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How to calculate GHG emissions in freight transport? A review of the main existing online tools

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ABSTRACT

About 23 percent of global greenhouse gas emissions are caused by the transportation sector. According to the Organization for Economic Co-operation and Development freight transport-related demand in 2050 is expected to triple compared to the values recorded in 2019. In order to comply with regulations that aim to meet precise targets in terms of reducing greenhouse gas emissions, it is necessary to objectively measure the impact of transportation activities with the aim of mitigating emissions. To do this, it is mandatory to have accurate and user-friendly calculation tools. The purpose of this paper is to compare the most widely used tools to assess CO_2e transport emissions in transportation, also comparing them to the GLEC methodology, which is compliant with ISO regulations universally recognized as the most appropriate procedure. 3 case studies related to intermodal transport scenarios are assessed and compared using the considered tools. Based on the analyses performed, this research finally proposes some recommendations for reliable calculation of CO_2e emissions, in compliance with ISO 14083.

1. Introduction

After the Covid-19 pandemic, global freight transport has picked up again (“OECD Statistics,” n.d.). This trend is a consequence of the dynamics of international trade and the increasing interdependence of supply chains, supported by the growth of the world’s population and the spread of technologies that facilitate the purchase of products not available locally. These changes have led not only to a relocation of production facilities outside the company’s home country, but also to an increasing geographic distance of demand from supply. The growth of freight transport results in a greater amount of greenhouse gas emissions (hereinafter GHG emissions) attributable to the transport sector. In 2022 the transport sector accounted for 22.96 percent of GHG emissions (IEA Agency, 2022). According to (Greene, 2023), freight transport, in particular, is responsible for 8 % of global GHG emissions, which become 11 % if warehouses and ports are included.

Many institutions and organizations set clear targets in terms of reducing GHG emissions. The IMO (International Maritime Organization) has the ambition to achieve zero GHG emissions from international shipping by 2050 (“IMO’s work to cut GHG emissions from ships,” n.d.). In 2011, the European Commission published a document titled “White Paper on Transport” (Directorate-General for Mobility and Transport (European Commission), 2011) that calls for a 20 percent reduction in GHG emissions compared to 2008 levels as one of the targets to be achieved by 2030. In 2019, the European Commission also published a policy paper on climate and environmental challenges titled “The European Green Deal” (European Commission, 2019) which calls for an even more significant reduction in GHG emissions from transport to achieve “zero climate impact” by 2050, in line with the Paris Agreement on climate change. In addition, in 2021 the Commission presented “Fit for 55” ("Fit for 55", 2021) a package of climate neutrality directives and regulations aimed at reducing the European Union’s carbon emissions by at least 55 percent by 2030, an essential goal to achieve climate neutrality by 2050.

The main greenhouse gas is carbon dioxide (CO_2), but there are other pollutant gases such as methane gas (CH4), second in concentration, which is the main component of natural gas and has a major impact on climate. Greenhouse gases also include nitrogen oxide (N2O), ozone (O3), water vapor (H2O) and industrial gases such as sulfur hexafluoride (SF6) or nitrogen trifluoride (NF3). Carbon footprint or GHG emissions are usually expressed in terms of CO_2 equivalent (CO_2e), a metric measure used to compare emissions of various greenhouse gases based

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on their global-warming potential (GWP) by converting quantities of other gases into the equivalent amount of carbon dioxide with the same global warming potential ("Glossary," n.d.).

In the literature, many authors focused on measuring the impacts of road transport (McKinnon and Piecyk, 2009; Soylu, 2007; Talbi, 2017) by considering different case studies and contexts. (McKinnon and Piecyk, 2009) examined some methods of tracking carbon emissions in road freight transport by using data from the UK. (Talbi, 2017) analysed factors influencing changes in CO_2 emissions from the Tunisian road transport sector over a 34-year period, while (Soylu, 2007) estimated emissions from Turkish road transport including car emissions. (Bastida-Molina et al., 2020) presented a methodology to verify the sustainability of the transport by introducing EVs, while (Jahangir Samet et al., 2023) propose the use of battery electric trucks in Finland and Switzerland. (Liaquat et al., 2010) examined the production and use of biofuel in developing countries to reduce environmental pollution and oil dependency. Other authors instead focus on environmental issues related to maritime transport (Christodoulou et al., 2019; Poulsen and Sampson, 2020; Wang et al., 2020), ship emissions in ports (Spengler and Tovar, 2021; Styhre and Winnes, 2019) and terminals (Budiyanto et al., 2022; Kim et al., 2012; Yu et al., 2017; Zhong et al., 2019). (Sys et al., 2016) examined the potential effects of emerging international maritime emission regulations on competition between seaports, while (Styhre et al., 2017) analyzed the level of GHG emissions from ships at ports. (Hasan et al., 2020) investigate the mitigation potential of various transport policies, considering their costs, benefits and ethical aspects using a multi-criteria analysis technique. (Boies et al., 2008) study emission- reduction strategies to meet state-wide greenhouse gas emissions reduction targets in Minnesota.

