DECLARATIONS REGARDING THE ENERGY CONSUMPTION AND EMISSIONS OF THE GREENHOUSE GASES IN THE ROAD FREIGHT TRANSPORT SECTOR

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Abstract

This manuscript is focused on the matter concerning the emissions of the greenhouse gases produced by the road freight transport mode. Those emissions influence the ozone layer structure and help to create the greenhouse impact causing the global warming, i.e. issues particularly related to the weather change aspects as well as extreme weather occurrences. In the first part of the paper, the calculation approaches, energy consumption examination as well as evaluation of emissions of the greenhouse gases created by the transport modes operation are performed by the EN 16258:2013 standard. The research chapter outlines the implementation of the approach technique to particular consignment on a specific transport section, while the sum of the energy consumption and greenhouse gases emissions production per pallet of goods weighing 1000 kg is specified. The resulting values form the fundamentals for declarations of energy consumption and greenhouse gas emissions. The proper and precise examinations of energy consumption and emissions production can help to identify the share of external costs for specific transport modes quite accurately. This ensures that such costs are fairly carried by the individual producers thereof.

Keywords: Transport sector, road freight transport, declarations, consumption of the energy, emissions

1. Introduction

Transport, as an essential part of the supply chain, has considerable financial impact on aspect of live in the EU countries. Along with the progress of individual modes of transport in the 1990´s, warning signs of the environmentally negative effect of various modes of transport occurred. Originally, it was related to the influence on the environment in urban areas whereas fossil fuel emissions generated by engines and noise pollution began to achieve allowed limits. The matter regarding the reduction of the environmentally

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negative effect of transport modes consequently initiated to be solved by a broad scope of governmental and non-governmental scientific and development organizations [1, 2].

Plans to decrease an environmentally negative effect of the transport operation started to develop not only at the urban and county levels, but as well at the international grades over time. Scientists began to be focused on the problems and research studies dealing with a much broader scope of environmentally negative factors and their influence on the global environment. Those initiatives include, among other things, a lot of recommendations to solve the situation, suggestions considered to be more or less appropriate in regard to the sustainable increase of national economies as well as standards of inhabitants' lives. That represents an essential dichotomy, i.e. how do we eliminate the environmentally negative effects of the transport operation while maintaining the current level of economic growth and standards of lives [2-4]?

This paper aims to the issues regarding the greenhouse gas emissions generated by individual means of road freight transport. Emissions raised from the exhaust gases influence the ozone layer structure and help to create the greenhouse impact causing the global warming, i.e. issues particularly related to the weather change aspects as well as extreme weather occurrences [5]. The authors are aware of the fact that this is only one of the many contributory factors that cause this effect and that from the global point of view transport is not the most significant producer of these gases. However, the positive attitude of transport companies towards the protection of the environment is a first and significant step on the way to reducing overall greenhouse gas emissions in the road freight transport sector [6,7].

2. Methodology for the calculation and declaration of energy consumption and greenhouse gas emissions for transport services according to the EN 16258:2013 standard

The EN 16258:2013 standard determines an approach technique and requests to specify the energy consumption and emissions related to the greenhouse gases in connection with the transport services. This standard was created in order to unify the variety of carbon footprint specifications as well as identify their distinctions. In regard to road vehicles energy consumption and emissions level calculation, these aspects are taken into consideration in terms of production and distribution of fuels or electric energy. That provides that the standard supposes the "Well-to-Wheel" (WtW) technique regarding the calculations and declarations (see Figure 1).

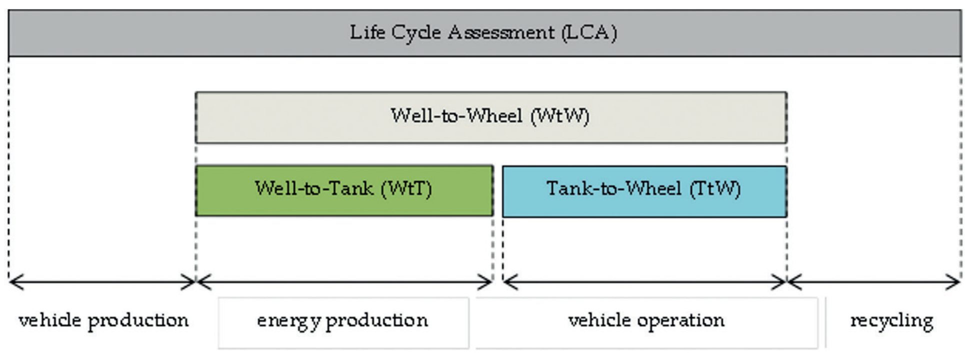

Fig. 1. Vehicle life cycle assessment, Source: Authors based on [8]

