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Customized Approach to Greenhouse Gas Emissions Calculations in Railway Freight Transport

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Featured Application: This proposed and verified customized approach to greenhouse gas emission calculations in railway freight transport for the automotive industry is the basis for creating a software tool to support logistic planning and decision making.

Abstract: The topic of global warming is and will continue to be a crucial topic of this millennium. Freight transport, as a producer of greenhouse gas (hereinafter GHG) emissions, makes a significant contribution to the greenhouse effect. Large supply chains and large volumes of freight transport, which imply the production of significant volumes of GHG emissions, characterize the automotive industry (hereinafter AI). Thanks to these premises, it is necessary to seek and develop tools for reducing the volume of GHG emissions produced from the logistic activities of the AI, while maintaining the required level of logistic services. The assumptions for the calculation of GHG emissions from railway freight transport (hereinafter RFT) in the AI were identified through the use of semi-structured interviewing. Available railway freight GHG emission calculators were identified and analyzed from the perspective of suitability for the AI using a comparative content analysis. The main result of this manuscript is the proposal of a fully customized approach to GHG emission calculations in RFT for the AI. This approach was proposed, applied, and verified in the form of an interpretative case study. The use of this approach can be expected in support of logistic planning and decision making.

Keywords: logistics; transportation; railway freight transport; greenhouse gas emissions; greenhouse gas emission calculator; automotive industry

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1. Introduction

In the past several decades, global warming has become a severe issue that needs a response in order to reduce CO_2 from all sectors [1]. Due to global warming, focus is given to one of CO_2's origins, which is the continuous increase in greenhouse gas (hereinafter GHG) emissions caused by various human activities [2]. There are a number of studies and reasons to analyze direct relationships between emission sources, air pollutant concentrations, and health end-points, e.g., Lee et al. [3]. Next to the United States, China is the second largest source of CO_2 emissions in the world [4]. Organic carbon is one of the major components of ambient $PM_{2.5}$ (particulate matter (PM) $\leq$ 2.5 μm in aerodynamic diameter) and a significant portion of organic carbon is from secondary organic aerosol formation; results from studies suggest that the anthropogenic origin of secondary organic carbon is dominant [5]. Epidemiological studies suggest that ambient particulate matter has significant associations with adverse respiratory and cardiovascular health effects [6]. Lee et al. [7] added that it is important to understand which emission sources contribute to elevated daily $PM_{2.5}$ levels in order to develop effective control strategies. One approach to solving this problem involves the use of green energies and the reduction of CO_2 emitted from all sectors [8]. On the other hand, it must also be stated that extensive forest fires, including wildfires, prescribed burnings, agricultural waste burnings, and domestic biofuel combustion are important sources of primary air pollutants and precursors of secondary pollutants too [9–12]. With the improvement of people's living standards, energy consumption by the transport sector will increase dramatically and, in many areas, the environmental problems and health effects caused by the transport sector have become increasingly serious [13]. The transport sector is the second largest contributor to CO_2 emissions in the world [14]. Regarding the transportation sector, it emitted above one-fourth of global CO_2 emissions [8]. It is believed that CO_2 emissions from the transport sector are growing faster than total CO_2 emissions [15]. Freight transport is an important source of energy consumption and GHG emissions [16,17].

The authors of this manuscript closely focus on GHG emissions from railway freight transport (hereinafter RFT) in the AI. The main purpose of the manuscript is to propose a customized approach to GHG emission calculations in RFT. The AI has been the most crucial industry of the domestic economy long-term but also of the whole European Union (hereinafter EU). The transport sector contributes about 10% of the gross domestic product in the Czech Republic [18]. Many domestic and global suppliers are connected to the AI. Suppliers participating in the automotive production chain in the Czech Republic make up 23% of the Czech Republic's industrial production [18]. Many material flows are connected to the AI (e.g., materials, car bodies, containers, finished cars), which means a lot of transport, which produces GHG emissions.

Logistics with low emissions have become a preferred aim in all transport modes, especially in the EU [19,20]. The EU is on the correct path to achieve its GHG emissions reduction goal for 2020 and yet has submitted a plan to further reduce emissions by at least 55% in 2030 [21–23]. Chen et al. [24] discussed and analysed the energy consumption and carbon emissions of roads and railways in China's transport sector, and they modelled scenarios of that sector's energy consumption and carbon emissions until 2025. Wang et al. [25] studied a reduction in emissions in the transport sector, discussed current trends between RFT and road and waterway freight transport, identified de-carbonation potentials for the transport sector, and predicted transport emissions under different scenarios. Since 2019, the rate of emissions growth has continued to decrease, with transport emissions to be reduced in the near future. Feng et al. [26] defined a concept of carbon-saving profit for studying railway freight prices and discussed a maximization model of railway freight based on an established low-carbon economy. Kaewunruen et al. [27] mentioned the importance of efficient and feasible approach development for recovering and recycling wasted rolling stocks. Krezo et al. [28] discovered that emissions from materials contribute more than nine times the CO_{2e} emissions of machines used in renewal projects, and in addition, that extending the lifespan of rail infrastructure assets through maintenance is beneficial in terms of reducing CO_{2e} emissions. Furthermore, Krezo et al. [29] examined the CO_2 impact of railway resurfacing in ballasted track bed maintenance. Kaewunruen et al. [30] assessed global warming potentials due to railway tunnel construction and maintenance.

The European standard EN 16258 Methodology for the calculation and declaration of energy consumption and GHG emissions in transport (freight and passenger) was approved by the European Committee for Standardisation in 2012 [31–33]. Currently, there are three main approaches to the measurement of energy consumption and produced emissions [32]: Well-to-Wheel (hereinafter WtW), Well-to-Tank (hereinafter WtT) and Tank-to-Wheel (hereinafter TtW):

- Well-to-Wheel (the sum total of Well-to-Tank together with Tank-to-Wheel): an approach based on the monitoring of energy consumption and associated emissions production, which covers the whole process from the production of electricity or fuel, through supply to appropriate means of transport via the distribution network, to consumption associated with the operation of transport means. This approach is based on the sum of Tank-to-Wheel and Well-to-Tank values (Figure 1).

- Well-to-Tank: Energy consumption and emission production associated with energy or fuel production—this indicator covers all activities from mining of raw materials via energy or fuel production to delivery to relevant means of transport via the distribution network. This indicator does not include the mode of transport (Figure 1).
- Tank-to-Wheel: Consumption of energy and associated emissions production connected with transport means operations. This approach does not include the additional life cycle of the fuel and transport means (Figure 1).

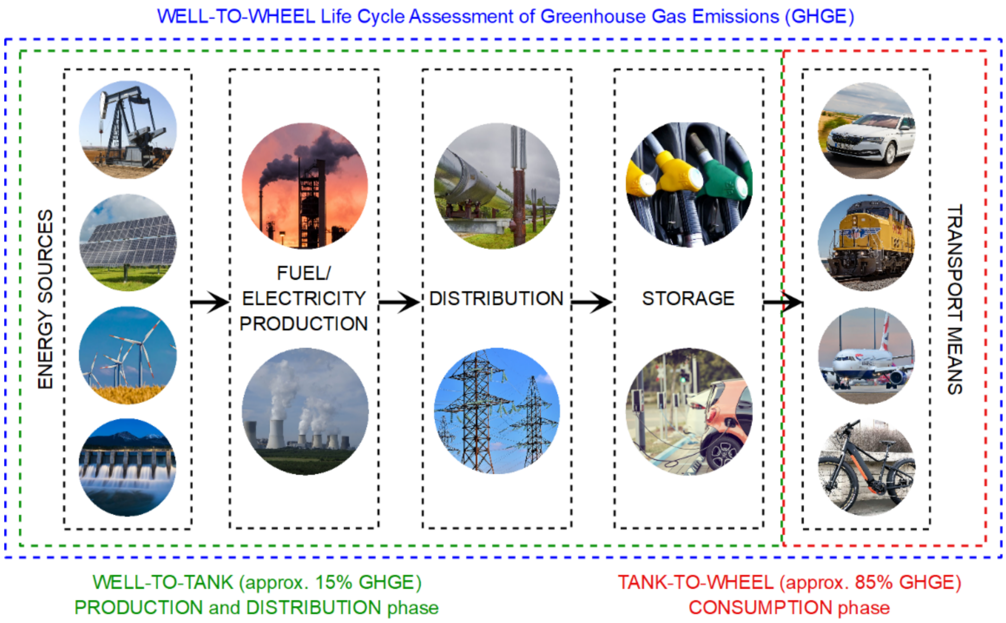

Figure 1. WELL-to-WHEEL Life Cycle Assessment of GHG Emissions [authors].

Skrúcaný et al. [33] described a comparison of energy consumption and GHG production of three modes of transport (road, rail and water) according to current legislation—EN 16258. Another option is to use the life cycle assessment (LCA) method and a life cycle cost (LCC) analysis method [34]. These methods summarize energy consumption, GHG emissions, and costs from the perspective of the whole life cycle during the conception stage, construction stage, operation and maintenance stage, and disposal stage [34]. In some cases, the authors describe only these stages: construction, operation, maintenance, and dismantlement or demolition [1,35]. However, the authors of this manuscript, in contrast to the LCA method, focused only on the monitoring of energy consumption and associated emissions production, which covers the whole process from production of electricity or fuel, through to supply on appropriate means of transport via the distribution network, to consumption associated with the operation of transport means (WtW approach) [32]. Conception, construction, operation, maintenance, and disposal stages in connection with railway infrastructure are not included.