The ability to correctly quantify GHG emissions is a prerequisite for their reduction and may become necessary for companies to demonstrate their compliance with current and future regulations. Using a database on CO_2e emissions from trucks, (Gable et al., 2022) simulated two different scenarios, one of which involves a tax of 300 euros per ton of CO_2e, to assess whether taxation might be a good strategy for decreasing emissions. (Gable et al., 2022) (Dehdari et al., 2023)conducted a literature survey to assess how detailed the calculation of CO_2e emissions in road transport is, concluding that there is a need for the scientific community to provide models that support decision-making processes to sustainably reduce CO_2e emissions. No research is focusing on intermodal transport even if it is increasingly encouraged and used. (Bouman et al., 2017) present the results of a review of around 150 studies to provide a comprehensive overview of CO_2 emissions reduction potentials and measures published in the literature. (Petro and Konečný, 2017) deals with the calculation of external costs produced by transport services. (Linton et al., 2015) present a number of approaches for modelling a road transport system and the related CO_2 emissions. (Pregger and Friedrich, 2009) provides typical default values for driving parameters of stack height and exhaust gas temperature, velocity and flow rate for various industrial sources. (Fan et al., 2018) highlight the importance of considering air pollutants in optimization studies and evaluate the limitation of the current air emissions assessments, particularly in relation to transportation.

Several methodologies and tools for measuring emissions related to freight transport are available that can help different stakeholders in the decision-making process to improve transport sustainability. At present, it is not mandatory to calculate emissions in the transport sector, although many companies are considering providing information on emissions produced during the transport of goods, both to improve their image and appear "greener" and sustainable, but also to prepare for reports that will probably soon be at least strongly recommended. Calculating emissions is not always simple, and requires some know-how and staff training.

The ISO 14083, recently issued in 2023, defined an international standard for the calculation of CO2 emission in logistic chains both for passengers and freight. In addition, there are a number of available online commercial tools and methods to calculate GHG emissions. Among the most important methods for the calculation of only freight transport emission is the GLEC methodology, which is based on the standards set by ISO 14083.

In July 2023, the European Commission unveiled a package of proposals to make freight transport greener. These include a proposal for a single methodology for calculating greenhouse gas (GHG) emissions from transport services, called CountEmissionsEU. The proposed regulation establishes a common regulatory framework for accounting GHG emissions from transportation services. The regulation establishes ISO14083 as the reference methodology for calculating GHG emissions from transportation services.

The purpose of this paper is to compare the currently most widely used tools for calculating GHG emissions from freight transport, defining a necessary data set and assessing the strengths and weaknesses of each tool against the GLEC methodology – which underpins current GHG emissions regulations – and the international standard ISO 14083. The comparison is made using a number of case studies related to intermodal transport.

The paper is structured as follows. Section 2 presents a background related to main regulation currently in force together with some insights related to the input dataset and the methodology used for the tools' comparison. Section 3 shows a comparative analysis between the main existing tools for calculating GHG emissions in freight transport. Section 4 presents the results obtained by calculating GHG emissions with the tools under comparisons for some case studies. Finally, in Sections 5 a discussion of the obtained results is provided while in Section 6 some conclusions are outlined.

2. Materials and methods

There are several tools and methodologies for calculating CO_2e emissions generated by freight transport. From those available online, with the support of experts and companies working in the transportation industry (STEP 1) the 5 most common and widely used ones were selected (STEP 2), all of which comply with EN 16258 and/or ISO 14083:

1. GLEC framework ("Smart Freight Centre," n.d.)
2. GreenRouter ("GreenRouter – Carbon accounting and reduction strategies," n.d.)
3. EcoTransit ("EcoTransIT World – Emission Calculator," 2020)
4. TK'Blue ("TK'Blue," n.d.)
5. Route scanner ("Routescanner – worldwide container shipping platform," n.d.)

Each of these tools was analyzed by testing their functionality also directly speaking with software firms when possible (STEP 3). The output of this first analysis was an initial highlighting of the strengths and weaknesses of each tool. A comparative analysis of these tools was then conducted using 3 case studies and different transportation modes (STEP 4), with the ultimate goal of providing potential users with the tools to choose the tool closest to their needs (STEP 5).

Fig. 1 summarizes the methodology used in this research.

