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Assessment of International Trade-Related Transport CO_2 Emissions—A Logistics Responsibility Perspective

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Abstract: International supply chains generate substantial amounts of CO_2 emissions. However, established methodologies for national freight transport emission assessments do not consider such international perspectives sufficiently. This research aims to show how logistic responsibility may be used in ex post transport CO_2 emission assessments, for macrologistic or supply chain levels. We propose an original approach to estimate and allocate CO_2 emissions generated by international freight transport between trade countries. The proposed method relies on the applied Incoterms® rules in sales contracts. A new indicator, the index of responsibility for transport emissions (RTE-index), is introduced to allocate bilateral trade-related transport CO_2 emissions. This is the first time that the Incoterms® clauses are used for macrologistic assessments of international trade-related transport CO_2 emissions. Our approach is exemplified using bilateral trade-related transport flows between Serbia and other European countries. The introduced RTE-index is expected to help visualise average national trade-related transport CO_2 emission responsibilities; increase awareness regarding environmental considerations among trade parties, logistics companies, and national organisations; and provide new perspectives for environmental transport policy actions.

Keywords: international supply chain; Incoterms® clauses; trade-related transport emissions; logistics responsibility; CO_2 emission; Europe

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Citation: Stojanović, Đ.; Ivetić, J.; Veličković, M. Assessment of International Trade-Related Transport CO_2 Emissions—A Logistics Responsibility Perspective. *Sustainability* **2021**, *13*, 1138. https://doi.org/10.3390/su13031138

Academic Editor: Florian Kellner

Received: 17 November 2020
Accepted: 11 January 2021
Published: 22 January 2021

1. Introduction

International transportation activities are responsible for one-third of the global trade-related emissions, with wide variations between countries, ranging from 14% for Indian and Chinese export emissions to approximately two-thirds of the total export emissions attributable to USA [1]. Trade-related freight transport is responsible for approximately 30% of all transport-related CO_2 emissions from fuel combustion and more than 7% of the global emissions [2]. Carbon emissions primarily depend on the distance, transport mode, and traded quantities. The transportation sector is the second-largest contributor to greenhouse gases (GHG) in the European Union (EU) and the only one that records the increase in GHG emissions. The transportation modes with the most rapid increase in international traffic before the COVID-19 pandemic recorded the largest increase in GHG emission; these included aviation, shipping, and road transport [3].

Road transport is responsible for over a half of all the trade-related CO_2 freight emissions owing to its high emission intensity per tonne-kilometre compared with other modes as well as its dominant role in the transport modal share [2]. Moreover, around 10% of international trade (measured in tonne-kilometres) within domestic borders contributes to around 30% of the CO_2 emissions. This is because the first and last steps in international supply chains are usually achieved by road transport, which is the most competitive mode [2].

In Europe, the carbon intensity of freight movement must be reduced to one-sixth of the level recorded in 2015 by 2050, by which time Europe is expected to double its surface transport [4]. However, the total transport emissions in Europe increased by more than

23% in the last three decades, where the share of road transport emissions is almost 95% [5]. The European Commission has already recognised that it will be more difficult to reduce GHG emissions in the transport sector than in the entire EU economy [6].

However, international transport emissions are largely overlooked both in international agreements and database development efforts [1]. The importance of developing a database, a standard measurement method, and an adequate monitoring system to improve assessment of the environmental effects of international freight transport has become more pronounced over the past few decades [1,7,8].

To provide additional perspective on the distribution of international freight transport between countries, we propose a method with more sophisticated allocation of logistics emissions between trade countries by taking into account the logistic responsibilities and roles of logistics intermediaries. Thus, from the logistical perspective, any of the trade parties may assume responsibility for international transport (main carriage). The extent of the exporter's or importer's responsibility for international delivery is usually determined by the International Commercial Terms, or Incoterms®, rules in sales contracts. Incoterms® rules are three-letter abbreviations that reflect the trade parties' respective obligations in connection with the delivery of goods [9]. In other words, the Incoterms® rules determine the division of logistics costs, responsibilities, and liabilities for deliveries between the trade parties. Thus, the Incoterms® rules determine the responsibility distribution for selection of transportation mode and route, shipment characteristics, and all consequent logistics-related emissions between the trading parties.

Very few studies have been reported thus far on the relationships between the Incoterms® clauses and responsibility distribution for transport-related emissions. In some studies [6,10], it was revealed that the chosen Incoterms® clauses and outsourced transport decisions to freight forwarders and other logistics intermediaries partly impacted the shippers' decarbonisation initiatives and limitations. McKinnon and Piecyk [6] noticed that responsibility in delivery often determined the scope of carbon reduction targets in logistics among UK-based trading companies. However, it is difficult to estimate the extent to which the choice of Incoterms® rules is currently influenced by environmental considerations. As a follow-up to these few survey-based studies, the present research attempts to go a step forward and establish the relationship between responsibility for international delivery, expressed as Incoterms® clauses in international sales contracts, and division of national trade-related transport emissions in bilateral trades. This is also in line with a recent study by Stojanović and Ivetić [11], which suggested that Incoterms® clauses may be used in macrologistic assessments and benchmarking. The focus of this study is on transport emissions in supply chains because freight transport accounts for 80–90% of the logistics-related emissions [12].

