**Cargo [to]**	**F(VOS)/delivery [l]**	**N. trucks/delivery**	**F(diesel)/delivery [l]**	**F(Elect)/delivery [kWh]**	**N. trains**
Supplier 1	503	511	5	3,603	3,802.68	21	2,910	10,935	1
Supplier 2	539	560	4	2,111	3,104.64	16	3,189	11,984	1
Supplier 3	128	114	6	18,345	4,055.04	88	2,597	9,758	4
Supplier 4	181	176	2	2,946	2,801.88	43	2,005	7,533	2
Supplier 5	564	594	6	7,329	7,106.40	35	6,766	25,423	2
Supplier 6	8	19	6	6,736	98.60	33	216	813	2
Supplier 7	564	591	4	2,174	3,248.64	16	3,366	12,647	1

Table 1. Incoming data trips.

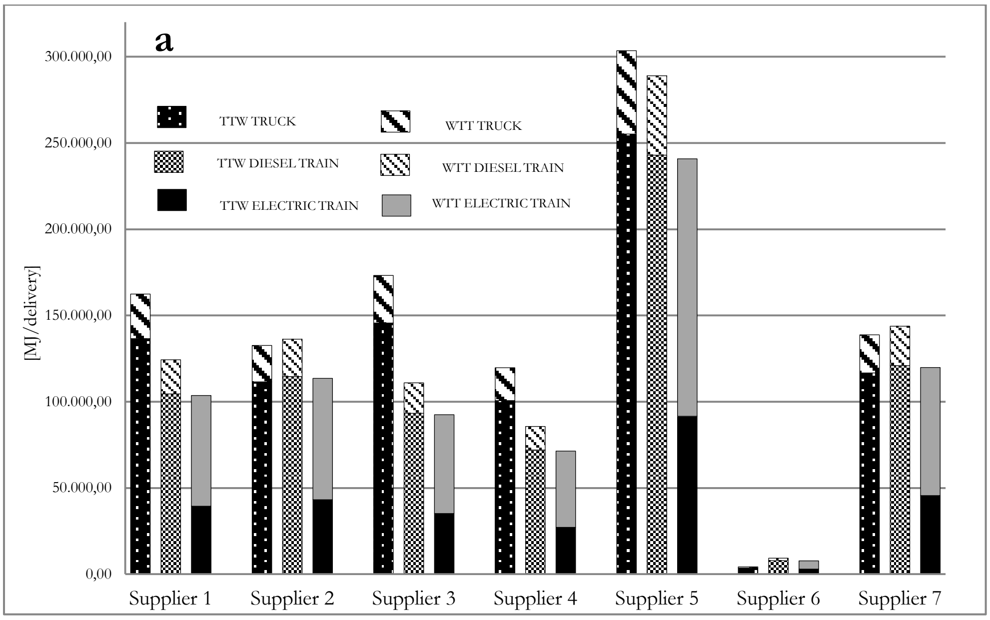


Figure 4a). Energy Consumption for different modes of transport (incoming trips): Energy Consumption WTW = TTW + WTT [MJ/delivery].

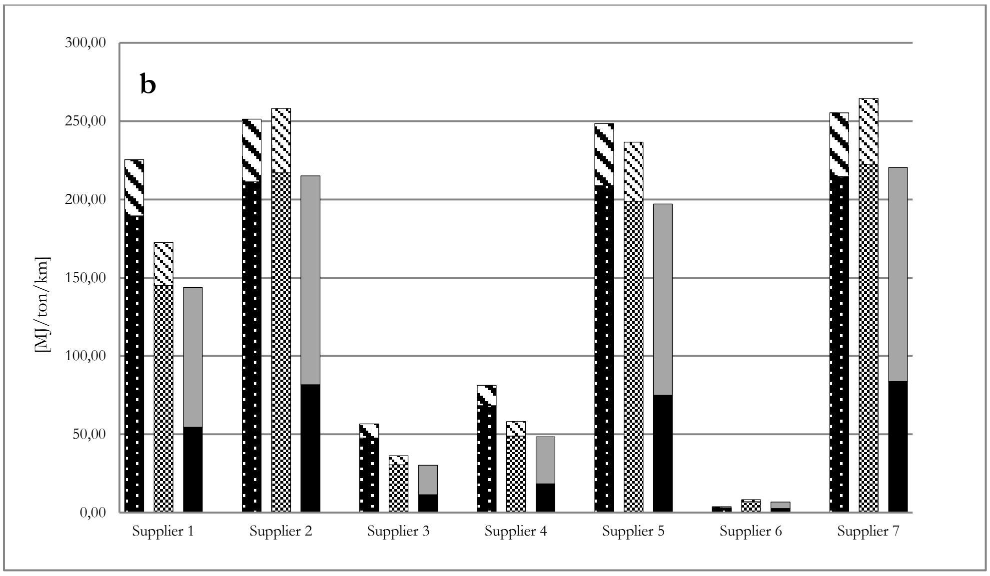


Figure 4b). Energy Consumption for different modes of transport (incoming trips): Energy Consumption WTW = TTW + WTT [MJ/ton].

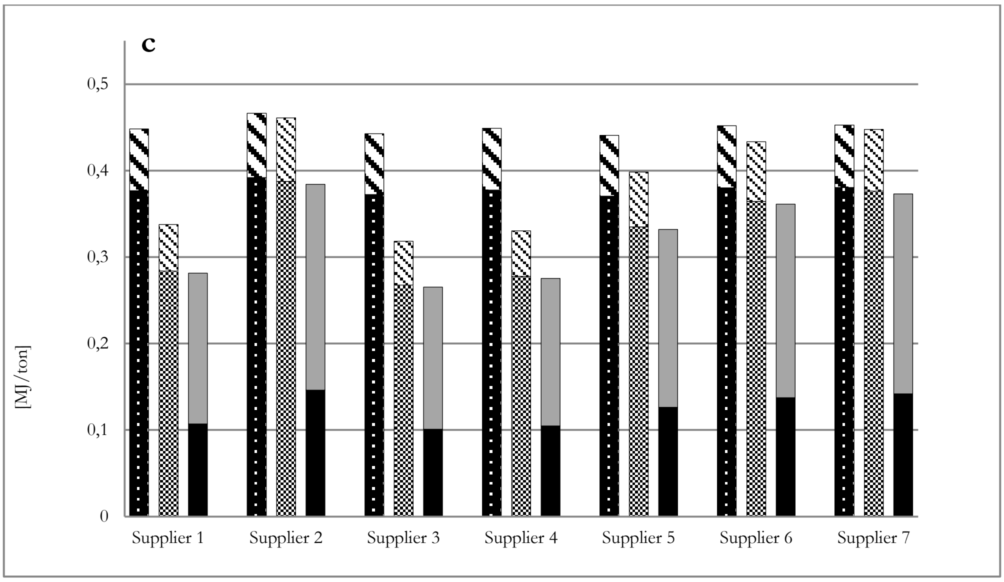


Figure 4c). Energy Consumption for different modes of transport (incoming trips): Energy Consumption WTW = TTW + WTT [MJ/ton/km].