Reducing GHG emissions from freight transport can be achieved, for example, by supply chain pooling [36]. Supply chain logistic pooling consists of several independent companies sharing logistic activities and can be initiated for environmental reasons to optimize transportation and reduce the companies' GHG emissions [37,38]. Lee et al. [39] stated that it is important to accurately estimate GHG emissions with their uncertainties to reduce GHG emissions and mitigate climate change. GHG emission calculators are useful tools for estimating GHG emissions and for providing information that can help to develop behavioral and policy change [40,41].

The aim of this article is to propose a fully customized approach to GHG emission calculations in RFT for the AI. The aim of this article also supports the fact that the AI has global impacts not only from an economic point of view but also from a social and especially environmental point of view. The economies of some countries, such as China, Japan, USA, and Germany, are completely dependent on the AI. The AI industry has very specific supply chains that consist of many logistic chain members located worldwide. This places enormous demands on the management of these supply chains but above all on transport, as one of the most important logistic activities. Inbound and outbound logistic processes within the AI produce significant volumes of GHG emissions with global, social, and environmental impacts. This implies the need to develop fully customized tools for calculating GHG emissions. The novelty of this research lies in the proposal of a fully customized and unique approach to GHG emission calculations in RFT for the AI.

2. Materials and Methods

This manuscript's methodological approach consists of four basic steps. In the first step, the assumptions for the GHG emission calculation from RFT in the AI are identified and synthesized using the scientific method of three-round semi-structured interviews (theoretically described in Section 2.1).

In the second step, available railway freight GHG emission calculators were identified and then analyzed from the perspective of suitability for calculating GHG emissions in the AI. In the second step, the scientific method of comparative content analysis (theoretically defined in Section 2.2) was used.

In the third step, a fully customized approach to GHG emission calculations in RFT for the AI is designed (Section 3.3).

In the fourth step, the fully customized approach to GHG emission calculations in RFT for the AI was applied and verified (Section 3.4) using the scientific method of interpretative case study (theoretically described in Section 2.3).

2.1. Semi-Structured Interviews

Semi-structured interviews were used to identify assumptions for the GHG emission calculations from RFT in the AI with four respondents from one company, which is a leader in the AI Czech Republic market. This method was used in the first processing step in the form of a three-round semi-structured interview (Section 3.1).

This scientific method is very suitable in situations where the scientific team reduces the number of research topics [42]. At the same time, it is used as part of an inductive approach to identify topics related to the research aim [43]. Semi-structured interviews are suitable for gaining insights into the complex field of public perception too; the intention is to understand subject-oriented perspectives using a structured procedure [44]. A small sample is sufficient within semi-structured interviews [45]. These semi-structured interviews allow the collecting of direct insights of respondents [46].

This method was used, for example, by Karolemeas et al. [47] to develop a methodological framework for identifying suitable locations for the deployment of electric vehicle charging points in urban environments; by Kaupa and Naude [48] to report on a study that investigated the critical success factors in supply chain management of essential medicines in the public health care delivery system in Malawi; by Schlegel et al. [49] to investigate how big data analytic capabilities enable the implementation of integrated business planning—the advanced form of sales and operations planning—by counteracting the increasing information processing requirements.

2.2. Comparative Content Analysis

This method is used to identify, analyze, and compare available RFT GHG emission calculators potentially suitable for the AI. This method is used in the second processing step (Section 3.2).

The method of comparative content analysis is generally very well-known and very often used. It was first used in the 18th century and has been used to analyze content and to compare, for example, across different sources, topics, frequencies, etc. [50]. Lutz and

Collins identified that this type of analysis allows researchers to identify and compare patterns of representation that are regularly unnoticed and elusive to detect [51]. Bryman [52] stated that it is the most common and suitable method used in the analysis of qualitative data. Researchers [53] emphasize three main characteristics of the method: its reductive quality, which helps researchers to derive more specific meanings from massive data; its systematicity, because the analysis should have comprehensive procedures of integrity; and its flexibility, due to the fact that the coding and data summaries contain subjectivity.

This method was used, for example, by Sousa [54] to assess local planning attitudes in Portugal towards demographic change, and in particular towards population decrease in terms of housing development; by Fischhendler and Tenenboim-Weinblatt [55] to examine the use of different types of arguments in mega-project justification, with a focus on the peace dividend as a political intangible benefit; and by Kim [56] to discover the lesser-known phenomenon of creating shared value in East Asia, to improve understanding of the concept and its applications so that businesses may pursue sustainable management.

2.3. Interpretative Case Study

This method is used to verify the fully customized approach to GHG emission calculations in RFT for the AI. This method is used in the fourth processing step (Section 3.4).

The interpretative case study is very suitable for exploratory research [57]. An interpretative qualitative approach is best suited for research in companies due to the fact that the interpretative case study approach minimizes the distance between the explorer and the key decision-maker [58]. The fundamental decisions within the interpretive case studies lie in the area of previous theories, the unit(s) of analysis, the number and selection of cases, the techniques of data collection, and the method(s) by which the collected data will be analyzed [59].

This method was used, for example, by Frishammar et al. [60] to present an omnichannel strategy typology showing how shopping malls can meet the evolving digitalization challenge; by Alvarez et al. [61] to examine how a state-owned Colombian multiutility conglomerate has used management accounting practices to shape efficiency; and by Diab [62] to provide a political explanation of management, accounting, and control practices in a traditional and unstable African setting.

3. Mathematical Formulation

The mathematical formulation chapter is composed of these sections: identification and synthesis of assumptions for GHG emission calculation from RFT (Section 3.1), analysis of available railway freight emission calculators (Section 3.2), proposal of a customized approach to GHG emission calculations in RFT for the AI (Section 3.3), application of the customized approach to GHG emission calculations in RFT for the AI (Section 3.4).

3.1. Identification and Synthesis of Assumptions for GHG Emission Calculations from RFT

Three independent researchers used a three-round semi-structured interview in January 2021 with four respondents from a company that is the leader of the Czech Republic AI market [63–66]. All respondents were highly qualified and well-founded in the field of GHG emission calculations. The three-round semi-structured interview was focused on the following topics:

- GHG emission calculations from RFT;
- GHG emission calculators or similar tool-use related to RFT;
- Cargo types related to RFT;
- Vehicle types and their specifications related to RFT;
- RFT restrictive assumptions;
- Requirements for GHG emission calculations related to RFT.

The questions applied during interviewing are in Appendix A. The aggregated answers obtained from the three-round semi-structured interview are shown in Appendix B. A summary of the parameters of the railway cars used for RFT of passenger cars (hereinafter PC) is in Appendix C (Table A1), of car bodies (hereinafter CB) is in Appendix D (Table A2), and of freight containers (hereinafter FC) is in Appendix E (Table A3). The summary in Appendices C–E is divided into vehicles for the transport of PC, CB, and FC.

The most crucial conclusions and findings obtained from the three-round semi-structured interview are as follows: the issue of GHG emission calculations from RFT is essential for this leading company in the AI operating on the market in the Czech Republic, because the company strives to minimize negative logistic impacts on the environment and to society as a whole. Due to the fact that the respondents also requested calculations of sulfur dioxide emissions (in addition to carbon dioxide emissions), although sulfur dioxide is not a greenhouse gas, this will also be considered in the next steps. The company does not currently use any RFT emission calculators or other similar tools, as there is no suitable calculator available to meet company requirements, restrictive conditions, and other limitations. Logistic processes related to RFT are very extensive with many specific conditions. Due to this fact, there is currently no suitable railway freight emission calculator or other similar tool that contains all the required specifics of the company. The aggregated conclusions and findings were also confronted by representatives of the logistic departments of two other AI international companies operating on the Czech market, who also confirmed the identified conclusions and findings.

3.2. Analysis of Available Emission RFT Calculators

Four independent researchers applied a content analysis and comparative analysis of RFT emission calculators available in February 2021 based on the outputs of the interviews. The following RFT emission calculators were identified:

- No. 1—EcoPassenger [67];
- No. 2—Carbon Foot Print [68];
- No. 3—EcoTree [69];
- No. 4—The Engineering ToolBox [70];
- No. 5—EcoTransIT World [71];
- No. 6—CN [72];
- No. 7—CarbonCare [73];
- No. 8—World Land Trust [74];
- No. 9—ScotRail [75];
- No. 10—BNSF Railway Carbon Estimator [76];
- No. 11—Logward [77];
- No. 12—Trees for All [78].

The results of the analysis of RFT emission calculators are presented in Table 1.

Table 1. The content analysis results of RFT emission calculators (authors based on [67–78]).