2.1. Main regulations

The EN 16258 standard – 2012 ("European Standards," n.d.). The EN 16258 standard – 2012 titled "*Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services*" was the main regulation the calculation and the reporting of GHG emissions. It indicates what should be included within the emission calculation and what, instead, can or should be excluded. This standard requires the calculation of indirect emissions, i.e. those generated during the production or transportation of fuel and the construction and maintenance of the infrastructure used. In other words, EN 16258

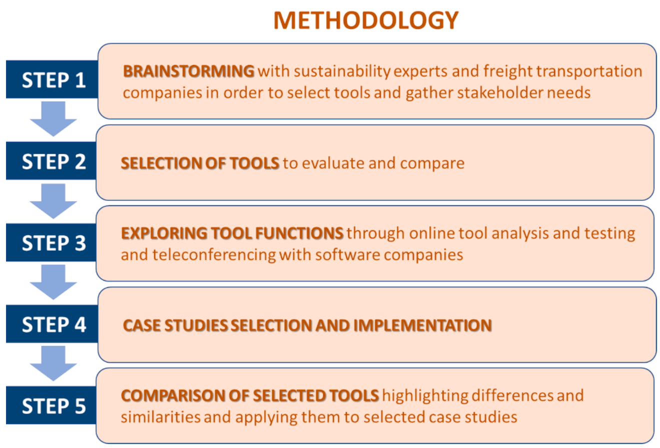


Fig. 1. Methodology used for the research.

considers Well-to-Tank (WTT), that is, emissions related to all processes (extraction, processing, storage and delivery) between the energy source to the point of use. Previously, only direct consumption and externalities, Tank-to-Wheels (TTW), i.e., emissions directly implicated in the use of transportation means, were considered (Fig. 2). The standard also requires that total emissions (Well-to-Wheel or WTW), WTT and TTW be specified separately. Emissions are often expressed in terms of CO_2 equivalent, calculated as a function of global warming potential (GWP) and the quantities of individual gases.

In 2023 the new ISO 14083 titled *"Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations"* has been approved by CEN (European Committee for Standardization) ("European Standards," n.d.) and released replacing the existing EN 16258. The concepts contained in the standard are similar but improved and refined. In the new standard, for example, the scope is the quantification and reporting of GHG emissions arising from the operations of transport chains of passengers and freight. Each transport chain needs to be decomposed in its Transport Chain Element (TCEs) which has to be calculated separately. For more details please refer to the full version of the standard (ISO standards, n.d.).

2.2. Input dataset

Depending on the tool/methodology used to calculate emission, an accurate input data set is required. The more detailed the data provided, the more accurate the final output will be, since less default data will need to be used. When the transportation service is outsourced, the company commissioning the service may not know much of this data.

Not all tools (Section 3 and Table 1) allow for detailed input. Commercial versions of the tools, when available, allow detailed setting of many parameters, making very accurate calculations possible. Table 1 divides input data into "*basic data*" and "*additional data*".

Since the routing systems for road transport included in the available tools usually provide the minimum distance traveled between two points, it would be useful to have additional data on actual routes and distances, which may not be the minimum ones.

2.3. Tools and methodologies compared

This Section provides a description of the 5 selected tools[1] used to assess GHG emissions in freight transport (see Table 2).

2.3.1. GLEC framework "Smart Freight Centre," n.d.)

The GLEC- Global Logistic Emission Council- framework was developed by a community of organizations dedicated to driving widespread, transparent, and consistent calculation and reporting of logistics GHG emissions and is currently the main globally recognized method for calculating all greenhouse gases defined by the Kyoto Protocol within multimodal logistics chains. The GLEC approach is in line with the Greenhouse Gas Protocol, UN-led Global Green Freight Action Plan and CDP Reporting ("Smart Freight Centre," n.d.), and is compliant with the international standard ISO 14083 released in 2023 (Gould, 2023). This new standard replaces the EN 16258, described in Section 2.1. In addition to being used to quantify emissions, this methodology can also be applied to assess the impact of new investments, purchases and strategies. It can be used by both companies and logistics providers but, also by investors and governments, as it covers all emission scopes defined by the GHG Protocol. The GLEC methodology is not a standard but an approach that defines the steps and standard values to be used for emissions calculation. Unlike other tools, many of which are based on this methodology, the calculations must be done manually. To improve data compatibility and comparability, the GLEC approach is built on existing principles, harmonizes practices already widespread in the industry, and emissions are expressed in terms of CO_2 equivalent. Like other approaches, it considers WTW consumption and provides factors for converting local consumption and tank-to-wheel to CO_2 equivalent. Global averages are provided for these factors (for more precise analyses, the location where the energy was generated must be taken into account).

In the recently released third version of the GLEC, the methodology was updated and aligned more closely with standard ISO 14083. Emissions are now calculated per transport chains which are based on TCEs' emissions (Fig. 3). A TCE is defined by goods transported by a single vehicle or transiting through a single hub. Therefore, each change of vehicle or hub requires the identification of a separate TCE and, thus, a separate calculation of its GHG emissions. In line with the GHG Protocol, which also aims to consider all of an organisation's emissions, both direct and indirect, the methodology distinguishes between Scope 1, Scope 2 and Scope 3 emissions ("Homepage | GHG Protocol," n.d.). Scope 1 includes direct emissions from assets owned and controlled by the reporting company; Scope 2 includes indirect emissions electricity, heat and steam purchased by the reporting company, and Scope 3 relates to emissions resulting from transport carried out by third parties.

Since the data collection phase is complex, it is often needed to approximate the data required to compute CO_2 emissions. The type of data used and its accuracy have a substantial influence on the final results.