Figures 4a) – 4c) show the tank-to-wheel (TTW) and well-to-tank (WTT) energy consumption (their sum is the well-to-wheel (WTW) energy consumption) for the seven suppliers, while Figures 5a) – 5c) show the GHG emissions for the same suppliers. For each supplier, the first column refers to the truck, the second column refers to the diesel train and the last column refers to the electric train. Each column is divided into two parts: the lower part depicts the TTW data while the upper part depicts the WTT data. Thus, the sum of these two parts shows the WTW data.

GHG emissions graphs (see Figure 5a) – 5c)) show similar behaviour.

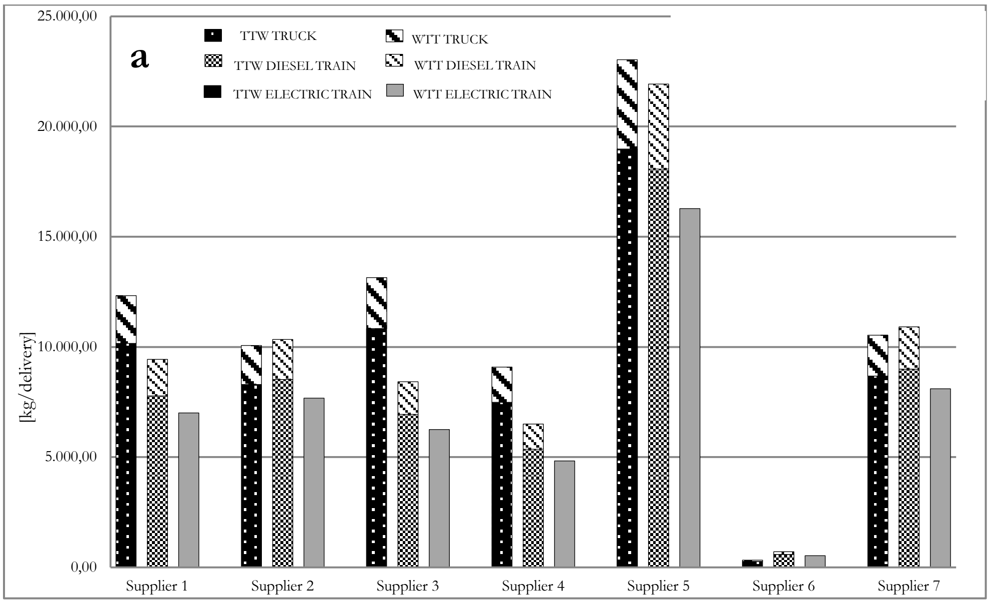


Figure 5a). GHG emissions for different modes of transport (incoming trips): GHG emissions WTW = TTW + WTT [kg/delivery].

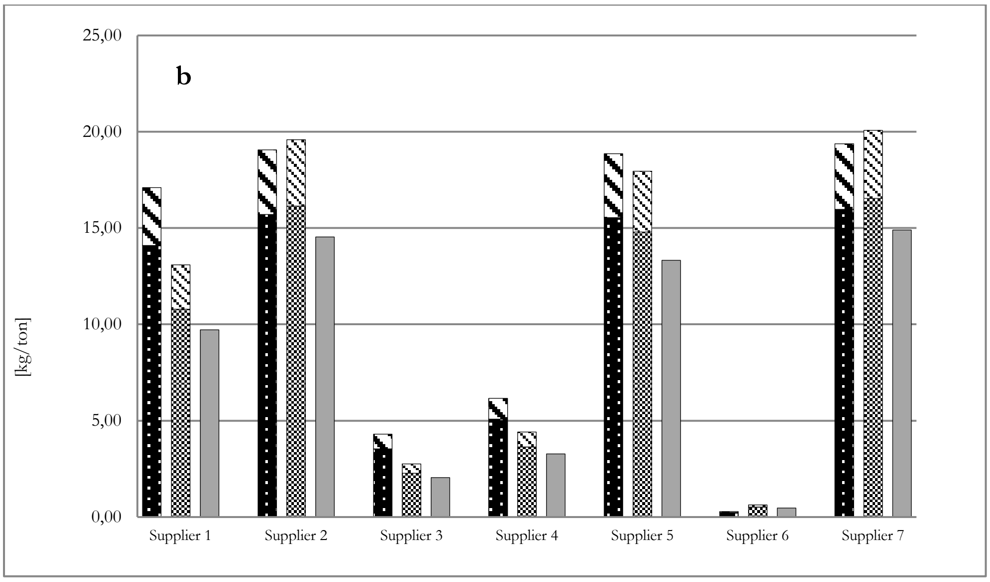


Figure 5b). GHG emissions for different modes of transport (incoming trips): GHG emissions WTW = TTW + WTT [kg/ton].

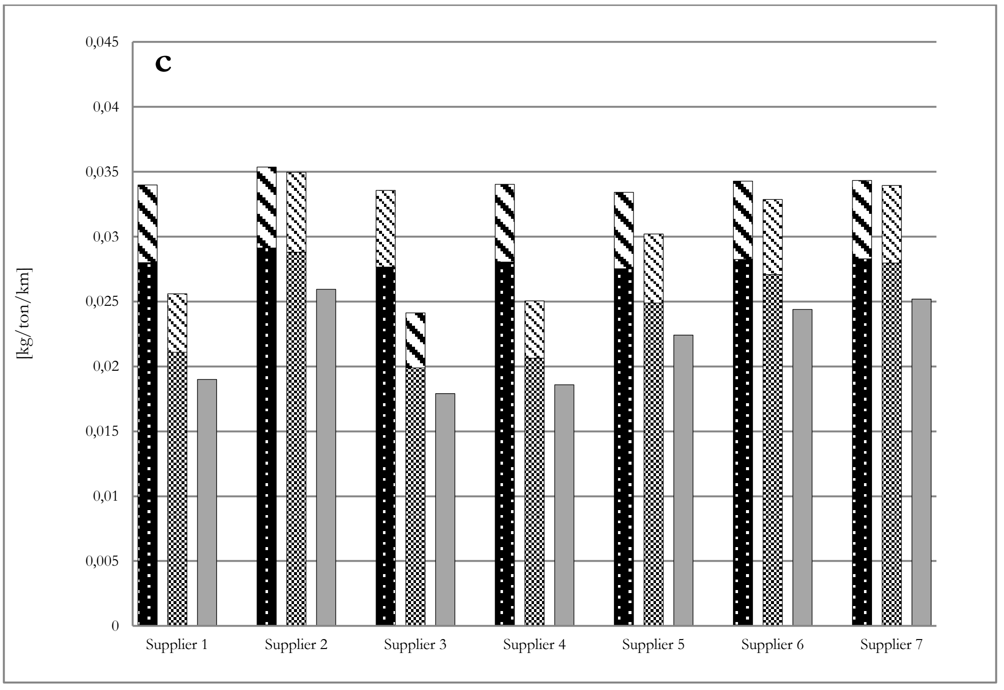


Figure 5c). GHG emissions for different modes of transport (incoming trips): GHG emissions WTW = TTW + WTT [kg/ton/km].