No.	Source	Railway Transport	Transport of PC, CB, and FC	Own Vehicle Option	Restrictive Condition Implementation	One-Way and Return Transport	CO_{2e} and SO_{2e} Outputs	Total and Average Emission Outputs	WtW, WtT and TtW Calculation Approach
1	[67]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
2	[68]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
3	[69]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
4	[70]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
5	[71]	RFT	NA	Y	NA	Y	Y	Only total emissions	Y
6	[72]	RFT	NA	NA	NA	NA	Only CO_{2e}	Only total emissions	NA
7	[73]	RFT	NA	NA	NA	NA	Only CO_{2e}	Only total emissions	Y
8	[74]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
9	[75]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA
10	[76]	RFT	NA	NA	NA	NA	Only CO_{2e}	Only total emissions	NA
11	[77]	RFT	NA	NA	NA	NA	Only CO_{2e}	Only total emissions	NA
12	[78]	RPT	NFA	NFA	NFA	NFA	NFA	NFA	NFA

Notes: PC—passenger cars, CB—car bodies, FC—freight containers, CO_{2e}—carbon dioxide equivalent, SO_{2e}—sulfur dioxide equivalent, WtW—Well-to-Wheel approach, WtT—Well-to-Tank approach, TtW—Tank-to-Wheel approach, RPT—railway passenger transport only, RFT—railway freight transport only, Y—Yes, N—No, NA—not available, NFA—not further analyzed due to inapplicability to RFT.

Important indicators that are crucial for the manuscript and the proposed approach are shown in the columns. The emission calculators no. 1–4, 8–9, and 12 were not further analyzed because they are not suitable for RFT emission calculations. These emission calculators can only be used to calculate emissions from passenger railway transport. None of the analyzed RFT emission calculators allow the transport of PC, CB, or FC because calculators no. 5–7 and 10–11 allow the transport of general cargo. At the same time, no emission railway freight calculator allows the implementation of specific restrictive conditions customized for the AI. A single emission calculator (no. 5) allows you to enter the specifications of your own railway car and then calculate GHG emissions with it. This emission calculator (no. 5) also allows you to calculate GHG emissions for one-way and return transport and differentiates the resulting GHG emissions in CO_{2e} and SO_{2e} equivalents. All analyzed GHG emission calculators present only the total resulting GHG emissions. None of the GHG emission calculators present average GHG emissions related to transport distance, cargo weight or ton-kilometers. Two analyzed GHG emission calculators (no. 5 and 7) use WtW, WtT, and TtW calculation approaches and differentiate the resulting GHG emissions according to these calculation approaches.

In conclusion, we can state that none of the identified and analyzed GHG emission calculators in the field of RFT is suitable for the needs of GHG emission calculations in the AI, because it does not meet the identified assumptions (Table 1) based on the results of the interviews (Appendices A and B). Based on the results of the analysis, it can be further stated that a market gap has been identified and that there is a need to develop an appropriate approach and tool for calculating GHG emissions in the area of RFT that is fully customized for the AI.

3.3. Proposal of a Customized Approach to GHG Emission Calculations in RFT for the AI

A proposal for a customized approach to the GHG emission calculations in the context of RFT for the AI is presented in Figure 2. The proposed approach is based on the conclusions obtained from the semi-structured interviews and comparative content analysis of available GHG emission calculators.

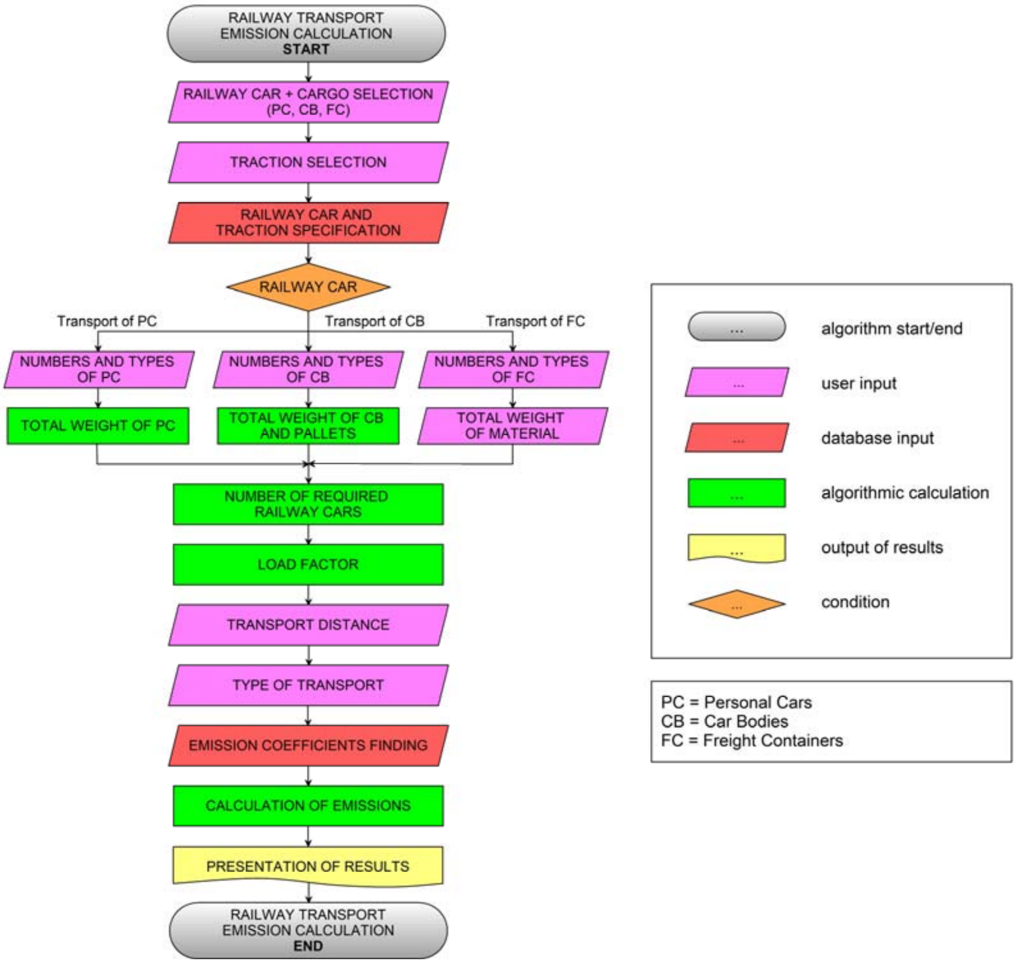

Figure 2. Diagram of the customized approach to GHG emission calculations for RFT [authors].

The customized approach to GHG emission calculations for RFT consists of five consecutive user steps. In the first step, the user selects a specific type of transported cargo (PC, CB, or FC) and a specific railway car ($RC_{1–32}$). In the second step, the user selects between dependent or independent traction, or can choose the ratio of dependent and independent traction. Subsequently, information about the selected railway car and information about the selected traction is retrieved from the database of railway cars. In the next steps, the GHG emission calculations are different according to the type of transported cargo (PC, CB or FC).

In the third step:

- In the case of PC transport, the user enters the number of individual types of transported PC;
- In the case of CB transport, the user enters the number of individual types of transported CB;
- In the case of FC transport, the user enters the number of individual types of transported FC and the total weight of transported material.

Subsequently, the total weight of the transported cargo is algorithmically calculated as follows:

- In the case of PC transport, as the total weight of all transported PC;
- In the case of CB transport, as the total weight of all transported CB including all transported pallet weight;
- In the case of FC transport, as the total weight of all transported FC including all transported material weight.

The required number of railway car(s) of the type specified for transport is determined from the input parameters entered by the user, information from the database and restrictive assumptions. Subsequently, the load factor for this transport is calculated for all railway car(s). In the fourth step, the user inserts the total transport distance. In the fifth step, the user decides whether it is a one-way or return transport. Subsequently, the emission coefficients for the calculated load factor are found in the emission coefficients database. Based on all inputs, GHG emissions are algorithmically calculated. Finally, the results of GHG emissions are presented according to the requirements of the company.

An overview of all the variables used is shown in alphabetical order in Appendix F. The following restrictive assumption (Equation (1)) must be taken into consideration with regard to the transported weight of the cargo:

$$\text{for } RC_1 \text{ to } RC_{32}\text{: } V\,[t] \leq (n_c\,[-] \times V_{max}\,[t]),\; n_c \in N, \tag{1}$$

where $RC_{1–32}$ represent different types of railway cars, V is the weight of the freight, n_c is the required number of railway cars for transport, and V_{max} is the maximum freight weight of the railway cars required for transport.

The following universal and specific restrictive assumptions (Equation (2)) must be taken into consideration with regard to the transported volume of the cargo:

$$\begin{gathered}
\text{for } RC_1 \text{ to } RC_{32}\text{: } LV\,[-] \leq (n_c\,[-] \times LV_{max}\,[-]),\; n_c \in N, \\
\text{for } RC_1 \text{ to } RC_{25}\text{: } LV\,[-] \leq (n_c\,[-] \times LV_{max}\,[-]),\; n_c \in N,\; LV_{max} = <10;11>, \\
\text{for } RC_{26} \text{ to } RC_{29}\text{: } LV\,[-] \leq (n_c\,[-] \times LV_{max}\,[-]),\; n_c \in N,\; LV_{max} = <8;10>, \\
\text{for } RC_{30} \text{ to } RC_{32}\text{: } LV\,[-] \leq (n_c\,[-] \times LV_{max}\,[-]),\; n_c \in N,\; LV_{max} = <1;4>,
\end{gathered} \tag{2}$$

where $RC_{1–32}$ represent different types of railway cars, LV is the load volume of the freight, n_c is the required number of railway cars for transport, and LV_{max} is the maximum load volume of the railway car required for transport.