The purpose of this study is to mitigate a part of the shortcomings related to international freight transport CO_2 emission assessments. We explored the possibility of assessing CO_2 emissions in the process of international freight transport and divided them based on the responsibility for international deliveries in trade flows. The average proportions of the responsibilities shared between countries in a bilateral trade were determined by the Incoterms® rules applied in international sales contracts on an annual basis.

A key related research question may be formulated as follows: Can we assess the share of CO_2 emissions in bilateral trade flows controlled by national logistics providers and freight forwarders? In other words, is it possible to recognise some general preferences regarding the responsibilities of logistics intermediaries for international transport CO_2 emissions at the national level?

A new method for sharing the responsibilities for transport emissions between countries, based on delivery of goods in sales contracts, is proposed in this paper. The proposed approach decouples the trade of products and logistics services and could be considered as a type of specific "service-based" or "logistics-responsibility-based" calculation. This responsibility is assessed and allocated according to the related Incoterms® clauses in international sales contracts. This work aims to show how the applied Incoterms® clauses may be converted to a unique indicator, which allocates transport emissions in bilateral trade. Further, countries involved in the bilateral trade may be ranked according to their responsibility for emissions. Combined with other trade and logistics data, such indicators are expected to support national transport-policy environmental measures. A case study for Serbia is used to exemplify the presented approach. The proposed method also represents an attempt to quantify the national role in international trade-related transport emissions as a useful indicator for more comprehensive macrologistic environmental policy developments.

The main contribution of this study is a new perspective on the assessment and allocation of international trade-related transport CO_2 emissions between trade countries. In addition to production- and consumption-based standards, the Incoterms® clauses applied in sales contracts could be converted to supportive indicators for more accurate transport emission assessments and allocations in international deliveries. Such assignments highlight the logistical perspectives in international delivery and propose sharing of the total transport emissions in bilateral trade instead of the well-known extreme solutions. This study also contributes to the scarce literature on quantitative methods for sustainable supply chains [13].

The remainder of the paper is organised as follows. In Section 2, a brief literature review is given. Section 3 contains the description of the methodology. The main results of the study are presented in Section 4. The discussion, research limitations, and implications are presented in Section 5. Some final remarks and conclusions are provided in Section 6.

2. Literature Review

The responsibility for delivery is often transferred from a sales party to its logistics service providers, freight forwarders, and other logistics intermediaries to manage and control international delivery and to gain a competitive advantage via logistics expertise [11,14,15]. These companies have intermediary roles between the exporters and importers, carriers, ports, logistics centres, warehouses, customs, and all other parties within the supply chains. They usually choose the transport modes, transport routes, transport nodes, and involved parties (carriers, ports, agents, etc.), and design the most efficient and cost-effective transportation chains. Their logistics goals are usually summarised in the literature as the 7R principle: right time, right place, right price, right receiver, right product, right quantity, and right condition. Hence, the logistics intermediaries' skills and competencies impact the distribution of logistic responsibilities between the trade parties.

The choice of the most suitable Incoterms® clauses in the sales contract could increase the logistic routing flexibility, improve consistency, and afford financial benefits [16]. It also reduces the risks, minimises the costs, and improves the overall efficiency and effectiveness of delivery to the end customer [17]. However, the preferences regarding their usage are heavily underutilised in transport and logistic research at the national level [11,17].

The significance of international freight transport emission assessments has been recognised in the literature. However, there are many open questions regarding the assessment methodology as well as sharing and continuous monitoring of international transport emissions [18]. On the international level, trade-related GHG emissions can be allocated to countries in different ways. At present, there are three commonly used top-down allocation methods: territorial-based, production-based, and consumption-based [19,20]. The territorial approach assumes calculation of the national inventories according to the Kyoto Protocol. The production-based approach is closely related to the territorial approach but also includes international transport [20], whereas the consumption-based approach is focused on CO_2 emissions embodied in domestic final demand (i.e., consumption by the import countries) [21]. Transport emissions are assigned either to the export or import countries following the widely accepted logic that the responsibility for emissions in international trade is on either the country of production or the country of consumption. According to production standards, CO_2 emissions from international transport are the emissions caused by countries that export products using international transport services, whereas the assessment for consumption-based standard is that the importing country using international transport services emits CO_2 [22]. It should be noted that the production-based and demand-based standards provide different emission values from international transport for each country and region owing to different methodologies and uncertainty. The consumption-based approach, also known as carbon footprint, may also be used to assess emissions on the supply-chain and product levels using process-based life cycle assessment (LCA). Besides the top-down approach, there is also the bottom-up approach, which is often recognised as more accurate and suitable for decision-making and policy designs [23].