Thus, WtW consists of the above mentioned energy and emissions related to the production of fuels or electric energy, Well-to-Tank (WtT), as well as the energy consumption and emissions of the greenhouse gases in connection with the vehicle of Tank-to-Wheel (TtW) operation [9-11].

Applying the Well-to-Wheel technique defines fuel energy consumption as well as CO_{2eq} production for driving circumstances corresponding to the European homologation cycle. Furthermore, this standard defines the individual operations and activities inevitable to determine the energy consumption and emissions of the greenhouse gases properly [12,13].

The vehicle operation must cover functions of the entire vehicle systems, incorporating drive system (vehicle engine system with accessories), auxiliary systems, subsidiary devices used to maintain the area temperature under the load, as well as vehicle handling and reloading mechanisms.

Energy processes to consume the engine fuel must cover the extraction or production of primary energy, refinement, transformation, energy carriage and distribution while all production phases. The procedure to specify the energy consumption and the level of emissions of the greenhouse gases regarding the transport services must take into account all the vehicles utilized to ensure the transport services inclusive those utilized for subcontracted operations. Moreover, it must cover the total engine fuel consumption of each operator as well as all the movements in terms of loading and unloading [14].

The calculation itself for a particular transport service must consist of parts as follows:

1. Defining the individual routes (legs) making up the particular transport service.
2. Performing the calculation related to the energy consumption and emissions level of the greenhouse gases for each leg regarding the particular transport service.
3. Specifying the sum of outcomes for each leg regarding the particular transport service [15,16].

The specification of the total energy consumption and emissions level of the greenhouse gases is executed by following equations 1-4:

$$E_w(VOS) = F(VOS)e_w,\ [\mathrm{MJ}] \tag{1}$$

$$G_w(VOS) = F(VOS)g_w,\ [\mathrm{kgCO_{2eq}}] \tag{2}$$

$$E_t(VOS) = F(VOS)e_t,\ [\mathrm{MJ}] \tag{3}$$

$$G_t(VOS) = F(VOS)g_t,\ [\mathrm{kgCO_{2eq}}] \tag{4}$$

Where:

$E_w\ (VOS)$ – Well-to-Wheel energy consumption of the VOS;

$G_w\ (VOS)$ – Well-to-Wheel greenhouse gas emissions of the VOS;

$E_t\ (VOS)$ – Tank-to-Wheel energy consumption of the VOS;

$G_t\ (VOS)$ – Tank-to-Wheel greenhouse gas emissions of the VOS;

$F\ (VOS)$ – overall fuel consumption of the VOS;

e_w – Well-to-Wheel energy factor for consumed fuel;

g_w – Well-to-Wheel greenhouse gases factor for consumed fuel;

e_t – Tank-to-Wheel energy factor for consumed fuel;

g_t – Tank-to-Wheel greenhouse gases factor for consumed fuel.

The energy and greenhouse gases factors values are adopted from the EN16258:2012 standard. The total values of the energy consumption and emissions of the greenhouse gas regarding the vehicle operation system (VOS) must be assigned to the specific loading unit. The EN16258:2012 standard utilizes the unit of tkm as the unit to define the transportation performance which stands for the product of the transported load weight and the traveled kilometers [17-19]. The transported load weight consists of the transported material itself, packages, container(s), pallet(s), etc. The general equations to assign the load are as follows:

$$S(leg) = \frac{T(leg)}{T(VOS)},\ [\text{-}] \tag{5}$$

$$E_w(leg) = E_w(VOS)S(leg),\ [\mathrm{MJ}] \tag{6}$$

$$G_w(leg) = G_w(VOS)S(leg),\ [\mathrm{kgCO_{2eq}}] \tag{7}$$

$$E_t(leg) = E_t(VOS)S(leg),\ [\mathrm{MJ}] \tag{8}$$

$$G_t(leg) = G_t(VOS)S(leg),\ [\mathrm{kgCO_{2eq}}] \tag{9}$$

Where:

$S\ (leg)$ – factor to calculate the share of energy consumption and emissions level of the vehicle operation system (VOS) to be assigned to the particular transport service;

$T\ (leg)$ – transportation performance for the leg of the particular transport service;

$T\ (VOS)$ – transportation performance of the VOS.

3. Declaration of energy consumption and greenhouse gas emissions for transport services

The theoretical example presented here is based on the following details. A selected transport company receives a contract to transport a pallet with a total weight of 1,000 kg, including packaging and handling equipment, from Point A to Point B, over a total distance of 100 km. At Points A and B, there are logistics centers with collection and distribution services. As a result, the specified transport service consists of several VOS journeys (legs). For the first leg, a N2 vehicle (commercial truck) is used. This vehicle transports the pallet from the customer to the logistics center together with other consignments. The second leg involves the transshipment of the pallet from the commercial truck to a semi-trailer using a forklift truck. The third leg is the longest leg of the specified transport service. The pallet is transported between points A and B in a semi-trailer that is part of an N3 + O4 combination (articulated vehicle). The fourth leg involves the transshipment of the pallet from the semi-trailer to a delivery service vehicle using a forklift truck. The last leg involves the delivery of the pallet to the recipient by means of a N2 vehicle [20,21].

3.1. VOS Leg 1 – Collection service

The collection vehicle collects the 1,000 kg pallet and transports it to the logistics center. This vehicle travels a VOS distance of 21 km and consumes 4 liters of diesel oil with no biofuel share. The vehicle starts from the S0 vertex and gradually delivers and dispatches consignments to and for other customers. The tracked consignment is loaded using a manual lifting device at vertex S2 and transported back to the S0 vertex via the S3 – S5 vertices. This section of the transport service is identified as TS (marked in red in Figure 2). The VOS is defined as a cycle from S0 to S0 [22-24].

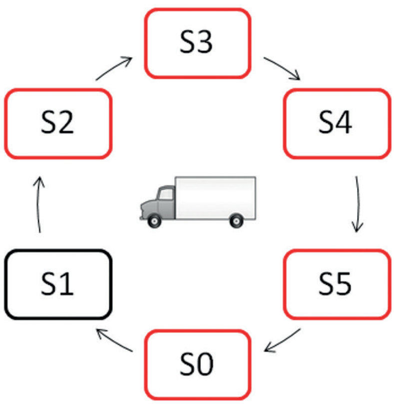

Fig. 2. Transport service (TS) at Point A, Source: Authors

Table 1 shows the parameters and calculated transport performances for both the VOS and for the specified TS at Point A that are necessary for the subsequent calculations.

Tab. 1. Parameters for collection service at Point A, Source: Authors

Route	S0	S1	S2	S3	S4	S5	S0	In total
Distance [km]	0	2	4	3	6	4	2	21
Cargo [t]	0	2	5	4	8	6	8	
Transport performance T (VOS) [tkm]	0	4	20	12	48	24	16	124
Transport performance T (leg) [tkm]	0	0	0	3	6	4	2	15

The factors for calculating the energy consumption and greenhouse gas emissions for diesel are presented in Table 2.