The GLEC framework considers 4 types of data reported in descending order of precision and accuracy:

- PRIMARY DATA are the actual data collected directly from the carriers. These data provide as much detail as possible but, they are difficult to obtain and it needs to be verified how they were obtained and measured.
- PROGRAM DATA are data collected in Green freight programs that serve as a neutral platform for collecting and sharing reliable data between transportation operators and their customers.
- MODELED DATA Companies and tool providers model fuel use and emissions using available information on goods types, consignment sizes, journey origin, destination and intermediate handling locations, and any information about the vehicles used, load factors, etc. The relevance of this type of data is variable depending on the accuracy of the input data and the algorithm used.
- DEFAULT DATA represent average values relative to the industry operating in. They are the least precise data but provide general indications that allow equally general assessments. It should be noted here that outputs may be significantly divergent from actual conditions.

[1] Note that the demo versions of the selected tools were used.

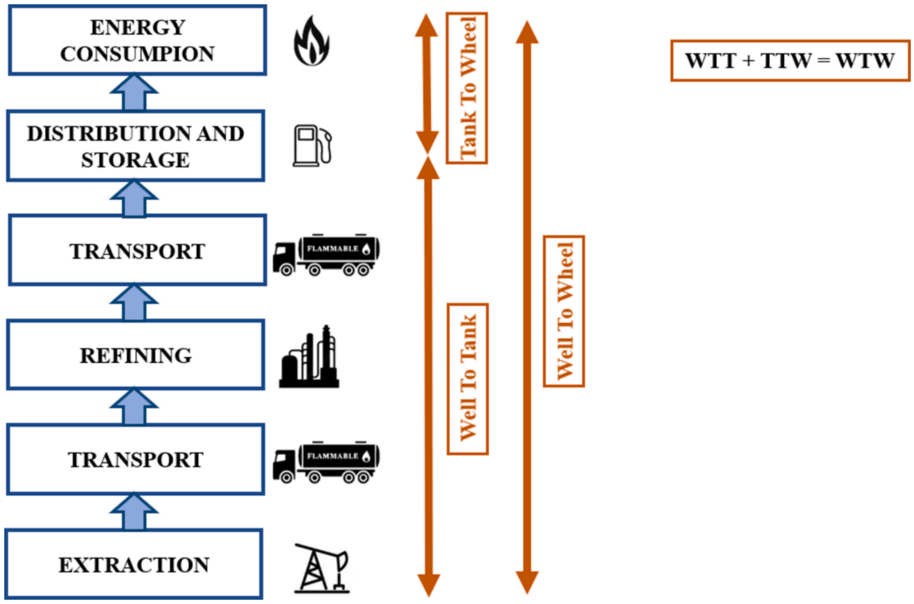


Fig. 2. Fuel life cycle.

Table 1
Input dataset for emission calculation.

BASIC DATA	
Freight	Gross weight (tons/TEU)
Locations	Origin and destination of the individual legs involving the different transport modes included in the intermodal transport
Transport modes	Basic information related to the transport modes used in the intermodal transport
ADDITIONAL DATA	
Transport modes	Vehicle type used, fuel type, biofuel type, emission classes, traction type for rail transport, load factor, empty trips factor
Routing and distances	Actual distance travelled

2.3.2. GreenRouter

GreenRouter ("GreenRouter – Carbon accounting and reduction strategies," n.d.) is an Italian platform created in 2016 with the aim of analyzing and reducing the overall impact of emission generated by companies. This impact is related to both the transportation performed and the buildings used along the production chain to the final points of sale. GreenRouter finances various projects to reduce environmental impact such as the creation of hydroelectric power plants and the planting of small forests.

This tool requires the following inputs: information regarding the type of transport (e.g., groupage), type of trip (e.g., direct, transit point, multimodal etc.), period in which the transport is performed, intermodal transport unit if this type of transport is planned, type of goods and any need for temperature-controlled travel, weight of goods and point of departure and arrival.

In accordance with CLECAT guidance (Schmied and Knorr, 2012), logistics site emissions are taken into account in addition to transport-

Table 2
Comparison of the tools/methodologies selected.

Features	Tools and Methodologies Considered				
	GLEC	GreenRouter	EcoTransIT	TK'Blue	Route scanner
Transport modes	All	All	All	All	All except air transport
Logistic hubs	Included	Included only in the commercial version	Included only in the commercial version	**Not available**	Included
Allocation units	Weight, TEU	Weight, TEU	Weight, TEU	Weight	TEU
Accounting for fuel emissions	WTW	WTW (WTT and TTW are also available)	WTW (WTT and TTW are also available)		WTW
Default data sources	Calculated considering multiple data providers depending on mode of transport and geographical location	GLEC framework and other sources	Handbook for Emission Factors, MOVES, International Maritime Organization, Clean CargoSmall Emitters Tool Eurocontrol, other sources	**Not available**	GLEC framework
Calculation of distances	Distances provided by the user	If not provided by the users, distances are calculated with external routing systems	Own internal routing system or provided by users in the commercial version	Distances provided by the user	Own internal routing system
Reporting	CO_2e	CO_2e and PM_x	CO_2, CO_2e, NO_x, SO_x, PM_{10}, NMHC	CO_2e	CO_2e
Externalities costs	Not included	Not included	Included only in the commercial version	Included	Not included
Load Factor (LF), Empty Trip Factor (ETF)	LF and ETF can be sometimes selected between predetermined values	LF and ETF can be both set in the commercial version (in the demo version only ETF can be set)	LF and ETF can be set	**Not available**	Cannot be set