Some authors have revealed the significant role of the transportation sector in national emissions either in terms of production-based [19] or consumption-based emissions [24,25]. Yoon et al. [22] suggest that CO_2 emissions from international transport according to these emission standards should be carefully considered during energy policy design to limit CO_2 emissions globally. Gurtu et al. [13] note the necessity to include international trade-related transport CO_2 emissions in the sourcing decisions of corporate organisations and to explore how they affect the national transport emission inventories. This is especially important for road freight transport, which is the dominant transport mode in the EU [26] and the leading source of emissions in the transportation sector [27]. However, the focus has most often been on international air [28] or maritime [29] transportation modes. Janic and Vleugel [30] explored the effects of road transport service substitution by rail freight transport service in the European corridor and found that there was a particularly favourable effect on GHG emissions. It could be noted that models which interrelate the externalities and modal split in the national transport and logistic networks also exist (e.g., [31–34]). Such models calculate and incorporate external costs in national total transport or logistics costs, keeping the focus on domestic flows.

In general, the literature on emissions by international freight transport is limited, with a lack of quantitative models on sustainable supply chains [13,35]. There is no single widely accepted method to estimate and allocate national emissions of international freight transport [13,36–38]. There were also limited attempts to develop a model to assess the international freight transport emissions and include them in decision-making at the national level [1,2]. Some studies used predictive models to assess trade-related transport emissions by modes, using both the bottom-up [1] and top-down [39] approaches. Cadarso et al. [38] proposed the consumption-based model to quantify and allocate the responsibility for environmental impact of international transport by imports for each sector in the economy related to offshoring. Yoon et al. [22] proposed a multi-regional input–output (MRIO) model to assign responsibilities between three types of countries: exporters, importers, and transporters or service-supporting countries of goods, subject to international carriage. Gurtu et al. [13] argued that carbon emissions should be distributed to both export and import countries, and they noted a need for future research to explore how this perspective should be established in future emissions standards.

3. Methodology

For the purpose of this research, an original origin–destination–Incoterms® rules–transport mode–bottom-up approach was used to estimate and allocate the international trade-related transport CO_2 emissions. The proposed method takes into account the freight transport volumes by the transportation modes. Using ex post analysis, the current overall responsibility for trade-related transport emissions and reasoning about the effects of potential changes in the delivery responsibilities on estimated CO_2 emissions were both estimated.

To exemplify the proposed idea, we used a comprehensive dataset on the bilateral trade flows between Serbia and 41 European countries in 2016. Only countries with trading in both directions were included in this dataset. The data were depersonalized, were partly aggregated over the set of applied Incoterms® rules per country, and included the dispatch and destination countries, flow direction (import/export), transport mode on the Serbian border, applied Incoterms® rules, and gross trade weights and values. The dataset included both Incoterms® 2000 and Incoterms® 2010 clauses for the observed period. The dataset enables calculation of national-level measures based on the percentage share of goods transported under the C and D Incoterms® rules for total gross weight. These are the rules in which the sellers, and consequently their freight forwarders, assume the responsibility for the main carriage in the delivery process. This binary division has already been used in literature [40].

To quantify the national relative share of responsibilities for CO_2 emissions in bilateral trades over a given time range, we introduced a measure called the index of responsibility for transport emissions (RTE-index), which directly assigns a value between 0% and 100% to one party in the bilateral trade (and the complementary percentage to the other one indirectly). The assigned value corresponds to the national cumulative share of responsibility for both trading directions and all four major transportation modes; however, it can also be calculated for each of the eight "flow direction × transportation mode" combinations, thus enabling more specific insights. For example, if the RTE-index for Serbia in trade with Belgium is 47.45%, it means that Serbia is responsible for 47.45% of the total bilateral trade-related transport emissions and Belgium is responsible for the remaining 52.55% of the transport emissions. The framework for the proposed method implementation is shown in Figure 1.

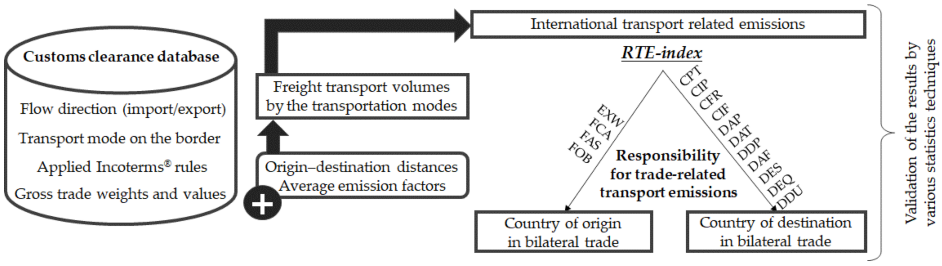

Figure 1. Framework for the proposed method implementation.