Tab. 2. Energy and greenhouse gas emissions factors for diesel, Source: Authors based on [9]

Type of fuel	Energy consumption factor		GHG emission factor	
	Tank-to-Wheel (e_t) [MJ/l]	Well-to-Wheel (e_w) [MJ/l]	Tank-to-Wheel (g_t) [kgCO_{2eq}/l]	Well-to-Wheel (g_w) [kgCO_{2eq}/l]
Diesel	35.9	42.7	2.67	3.24

The first step in the calculation is to calculate the energy consumption and greenhouse gas emissions for the VOS, where F (VOS) is the total volume of the fuel consumed.

$$E_w\,(VOS) = F\,(VOS) * e_w = 4 * 42.7 = 170.80\ MJ$$
$$G_w\,(VOS) = F\,(VOS) * g_w = 4 * 3.24 = 12.96\ kgCO_{2eq}$$
$$E_t\,(VOS) = F\,(VOS) * e_t = 4 * 35.9 = 143.60\ MJ$$
$$G_t\,(VOS) = F\,(VOS) * g_w = 4 * 2.67 = 10.68\ kgCO_{2eq}$$

The second step is to determine the factor for calculating the share of energy consumption and emissions of the VOS to be allocated to the leg of the specified transport service.

$$S\,(leg) = (T\,(leg)) / (T\,(VOS)) = 15/124 = 0.121$$

The third step is to allocate the leg share from each of the four results of the first step.

$$E_w\,(leg) = E_w\,(VOS) * S\,(leg) = 170.8 * 0.121 = 20.667\ MJ$$
$$G_w\,(leg) = G_w\,(VOS) * S\,(leg) = 12.96 * 0.121 = 1.568\ kgCO_{2eq}$$
$$E_t\,(leg) = E_t\,(VOS) * S\,(leg) = 143.6 * 0.121 = 17.376\ MJ$$
$$G_t\,(leg) = G_t\,(VOS) * S\,(leg) = 10.68 * 0.121 = 1.292\ kgCO_{2eq}$$

3.2. VOS Leg 2 – Transshipment of goods at Point A

The following step is the transshipment of the pallet from the collection service vehicle to an articulated vehicle (see Figure 3).

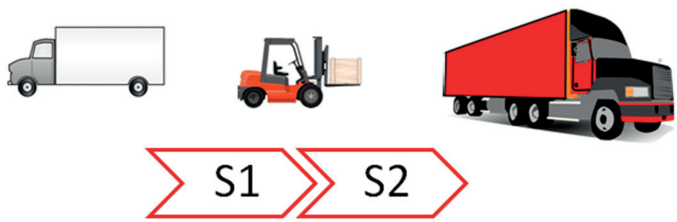

Fig. 3. VOS Leg 2 – Transshipment of goods, Source: Authors

For the purposes of the calculations, the logistics center at Point A is assumed to use a Linde forklift truck powered by a CNG combustion engine. The consumption given by the manufacturer is 3.7 m^3 per engine hour, which is 2.6 kg per hour of engine operation. The transshipment of the pallet from the collection vehicle to the semi-trailer is set at 5 minutes. The CNG consumption for VOS Leg 2 is therefore 0.2166 kg. The energy consumption and emissions factors for CNG are presented in Table 3.

Tab. 3. Energy consumption and greenhouse gas emissions factors for CNG, Source: Authors based on [9]

Type of fuel	Energy consumption factor		GHG emission factor	
	Tank-to-Wheel (e_t) [MJ/kg]	Well-to-Wheel (e_w) [MJ/kg]	Tank-to-Wheel (g_t) [$kgCO_{2eq}$/kg]	Well-to-Wheel (g_w) [$kgCO_{2eq}$/kg]
CNG	45.1	50.5	2.68	3.07

$E_w\ (VOS) = F\ (VOS) * e_w = 0.2166 * 50.5 = 10.938\ MJ$

$G_w\ (VOS) = F\ (VOS) * g_w = 0.2166 * 3.07 = 0.665\ kgCO_{2eq}$

$E_t\ (VOS) = F\ (VOS) * e_t = 0.2166 * 45.1 = 9.769\ MJ$

$G_t\ (VOS) = F\ (VOS) * g_t = 0.2166 * 2.68 = 0.580\ kgCO_{2eq}$

As the transshipment relates only to the tracked pallet, the resulting values for this leg of the transport service correspond with the resulting values for the whole VOS. Therefore, it is true, that:

$E_w\ (leg) = 10.938\ MJ$

$G_w\ (leg) = 0.665\ kgCO_{2eq}$

$E_t\ (leg) = 9.769\ MJ$

$G_t\ (leg) = 0.580\ kgCO_{2eq}$

3.3. VOS Leg 3 – Transport of pallet by articulated vehicle

The articulated vehicle, a combination of a N3 truck and O4 semi-trailer, travels a total distance of 100 km from the S1 vertex at Point A to the S2 vertex at Point B (see Figure 4).