The maximum load volumes of railway cars for transportation of PC and CB are defined in accordance with the following algorithmic techniques (Equation (3)):

$$\begin{gathered}
\text{IF transport of PC in } RC_{1\text{-}25} \text{ from plant A THEN } LV_{max} = 10, \\
\text{IF transport of PC in } RC_{1\text{-}25} \text{ from plant B THEN } LV_{max} = 11, \\
\text{IF transport of CB in } RC_{26} \text{ OR } RC_{28} \text{ THEN } LV_{max} = 8, \\
\text{IF transport of CB in } RC_{27} \text{ OR } RC_{29} \text{ THEN } LV_{max} = 10,
\end{gathered} \tag{3}$$

where $RC_{1–32}$ represent different types of railway cars and LV_{max} is the maximum load volume of the railway car required for transport.

The maximum load volumes of railway cars for transportation of FC are defined in accordance with the following algorithmic techniques (Equation (4)):

$$\begin{gathered}
\text{IF transport of FC in } RC_{30} \text{ OR } RC_{31} \text{ THEN for } FC_1\text{: } LV_{max} = 2, \\
\text{IF transport of FC in } RC_{30} \text{ OR } RC_{31} \text{ THEN for } FC_2\text{: } LV_{max} = 1, \\
\text{IF transport of FC in } RC_{30} \text{ OR } RC_{31} \text{ THEN for } FC_3\text{: } LV_{max} = 1, \\
\text{IF transport of FC in } RC_{32} \text{ THEN for } FC_1\text{: } LV_{max} = 4, \\
\text{IF transport of FC in } RC_{32} \text{ THEN for } FC_2\text{: } LV_{max} = 2, \\
\text{IF transport of FC in } RC_{32} \text{ THEN for } FC_3\text{: } LV_{max} = 2,
\end{gathered} \tag{4}$$

where $RC_{30–32}$ represent different types of railway cars for transportation of FC, $FC_{1–3}$ is the different types of FC, and LV_{max} is the maximum load volume of the railway car.

Loading of FC is possible in the following combinations only for RC_{32} in accordance with the algorithmic techniques (Equation (5)):

$$\begin{gathered}\text{IF transport of FC in } RC_{32} \text{ THEN for } FC_1 = 2 \text{ AND } FC_2 = 1,\\ \text{IF transport of FC in } RC_{32} \text{ THEN for } FC_1 = 2 \text{ AND } FC_3 = 1,\\ \text{IF transport of FC in } RC_{32} \text{ THEN for } FC_2 = 1 \text{ AND } FC_3 = 1,\end{gathered} \tag{5}$$

where RC_{32} represents type of railway cars for transportation of FC and $FC_{1\text{–}3}$ is the different types of FC.

The weight of the freight is determined according to Equation (6):

$$\begin{gathered}\text{for PC: } V = \{(n_{pc1} \times V_{PC1}) + (n_{pc2} \times V_{PC2}) + \ldots + (n_{pc8} \times V_{PC8})\}\ [\text{t}],\\ n_{pck} \in \mathbb{N},\ k \in <1;8>,\\ \text{for CB: } V = \{(n_{cb1} \times (V_{CB1} + V_{P1})) + (n_{cb2} \times (V_{CB2} + V_{P2}))\}\ [\text{t}],\\ n_{cbl} \in \mathbb{N},\ l \in <1;2>,\\ \text{for FC: } V = \{(n_{fc1} \times (V_{FC1} + V_{C1})) + (n_{fc2} \times (V_{FC2} + V_{C2})) + (n_{fc3} \times (V_{FC3} + V_{C3}))\}\ [\text{t}],\\ n_{fcm} \in \mathbb{N},\ m \in <1;3>,\end{gathered} \tag{6}$$

where V is the weight of the freight, n_{pck} is the number of transported PC of type k, V_{PCk} is the weight of the PC of type k, k is the type of transported PC, n_{cbl} is the number of transported CB of type l, V_{CBl} is the weight of the CB of type l, V_{Pl} is the weight of the pallet for CB of type l, l is the type of transported CB, n_{fcm} is the number of transported FC of type m, V_{FCm} is the weight of the FC of type m, V_{Cm} is the weight of the freight in FC of type m, and m is the type of transported FC.

The railway car(s) load factor is calculated according to Equation (7):

$$LF = \text{round up } [V/(n_c \times V_{max})]\ [-],\ LF \in <0;1>,\ n_c \in \mathbb{N}, \tag{7}$$

where LF is the railway car(s) load factor, V is the weight of the freight, n_c is the required number of railway cars for transport, and V_{max} is the maximum freight weight of the railway car(s) required for transport.

The appropriate emission coefficients are identified in accordance with the following algorithmic techniques (Equation (8)) with regard to the type of transport:

$$\begin{gathered}\text{IF return transport THEN search emission coefficients values}\\ \text{for } C_{dWtTb}, C_{dWtTf}, C_{dTtWb}, C_{dTtWf}, C_{iWtTb}, C_{iWtTf}, C_{iTtWb} \text{ and } C_{iTtWf},\\ \text{IF one-way transport THEN search emission coefficients values}\\ \text{for } C_{dWtTb}, C_{dWtTf}, C_{dTtWb}, C_{dTtWf}, C_{iWtTb}, C_{iWtTf}, C_{iTtWb}, C_{iTtWf}, C_{d0WtTb}, C_{d0WtTf},\\ C_{d0TtWb}, C_{d0TtWf}, C_{i0WtTb}, C_{i0WtTf}, C_{i0TtWb} \text{ and } C_{i0TtWf},\end{gathered} \tag{8}$$

where C_{dWtTb} is the appropriate emission coefficient of CO_2 or SO_2 of biogenic origin (hereinafter BO) calculated using the WtT approach for dependent traction, C_{dWtTf} is the appropriate emission coefficient of CO_2 or SO_2 of fossil origin (hereinafter FO) calculated using the WtT approach for dependent traction, C_{dTtWb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction, C_{dTtWf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for dependent traction, C_{iWtTb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction, C_{iWtTf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction, C_{iTtWb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction, C_{iTtWf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction, C_{d0WtTb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for dependent traction, C_{d0WtTf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for dependent traction, C_{d0TtWb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction, C_{d0TtWf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the TtW approach for dependent traction, C_{i0WtTb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction, C_{i0WtTf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction, C_{i0TtWb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction, and C_{i0TtWf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction.

Specific values of emission coefficients already include the route profile, the energy mix of the state, and the average speed of the vehicle, etc. CO_2 and SO_2 emissions are calculated for a specific shipment realized by RFT. The proposed approach is divided according to the identified requirements of the company into return transportation and one-way transportation. In the case of return transportation, Equations (9)–(22) are applied. In the case of one-way transportation, Equations (9)–(37) are applied.

The total CO_2 or SO_2 emissions produced by return transportation are calculated as Equation (9):

$$T\ [kg_{CO2e/SO2e}] = R\ [kg_{CO2e/SO2e}], \tag{9}$$

where T corresponds to the total CO_2 or SO_2 emissions produced by transportation and R is the total CO_2 or SO_2 emissions produced by the return transportation.

The total CO_2 or SO_2 emissions R produced by the return transportation are calculated using the WtW approach (Equation (10)):

$$R\ [kg_{CO2e/SO2e}] = R_{WtT}\ [kg_{CO2e/SO2e}] + R_{TtW}\ [kg_{CO2e/SO2e}], \tag{10}$$

where R_{WtT} is the CO_2 or SO_2 emissions calculated using the WtT approach and R_{TtW} is the CO_2 or SO_2 emissions calculated using the TtW approach.

R_{WtT} is the CO_2 or SO_2 emissions calculated using the WtT approach consisting of two parts (Equation (11)):

$$R_{WtT}\ [kg_{CO2e/SO2e}] = R_{WtTb}\ [kg_{CO2e/SO2e}] + R_{WtTf}\ [kg_{CO2e/SO2e}], \tag{11}$$

where R_{WtTb} is the CO_2 or SO_2 emissions of BO calculated using the WtT approach and R_{WtTf} is the CO_2 or SO_2 emissions of FO calculated using the WtT approach.

R_{TtW} is the CO_2 or SO_2 emissions calculated using the TtW approach consisting of two parts (Equation (12)):

$$R_{TtW}\ [kg_{CO2e/SO2e}] = R_{TtWb}\ [kg_{CO2e/SO2e}] + R_{TtWf}\ [kg_{CO2e/SO2e}], \tag{12}$$

where R_{TtWb} is the CO_2 or SO_2 emissions of BO calculated using the TtW approach and R_{TtWf} is the CO_2 or SO_2 emissions of FO calculated using the TtW approach.