For ease of computations, the following notations are introduced:

- *fd* denotes the flow direction and range over the set *FD* = {exp, imp}.
- *tm* denotes the transportation mode and ranges over the set *TM* = {road, rail, air, waterborne}.
- *i* denotes the applied Incoterms® 2000 and Incoterms® 2010 rules and ranges over the set *I = {EXW, FCA, FAS, FOB, CFR, CIF, CPT, CIP, DAF, DES, DEQ, DAP, DAT, DDU, DDP,}*. The set *I* is further partitioned into two disjunctive subsets *IEF = {EXW, FCA, FAS, FOB}* and *ICD = {CFR, CIF, CPT, CIP, DAF, DES, DEQ, DAP, DAT, DDU, DDP}.*
- *TV(fd, i, tm)* denotes the transport volume (i.e., gross weight of transported goods) for a given triplet of parameters *fd, i, tm*.
- *EF(tm)* denotes the average CO_2 emission factor per given transport mode (Table 1).
- *D* represents the average distance between the trading countries.
- *Ch(fd, i)* denotes a characteristic function (a type of binary classifier used to allocate responsibilities between the countries) defined as follows:

$$Ch(fd,i) = \begin{cases} 1, & (fd,i) \in \{(imp,i) \mid i \in ICD\} \cup \{(exp,i) \mid i \in IEF\} \\ 0, & (fd,i) \in \{(exp,i) \mid i \in ICD\} \cup \{(imp,i) \mid i \in IEF\} \end{cases} \tag{1}$$

The international freight transport CO_2 emissions were calculated by the activity-based method from the Guidelines for Measuring and Managing CO_2 Emission from Freight Transport Operations [41]. The CO_2 emissions were calculated using the following formula:

$$CO_2 \text{ emissions } (fd,\ tm,\ i) = TV(fd,\ tm,\ i) \times D \times EF(tm) \tag{2}$$

The CO_2 responsibility shares were calculated using Equations (1) and (2) as follows:

$$CO_2 \text{ shares } (fd,\ tm,\ i) = CO_2 \text{ emissions } (fd,\ tm,\ i)\ \times\ Ch(fd,\ i) \quad (3)$$

Finally, the RTE-index was defined as a ratio of the total cumulative CO_2 responsibility shares and the total cumulative CO_2 emissions for all combinations of parameters:

$$\text{RTE} - \text{index} = \frac{\sum_{fm \in FD} \sum_{i \in I} \sum_{tm \in TM} CO_2 \text{ shares } (fd,\ tm,\ i)}{\sum_{fm \in FD} \sum_{i \in I} \sum_{tm \in TM} CO_2 \text{ emissions } (fd,\ tm,\ i)} \times 100\% \quad (4)$$

The transport activity is related to the loaded vehicles, which move from the exporting to importing country. Therefore, the transport task starts with vehicle loading at the country of origin and finishes after delivering of the goods at the country of destination. The activities were determined by the transport volumes per direction of international trade and distances between the origin and destination countries. The empty runnings were excluded from the calculations. The average distance between the countries is the average transportation distance for each origin–destination pair (source: www.distancefromto.net); the same average distance values were used for all transport modes and both directions. The average emission factors per transport mode (Table 1) were as recommended by McKinnon and Piecyk [42].

Table 1. Average CO_2 emission factors in international freight transport [41].

Transport Mode	Average CO_2 Emission Factor [gCO_2/tkm]
Road	62
Rail	22
Air	602
Water	31

The calculated RTE-indices were subjected to some initial statistical analyses. Firstly, a Kolmogorov–Smirnov normality test was performed, and the result indicated that the distribution of indices significantly deviated from the normal distribution, implying the further use of nonparametric inferential tests. In order to analyse an impact of EU-membership on RTE-indices, the examined sample of 41 trading countries was split into two subsamples as 28 EU and 13 non-EU countries, and the RTE-indices for Serbia were compared between these two groups using the Mann–Whitney U-test. Further, we calculated eight different percentage shares of responsibility for the CO_2 emissions for Serbia, in order to compare emission responsibilities for different modes of transport and different trading directions. Note that not all modes of transport were used in each of the trading countries, so the sample sizes of groups differed from 19 to 41, total N = 251, which made it suitable for nonparametric comparison. We chose to analyse the eight groups of coefficients by Kruscal–Wallis ANOVA by ranks, as independent samples (rather than grouping by country) because there were only 12 countries out of the 41 where all eight "transport mode x trade direction" combinations were available for 2016. Therefore, the choice of the paired test would require drastic sample restrictions.

4. Research Results

The modal distribution of the four most frequently used transport modes for international trades between Serbia and the other European countries in 2016 are given in Figure 2. This distribution was calculated as a percentage share of the freight movements over the period of interest, expressed in tonne-kilometres, for both trade directions (import and export).

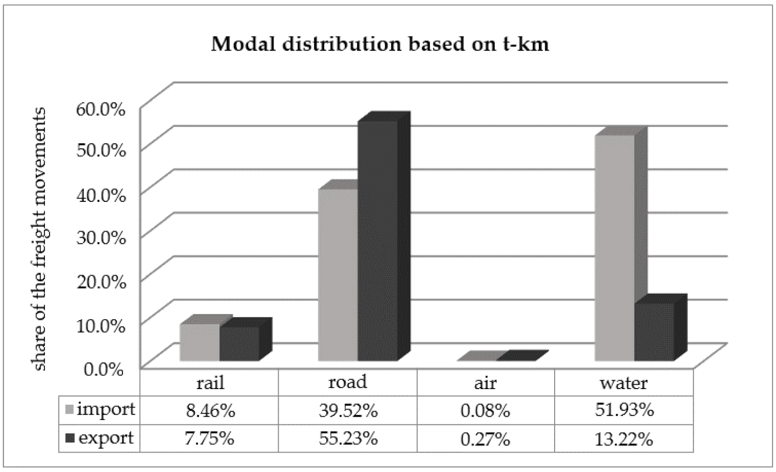

Figure 2. Distribution of emission shares for the various transport modes.