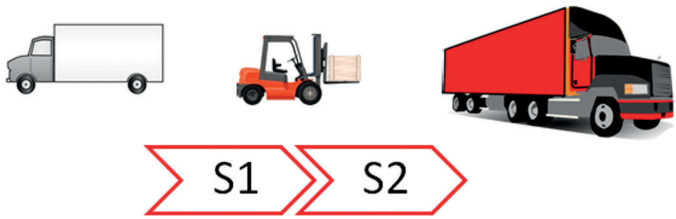

Fig. 4. VOS Leg 3 – Transport service, Source: Authors

For the purposes of the calculations, the articulated vehicle is loaded with 24,000 kg of cargo. The transport performance on this route is 2,400 tkm. The truck consumes a total of 33 liters of diesel with a 6% biocomponent. The factors for calculating the energy consumption and emissions of diesel with a 6% biocomponent are presented in Table 4.

Tab. 4. Energy consumption and greenhouse gas emissions factors for diesel with 6% biocomponent, Source: Authors based on [9]

Type of fuel	Energy consumption factor		GHG emission factor	
	Tank-to-Wheel (e_t) [MJ/l]	Well-to-Wheel (e_w) [MJ/l]	Tank-to-Wheel (g_t) [$kgCO_{2eq}$/l]	Well-to-Wheel (g_w) [$kgCO_{2eq}$/l]
Diesel/bio	35.7	44.2	2.51	3.16

The energy consumption and production of GHG emissions is first calculated for the whole VOS.

$$E_w\ (VOS) = F\ (VOS) * e_w = 33 * 44.2 = 1458.6\ MJ$$
$$G_w\ (VOS) = F\ (VOS) * g_w = 33 * 3.16 = 104.28\ kgCO_{2eq}$$
$$E_t\ (VOS) = F\ (VOS) * e_t = 33 * 35.7 = 1178.1\ MJ$$
$$G_t\ (VOS) = F\ (VOS) * g_t = 33 * 2.51 = 82.83\ kgCO_{2eq}$$

The factor for allocating the share of VOS energy consumption and emissions to the leg of the specified transport service is then determined.

$$S\ (leg) = (T\ (leg)) / (T\ (VOS)) = 100 / 2400 = 0.042$$

The leg share in the energy consumption and GHG emissions production of the VOS is subsequently calculated.

$E_w\ (leg) = E_w\ (VOS) * S\ (leg) = 1458.6 * 0.042 = 61.261\ MJ$
$G_w\ (leg) = G_w\ (VOS) * S\ (leg) = 104.28 * 0.042 = 4.380\ kgCO_{2eq}$
$E_t\ (leg) = E_t\ (VOS) * S\ (leg) = 1178.1 * 0.042 = 49.480\ MJ$
$G_t\ (leg) = G_t\ (VOS) * S\ (leg) = 82.83 * 0.042 = 3.479\ kgCO_{2eq}$

3.4. VOS Leg 4 – Transshipment of goods at Point B

After the arrival of the articulated vehicle at the S2 vertex at Point B, the consignment is transshipped to a delivery vehicle (see Figure 5).

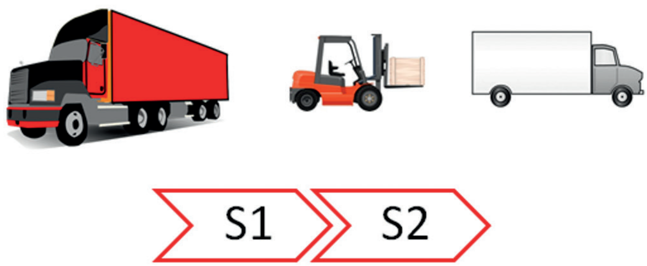

Fig. 5. VOS Leg 4 – Transshipment of goods, Source: Authors

For the purposes of the calculations, the logistics center at Point B is assumed to operate Desta forklift trucks powered by LPG (liquefied petroleum gas) combustion engines. The consumption of the forklift truck as given by the manufacturer is 2.1 kg per engine hour [25]. The transshipment time is set at 5 minutes. The energy consumption and emissions factors for LPG are presented in Table 5.