The CO_2 or SO_2 emissions of BO calculated using the WtT approach R_{WtTb} are calculated according to Equation (13):

$$\begin{aligned} R_{WtTb}\ [kg_{CO2e/SO2e}] = \{&S_{d1}\ [-] \times C_{dWtTb}\ [kg_{CO2e/SO2e}/tkm] \\ &+ S_{i1}\ [-] \times C_{iWtTb}\ [kg_{CO2e/SO2e}/tkm]\} \times V\ [t] \times L_1\ [km], \end{aligned} \tag{13}$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction, C_{dWtTb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the WtT approach for dependent traction, S_{i1} is the share of the total length of transport realized by RFT using independent traction, C_{iWtTb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction, V is the weight of the freight, and L_1 is the total transport distance.

The CO_2 or SO_2 emissions of FO calculated using the WtT approach R_{WtTf} are calculated according to Equation (14):

$$R_{WtTf}\ [kg_{CO2e/SO2e}] = \{S_{d1}\ [-] \times C_{dWtTf}\ [kg_{CO2e/SO2e}/tkm] + S_{i1}\ [-] \times C_{iWtTf}\ [kg_{CO2e/SO2e}/tkm]\} \times V\ [t] \times L_1\ [km], \quad (14)$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction, C_{dWtTf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the WtT approach for dependent traction, S_{i1} is the share of the total length of transport realized by RFT using independent traction, C_{iWtTf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction, V is the weight of the freight, and L_1 is the total transport distance.

The CO_2 or SO_2 emissions of BO calculated using the TtW approach R_{TtWb} are calculated according to Equation (15):

$$R_{TtWb}\ [kg_{CO2e/SO2e}] = \{S_{d1}\ [-] \times C_{dTtWb}\ [kg_{CO2e/SO2e}/tkm] + S_{i1}\ [-] \times C_{iTtWb}\ [kg_{CO2e/SO2e}/tkm]\} \times V\ [t] \times L_1\ [km], \quad (15)$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction, C_{dTtWb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction, S_{i1} is the share of the total length of transport realized by RFT using independent traction, C_{iTtWb} is the appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction, V is the weight of the freight, and L_1 is the total transport distance.

The CO_2 or SO_2 emissions of FO calculated using the TtW approach R_{TtWf} are calculated according to Equation (16):

$$R_{TtWf}\ [kg_{CO2e/SO2e}] = \{S_{d1}\ [-] \times C_{dTtWf}\ [kg_{CO2e/SO2e}/tkm] + S_{i1}\ [-] \times C_{iTtWf}\ [kg_{CO2e/SO2e}/tkm]\} \times V\ [t] \times L_1\ [km], \quad (16)$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction, C_{dTtWf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for dependent traction, S_{i1} is the share of the total length of transport realized by RFT using independent traction, C_{iTtWf} is the appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction, V is the weight of the freight, and L_1 is the total transport distance.

The share of the total length of transport realized by RFT using dependent traction S_{d1} is calculated according to Equation (17):

$$S_{d1}\ [-] = L_{1d}\ [km]/L_1\ [km],\ L_{1d} \leq L_1,\ S_{d1} \in <0;1>, \quad (17)$$

where L_{1d} is the length of transport realized by RFT using dependent traction and L_1 is the total transport distance.

The share of the total length of transport realized by RFT using independent traction S_{i1} is calculated according to Equation (18):

$$S_{i1}\ [-] = L_{1i}\ [km]/L_1\ [km],\ L_{1i} \leq L_1,\ S_{i1} \in <0;1>, \quad (18)$$

where L_{1i} is the length of transport realized by RFT using independent traction and L_1 is the total transport distance.

The following (Equation (19)) must always apply to variables from Equations (17) and (18):

$$S_{d1}\ [-] + S_{i1}\ [-] = 1,\ \{S_{d1}, S_{i1}\} \in <0;1>, \quad L_{1d}\ [km] + L_{1i}\ [km] = L_1\ [km], \quad (19)$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction, S_{i1} is the share of the total length of transport realized by RFT using independent traction, L_{1d} is the length of transport realized by RFT using dependent traction, L_{1i} is the length of transport realized by RFT using independent traction, and L_1 is the total transport distance.

If the transport is carried out exclusively with the use of dependent traction, the following applies (Equation (20)):

$$\begin{aligned} S_{d1}\ [-] &= 1, \\ S_{i1}\ [-] &= 0, \end{aligned} \tag{20}$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction and S_{i1} is the share of the total length of transport realized by RFT using independent traction.

If the transport is carried out exclusively with the use of independent traction, the following applies (Equation (21)):

$$\begin{aligned} S_{d1}\ [-] &= 0, \\ S_{i1}\ [-] &= 1, \end{aligned} \tag{21}$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction and S_{i1} is the share of the total length of transport realized by RFT using independent traction.

If the transport is carried out with the use of dependent and independent traction, the following applies (Equation (22)):

$$S_{d1}\ [-] + S_{i1}\ [-] = 1, \tag{22}$$

where S_{d1} is the share of the total length of transport realized by RFT using dependent traction and S_{i1} is the share of the total length of transport realized by RFT using independent traction.

The total CO_2 or SO_2 emissions produced by one-way transportation are calculated as Equation (23):

$$T\ [kg_{CO2e/SO2e}] = R\ [kg_{CO2e/SO2e}] + O\ [kg_{CO2e/SO2e}], \tag{23}$$

where T corresponds to the total CO_2 or SO_2 emissions produced by transportation, R is the total CO_2 or SO_2 emissions produced by the return transportation, and O is the additional CO_2 or SO_2 emissions (the penalty for an unloaded railway cars).

The additional CO_2 or SO_2 emissions (the penalty for an unloaded railway cars) O are calculated using the WtW approach (Equation (24)):

$$O\ [kg_{CO2e/SO2e}] = O_{WtT}\ [kg_{CO2e/SO2e}] + O_{TtW}\ [kg_{CO2e/SO2e}], \tag{24}$$

where O_{WtT} is the CO_2 or SO_2 emissions calculated using the WtT approach and O_{TtW} is the CO_2 or SO_2 emissions calculated using the TtW approach.

O_{WtT} is the CO_2 or SO_2 emissions calculated using the WtT approach consisting of two parts (Equation (25)):

$$O_{WtT}\ [kg_{CO2e/SO2e}] = O_{WtTb}\ [kg_{CO2e/SO2e}] + O_{WtTf}\ [kg_{CO2e/SO2e}], \tag{25}$$

where O_{WtTb} is the CO_2 or SO_2 emissions of BO calculated using the WtT approach and O_{WtTf} is the CO_2 or SO_2 emissions of FO calculated using the WtT approach.

O_{TtW} is the CO_2 or SO_2 emissions calculated using the TtW approach consisting of two parts (Equation (26)):

$$O_{TtW}\ [kg_{CO2e/SO2e}] = O_{TtWb}\ [kg_{CO2e/SO2e}] + O_{TtWf}\ [kg_{CO2e/SO2e}], \tag{26}$$

where O_{TtWb} is the CO_2 or SO_2 emissions of BO calculated using the TtW approach and O_{TtWf} is the CO_2 or SO_2 emissions of FO calculated using the TtW approach.

The additional transport distance L_2 as a penalty for unloaded railway cars is calculated according to Equation (27):

$$L_2\ [\text{km}] = L_1\ [\text{km}] \times l\ [-], \tag{27}$$

where L_1 is the transport distance and l is the internal coefficient defined by the company.

The CO_2 or SO_2 emissions of BO calculated using the TtW approach O_{WtTb} are calculated according to Equation (28):

$$\begin{aligned} O_{WtTb}\ [kg_{CO2e/SO2e}] = \{&S_{d2}\ [-] \times C_{d0WtTb}\ [kg_{CO2e/SO2e}/\text{tkm}] \\ &+ S_{i2}\ [-] \times C_{i0WtTb}\ [kg_{CO2e/SO2e}/\text{tkm}]\} \times V\ [t] \times L_2\ [\text{km}], \end{aligned} \tag{28}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction, C_{d0WtTb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for dependent traction, S_{i2} is the share of the additional length of transport realized by RFT using independent traction, C_{i0WtTb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction, V is the weight of the load, and L_2 is the additional transport distance.

The CO_2 or SO_2 emissions of FO calculated using the WtT approach O_{WtTf} are calculated according to Equation (29):

$$\begin{aligned} O_{WtTf}\ [kg_{CO2e/SO2e}] = \{&S_{d2}\ [-] \times C_{d0WtTf}\ [kg_{CO2e/SO2e}/\text{tkm}] \\ &+ S_{i2}\ [-] \times C_{i0WtTf}\ [kg_{CO2e/SO2e}/\text{tkm}]\} \times V\ [t] \times L_2\ [\text{km}], \end{aligned} \tag{29}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction, C_{d0WtTf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for dependent traction, S_{i2} is the share of the additional length of transport realized by RFT using independent traction, C_{i0WtTf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction, V is the weight of the freight, and L_2 is the additional transport distance.