Figure 4a) shows energy consumption WTW per delivery. Even if supplier 5 and 7 are located the same distance from the company, energy consumption for supplier 5 is higher than supplier 7, due to the larger quantity delivered. This is clearly seen in Figure 4b), which shows the WTW energy consumption per ton. Here, energy consumption of supplier 5 is slightly less than that of supplier 7, since supplier 5 can better utilize the vehicle's capacity, due to the larger quantity transported. For the same reason, supplier 3 exhibits the best efficiencies. Figure 4c) shows energy consumption per ton and kilometer. Here, the values for trucks are similar, due to the similar utilization rates (from 0.94 for supplier 2 to 0.99 for supplier 5). For trains, however, supplier 3's high utilization rate (0.77) results in the lowest energy consumption per ton and distance, while supplier 2's lower utilization rate (0.53) results in the highest consumption value.

This variability is based on the assumption that the goods of the company are transported on their own. In reality, however, the residual train capacity might be filled with other goods. For the calculation of the specific GHG emissions, delimitation might become demanding.

When comparing tank-to-wheel calculations, electric trains are always the best choice regarding energy consumption and emissions. This is understandable, since an electric vehicle does not emit GHGs while it is operating, and its G_t is thus zero.

In contrast, the high WTT values for emissions and energy consumption for electric trains stem from Italy' extensive use of fossil fuels for power production. Data shown in Figure 4a and in Figure 5a are reported in Table C in the Appendix.

4.1.2 Outgoing trips

An outgoing trip is one from the company to a customer. Table 2 presents data for the trips from the company to its customers (Customers 1 – 6). Customers located more than 300 km away receive large quantities of goods. Since the number of journeys is not known, the calculation takes the total load and divides it by the load capacity of the train. This way, the trains are completely filled by the company's shipments, without sharing the train with others companies. In reality, only part of the train is filled by the company's goods, and so only part of the emissions are attributable to the company. The VOS consists of the vehicle operation per year from the company to its customers. The fuel consumption (F) is calculated for the current mode of transport. Then, the new modes of transport (i.e., by train) are analyzed. Here, the railway distances are measured and, given the capacity of a train and the total load to be delivered, the number of trains is calculated. Next, the fuel consumption of diesel and electric trains is calculated. Finally, E_t, E_w, G_t and G_w values are calculated (see Table D, Appendix).

Destination	**Road Distance [km]**	**Railway Distance [km]**	**Cargo [to]**	**F(VOS) [l]**	**N. trucks**	**F(diesel) [l]**	**F(Elect) [kWh]**	**N. trains**
Customer o1	346	371	8,773	31,264.56	251	19,016	71,455	9
Customer o2	382	395	16,402	64,496.88	469	38,242	143,701	17
Customer o3	484	480	6,776	33,802.56	194	19,135	71,904	7
Customer o4	405	480	213	1,020.60	7	2,734	10,272	1
Customer o5	548	572	13,150	74,177.28	376	45,606	171,371	14
Customer o6	542	561	4,791	26,731.44	137	15,974	60,027	5

Table 2. Outgoing trips data.

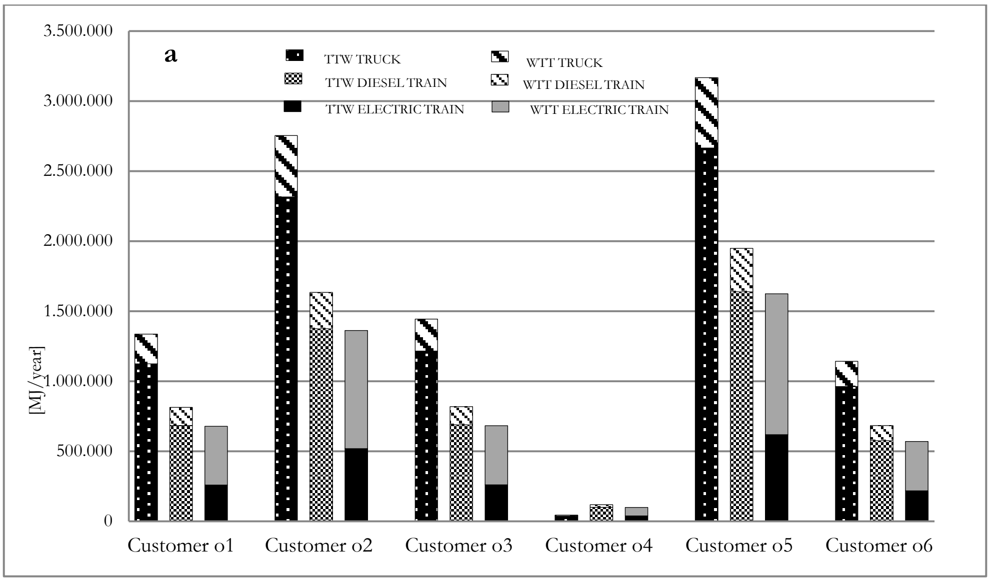


Figure 6a). Energy Consumption for different modes of transport (outgoing trips): Energy Consumption WTW = TTW + WTT [MJ/year].

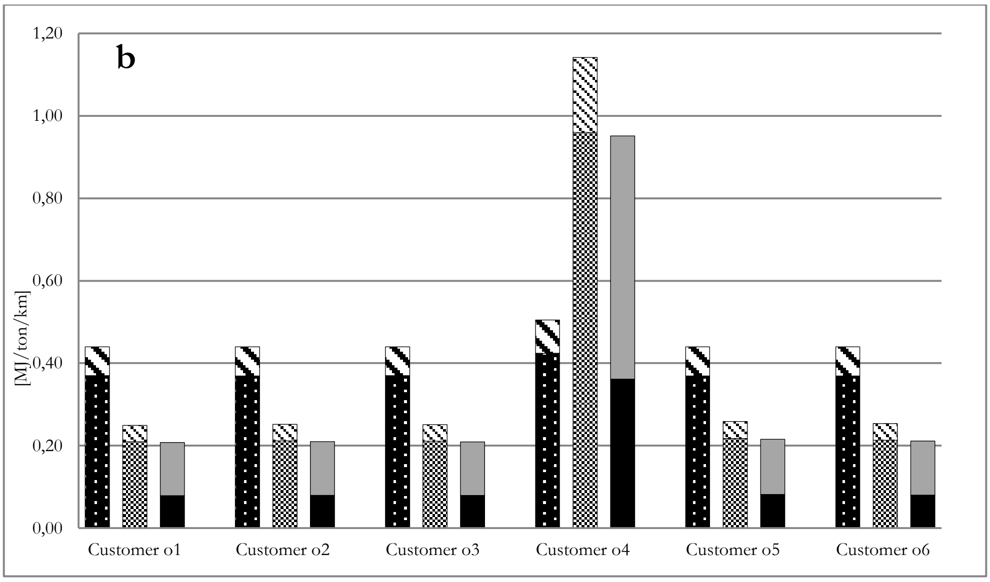


Figure 6b). Energy Consumption for different modes of transport (outgoing trips): Energy Consumption WTW = TTW + WTT [MJ/ton/km].

Figures 6a) and 6b) show the energy consumption per year and energy consumption per ton and kilometre, respectively. For each customer, the first column refers to the truck, the second, to the diesel train and the last, to the electric train. Each column is divided into two parts: the lower depicts the TTW data and the upper, the WTT data. Thus, the sum of these two parts shows the WTW data.