According to Figure 2, the most favourable modes of transport for import into Serbia in 2016 were over water and then by road, whereas those for export from Serbia were by road and then over water. The rail and air transport modes are less represented and even in both trade directions. The high share of water and rail transportation for import (in total they cover almost 60%) was a surprising trend and is considered positive from the perspective of both cost and environmental consequences. The choice of transport mode may also indicate the types of imported goods, which are raw materials and semi-finished products with lower weight/value rates.

Next, the RTE-index for Serbia, i.e., total percentage share of responsibility for trade-related transport CO_2 emissions attributable to the Republic of Serbia (RS), was calculated for trade with each of the 41 remaining countries in the data. This index subsumes all four modes of transport and both trade directions, i.e., a unique value is associated with each country. Descriptive statistics of the obtained samples are given in Table 2 and illustrated in Figure 3.

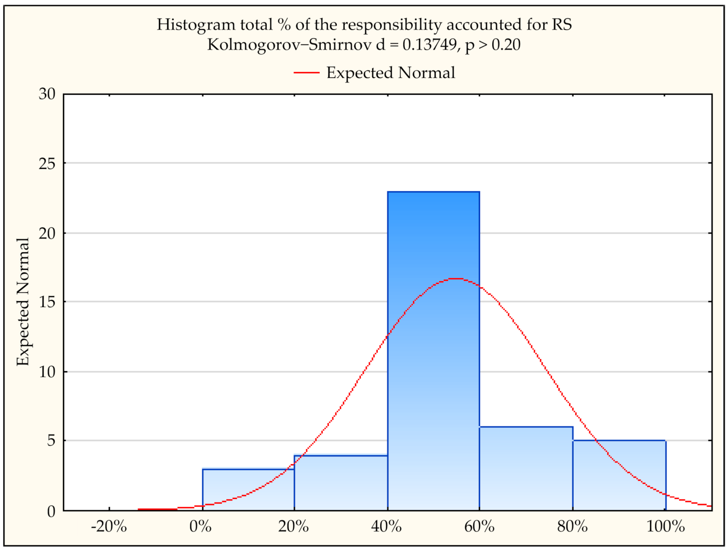

Figure 3. Histogram of the index of responsibility for transport emissions (RTE-index) distribution and normality test.

Table 2. RTE-index descriptive statistics.

	N	Range	Mean	CI 95% for Mean	Median	Std. Dev.	Coef. Var.
RTE-index for RS	41	3.47–97.15	54.76	48.57–60.95	55.53	19.61	35.81%

The RTE-index ranges from 3.47% (trade with Andorra) to 97.15% (trade with Ukraine). However, the percentage share with most countries is relatively evenly distributed between the trading parties; the share accounted for by Serbia is 40–60% for 23 out of the 41 countries (56.1% of the sample). The share distribution is almost symmetric about a mean value of 54.76% and median of 55.53% but steeper than the normal distribution. It is noted that the national responsibilities for emissions are relatively evenly distributed between the trade countries, although the average responsibility of Serbian logisticians is slightly lower. This could indicate the competitive skills and knowledge of Serbian freight forwarders and logistics companies for planning and organising international delivery in Europe. Figure 4 depicts the national distribution of the calculated RTE-indices for all countries included in this study.

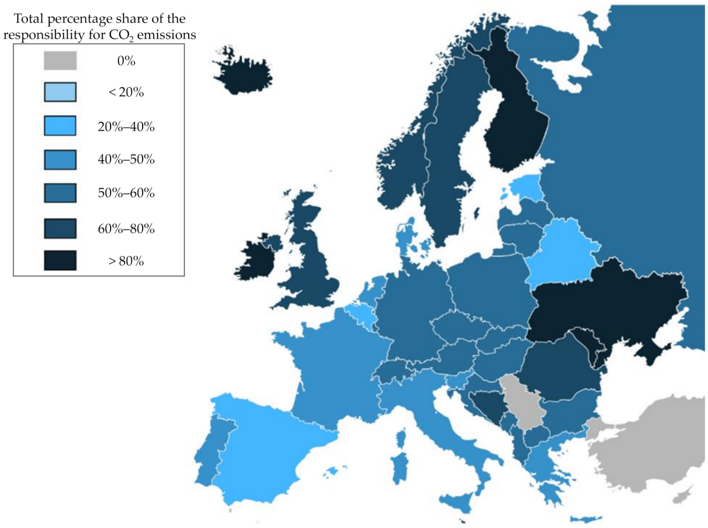

Figure 4. Spatial/national distribution of calculated RTE-indices for Serbia.