The CO_2 or SO_2 emissions of BO calculated using the WtT approach O_{TtWb} are calculated according to Equation (30):

$$\begin{aligned} O_{TtWb}\ [kg_{CO2e/SO2e}] = \{&S_{d2}\ [-] \times C_{d0TtWb}\ [kg_{CO2e/SO2e}/\text{tkm}] \\ &+ S_{i2}\ [-] \times C_{i0TtWb}\ [kg_{CO2e/SO2e}/\text{tkm}]\} \times V\ [t] \times L_2\ [\text{km}], \end{aligned} \tag{30}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction, C_{d0TtWb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction, S_{i2} is the share of the additional length of transport realized by RFT using independent traction, C_{i0TtWb} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction, V is the weight of the freight, and L_2 is the additional transport distance.

The CO_2 or SO_2 emissions of FO calculated using the TtW approach O_{TtWf} are calculated according to Equation (31):

$$\begin{aligned} O_{TtWf}\ [kg_{CO2e/SO2e}] = \{&S_{d2}\ [-] \times C_{d0TtWf}\ [kg_{CO2e/SO2e}/\text{tkm}] \\ &+ S_{i2}\ [-] \times C_{i0TtWf}\ [kg_{CO2e/SO2e}/\text{tkm}]\} \times V\ [t] \times L_2\ [\text{km}], \end{aligned} \tag{31}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction, C_{d0TtWf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2

of FO calculated using the TtW approach for dependent traction, S_{i2} is the share of the additional length of transport realized by RFT using independent traction, C_{i0TtWf} is the appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction, V is the weight of the freight, and L_2 is the additional transport distance.

The share of the additional length of transport realized by RFT using dependent traction S_{d2} is calculated according to Equation (32):

$$S_{d2}\,[-] = L_{2d}\,[\text{km}]/L_2\,[\text{km}],\ L_{2d} \leq L_2,\ S_{d2} \in <0;1>, \tag{32}$$

where L_{2d} is the additional length of transport realized by RFT using dependent traction and L_2 is the additional transport distance.

The share of the additional length of transport realized by RFT using independent traction S_{i2} is calculated according to Equation (33):

$$S_{i2}\,[-] = L_{2i}\,[\text{km}]/L_2\,[\text{km}],\ L_{2i} \leq L_2,\ S_{i2} \in <0;1>, \tag{33}$$

where L_{2i} is the additional length of transport realized by RFT using independent traction and L_2 is the additional transport distance.

The following (Equation (34)) must always apply to variables from Equations (32) and (33):

$$\begin{gathered} S_{d2}\,[-] + S_{i2}\,[-] = 1,\ \{S_{d2}, S_{i2}\} \in <0;1>, \\ L_{2d}\,[\text{km}] + L_{2i}\,[\text{km}] = L_2\,[\text{km}], \end{gathered} \tag{34}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction, S_{i2} is the share of the additional length of transport realized by RFT using independent traction, L_{2d} is the additional length of transport realized by RFT using dependent traction, L_{2i} is the additional length of transport realized by RFT using independent traction, and L_2 is the additional transport distance.

If the transport is carried out exclusively with the use of dependent traction, the following applies (Equation (35)):

$$\begin{gathered} S_{d2}\,[-] = 1, \\ S_{i2}\,[-] = 0, \end{gathered} \tag{35}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction and S_{i2} is the share of the additional length of transport realized by RFT using independent traction.

If the transport is carried out exclusively with the use of independent traction, the following applies (Equation (36)):

$$\begin{gathered} S_{d2}\,[-] = 0, \\ S_{i2}\,[-] = 1, \end{gathered} \tag{36}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction and S_{i2} is the share of the additional length of transport realized by RFT using independent traction.

If the transport is carried out with the use of dependent and independent traction, the following applies (Equation (37)):

$$S_{d2}\,[-] + S_{i2}\,[-] = 1, \tag{37}$$

where S_{d2} is the share of the additional length of transport realized by RFT using dependent traction and S_{i2} is the share of the additional length of transport realized by RFT using independent traction.

In the following Section 3.4, the proposed customized approach to GHG emission calculations in RFT for the AI will be applied and verified in the form of an interpretative case study, theoretically described in Section 2.3.

3.4. Case Study Assumptions and Calculations

The proposed customized approach to GHG emission calculations in RFT for the AI is applied and verified in the form of the interpretative case study. This case study was conducted in a company, which is the leader of the AI operating on the Czech Republic market. The proposed approach was tested for real transport requirement with these parameters:

- Type of cargo: FC;
- Railway car: RC_{32} (Sggns S183);
- Traction: 62% dependent traction (S_{d1} = 0.62), 38% independent traction (S_{i1} = 0.38);
- Numbers and types of FC: 24 FC_2;
- Weight of the freight in one FC_2 (V_{C2}): 27.25 t;
- Total transport distance (L_1): 472 km;
- Length of transport realized by RFT using dependent traction (L_{1d}): 292.64 km;
- Length of transport realized by RFT using independent traction (L_{1i}): 179.36 km;
- Type of transport: return.

The maximum load volume of railway car RC_{32} for transportation of FC_2 is defined (according to Equation (4)) as follows (Equation (38)):

$$\text{IF transport of FC in } RC_{32} \text{ THEN for } FC_2\text{: } LV_{max} = 2, \tag{38}$$

where RC_{32} represents type of railway car for transportation of FC, FC_2 is the type of FC, and LV_{max} is the maximum load volume of the railway car RC_{32}.

Due to the fact, that 24 $FC_{2'}$s are transported and the LV_{max} of FC_2 is 2 (according to Equation (4)), it will be necessary to use 12 RC_{32}'s for this transport (n_c = 12).

The weight of the freight is determined as follows (Equation (39) according to Equation (6)):

$$\begin{gathered}\text{for FC: } V = \{(0 \times (2.2 + 0)) + (24 \times (3.8 + 27.25)) + (0 \times (3.9 + 0))\} \text{ [t]}, \\ \text{for FC: } V = \{(0 + 745.2 + 0)\} \text{ [t]}, \\ \text{for FC: } V = 745.2 \text{ [t]},\end{gathered} \tag{39}$$

where V is the weight of the freight.

The following restrictive assumption (Equation (40)) must be taken into consideration with regards to the transported weight of the cargo (according to Equation (1)):

$$\begin{gathered}\text{for } RC_{32}\text{: } 745.2 \text{ [t]} \leq (12 \text{ [}-\text{]} \times 67.5 \text{ [t]}), \\ \text{for } RC_{32}\text{: } 745.2 \text{ [t]} \leq 810.0 \text{ [t]},\end{gathered} \tag{40}$$

where RC_{32} represents type of railway car, V is the weight of the freight, n_c is the required number of railway cars for transport, and V_{max} is the maximum freight weight of the railway cars required for transport. The restrictive assumption (according to Equation (1)) is met.

The following specific restrictive assumption (Equation (41)) must be taken into consideration with regards to the transported volume of the cargo (according to Equation (2)):

$$\begin{gathered}\text{for RC32: } 24 \text{ [}-\text{]} \leq (12 \text{ [}-\text{]} \times 2 \text{ [}-\text{]}), \\ \text{for RC32: } 24 \text{ [}-\text{]} \leq 24 \text{ [}-\text{]},\end{gathered} \tag{41}$$

where RC_{32} represents type of the railway car, LV is the load volume of the freight, n_c is the required number of railway cars for transport, and LV_{max} is the maximum load volume of the railway car required for transport. The restrictive assumption (according to Equation (2)) is met.

The railway car load factor is calculated as follows (Equation (42) according to Equation (7)):

$$LF = \text{round up}\ [745.2/(12 \times 67.5)]\ [-],$$
$$LF = 0.92\ [-], \tag{42}$$

where LF is the railway car load factor.

The appropriate CO_2 emission coefficients for return transport and LF = 0.92 (according to Equation (7)) are searched in the database of GHG emission coefficients (according to Equation (8)) [79]:

- C_{dWtTb} = 0.001802327 [kg_{CO2e}/tkm];
- C_{dWtTf} = 0.009762854 [kg_{CO2e}/tkm];
- C_{dTtWb} = 0.000000000 [kg_{CO2e}/tkm];
- C_{dTtWf} = 0.000000000 [kg_{CO2e}/tkm];
- C_{iWtTb} = 0.000109177 [kg_{CO2e}/tkm];
- C_{iWtTf} = 0.002784794 [kg_{CO2e}/tkm];
- C_{iTtWb} =0.001200000 [kg_{CO2e}/tkm];
- C_{iTtWf} = 0.015700000 [kg_{CO2e}/tkm].

The total CO_2 emissions produced by return transportation are calculated as Equation (43) (according to Equation (9)):

$$T = 5167.724435009\ [kg_{CO2e}], \tag{43}$$

where T represents the total CO_2 emissions produced by transportation.