It is noteworthy that, for customers 2 and 5, energy consumption per year is high, whereas energy consumption per ton/km is low. This is due to the large quantities transported (high utilization rates). In the case of city 4 (213 tons transported), trucks consume and emit less. Only a small part of the train's 1000-ton capacity is used. In order to guarantee comparability without external influences, it is once again assumed that the goods of the company are transported on their own, although, in reality, the train's residual capacity might be filled with other goods. Thus, if only a small part of the train is filled with company goods, it is not an efficient trip.

GHG emissions graphs (Figures 7a) and 7b)) show similar results. For each customer, columns 1, 2 and 3 refer to the truck, the diesel train and the electric train, respectively. Here again, each column is divided into two parts, so that the lower depicts the TTW data, the upper, the WTT data and their sum, the WTW data.

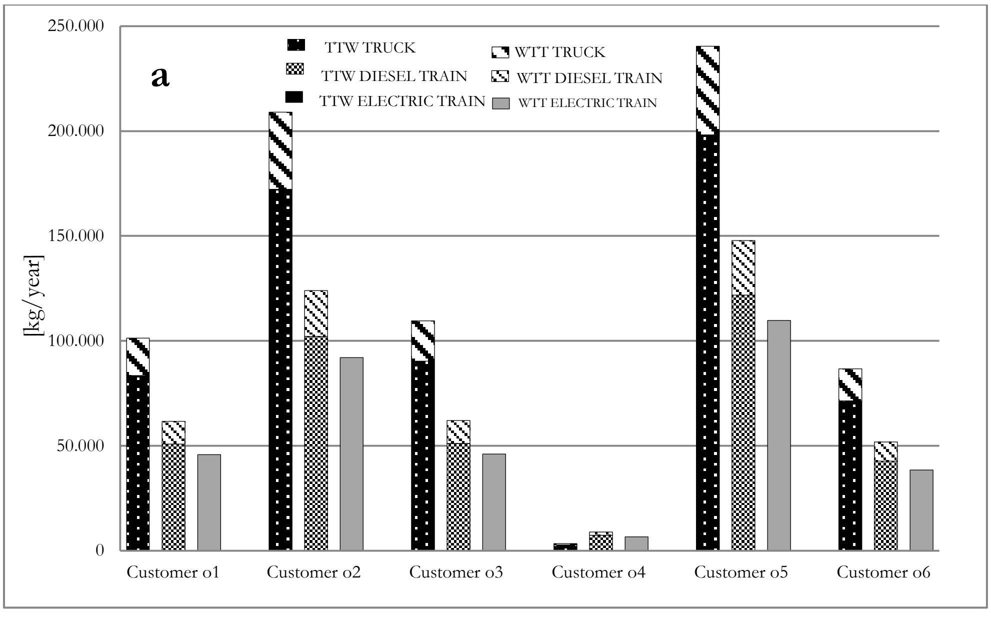


Figure 7a). GHG emissions for different modes of transport (outgoing trips): GHG emissions WTW = TTW + WTT [kg/year].

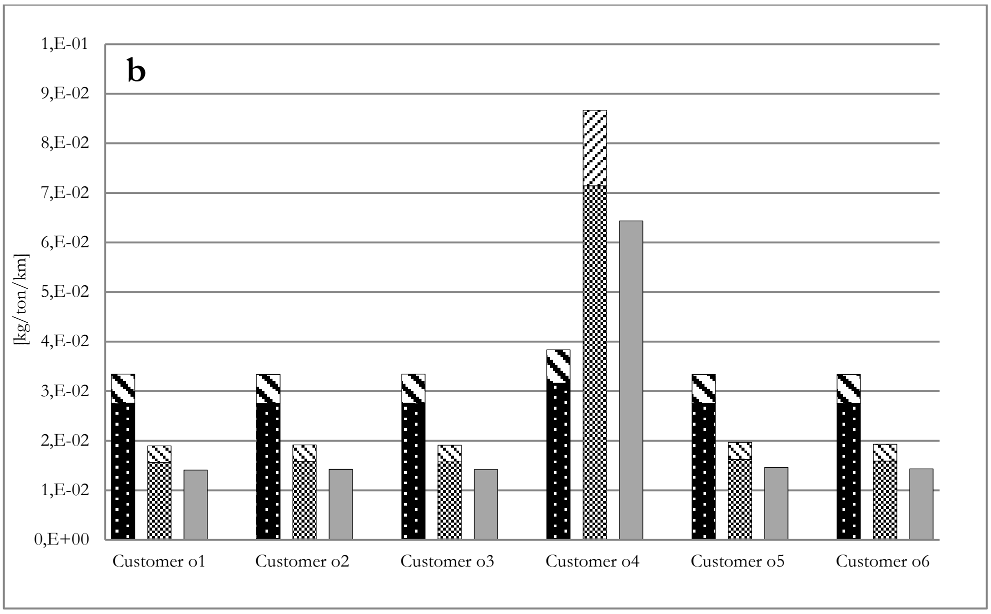


Figure 7b). GHG emissions for different modes of transport (outgoing trips): GHG emissions WTW = TTW + WTT [kg/ton/km].

Data shown in Figures 6a and 7a are reported in Table D in the Appendix.

4.2 INTERMODAL TRIPS

On intermodal trips, outgoing goods are first sent to a freight village for cargo consolidation and then delivered to customers. The first leg of the journey, from the company to the freight village, is made by truck; the second leg, from the freight village to each customer, is made by train (in Table 3, the subscript “I” refers to the first section by truck, while the subscript “II” refers to the second section by electric train). Note that the customers considered here are not the same as in the previous scenario (Section 4.1.2).

Destination	Road Distance [km]	Road Distance from Freight Village [km]	Railway Distance from Freight Village [km]	Cargo [to]	N. trucks	N. trains	F(VOS) only truck [l]	$F(VOS)_I$ [l]	$F(Elect)_{II}$ [kWh]	$F(VOS)_{TOT}$
Customer i1	451	526	490	173,200.0	4,949	174	803,519.6	254,774.5	1,824,564.0	2,079,338.5
Customer i2	416	492	453	47,200.0	1,349	48	202,026.2	69,446.5	465,321.6	534,768.1
Customer i3	496	571	537	47,200.0	1,349	48	240,877.4	69,446.5	551,606.4	621,052.9
Customer i4	483	558	537	47,200.0	1,349	48	234,564.1	69,446.5	551,606.4	621,052.9
Customer i5	566	641	629	45,070.8	1,288	46	262,442.9	66,306.2	619,187.6	685,493.8
Customer i6	550	625	618	45,070.8	1,288	46	255,024.0	66,306.2	608,359.2	674,665.4
Customer i7	486	581	555	45,070.8	1,288	46	225,348.5	66,306.2	546,342.0	612,648.2
Customer i8	558	633	625	45,070.8	1,288	46	258,733.4	66,306.2	615,250.0	681,556.2
Company - Freight Village	143									

Table 3. Intermodal trips data.

For each customer (1-8), the road and railway distances, the quantity delivered, the numbers of trucks and trains are known (see Table 3). The vehicle operating system (VOS) consists of the vehicle operation per year from the company to the customers. The total fuel consumptions (F) for the modes of transport are calculated. Then, E_t, E_w, G_t and G_w values for both modes of delivery (directly by truck or through the freight village by truck and electric train) are obtained. The calculations are made using both the EN 16258 based tool and the EcoTransIT tool (see Table E, Appendix).