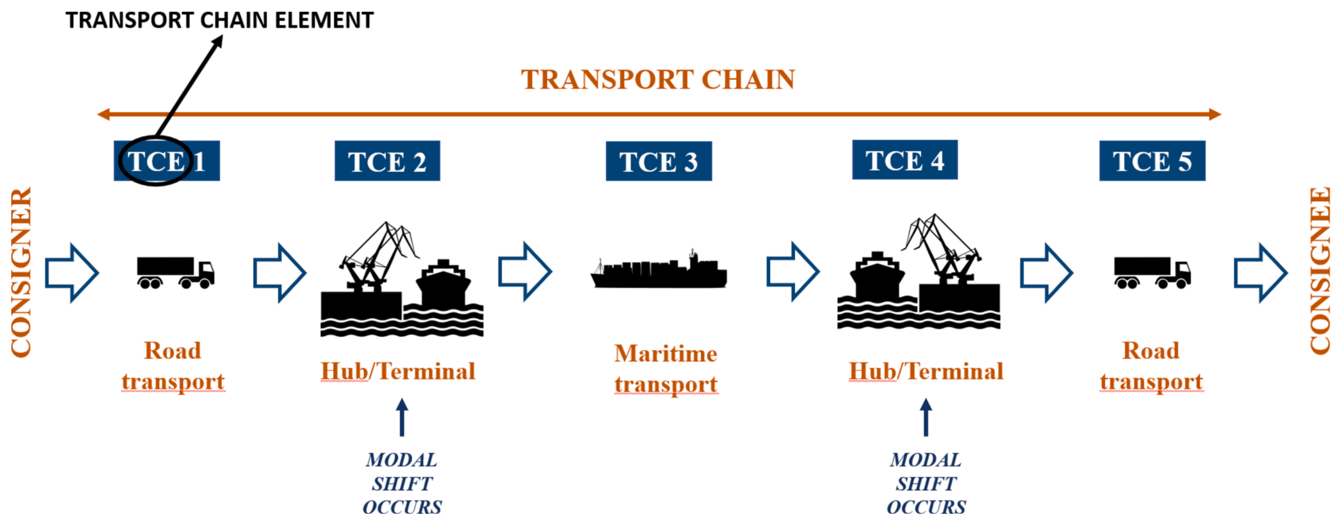


Fig. 3. Example of a transport chain and the related TCEs.

derived emissions by including the energy required for temperature control and any refrigerant losses in the calculation. The tool then requires input of the logistics site's geographic data, size, type of activity, and consumption broken down into: electrical, fuel, refrigerant, water, and steam/heat.

When the user is unable to provide the distances traveled while transporting goods, GreenRouter allows the user to use a built-in external routing system to estimate these distances.

GreenRouter includes the major modes of transport; only inland waterway transport is excluded. Emission intensity factors can be provided by the customers and the carriers that use this tool. Where this information is not available, it is possible to employ that provided by GreenRouter, which in turn is based on values provided by other users (GLEC and other sources). Information regarding the truck is requested for road transport vehicles: category according to the European emission standard, fuel used, percentage of empty trips, and other specific information.

As output of the emission calculation, GreenRouter provides: distance, total emissions, emissions per kilometer, total emissions divided by scope and by transport mode.

GreenRouter has been recognized by SFC as a tool in line with GLEC methodology and is EN 16258 compliant, certified by SGS (Sistema Gestione Sicurezza – Safety Management System).

There is no free version of the software but a trial simplified version limited in time is available upon request. The commercial version allows much more accurate calculations and has several modules that can be activated and partly customized according to companies' needs.

2.3.3. EcoTransIT

EcoTransIT World (ETW) ("EcoTransIT World – Emission Calculator," 2020) is an emission calculation software developed EcoTransIT World organization in 2010. It is approved by the Smart Freight Centre, as it follows the GLEC approach and it complies with the European standard EN 16258, the GHG Protocols. Its developers were part of the ISO working group.

ETW allows automatic calculation of emissions for a complex logistics chain, including all modes of transportation. The tool is not limited to emissions attributable to transportation but, it also allows calculation of those allocable to logistics buildings, which are necessary to be compliant with the GLEC methodology and the new ISO 14083 standard.

For GHG emissions, the composition of the fuel used is taken into account; biofuels specific to only certain regions are also considered. As for the pollutants released into the atmosphere, the emission class of the vehicles used is taken into account.