The total CO_2 emissions R produced by the return transportation are calculated using the WtW approach as Equation (44) (according to Equation (10)):

$$R = 2908.886118209 + 2258.838316800\ [kg_{CO2e}]. \tag{44}$$

R_{WtT} is the CO_2 emissions calculated using the WtT approach consisting of two parts (Equation (45) according to Equation (11)):

$$R_{WtT} = 407.635548192 + 2501.250570017\ [kg_{CO2e}]. \tag{45}$$

R_{TtW} is the CO_2 emissions calculated using the TtW approach consisting of two parts (Equation (46) according to Equation (12)):

$$R_{TtW} = 160.390886400 + 2098.447430400\ [kg_{CO2e}]. \tag{46}$$

The CO_2 emissions of BO calculated using the WtT approach R_{WtTb} are calculated as Equation (47) (according to Equation (13)):

$$R_{WtTb}\ [kg_{CO2e}] = \{0.62\ [-] \times 0.001802327\ [kg_{CO2e}/tkm]$$
$$+\ 0.38\ [-] \times 0.000109177\ [kg_{CO2e}/tkm]\} \times 745.2\ [t] \times 472\ [km],$$
$$R_{WtTb}\ [kg_{CO2e}] = 407.635548192. \tag{47}$$

The CO_2 emissions of FO calculated using the WtT approach R_{WtTf} are calculated as Equation (48) (according to Equation (14)):

$$R_{WtTf}\ [kg_{CO2e}] = \{0.62\ [-] \times 0.009762854\ [kg_{CO2e}/tkm]$$
$$+\ 0.38\ [-] \times 0.002784794\ [kg_{CO2e}/tkm]\} \times 745.2\ [t] \times 472\ [km],$$
$$R_{WtTf}\ [kg_{CO2e}] = 2501.250570017. \tag{48}$$

The CO_2 emissions of BO calculated using the TtW approach R_{TtWb} are calculated as Equation (49) (according to Equation (15)):

$$\begin{gathered}R_{TtWb}\ [kg_{CO2e}] = \{0.62\ [-] \times 0.000000000\ [kg_{CO2e}/tkm] \\ + 0.38\ [-] \times 0.001200000\ [kg_{CO2e}/tkm]\} \times 745.2\ [t] \times 472\ [km], \\ R_{TtWb}\ [kg_{CO2e}] = 160.390886400.\end{gathered} \quad (49)$$

The CO_2 emissions of FO calculated using the TtW approach R_{TtWf} are calculated as Equation (50) (according to Equation (16)):

$$\begin{gathered}R_{TtWf}\ [kg_{CO2e}] = \{0.62\ [-] \times 0.000000000\ [kg_{CO2e}/tkm] \\ + 0.38\ [-] \times 0.015700000\ [kg_{CO2e}/tkm]\} \times 745.2\ [t] \times 472\ [km], \\ R_{TtWf}\ [kg_{CO2e}] = 2098.447430400.\end{gathered} \quad (50)$$

Finally, the resulting GHG emissions are presented according to the requirements of the company as total GHG emissions, average GHG emissions per 1 km, average GHG emissions per 1 t, and average GHG emissions per 1 tkm (Table 2, Section 4).

The same procedure as in Equations (43)–(50) can be used to calculate SO_2 GHG emissions. The proposed customized approach was also tested except with FC transport instead of PC and CB transport, but due to the range of the manuscript, the individual calculations are not listed here. The proposed customized approach to GHG emission calculations in RFT for the AI (Section 3.3) has been applied and verified.

4. Results and Discussion

The aim of this article was to propose a fully customized approach to GHG emission calculations in RFT for the AI. Firstly, the requirements for the calculation of GHG emissions from RFT in the AI were identified using three-round semi-structured interviews with highly qualified and well-founded employees of a leading company in the AI operating on the Czech Republic market. As a result, it was found that the area of GHG emission calculations is essential for the company because the company strives to minimize negative logistic impacts on the environment and society. The company does not currently use any RFT emission calculators or other similar tools, as there is no suitable calculator available to meet company requirements or restrictive assumptions. Following this, available railway freight GHG emission calculators were identified and analyzed from the perspective of suitability for the AI using comparative content analysis. As a result, we can state that none of the analyzed GHG emission calculators in the field of RFT is suitable for the needs of GHG emission calculations in the AI because it does not meet all the identified assumptions based on the results of the three-round semi-structured interview. Finally, a fully customized approach to GHG emission calculations in RFT for the AI was proposed, applied, and verified in the form of an interpretative case study. The summary of results for the test calculation is presented in Table 2.

Table 2. Summary of results for test calculations [authors].

CO_2 Emissions	WtT Biogenic Origin [kg_{CO2e}]	WtT Fossil Origin [kg_{CO2e}]	TtW Biogenic Origin [kg_{CO2e}]	TtW Fossil Origin [kg_{CO2e}]
Total by origin	407.635548192	2501.250570017	160.390886400	2098.447430400
Average per 1 km	0.863634636	5.299259682	0.339811200	4.445863200
Average per 1 t	0.547014960	3.356482246	0.215232000	2.815952000
Average per 1 tkm	0.001158930	0.007111191	0.000456000	0.005966000
Total WtT	2908.886118209		NC	
Total TtW	NC		2258.838316800	
Total WtW	5167.724435009			

Notes: CO_{2e}—carbon dioxide equivalent, WtT—Well-to-Tank approach, TtW—Tank-to-Wheel approach, WtW—Well-to-Wheel approach, NC—not calculable.

The CO_2 emissions are presented in Table 2, according to the requirements of the company, as total GHG emissions, average GHG emissions per 1 km, average GHG emissions per 1 t, and average GHG emissions per 1 ton-kilometer. At the same time, the presented results are divided into emissions by origin (BO and FO) and by approach (WtT, TtW, and WtW approach). The total CO_2 emissions of the test calculation calculated by the WtW approach are 5167.72 kg_{CO2e}. These CO_2 emissions consist of emissions calculated by the WtT approach (2908.88 kg_{CO2e}) and TtW approach (2258.83 kg_{CO2e}). The overall results of the model calculation were compared with the results of the EcoTransIT emission calculator [71] and can be considered valid. If the input parameters change, the results also change in a reasonable manner.

This proposed fully customized approach to GHG emission calculations in RFT can be used by all companies in the AI worldwide, because the company that was used in the interpretive case study has plants around the world and the proposed approach was also tested for shipments in individual plants.

This study contains some limitations that are worth discussing. The first limitation is the processed theoretical background. The authors cannot guarantee the use of all available sources, but the processed theoretical background contains all the essential knowledge in the field and the basic axioms. At the same time, the existence of other available materials that were not used in the processed theoretical background cannot be ruled out. Another limitation is the area of identification of assumptions for the GHG emission calculations from RFT. These assumptions were identified and synthetized by using three-round semi-structured interviews. It cannot be completely ruled out that there may be a company in the AI that will have a specific requirement for GHG emission calculations that is not implemented in the proposed approach. On the other side, semi-structured interviews were conducted with highly qualified and well-founded employees of a company which is the leader in the AI Czech Republic market. These employees have sufficient experience across the entire AI to be able to define all requirements for GHG emission calculations. The last potential limitation may lie in the selection of available GHG emission calculators for analysis. Again, the existence of other GHG emission calculators than those analyzed cannot be ruled out. In any case, analyzed GHG emission calculators were selected in a clear, scientific, and objective procedure.

5. Conclusions

The issue of global warming and related GHG emissions are a current topic from not only a scientific but also a practical perspective. This is an area of interest to many stakeholders, such as residents, employees, politicians, activists, shareholders, company leaders, state control bodies, state administrations, and local self-governments. From the point of view of the Czech Republic, the AI has an ambivalent character. On the one hand, it is a significant driver of the Czech economy. However, on the other hand, due to large supply chains, it negatively affects the environment and human society as a whole. Automotive companies are constantly striving to reduce negative environmental and social impacts, but appropriate tools must be in place. None of the analyzed GHG emission calculators in the field of RFT is suitable for the needs of GHG emission calculations in the AI because they does not meet all the identified conditions and requirements based on the results of the three-round semi-structured interview. A fully customized approach to GHG emission calculations in RFT for the AI was proposed, tested, and validated. We assume that the proposed approach can be transformed into a software tool (software emission calculator fully customized for the AI) which will be used to support logistic planning and decision making. The possible extension of this research may focus on the proposal of a framework for GHG emission calculations in multimodal transport. Another option is to specialize in RFT in the context of GHG emission calculations in another very specific sector, such as the chemical industry.

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Appendix A

Semi-structured interviews—questions:

1. Is the field of producing GHG emissions from RFT relevant for your company?
2. Do you use any tool for calculating GHG emissions?
3. Where do you analyze the GHG emissions produced by RFT?
4. What emissions do you track in logistic processes connected with RFT?
5. What kind of freight do you transport using RFT?
6. Define restrictive conditions for RFT.
7. What type of transport do you use?
8. How do you want to present the resulting GHG emissions?

Appendix B

Semi-structured interviews—aggregated answers:

1. Is the field of producing GHG emissions from RFT relevant for your company? Yes, of course. This area is very popular for our company, because our company strives to minimize the negative impacts on the environment. The issue of GHG emission calculations is one of the tools to achieve the above goal.
2. Do you use any tool for calculating GHG emissions? Our company does not currently use any RFT emissions calculators or another similar tool. There is no appropriate GHG emissions calculator available to meet our assumptions and restrictive conditions. Our logistic processes related to the RFT are very comprehensive and specific with many unique conditions. There are currently no suitable RFT emission calculators or another similar tool that contains all required specifics of our company.