For each customer in Figures 8 and 9, the first two columns refer to deliveries made directly by truck, while the second two columns refer to deliveries made via the freight village. The first and third columns refer to the calculations made with the EN 16258 based tool, while the second and fourth columns refer to the calculations made using the EcoTransIT tool. As before, the lower part of each column depicts the TTW data while the upper part depicts the WTT data. Thus, the sum shows the WTW data.

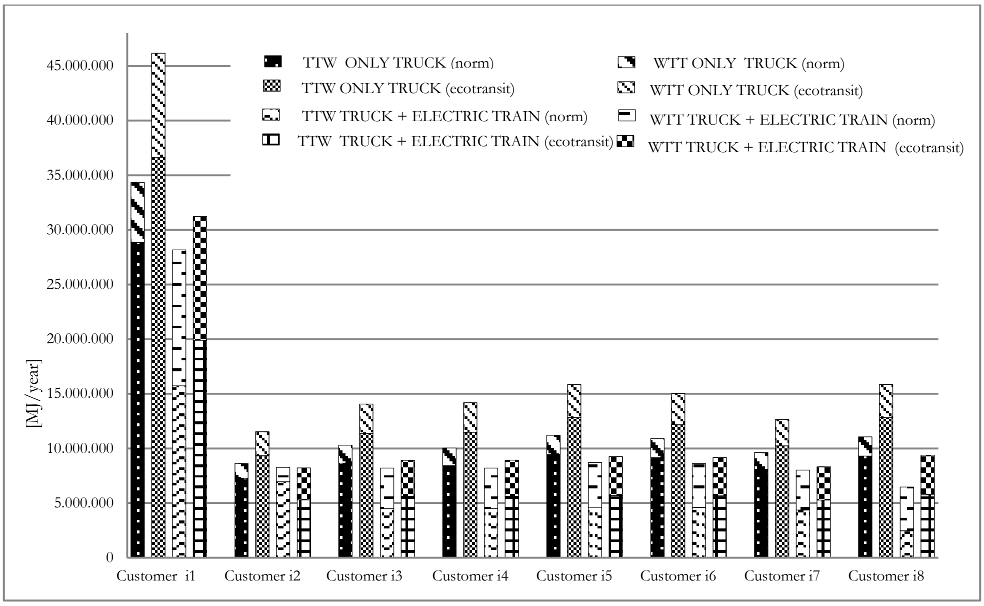


Figure 8. Energy Consumption for different mode of transport and different calculation methods (EN 16258 based tool and EcoTransIT) for the intermodal trips.

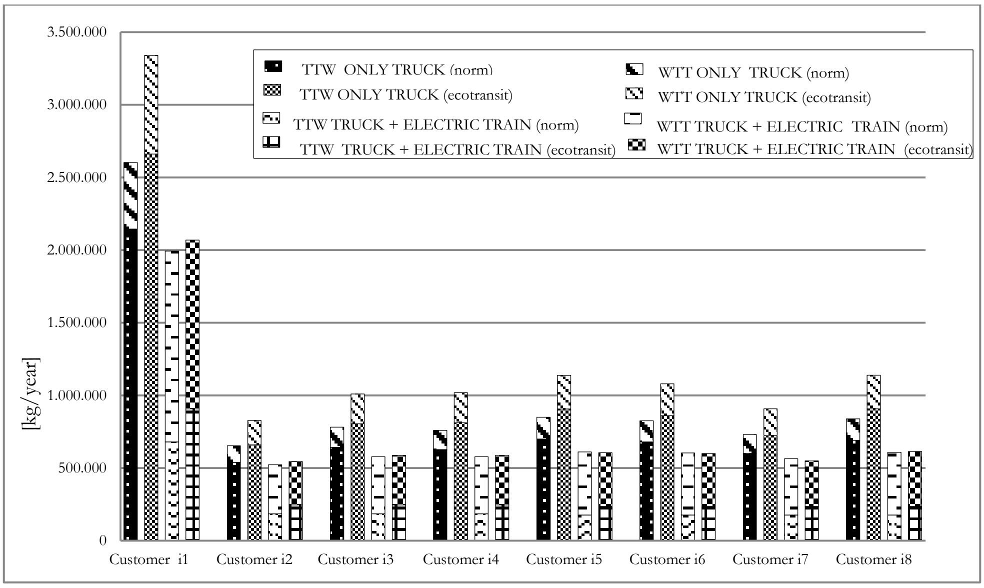


Figure 9. GHG emissions for different mode of transport and different calculation methods (EN 16258 based tool and EcoTransIT) for the intermodal trips.

The analysis of the results (Figures 8 and 9) for tank-to wheel and well-to-wheel measurements shows that the use of a freight village - and thus the use of both truck and electric train - significantly decreases emissions and energy consumption for all journeys. The EcoTransIt tool considers many more factors, and the algorithms include information and parameters related to electricity generation. Since the norm does not give any factors for electric train well-to-wheel calculations, the values of EcoTransIT are used in both cases.

The energy consumption and GHG emissions calculated with the EN 16258 based tool and EcoTransIT vary significantly. The difference is more noticeable in the “truck only” trips. Here, the EN 16258 based tool yields values for road trips that are lower than those from the EcoTransIT tool. One possible explanation for this difference is the capacity spectrum considered in each calculation: in the EcoTransIT software, trucks between 26 and 40 tons are included in the same group, while the EN 16258 based tool calculation only considers 35-ton trucks. A journey involving larger trucks needs fewer vehicles to carry a given cargo. Thus, fuel consumption and GHG emissions are lower.

4.3 ROUND TRIPS

In this section, round trips are considered. Once the trucks or trains have arrived at their destination (company or its customers), they return to their starting points. Note that the customers considered here are not the same as in the previous scenarios (Sections 4.1.2 and 4.2). The VOS consists of the vehicle operation per year from the company to the customers and then back to the company. Fuel consumption and GHG emissions are also analysed for these journeys. Assuming fully-loaded vehicles for the outbound trips, it is important to know if the returning trips are made with fully loaded, half loaded or empty vehicles. In the first case, the return journey belongs to the company that is using the vehicles. In the third case, vehicles cannot be used to carry other cargo, and the company that used them for the outbound trip must pay for the extra fuel consumption and GHG emissions. The second case is an intermediate state. The EN 16258 does not provide data on energy consumption and GHG emissions for truck return journeys with different load factors. In the EcoTransIT manual, these data are available (see Table F, Appendix), and so they are used within both tools to calculate energy consumption and GHG emissions for outbound and return trips. To obtain the well-to-wheel consumption and emissions it is necessary to use additional data (Table G, Appendix) pertaining to the upstream processes, i. e., diesel production. These values must be combined with the results of the tank-to-wheel process, by adding extra emissions (Table H, Appendix) and by dividing it with the efficiency value (for diesel, 78%) to know the total energy consumption.

Table 4 shows the company’s customers, the distance travelled, the number of trucks, and the amount of cargo delivered. The outbound trips are fully loaded, whereas the return trips are empty.