Tab. 5. Energy consumption and greenhouse gas emissions factors for liquefied petroleum gas (LPG), Source: Authors based on [9]

Type of fuel	Energy consumption factor		GHG emission factor	
	Tank-to-Wheel (e_t) [MJ/kg]	Well-to-Wheel (e_w) [MJ/kg]	Tank-to-Wheel (g_t) [$kgCO_{2eq}$/kg]	Well-to-Wheel (g_w) [$kgCO_{2eq}$/kg]
LPG	46.0	51.5	3.1	3.46

The calculation is the same as for the previous transshipment.

$E_w\ (VOS) = F\ (VOS) * e_w = 0.175 * 51.5 = 9.013\ MJ$
$G_w\ (VOS) = F\ (VOS) * g_w = 0.175 * 3.46 = 0.606\ kgCO_{2eq}$
$E_t\ (VOS) = F\ (VOS) * e_t = 0.175 * 46 = 8.05\ MJ$
$G_t\ (VOS) = F\ (VOS) * g_t = 0.175 * 3.1 = 0.543\ kgCO_{2eq}$

The results for the whole VOS are also identical to those for the "leg".

$E_w\ (leg) = 9.013\ MJ$

$G_w\ (leg) = 0.606\ kgCO_{2eq}$

$E_t\ (leg) = 8.050\ MJ$

$G_t\ (leg) = 0.543\ kgCO_{2eq}$

3.5. VOS Leg 5 – Transport of goods to recipient

The last leg involves the delivery of the goods to the recipient by a N2 truck. The total length of the route is 23 km. The vehicle gradually picks up goods from customers at the individual vertices. The vehicle is driven by a combustion engine designed for the combustion of FAME biofuel and consumed 5 liters [26,27]. The tracked consignment is loaded at vertex S0. The address for unloading the consignment is vertex S3. Once again, the VOS refers to the transport from S0 to S0. The assessed transport service (TS) is from S0, via S1 and S2, to S3 (see Figure 6, vertices marked in red).

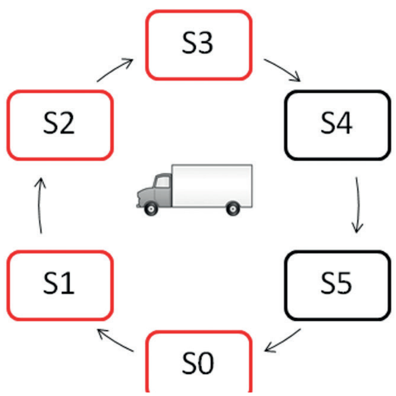

Fig. 6. Transport service (TS) at Point B, Source: Authors

Table 6 shows the parameters and calculated transport performances for both the VOS and for the specified TS at Point B.

Tab. 6. Parameters of transport service at Point B, Source: Authors

Route	S0	S1	S2	S3	S4	S5	S0	In total
Distance [km]	0	3	5	1	2	8	4	23
Cargo [t]	0	5	2	3	5	0	4	
Transport performance T (VOS) [tkm]	0	15	10	3	10	0	16	54
Transport performance T (leg) [tkm]	0	3	5	1	0	0	0	9

Table 7 shows the energy consumption and emissions factors for 100% FAME biodiesel.

Tab. 7. Energy consumption and greenhouse gas emissions factors for FAME biodiesel, Source: Authors based on [9]

Type of fuel	Energy consumption factor		GHG emission factor	
	Tank-to-Wheel (e_t) [MJ/l]	Well-to-Wheel (e_w) [MJ/l]	Tank-to-Wheel (g_t) [$kgCO_{2eq}$/l]	Well-to-Wheel (g_w) [$kgCO_{2eq}$/l]
FAME	32.8	68.5	0.0	1.92

As in the previous cases, the energy consumption and GHG emissions production is calculated for the whole VOS.