3. Where do you analyze the GHG emissions produced by RFT? We track produced GHG emissions by RFT in inbound and outbound logistics. The most important for us are transports within outbound logistics to foreign plants and to customers.
4. What emissions do you track in logistic processes connected with RFT? We track CO_2 and SO_2 emissions as part of logistic processes.
5. What kind of freight do you transport using RFT? We transport predominantly passenger cars (PC), car bodies (CB), and freight containers (FC). We have three kinds of vehicles there are: vehicles for the transportation of PC (see Appendix C, Table A1), vehicles for the transportation of CB (see Appendix D, Table A2), vehicles for the transportation of FC (see Appendix E, Table A3).
6. Define restrictive conditions for RFT. The fundamental restrictive conditions are the maximum freight weight of the vehicle, the maximum load volume of the vehicle and vehicle selection by type of transported freight. The following specific conditions are further applied to the transport of PC:
   - Different PC (PC1–PC8) with different weights (WPC1–WPC8) are transported.
   - The maximum number of PC is 10 PC for transport from plant A on one railway car.
   - The maximum number of PC is 11 PC for transport from plant B on one railway car.

   The following specific conditions are further applied to the transport of CB:
   - Different CB (CB_1–CB_2) with different weights (V_{CB1}–V_{CB2}) are transported.
   - Each CB is transported together with a pallet of different pallet weights (V_{P1}–V_{P2}).
   - The maximum number of transported CB including pallets is as follows: RC_{26}—8 CB, RC_{27}—10 CB, RC_{28}—8 CB, RC_{29}—10 CB.

   The following specific conditions are further applied to the transport of FC:
   - Different FC (FC_1–FC_3) with different weights (V_{FC1}–V_{FC3}) are transported (V_{FC1} = 2.2 t, V_{FC2} = 3.8 t, V_{FC3} = 3.9 t).
   - FC are preferably loaded on Sggns S183 railway cars (RC_{32}).
   - The options for loading railway cars are as follows: for Lgs 580 (RC_{30})—two FC_1 or one FC_2 or one FC_3, for Lgns 583 (RC_{31})—two FC_1 or one FC_2 or one FC_3, for Sggns S183 (RC_{32})—four FC_1 or two FC_2 or two FC_3, two FC_1 and one FC_2, two FC_1 and one FC_3, one FC_2 and one FC_3.
   - The aim is to maximize the load of railway cars during loading.
7. What type of transport do you use? We use one-way transport and return transport. When it is a one-way transport, our company uses multiplying of the produced emissions by specific coefficient.
8. How do you want to present the resulting GHG emissions? We would like to present the results in the form of: total GHG emissions, average GHG emissions per 1 km, average GHG emissions per 1 t and average GHG emissions per 1 tkm and according to the calculation approach and origin of GHG emissions (FO and BO).

Appendix C

A summary of the parameters of the railway cars used for RFT of PC is in Table A1.

Table A1. A summary of the parameters of the railway cars used for RFT of passenger cars [authors].

Railway Car	Type of Railway Car	V_{max}
RC_1	Laaers 509.8	18,000 kg
RC_2	Laaeks 911	15,000 kg
RC_3	Leks 3125	18,000 kg
RC_4	Laekks 552	17,000 kg
RC_5	Laaeks 553	18,500 kg
RC_6	Laaes 556	24,000 kg
RC_7	Laes 559	20,000 kg
RC_8	Laaers 560	34,000 kg
RC_9	Laaers 1160-Touax	34,000 kg
RC_{10}	Laaers 700–702	34,000 kg
RC_{11}	Laaers 800	34,000 kg
RC_{12}	Laeks 063C	18,000 kg
RC_{13}	Laeks 063F	18,000 kg
RC_{14}	Laeks 063A	19,000 kg
RC_{15}	Laaeks 89	22,500 kg
RC_{16}	Laaers 142, 142A	23,700 kg
RC_{17}	Laaers TAL 489M	25,200 kg
RC_{18}	Laaefrs TAL 497	23,000 kg
RC_{19}	Laes TA 364M	18,000 kg
RC_{20}	Laes TA 370M	18,900 kg
RC_{21}	Laaers 5.837	21,000 kg
RC_{22}	Laaers 5.850	33,000 kg
RC_{23}	Laaers 224Sc	24,000 kg
RC_{24}	Laaers 5.854	36,000 kg
RC_{25}	Laaers 6433CO	24,000 kg

Appendix D

A summary of the parameters of the railway cars used for RFT of CB is in Table A2.

Table A2. A summary of the parameters of the railway cars used for RFT of car bodies [authors].

Railway Car	Type of Railway Car	V_{max}
RC_{26}	Habiis 6	52,000 kg
RC_{27}	Habiis 8	51,500 kg
RC_{28}	Habiikks 10	43,000 kg
RC_{29}	Himrrs Doublwagon	47,500 kg

Appendix E

A summary of the parameters of the railway cars used for RFT of FC is in Table A3.

Table A3. A summary of the parameters of the railway cars used for RFT of containers [authors].

Railway Car	Type of Railway Car	V_{max}
RC_{30}	Lgs 580	27,000 kg
RC_{31}	Lgns 583	27,000 kg
RC_{32}	Sggns S183	67,500 kg

Appendix F

An overview of the variables used in alphabetical order:

- C_{d0TtWb}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction [$kg_{CO2e/SO2e}$/tkm]
- C_{d0TtWf}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the TtW approach for dependent traction [$kg_{CO2e/SO2e}$/tkm]

- C_{d0WtTb}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{d0WtTf}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{dTtWb}—appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{dTtWf}—appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{dWtTb}—appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the WtT approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{dWtTf}—appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the WtT approach for dependent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{i0TtWb}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{i0TtWf}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{i0WtTb}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{i0WtTf}—appropriate emission coefficient for the empty load of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{iTtWb}—appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the TtW approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{iTtWf}—appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the TtW approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{iWtTb}—appropriate emission coefficient of CO_2 or SO_2 of BO calculated using the WtT approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- C_{iWtTf}—appropriate emission coefficient of CO_2 or SO_2 of FO calculated using the WtT approach for independent traction [$kg_{CO2e/SO2e}/tkm$]
- FC_{1-3}—different types of FC [−]
- k—type of transported PC [−]
- l—type of transported CB [−]
- l—internal coefficient defined by the company [−]
- L_1—total transport distance [km]
- L_{1d}—length of transport realized by RFT using dependent traction [km]
- L_{1i}—length of transport realized by RFT using independent traction [km]
- L_2—additional transport distance [km]
- L_{2d}—additional length of transport realized by RFT using dependent traction [km]
- L_{2i}—additional length of transport realized by RFT using independent traction [km]
- LF—railway car(s) load factor [−]
- LV—load volume of the load [−]
- LV_{max}—maximum load volume of the railway car required for transport [−]
- m—type of transported FC [−]
- n_c—required number of railway cars for transport [−]
- n_{cbl}—number of transported CB of type l [−]
- n_{fcm}—number of transported FC of type m [−]
- n_{pck}—number of transported PC of type k [−]
- O—additional CO_2 or SO_2 emissions [$kg_{CO2e/SO2e}$]
- O_{TtW}—CO_2 or SO_2 emissions calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- O_{TtWb}—CO_2 or SO_2 emissions of BO calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- O_{TtWf}—CO_2 or SO_2 emissions of FO calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- O_{WtT}—CO_2 or SO_2 emissions calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- O_{WtTb}—CO_2 or SO_2 emissions of BO calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- O_{WtTf}—CO_2 or SO_2 emissions of FO calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- R—total CO_2 or SO_2 emissions produced by the return transportation [$kg_{CO2e/SO2e}$]

- $RC_{1–32}$—different types of railway cars [−]
- R_{TtW}—CO_2 or SO_2 emissions calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- R_{TtWb}—CO_2 or SO_2 emissions of BO calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- R_{TtWf}—CO_2 or SO_2 emissions of FO calculated using the TtW approach [$kg_{CO2e/SO2e}$]
- R_{WtT}—CO_2 or SO_2 emissions calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- R_{WtTb}—CO_2 or SO_2 emissions of BO calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- R_{WtTf}—CO_2 or SO_2 emissions of FO calculated using the WtT approach [$kg_{CO2e/SO2e}$]
- S_{d1}—share of the total length of transport realized by RFT using dependent traction [−]
- S_{d2}—share of the additional length of transport realized by RFT using dependent traction [−]
- S_{i1}—share of the total length of transport realized by RFT using independent traction [−]
- S_{i2}—share of the additional length of transport realized by RFT using independent traction [−]
- T—total CO_2 or SO_2 emissions produced by transportation [$kg_{CO2e/SO2e}$]
- V—weight of the freight [t]
- V_{CBl}—weight of the CB of type l [t]
- V_{Cm}—weight of the freight in FC of type m [t]
- V_{FCm}—weight of the FC of type m [t]
- V_{max}—maximum freight weight of the railway cars required for transport [t]
- V_{PCk}—weight of the PC of type k [t]
- V_{Pl}—weight of the pallet for CB of type l [t]

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