Destination	Road Distance [km]	Cargo [to]	N. trucks	F(VOS) [l]
Customer 1	492	173,200.0	4,949	876,567
Customer 2	561	47,200.0	1,349	272,444
Customer 3	409	47,200.0	1,349	198,627
Customer 4	470	47,200.0	1,349	228,251
Customer 5	550	45,070.8	1,288	255,024
Customer 6	525	45,070.8	1,288	243,432
Customer 7	550	45,070.8	1,288	255,024
Customer 8	300	45,070.8	1,288	139,104

Table 4. Round trip data.

In a second step, the analysis considers delivery by truck from the company to a freight village (outbound trip, fully loaded; return trip, empty). Then, fully loaded diesel or electric trains go from the freight village to each city. The return train trips are analyzed for three cases:

- with 20% of capacity used
- with 50% of capacity used
- with 80% of capacity used

The results are shown in Figure 10 and 11 and in Table H (see Appendix). For each customer in Figures 10 and 11, the first two columns refer to deliveries made directly by truck, while the other columns refer to deliveries made via the freight village. The first column refers to calculations made with the EN 16258 based tool while the others refer to calculations made with the EcoTransIT tool. Each column is divided into two parts, the lower depicting the TTW data and the upper depicting the WTT data. Thus, the sum of the two part yields the WTW data.

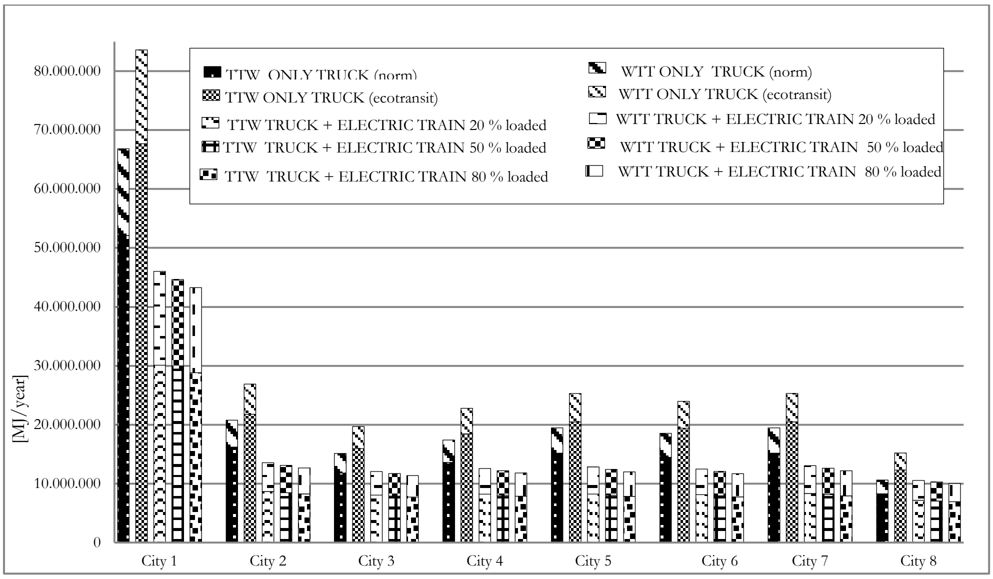


Figure 10. Energy consumption for different modes of transport, different calculation methods (EN 16258 based tool and EcoTransIT) and different return trip loads for the round trips.

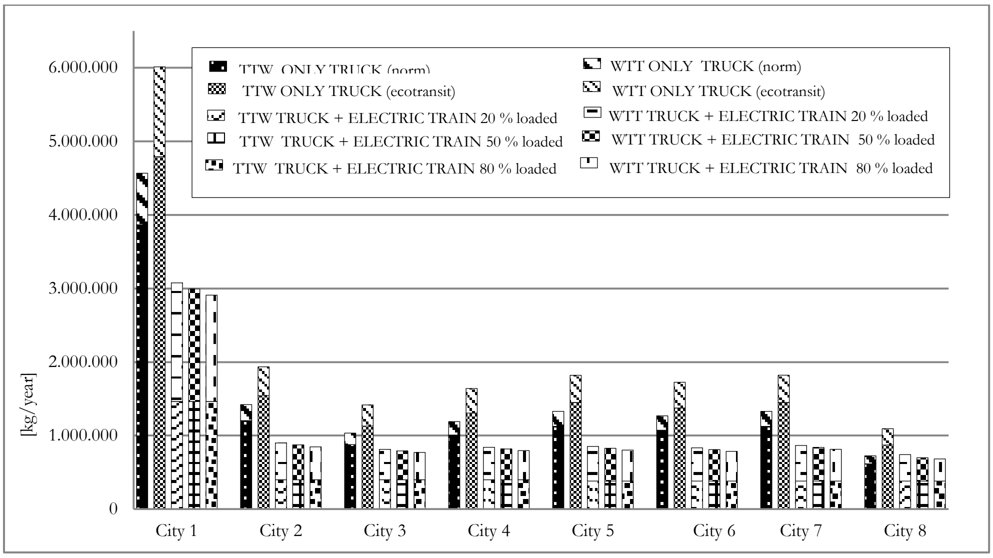


Figure 11. GHG emissions for different modes of transport, different calculation methods (EN 16258 based tool and EcoTransIT) and different return trip loads for the round trips.

A comparison of the EN 16258 based tool and the web software results reveals that the EcoTransIT energy consumption and GHG emissions are higher. One possible explanation is that the capacity of the trucks in the EN 16258 based tool is fixed and equal to 35 tons, whereas EcoTransIT also considers smaller vehicles, which would necessitate a bigger fleet having relatively higher consumption and emissions.

Comparing emission and consumption results for trucks and electric trains leads to the following conclusions. Electric trains are the best choice in all cases, but of course, railway connection must be available. This because return trip that for trucks is empty while for train not. When a train is full or partially full on its return trip, return energy consumption and GHG emissions are not wholly allocated to the original trip, but also, in part, to the new one. A train returning with 80% of its capacity used, for example, means that only 20% of the emissions and consumption of the return trip are allocated to the original trip. This is why, in our results, when the train returns fuller, it seems to consume less. Here, however, our results refer only to the consumption and emissions allocated to the original trip.

In Figure 11, the TTW for the trips made by truck and electric train with different load factors are the same: the train does not emit GHG, and the only emissions stem from the part of the trip made by truck.

5. Conclusions

The motivation of this paper is to evaluate and compare two tools for estimating the energy consumption and GHG emissions of various land-freight transportation scenarios. The EN 16258 based tool and the commercial software tool EcoTransIT are used to assess GHG emissions and energy consumption for an Italian steel manufacturer that utilizes trains and trucks to transport its freight.

Both the EN 16258 based tool and EcoTransIT can be effective in reaching Sustainable Supply Chain Management. The two methods have different strengths and weaknesses, however, and should be applied according to the situation at hand. For example, the EN 16258 based tool delivers more exact results when sufficient data is available. For instance, EcoTransIT does not allow one to consider the exact truck capacity, whereas the direct application of the EN 16258 based tool does. Even if exact values are not available, it is still possible to calculate valid results with the EN 16258 based tool, and the user has full control over the input parameters used. On the down side, the EN 16258 based tool is more time consuming than EcoTransIT, which may militate in favor of the latter. In the simplest case, the only input needed for EcoTransIT to calculate results is the amount of goods and the origin and destination of a journey.