To gain deeper insights into the obtained distribution, the calculated RTE-indices are correlated with the distances between the corresponding trading countries and the total trade values (import + export). Both correlations were observed to be statistically non-significant, and the results are given in Table 3. The possible reason for this is that the commodity values and distances have no significant impact on the responsibilities for delivery and consequently for CO_2 emissions, at least in the geographical, political, and economic context. The physical commodity characteristics, i.e., shipment size, weight, and transport technology requirements, are not known; therefore, these were not considered in this research. However, the commodity values could be partly related to these parameters, and one might suppose that the physical characteristics are related to the delivery responsibility in a similar manner.

Table 3. Spearman correlation coefficients and their significances.

Correlations with RTE-Indices	Valid N	Spearman Correlation Coefficient	t(N-2)-Statistics	*p*-Value
Distance between trading countries	41	−0.058014	−0.362908	0.718633
Total value of trade for year 2016	41	0.153136	0.967748	0.339134

The next goal was to explore the difference between trading with EU countries and trading with non-EU countries, in terms of CO_2 emission responsibility distributions. Serbia belongs to the Central European Free Trade Agreement (CEFTA) countries; however, it has different preferential trade agreements with the EU, CEFTA, European Free Trade Association (EFTA), and other European countries, including Turkey and Russia. Based on the results of the Mann–Whitney U-test ($U = 175.00$, $Z = -0.182$, $p = 0.855$), we concluded that the responsibilities accounted for by each of the trading countries did not depend on EU membership, i.e., on a particular geopolitical context.

To further explore possible reasons for the distribution of the total share of CO_2 responsibility for Serbia, we proceeded with more detailed analyses by considering the four main modes of transportation as well as trading directions. The results are given in Table 4 and illustrated by Figure 5.

Table 4. Percentage shares of responsibilities for Serbia based on transportation mode and flow direction.

Mode of Transport and Trade Direction	N	Mean	CI 95% for Mean	Median	Std. Dev.	Coef. Var.
Export by rail	21	31.00	17.17–44.83	24.12	30.38	98%
Export by road	41	56.03	49.36–62.71	54.67	21.15	37.7%
Export by air	40	66.56	56.94–76.17	82.31	30.07	45.2%
Export by water	20	68.85	51.63–86.08	83.54	36.80	53.4%
Import by rail	28	78.05	65.36–90.73	94.37	32.71	41.9%
Import by road	41	44.37	37.92–50.82	41.28	20.45	46.1%
Import by air	41	79.32	72.75–85.90	85.93	20.83	26.3%
Import by water	19	61.66	42.46–80.86	80.53	39.84	64.6%

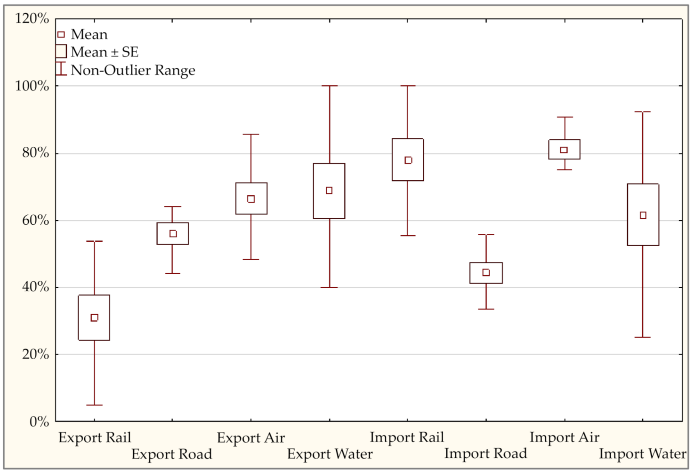

Figure 5. Box-and-whiskers plot of the responsibilities based on transportation mode and flow direction.

The responsibility index is lowest in the case of rail transport for export (31.00 ± 30.38%, median 24.12%) and highest in the case of air transport for import (79.32 ± 20.83%, median 85.93%). An average share of less than 50% was noted only in two cases, rail transport for export and road transport for import, whereas Serbia is on average responsible for more than half the transport CO_2 emissions in the remaining cases. However, in road transport, the responsibility is relatively evenly distributed between the trade countries in both directions. The inland water-based transport showed the highest variability and high responsibility in both directions. Serbia is a landlocked country, but the Danube river, which is considered the “backbone” of Europe, passes through this country and together with its tributaries supports this environmentally friendly transport mode. The air transport mode shows a significant responsibility on the part of the Serbian air forwarders and the smallest coefficient range in both directions; however, this transport mode is almost neglected in the modal share.

The Kruskal–Wallis ANOVA by ranks shows that the observed differences are statistically highly significant. For a total of 251 calculated coefficients, the H-statistic for seven degrees of freedom is 67.19, with a corresponding $p \approx 0.00$. The results of the pairwise comparisons for all groups, obtained by a multiple comparison test of the mean ranks and expressed by the corresponding two-tailed p-values, are presented in Table 5.

Table 5. Pairwise comparisons of all groups.