ETW provides two modes of data input: standard and extended. In the former, the user enters only: the weight transported, the mode of transportation mainly used, and the points of departure and arrival. In the Extended version, detailed values can be entered such as departure and arrival coordinates and all modes of transportation used with specific information related to each. With this information, the algorithm automatically calculates: the route of the different modes, transshipment support points and forced stops according to the voyage, which is particularly relevant for air travel. In addition, the composition of fuels used is defined as a function of the route and expected refueling. Additional inputs include the percentages of empty trips and the eventual presence of products that need to be transported at controlled temperatures. EcoTransIT is the only tool that allows the input of data concerning the possible reduction of travel speed for maritime transport aimed at reducing fuel consumption and thus emissions. During the data entry phase, the software automatically proposes the most commonly used vehicle and energy source model depending on: laws and regulations in force, weight transported, route to be covered (it takes into account, for example, the fact that some ports allow entry only to ships using a certain fuel category).

ETW provides the sources that are used to compute the calculations such as: Handbook for Emission Factors (MOVES) and International Maritime Organization (IMO).

In addition to the emissions required to comply with ISO 14083, ETW also considers the energy required to change transport mode. These changes are categorized according to the operations, hence the energy, required. These shifts are classified according to the operations, hence the energy, required. These categories are evaluated according to how the goods are transported: by container, liquid cargo, bulk cargo or other types. The values considered are as a result of the IFEU (Institute for Energy and Environmental Research) study considerations. All operations, by assumption, are performed using electricity as the source.

The tool results in both energy consumption and GHG emissions as CO_2e, both WTW, subdivided for the different modes of transportation involved.

The free version of the tool was used for the present research. The commercial version is more comprehensive in terms of the level of detail of the data that can be provided by individual companies with a consequent increased accuracy in the results obtained.

2.3.4. TK'Blue agency

TK'Blue is an agency "TK'Blue," n.d.), created in 2012 in France, that supports clients in choosing the best logistics provider.

Carriers (aka logistic providers) are evaluated using four indexes:

1. the TK'T index, which reflects the efficiency of the vehicles used and their performance status while also taking into consideration the skill of the drivers;
2. the GHG index that allows compliance with the Grenelle law (No. 2017–639), the European standard EN 16258 and the GLEC methodology. For this index, carriers must provide the data needed to calculate emissions (some of these data are also needed for the calculation of the first index, such as vehicle usage status). The data provided are then verified by the association and categorized according to their reliability (primary data, modeled or defaul);
3. index TK'CSR which measures the carrier's CSR (Corporate Social Responsibility) initiative using the French ministry's standard. which measures the carrier's CSR (Corporate Social Responsibility) initiative using the French ministry's standard;
4. index TK'Ext which allows calculating the cost of negative externalities such as traffic congestion, delivery delays and many other factors. This enables evaluation of the beneficial impact, in monetary terms, of the improving actions that are implemented such as the use of more efficient carriers or the adoption of less environmentally disruptive modes of transportation. For each transportation mode deployed, an analysis is provided listing the social costs and benefits obtained as a result of the choices implemented.

In addition, customizable tables and charts are made available to users, highlighting the most relevant information. The information provided is organized into five levels: by transportation methodology, by origin, by destination, by carrier, and finally by month.

This tool, in the free version requests as input data: weight of the cargo, delivery distance, type of vehicle including its category (for example Ro-Ro vs RoPax ships), whether the transport is considered as fully loaded or not and the performance level attributed to the carrier (low medium and high).

The free version of the tool was used for the present research. However, this version in not available anymore but a demo version can be requested.

2.3.5. Route scanner

Route Scanner ("Routescanner – worldwide container shipping platform," n.d.) was developed by the Port of Rotterdam in 2022 and it is a different tool from the others considered, as its main purpose is not to calculate emissions or other externalities. Route Scanner is a container schedule routing engine that aims to optimize the supply chain while minimizing externalities such as emissions but also lead times.

The tool requires: origin, destination, departure date, last arrival date, and mode of transportation you are willing to use. Air transport in not included. Route Scanner provides CO_2e emissions for each mode of transportation used along with all the necessary information about the specific services to be used, distances traveled, and partial and total lead times, sourcing directly from more than 233 operators.

Regarding sustainability, the calculated solutions can be sorted by minimum CO_2e missions. Moreover, Route Scanner is GLEC-accredited and ISO verified.

3. Comparative analysis

The 5 selected methods/tools were compared according to the following parameters (Table 1):

a) ***Transport modes***: indicates which transport modes can be included in the multimodal transport;
b) ***Logistic hubs***: indicates whether transshipment operations are included in the calculation as required by the ISO 14083 standard;
c) ***Allocation units***: indicates which unit of measure is used to allocate emissions such as weight, volume, TEU;
d) ***Accounting for fuel emissions***: indicates the emissions segment (TTW or WTW) that is considered by the instrument;
e) ***Default data***: indicates how data that are not directly provided by the user are calculated or where they are sourced;
f) ***Calculation of distances***: indicates how the distances traveled were calculated in case they are not provided by the user;
g) ***Reporting***: indicates which parameters are included in the final report (CO_2e, pollutants such as particulate etc.);
h) ***Externalities costs***: indicates whether the tool includes a note about calculating the impact, in economic values, of certain externalities such as noise, congestion, accidents and others.
i) ***Other useful data***: includes information about additional data that can be provided for a more accurate calculation of emissions (such as empty returns, load factors etc).