Neither method accounts for logistics operations, such as material handling, warehousing, and intermodal operations, all of which result in extra time and environmental costs. The main limit to the quality of the estimations, however, is the availability of specific data (fuel consumption, real distances, travel times, power production systems…), which means that default values must sometimes be used. Much of this specific data, however, is becoming more readily available from sources such as vehicle electronic control units, whether conditions, electricity grids, traffic control systems and so on. It is therefore conceivable that in the near future more accurate methods for estimating energy consumption and GHG emissions will be available. One interesting extension might be to use modeling and simulation tools to study the impact of the operations not included in the EN 16258, such as material handling, warehousing, and traffic conditions.

Although the case study was limited to one specific company and its customers, the challenges involved in allocating energy use and GHG emissions for manufacturing companies are evident. Developing a generalized, one-size-fits-all method for determining a company's transport emissions is hampered by moment to moment changes in transport operations and the availability of trucks of a certain size or the availability of facilities like freight villages. Empty return trips can only be avoided if suitable transport demand arises at the right place and the right time. It is extremely unlikely, for example, that the customer of a steel manufacturer will have the same quantity of goods for return transports. In summary, realistically allocating GHG emissions to different goods and customers will remain an on-going challenge.

The deep changes going on in goods transportation (e.g.: electric truck, self-driving vehicles, green logistics) will face the challenge of reducing GHG emissions. The tools analyzed in the paper, integrated in the new transportation systems, will become then the more and more important for environmental performances.

Appendix

Supplementary material.

- List of Abbreviations:
- VOS: vehicle operation system
- F: fuel consumption
- F(VOS): total fuel consumption for the VOS considered
- TTW: tank-to-wheel
- WTT: well-to-tank
- WTW: well-to-wheel
- E_t: tank-to-wheel energy consumption
- E_w: well-to-wheel energy consumption
- G_t: tank-to-wheel GHG emission
- G_w: well-to-wheel GHG emission

Vehicle	Consumption
Truck	0.36 l/km
Diesel train	5.695 l/km
Electric train	21.4 kWh/km

Table A. Fuel consumption data [source: EN 16258; MIT, 2011].

Factors	Value
e_t (MJ/l)	35.90
e_t (MJ/KWh)	3.60
e_w(MJ/l)	42.70
e_w(MJ/KWh)	9.47
g_t (kgCO$_2$/l)	2.67
g_t (kgCO$_2$/KWh)	0.00
g_w(kgCO$_2$/l)	3.24
g_w(kgCO$_2$/KWh)	0.64

Table B. Energy factors and greenhouse gas emission factors [source: EN 16258; EcoTransIT: Ecological Transport Information tool, IFEU, 2011].

		Supplier 1			**Supplier 2**			**Supplier 3**			**Supplier 4**		
		truck	**diesel train**	**electric train**	**truck**	**diesel train**	**electric train**	**truck**	**diesel train**	**electric train**	**truck**	**diesel train**	**electric train**
Energy Consumption [MJ/delivery]	WTT	25,858.22	19,788.99	64,190.80	21,111.55	21,686.56	70,346.08	27,574.27	17,659.06	57,281.81	19,052.78	13,631.55	44,217.54
	TTW	136,516.21	104,474.21	39,367.44	111,456.58	114,492.28	43,142.40	145,575.94	93,229.43	35,130.24	100,587.49	71,966.58	27,118.08
GHG emission [kg/delivery]	WTT	2,167.53	1,658.78	6,998.66	1,769.64	1,817.84	7,669.76	2,311.37	1,480.24	6,245.38	1,597.07	1,142.64	4,820.99
	TTW	10,153.16	7,770.09	0.00	8,289.39	8,515.16	0.00	10,826.96	6,933.78	0.00	7,481.02	5,352.39	0.00

		Supplier 5			Supplier 6			Supplier 7		
		truck	diesel train	electric train	truck	diesel train	electric train	truck	diesel train	electric train
Energy Consumption [M/delivery J]	WTT	48,323.52	46,006.49	149,234.18	670.51	1,471.59	4,773.48	22,090.75	22,887.07	74,240.24
	TTW	255,119.76	242,887.19	91,523.52	3,539.88	7,769.12	2,927.52	116,626.18	120,830.25	45,530.64
GHG emission [kg/delivery]	WTT	4,050.65	3,856.43	16,270.85	56.20	123.35	520.45	1,851.72	1,918.47	8,094.34
	TTW	18,974.09	18,064.31	0.00	263.27	577.81	0.00	8,673.87	8,986.54	0.00

Table C. Incoming trips: factors for different mode of transport; WTT: well-to-tank; TTW: tank-to-wheel.

		Customer o1			Customer o2			Customer o3		
		truck	diesel train	electric train	Truck	diesel train	electric train	truck	diesel train	electric train
Energy Consumption [MJ]	WTT	212,599.01	129,306.11	419,438.50	438,578.78	260,045.09	843,524.87	229,857.41	130,119.36	422,076.48
	TTW	1,122,397.70	682,660.22	257,236.56	2,315,437.99	1,372,885.11	517,323.60	1,213,511.90	686,953.68	258,854.40
GHG emission [kg]	WTT	17,820.80	10,838.89	45,730.94	36,763.22	21,797.90	91,968.64	19,267.46	10,907.06	46,018.56
	TTW	83,476.38	50,771.67	0.00	172,206.67	102,105.94	0.00	90,252.84	51,090.98	0.00

			Customer o4			Customer o5			Customer o6	
		truck	diesel train	electric train	Truck	diesel train	electric train	truck	diesel train	electric train
Energy Consumption [MJ]	WTT	6,940.08	18,588.48	60,296.64	504,405.50	310,117.81	1,005,948.94	181,773.79	108,626.43	352,358.49
	TTW	36,639.54	98,136.24	36,979.20	2,662,964.35	1,637,239.60	616,936.32	959,658.70	573,483.65	216,097.20
GHG emission [kg]	WTT	581.74	1,558.15	6,574.08	42,281.05	25,995.17	109,677.57	15,236.92	9,105.45	38,417.28
	TTW	2,725.00	7,298.71	0.00	198,053.34	121,766.85	0.00	71,372.94	42,651.85	0.00

Table D. Outgoing trips: factors for different mode of transport: WTT (well-to-tank; TTW: tank-to-wheel).