Multiple Comparisons of Mean Ranks for All Groups: Two-Tailed *p*-Values							
	Export Rail	**Export Road**	**Export Air**	**Export Water**	**Import Rail**	**Import Road**	**Import Air**
Export by road	ns						
Export by air	0.0041 **	ns					
Export by water	0.0018 **	ns	ns				
Import by rail	0.0000 **	0.0043 **	ns	ns			
Import by road	ns	ns	0.0211 *	0.0100 *	0.0000 **		
Import by air	0.0000 **	0.0046 **	ns	ns	ns	0.0000 **	
Import by water	ns	ns	ns	ns	ns	ns	ns

ns—not significant, * significant at level 0.05, ** significant at level 0.01.

The significant differences in the responsibilities for emissions are confirmed for both import and export by rail. For the same direction, the responsibility for rail transport is also significantly lower than that for inland water-based and air transport for export. For import, the responsibility for road transport, which is the most equally distributed between the trade countries, significantly differs from that of air and rail transport.

5. Discussion

To date, international trade-related transport emissions have been attributed completely either to the exporting (production-based standard) or importing (consumption-based standard) countries. The present study reveals that a more sophisticated approach is required to allocate transport emission responsibilities between countries in bilateral trades and proposes inclusion of the Incoterms® clauses from international sales contracts in such assessments. Consequently, Incoterms® clauses may be used as supportive international benchmark indicators for transport emission responsibilities and carbon leakages in international deliveries.

The proposed method supports the development of a national disaggregated international freight-flow model and logistics cost measurements, as suggested by Havenga and Simpson [34] and Havenga et al. [43]. When combined with other national transport performance indicators, it can help improve systemic transport performance sustainability measurement and support development of decision-making scenarios, sectoral decarbonisation, cross-national comparisons, and broader national sustainability goals.

One of the main advantages of the applied methodology is the usage of secondary data generated for the purpose of customs administration worldwide in a standardised manner. However, digital density is expected to accelerate and support “logistic transformation” and “smart logistics solutions” [44], and to create unforeseeable effects on businesses and business models [45]. The increasing use of digital technologies in transport, such as big data, blockchains, and Internet of Things (IoT), among others, may directly support the collection, processing, and analyses of data in a more accurate and comprehensive manner. Such data may be used in, among others, transport-policy developments focused on transportation and overall logistic emission control and reduction. This is in line with the EU Green Deal objective aimed at decarbonisation and climate neutrality by 2050 [46] as well as the coupled development of digital transformation and transport decarbonisation [47].

The presented results are based on the binary responsibility sharing approach. However, more sophisticated analyses may also be used. The responsibility could be assigned to different parties according to gradient division instead of the current binary approach. Gradient division can be obtained by the modified characteristic function (see Equation (1)) similar to that in [11] or by disaggregated trade flows by sector. It would be interesting to also consider a wider geographical area and case studies of other countries. Although Incoterms® clauses are internationally recognised commercial terms in international trade, they are still overlooked in national and international transport and logistics benchmarking. Cross-country comparisons are also possible and would be of interest to compare the results from different countries or to incorporate this indicator in a regional input–output model. Indirectly, this research also supports the viewpoint of [8], which proposed a need for comparison of different methods for assessment of transport emissions on an international level, to ultimately enable the comprehensive standard methodology and measurements.

Although the present research focuses on a macrologistic level, the adapted RTE-indices could be used at the supply-chain or company level to support increasing awareness regarding the environmental responsibilities of exporters, importers, and their logistic intermediaries, who usually design these supply chains. Logistic intermediaries are often the neglected link between the trading parties, carriers, and other logistic operators, although their role is crucial for transport chain designs and consequently transport emissions. Some previous studies have revealed that the logistic intermediaries may be less motivated to improve environmental performances and sustainable solutions than the exporters and importers [15,48], especially in the case of conflicts of interest between environmental performances and cost as well as time requirements [48]. Considering their findings and the well-known logistics and supply-chain goal expressed as the 7R principle in Section 1, the present research implies a need to extend this principle to 8R: right time, right place, right price, right receiver, right product, right quantity, right condition, and *right emissions.* The component "right emissions" could be further modified or developed into "right footprint", "right externalities", or any other term aimed at the same goal based on assessment purpose. Consequently, the results could be utilised to improve environmental considerations in these firms to support the development and implementation of environmental criteria and standards in supply-chain designs. Additionally, it may support systematic sustainability performance measurement and performance improvement, combined with other methods (e.g., those in [49]) and the development of a "sustainability culture" at the supply-chain or professional organisation level. Havenga and Simpson [34] advocated the sustainability culture as the fourth pillar of sustainability, besides social, economic, and environmental considerations.

However, there are many limitations related to the use of the Incoterms® clauses in different assessments, as was described in [11,50]. Among the main limitations are data sensitivity and the need for more in-depth analyses to obtain more reliable results. The data has to be crossed with other industry data, as the samples are not comprehensive and may not reflect the accurate shares of responsibilities for CO_2 emissions between countries. However, the sample sizes are significant, and the research goal was not to accurately measure the CO_2 emissions in international trade for a particular country but to indicate the utility of the proposed methodology. The limitations of the methodology related to CO_2 calculations in freight transport must also be considered [51]. The practical application of these indicators is possible only within the set of comprehensive measures, including their promotion and wider application. Further, the Incoterms® 2020 clauses were enforced in January 2020, but the changes in the rules are minor and should not affect the results of this study.