Logistics hubs are a source of non-negligible emissions within intermodal freight transport. For this reason, the ISO 14083 standard requires the inclusion of these emissions in the total calculation, and the GLEC methodology accordingly provides information and data to make their calculation possible. Neither GreenRouter nor EcoTransIT include this functionality in their free or demo versions.

The distance traveled is a key figure in the computation of emissions and is calculated differently depending on the means of transportation used. The GLEC methodology, provides the user with precise guidance on how to determine distances along with emission factors for different types of logistic sites. Both EcoTransIT and GreenRouter allow the user to accurately enter the starting and ending locations of the individual legs traveled; it is also possible to enter the precise coordinates. GreenRouter provides an estimate of the associated distances but it is also possible to enter the distance traveled independently if the user is able to provide it. EcoTransIT has its own internal routing system. In addition, for the subsequent emission calculation, this routing system creates route sections depending not only on the means of transport used (road, sea, rail) but also considering the specific characteristics of each route. For road routes, for example, urban, country road or motorway sections will be considered separately since emissions vary depending on the type of road. Similarly, rail routes will be divided into sections according to the type of traction affecting that area (electric traction or diesel traction).

In terms of reporting, all tools allow calculation of total CO_2e emissions. Some tools such as EcoTransIT, report other types of emissions along with the particulate matter figure.

Another useful piece of data provided by many tools is external costs, which help to assess the sustainability of a transport not only from the perspective of GHG emissions. TK'Blue provides an estimate of external costs related to accidents, pollution, noise and congestion. Other tools such as EcoTransIT provide an estimate of external costs deemed useful, but only in the commercial version.

Additional data such as LF and ETF can also significantly affect the final result. EcoTransIT allows to precisely set these data if they were available to the user, otherwise, the tool will suggest default data calculated on a statistical basis. GreenRouter allows, in the demo version, to set the ETF value while as for the LF it considers standard values depending on the type of goods selected for transport (light, average, heavy, container). However, in the commercial version of GrrenRouter these parameters can be both set, if available.

4. Case studies

To better compare the 5 selected tools, all of them was used to compute the emissions for 2 case studies (Table 3):

- case A consists of several scenarios, each of which involves the use of different modes of transportation summarized in Table 3. The transport starts from Turin and has as its final destination the Zaragoza intermodal terminal. For this first case, it was decided to transport a 16-ton load using a semi-trailer as the loading unit,

Table 3
Case studies.

Case Studies	From	To	Routes and Transport Modes			Quantity Transported	Loading Unit
			Road	Rail	Sea		
CASE A1	Turin	Zaragoza	Turin- Busto Arsizio Barcelona-Zaragoza	Busto Arsizio-Barcelona	–	16 tons	semitrailer
CASE A2	Turin	Zaragoza	Turin-Genoa Barcelona-Zaragoza	–	Genoa-Barcelona(RO-RO)	16 tons	semitrailer
CASE A3	Turin	Zaragoza	Turin-Genoa Barcelona-Zaragoza	–	Genoa-Barcelona(RO-PAX)	16 tons	semitrailer
CASE A4	Turin	Zaragoza	Turin-Zaragoza	–	–	16 tons	semitrailer
CASE B	Turin	Singapore	Turin-Genoa	–	Genoa-Singapore (Containership)	16 tons	40′ container

considering both intermodal transport and the solution of all road transport:

1. case A1 consists in a road-rail transport;
2. case A2 consists in a road-sea transport considering a Ro-Ro ship;
3. case A3 consists in a road-sea transport considering a Ro-Pax ship;
4. case A4 involves only road transport.

- case B involves the transport of 16 tons using a 40′ container (equivalent to 2 TEUs), originating in Turin and ending in the port of Singapore. From Turin to Genoa it is used road transport, while the leg Genoa-Singapore is carried out by sea using a container ship.

Fig. 4 shows and compares the different routes related to case study A according to the transportation modes used in the different scenarios analyzed.

Table 4 provides some additional data that were entered as inputs to the emissions calculation. As also specified in Table 1, not all tools gave the option to input data such as LF or ETF. Regarding the type of transport means used (such as type of container carrier or type of RORO or RoPax), depending on the database made available, it was possible to choose similar but not perfectly equal vessels.

4.1. Results for case study A

Fig. 5 summarizes the results obtained for the different scenarios of case study A. For scenario A3 it was not possible to calculate CO_2e emissions using EcoTransit because the free version of the tool does not allow calculation in the case of using RoPax. For case A it was not possible to use Route Scanner since the transport was not containerized.