$E_w\ (VOS) = F\ (VOS) * e_w = 5 * 68.5 = 342.5\ MJ$

$G_w\ (VOS) = F\ (VOS) * g_w = 5 * 1.92 = 9.6\ kgCO_{2eq}$

$E_t\ (VOS) =F\ (VOS) * e_t = 5 * 32.8 = 164\ MJ$

$G_t\ (VOS) = F\ (VOS) * g_t = 5 * 0 = 0\ kgCO_{2eq}$

Subsequently, the factor for allocating the share of VOS energy consumption and emissions to the leg of the specified transport service is determined.

$S\ (leg) = (T\ (leg)) / (T\ (VOS)) = 9 / 54 = 0.167$

The final step of the partial calculations is to calculate the share of the pallet in the energy consumption and GHG emissions production of the whole VOS.

$E_w\ (leg) = E_w\ (VOS) * S\ (leg) = 342.5 * 0.167 = 57.198\ MJ$

$G_w\ (leg) = G_w\ (VOS) * S\ (leg) = 9.6 * 0.167 = 1.603\ kgCO_{2eq}$

$E_t\ (leg) = E_t\ (VOS) * S\ (leg) = 164 * 0.167 = 27.388\ MJ$

$G_t\ (leg) = G_t\ (VOS) * S\ (leg) = 0 * 0.167 = 0\ kgCO_{2eq}$

The final calculation concludes the calculation of the partial results necessary for determining the overall greenhouse gas emissions production and energy consumption for the specified transport service for the transport of one pallet of goods weighing 1,000 kg.

4. Results

The previous part dealt with a theoretical example for calculating energy consumption and greenhouse gas emissions production. In this part, the partial calculations are used to determine/identify the carbon footprint of this pallet of goods on the given route. A recapitulation of the partial results of the calculations is presented in Table 8.

Tab. 8. Recapitulation of partial results, Source: Authors

Transport service	E_w (leg) [MJ]	G_w (leg) [kgCO$_{2eq}$]	E_t (leg) [MJ]	G_t (leg) [kgCO$_{2eq}$]
VOS(leg) 1	20.667	1.568	17.376	1.292
VOS(leg) 2	10.938	0.665	9.769	0.580
VOS(leg) 3	61.261	4.380	49.480	3.479
VOS(leg) 4	9.013	0.606	8.050	0.543
VOS(leg) 5	57.198	1.603	27.388	0.00
Total consumption	E_w (TS) [MJ]	G_w (TS) [kgCO$_{2eq}$]	E_t (TS) [MJ]	G_t (TS)[kgCO$_{2eq}$]
	159.077	8.822	112.063	5.894

The partial results include the leg shares for the specified transport service, travelling salesman problem at Points A and B. The resulting values form the basis for the declaration of energy consumption and greenhouse gas emissions production. The declaration contains all four results required in accordance with the EN 16256:2013 standard:

- Well-to-Wheel GHG emissions of the transport service (G_w)
- Tank-to-Wheel GHG emissions of the transport service (G_t)
- Well-to-Wheel energy consumption of the transport service (E_w)
- Tank-to-Wheel energy consumption of the transport service (E_t).

This example explains the methodology and use of the standard for calculations in road freight transport and is essential for calculating the energy consumption and emissions production of primary transport services [28].

5. Conclusions

The outlined technique to calculate the energy consumption and the level of produced emissions of the greenhouse gases related to the road freight transport sector is just one of the ways of checking the negative impacts of transport on the environment. The problems that arise in relation to the negative environmental impact of transport can be described as external costs (costs of air pollution by emissions, costs of traffic accidents, soil and groundwater contamination caused by fuel, congestion and noise costs, etc.). Within this context, the issue of the internalization of external costs has been discussed for several years, which means that the producers, including transport companies, should be adequately involved. The proper and accurate calculation of energy consumption and emissions production can help to accurately determine the share of external costs for specific forms of transportation. This ensures that such costs are fairly carried by the individual producers thereof.

The proper and accurate calculation of energy consumption and emissions production can provide individual carriers with important information on what possibilities exist for reducing energy consumption and emissions, thereby enabling the streamlining of transport services.

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