The responsibility for the main carriage, related to the C and D groups of the Incoterms® clauses, usually means that the last-mile transport may be organised and co-ordinated by the importers or their freight forwarders. The emissions from this last step are disregarded in this analysis. The same applies to the first-mile cases for the E and F clauses, but the transport emissions are then related to the exporters or their freight forwarders. Further, along with the transport emissions, there are other emissions in international delivery, namely loading, unloading, warehousing, packaging, customs administration, etc. Although transport emissions are recognised as dominant in logistics, as noted in Section 1, these other emissions are not considered by the proposed method and may be included in future research.

A significant limitation of the presented method is the use of average distances between countries for all transport modes. Moreover, we compared only the sharing responsibility in bilateral trade, disregarding any cross-country comparisons of quantity or value of trade flows. This means, for example, that we equally presented sharing responsibility in trade between Serbia and Luxembourg on the one hand, and Serbia and Russia or Germany, on the other hand. Further, in the case of multimodal transport, the CO_2 emissions are still calculated only for the transportation means used on the Serbian customs border, as recorded by the customs authorities. In other words, the multimodal transport chains are simply attributed to a particular mode of transport, owing to the lack of data. However, it is expected that all transport modes other than road transport may be at least bimodal because in most cases road transport is used for the first- and last-mile deliveries. In some cases, road transport recorded at the national border could also be related to bimodal transport, for example, owing to environmental regulations in some countries or geographical limitations. It is also supposed that multimodal transport chains with three or more transport modes may be rare in this geographical context. The return operation of the means of transport (vehicles, ships, cargo airplanes) are not included in the analyses. It may be expected that they are partly covered, as freight forwarders and carriers often organize return loads, by using available information from e-marketplaces with a comprehensive database of carriers and transport demands in Europe. However, empty returns are generally out of the scope of this study. Further research may also be directed towards including GHG transport emissions other than CO_2 (CO_2e) and towards exploring the awareness of exporters, importers, freight forwarders, transport managers, and other parties regarding environmental issues.

6. Final Remarks and Conclusions

It has been recognised in the literature that the long-term impact of global trade on CO_2 emissions has been ignored thus far and that this impact is mostly related to freight transport [2]. Recently, a reverse positive impact of green logistics performances of exporting countries on international trade (export probabilities and volumes) has been revealed, although the economic development of the trade countries may significantly impact these results [52]. Therefore, there is increasing importance placed on the assessment, control, and monitoring of international trade-related transport emissions.

Although the Incoterms® rules versions since 2010 have included environmental aspects in the sales contracts, such impact is still largely overlooked. This is the first time that the Incoterms® clauses in sales contracts have been used to assess and allocate the responsibility shares for international transport emissions between trade countries from the macrologistic perspective. The present research also confirmed the critical need for rethinking trade in terms of logistics and transport services, rather than only in terms of value, as has typically been the case in trade literature [1].

The United Nations has already recognised the governmental role in encouraging the use of Incoterms® clauses in sales contracts [53]. However, the results presented in this research indicate the possibility to advance a step further, by highlighting the value of these rules in monitoring and policymaking on supply chains and at the macrologistic level [11]. Companies, governmental institutions, and non-governmental organisations, as well as professional associations, should therefore devote more attention to education and professional training that reveal the links between Incoterms® rules and environmental transport and logistics issues.

The results presented herein show that the Incoterms® clauses in sales contracts could be converted to suitable sustainability indicators and used to assess responsibility for transport emissions. For example, we proposed a novel, supportive indicator, the RTE-index, to improve international trade-related transport emission distributions between trade countries. Further, we applied it to a real case at the national level for Serbia. However, the RTE-index may also be used at the supply-chain or organisational level.

The proposed method could also be applied as a stand-alone assessment or complemented by others, such as the production-based approach, and rendered more innovative, as described in [5]. However, it should be further improved before being implemented as an environmental indicator either at the supply-chain or national level because of the limitations noted above.

Author Contributions: Conceptualisation, Đ.S. and J.I.; methodology, J.I. and M.V.; software, J.I. and M.V.; validation, Đ.S., J.I. and M.V.; formal analysis, J.I. and M.V.; investigation, Đ.S.; resources, Đ.S.; data curation, Đ.S. and J.I.; writing—original draft preparation, Đ.S. and J.I.; writing—review and editing, Đ.S., J.I. and M.V.; visualisation, J.I.; supervision, Đ.S.; project administration, Đ.S.; funding acquisition, Đ.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia through project no. 451-03-68/2020-14/200156: "Innovative scientific and artistic research from the Faculty of Technical Sciences activity domain."

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of these data. Data was obtained from the Customs Administration of the Republic of Serbia and are available from the authors only with the permission of the Customs Administration of the Republic of Serbia.

Acknowledgments: The views expressed here are purely those of the authors. The authors wish to express their gratitude to the Customs Administration of the Republic of Serbia for providing the database for this research and to Damjan Ivetić for his help with creating Figure 4. We also thank the anonymous reviewers for careful reading and valuable comments.

Conflicts of Interest: The authors declare no conflict of interest.

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