		Customer i1				**Customer i2**			
		truck *	**truck + el. Train ***	**truck ****	**truck + el. Train ****	**truck ***	**truck + el. Train ***	**truck ****	**truck + el. Train ****
Energy Consumption [MJ]	WTT	5,463,934	9,546,000	12,442,657	11,314,211	1,373,778	2,192,797	1,314,294	2,914,899
	TTW	28,846,355	36,604,584	15,714,836	19,891,973	7,252,742	9,322,080	6,938,702	5,289,207
GHG emission [kg]	WTT	458,006	679,000	1,312,942	1,161,000	115,155	168,000	337,390	298,000
	TTW	2,145,397	2,661,000	680,248	908,000	539,410	660,000	185,422	247,000

		Customer i3				**Customer i4**			
		truck *	**truck + el. Train ***	**truck ****	**truck + el. Train ****	**truck ***	**truck + el. Train ***	**truck ****	**truck + el. Train ****
Energy Consumption [MJ]	WTT	1,637,967	2,674,937	3,710,166	3,296,259	1,595,036	2,698,683	3,710,166	3,305,561
	TTW	8,647,500	11,371,768	4,478,913	5,602,299	8,420,852	11,472,720	4,478,913	5,610,224
GHG emission [kg]	WTT	137,300	205,000	392,613	340,000	133,702	207,000	392,613	341,000
	TTW	643,143	805,000	185,422	247,000	626,286	812,000	185,422	247,000

		Customer i5				**Customer i6**			
		truck *	**truck + el. Train ***	**truck ****	**truck + el. Train ****	**truck ***	**truck + el. Train ***	**truck ****	**truck + el. Train ****
Energy Consumption [MJ]	WTT	1,784,612	3,014,091	4,085,514	3,548,828	1,734,163	2,860,124	4,021,951	3,502,044
	TTW	9,421,699	12,813,588	4,609,469	5,691,397	9,155,362	12,159,039	4,570,487	5,651,543
GHG emission [kg]	WTT	149,592	231,000	434,075	370,000	145,364	219,000	427,144	364,000
	TTW	700,722	907,000	177,038	236,000	680,914	861,000	177,038	236,000

		Customer i7				**Customer i8**			
		truck *	**truck + el. Train ***	**truck ****	**truck + el. Train ****	**truck ***	**truck + el. Train ***	**truck ****	**truck + el. Train ****
Energy Consumption [MJ]	WTT	1,532,370	2,405,414	3,657,910	3,042,327	1,759,387	3,015,517	4,000,735	3,619,827
	TTW	8,090,010	10,225,966	4,347,225	5,259,934	9,288,530	12,823,484	2,453,602	5,751,876
GHG emission [kg]	WTT	128,449	184,000	387,453	313,000	147,478	231,000	431,555	378,000
	TTW	601,680	724,000	177,038	236,000	690,818	908,000	177,038	236,000

Table E. Intermodal trips: factors for different modes of transport (E_t [MJ]; E_w [MJ]; Gt [kg]; Gw [kg]) using EN 16258 based tool (*) and EcoTransIT software(**).WTT (well-to-tank; TTW: tank-to-wheel).

		Full (100%)	**Average (50%)**	**Empty (0%)**
Energy consumption [MJ/km]	e_t	13.3	10.8	8.1
CO_2 [kg/km]	g_t	0.982	0.799	0.601
NO_x [kg/km]		0.00226	0.0019	0.00208
PM [kg/km]		0.0000221	0.0000194	0.000016

Table F. Energy consumption and emissions (TTW) of trucks (> 26-40 ton) [source: EcoTransIT Manual].

		Value
efficiency for DIESEL fuel		78%
CO_2 [kg/l]	g_W	0.39104
NO_x [kg/l]		0.0014976
SO_2 [kg/l]		0.00365248
PM [kg/l]		0.0019136

Table G. Energy consumption and emissions (WTW) of trucks (> 26-40 ton) [source: EcoTransIT Manual].

		City 1					**City 2**				
		truck *	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**	**truck ***	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**
Energy Consumption [MJ]	WTT	14,696,855	15,915,744	15,926,212	15,180,424	14,434,634	4,567,901	5,118,890	4,880,414	4,640,769	4,401,126
	TTW	52,107,031	67,661,432	30,081,866	29,446,564	28,811,262	16,195,285	21,761,568	8,658,040	8,453,899	8,249,758

GHG emission [kg]	WTT	697,929	1,221,000	1,612,000	1,529,000	1,445,000	216,922	393,000	500,000	474,000	447,000
	TTW	3,865,120	4,789,000	1,462,000	1,462,000	1,462,000	1,201,310	1,540,000	398,000	398,000	398,000

		City 3					**City 4**				
		truck *	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**	**truck ***	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**
Energy Consumption [MJ]	WTT	3,330,252	3,747,722	4,005,411	3,824,727	3,644,044	3,826,940	4,337,316	4,351,509	4,147,504	3,943,498
	TTW	11,807,257	15,932,422	8,045,549	7,882,680	7,719,810	13,568,242	18,438,912	8,207,491	8,033,709	7,859,928
GHG emission [kg]	WTT	158,148	287,000	413,000	392,000	371,000	181,735	333,000	441,000	418,000	396,000
	TTW	875,822	1,128,000	398,000	398,000	398,000	1,006,445	1,305,000	398,000	398,000	398,000

		City 5					**City 6**				
		truck *	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**	**truck ***	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**
Energy Consumption [MJ]	WTT	4,275,830	4,814,862	4,603,061	4,378,081	4,153,102	4,081,474	4,562,316	4,343,671	4,136,170	3,928,670
	TTW	15,159,760	20,469,076	8,218,744	8,027,096	7,835,446	14,470,680	19,395,454	8,119,416	7,934,460	7,749,504
GHG emission [kg]	WTT	203,052	369,000	471,000	446,000	421,000	193,822	350,000	452,000	428,000	404,000
	TTW	1,124,499	1,449,000	380,000	380,000	380,000	1,073,385	1,373,000	380,000	380,000	380,000

		City 7					**City 8**				
		truck *	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**	**truck ***	**truck ****	**truck + el. Train 20%**	**truck + el. Train 50%**	**truck + el. Train 80%**
Energy Consump	WTT	4,275,830	4,816,148	4,720,466	4,487,576	4,254,686	2,332,271	2,892,425	3,370,094	3,228,195	3,086,297

tion [MJ]	TTW	15,159,760	20,474,544	8,318,756	8,120,368	7,921,980	8,268,960	12,296,357	7,168,439	7,047,563	6,926,686
GHG emission [kg]	WTT	203,052	370,000	484,000	458,000	432,000	110,756	222,000	360,000	317,000	301,000
	TTW	1,124,499	1,449,000	380,000	380,000	380,000	613,363	870,000	380,000	380,000	380,000

Table H. Round trips: factors for different modes of transport (E_t [MJ]; E_w [MJ]; G_t [kg]; G_w [kg]) using EN 16258 based tool (*) and EcoTransIT software(**).WTT (well-to-tank; TTW: tank-to-wheel) and considering different loading factor for the return trip.

Abstract

The transportation sector, accounts for a large share of greenhouse gas (GHG) emissions. Therefore, practitioners and researchers alike are working to find more environmentally-friendly solutions. Along with new technologies that increase local efficiency in current road-freight transport, it is also necessary to explore the use of different transport modes and policies. To evaluate such alternative logistics processes, it is necessary to quantify their environmental impact using various tools and methodologies. In this paper, an EN 16258 based tool and the EcoTransIT tool are applied to a real-world case study to evaluate the GHG emissions and energy consumption of the current and alternative modes of transports. The objective of the paper is to assess the two tools applied to different modes of transport, i.e. direct delivery by truck versus intermodal transport with freight villages. The results allow decision-makers to select the most environmentally-friendly routes, implementing then a Sustainable Supply Chain.

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