Fig. 5 shows that the highest emissions are found when RoPax (A3 case) is used for sea transport. RoPax vessels (A2 case), in comparison with RoRo vessels, are much more pollutant since space and services dedicated to passengers – from accommodation to air conditioning – are very significant and causes an increase of emissions. Note that the ISO 14083 has determined a new way to allocate emissions between freight and passengers in this Ro-Pax vessels (Zis et al., 2020). The lowest total emissions are found instead when rail transport is used (A1 case), which is in fact considered the most sustainable mode for freight over the distance of about 1,000 km. Interestingly, the A2 (Ro-Ro) and A4 (all road) cases turn out to be very similar in terms of CO_2e emissions. This is due to the fact that, compared with container or bulk vessels, cargo density on RoRo vessels is lower, as a lot of space remain unused (in between every transport unit both horizontally and vertically).[2]

Fig. 6 shows that for road transport, the results obtained are very similar to each other except for the A4 case where TK'Blue has a lower value than the others.

In contrast, for rail transport, the results are very different from each other and there is a substantial variation in the data obtained with GreenRouter (−68 %) and EcoTransIT (−83 %) compared to the calculation with the GLEC methodology (Fig. 7).

Regarding maritime transport, when using a RoRo vessel (Fig. 8 (a)), EcoTransIt returns a value very similar to that calculated with the GLEC methodology, while GreenRouter provides again a higher value, 30 % higher than the GLEC value. As regards maritime transport with a RoPax vessel (i.e., a vessel transporting goods and people), due to the limitations posed by the tools used, it was possible to perform the calculation only with GLEC and GreenRouter. Also, in this case again GreenRouter provides a value about 30 % higher than the GLEC one (Fig. 8 (b)).

4.2. Results for case study B

Fig. 9 shows the results provided by the 5 tools when calculating the total CO_2 emissions for case study B.

Once again GreenRouter report the highest figure while TK'Blue the lowest. The other tools report similar values compared to the GLEC ones.

All the models used refer to the most common standards, derived from the GHG protocol. Some of them had adopted national standards where available, and all have evolved to ISO14083 as from the moment this standard has been published. TKBlue calculator was originally intended to qualify the degree of sustainability for road transport fleets. The comparisons shown in this study were made before the introduction of the ISO14083 standard and therefore the results show differences in some cases. As soon as the standard has been published the different engines adopted similar or the same algorithms. It is still possible, however, to obtain slightly different results depending on the assumptions taken by different models in considering specific kind of means of transport, or specific routings, or empty running percentages, load factors, etc.

When the emissions for the two transport modes used (road and sea) are analyzed separately, the emissions for road transport are very similar to each other and only slightly higher than the GLEC value (Fig. 10 (a)). As for sea transport (Fig. 10 (b)), once again a higher value is confirmed when using GreenRouter (+46 % compared to the GLEC result).

5. Discussion

The analysis of the results obtained by comparing the selected tools/methodologies highlights that, since they all comply to the ISO 14083 standard, comparable results are obtained although with some differences.

Some case studies related to different transport combinations have been tested using the selected tools and compared using a *low-medium–high* scale with respect to the GLEC methodology and ISO standard:

- flexibility of the tool with respect to user needs;
- accuracy of obtained results;
- degree of user-friendliness of the tool.

Table 5 reports the results of this comparison.

[2] Note that these results refer to a computation made in September 2023. In the meanwhile many tools have been updated in order to take into account of less pollutant RoRo ships. Therefore, nowdays, CO_2e emissions produced by road legs are higher than those produced in RoRo vessels legs.

Fig. 4. Scenarios A1, A2-A3, and A4.

Table 4
Additional data used in the case studies.

Features	CASE A	CASE B
Weight/TEU	16tons	16tons/2TEU
Type of goods (light/ standard/heavy)	standard	standard
Road transport features	Diesel/Euro 5	Diesel/Euro 5
Sea transport features	RORO-trailer onlyHFO (Heavy fuel oil)	HFO (Heavy fuel oil)
Load factor	60 %	60 %
Empty Trip factor	30 %	30 %

The commercial version of GreenRouter is quite flexible whereas the demo version presents some limitations (Table 1) which translate in less accuracy. The level of user-friendliness for the commercial version is deemed medium level since a training period is required.

The level of flexibility and accuracy of EcoTransIT's vary significantly whether the free or the commercial version is used. The commercial version allows for more detailed data entry and provides a wider range of transportation means to choose from. The degree of user-friendliness is high because the software is easy to use even for inexperienced users, even if a training period may be needed for the commercial version.

TK'Blue was found to be averagely flexible and accurate although some data were not comparable because the tool only reports the total emission figure during transport. In addition, TK'Blue almost always gives lower results than the other tools, maybe due to the way that data are provided.

Route scanner was found to be very easy to use and accurate. This is a consequence of the fact that the primary objective of this tool is not to calculate emissions but to organize transportation by minimizing CO2e emissions or lead time, depending on the user's preference. To do this, Route scanner makes use of precise and specific data provided directly by those providing the transportation service. On the other side, this results in a low level of flexibility because the user cannot set precise transport legs but can only choose from the different alternatives provided by the tool. Another disadvantage is that Route scanner only covers containerized goods transport.

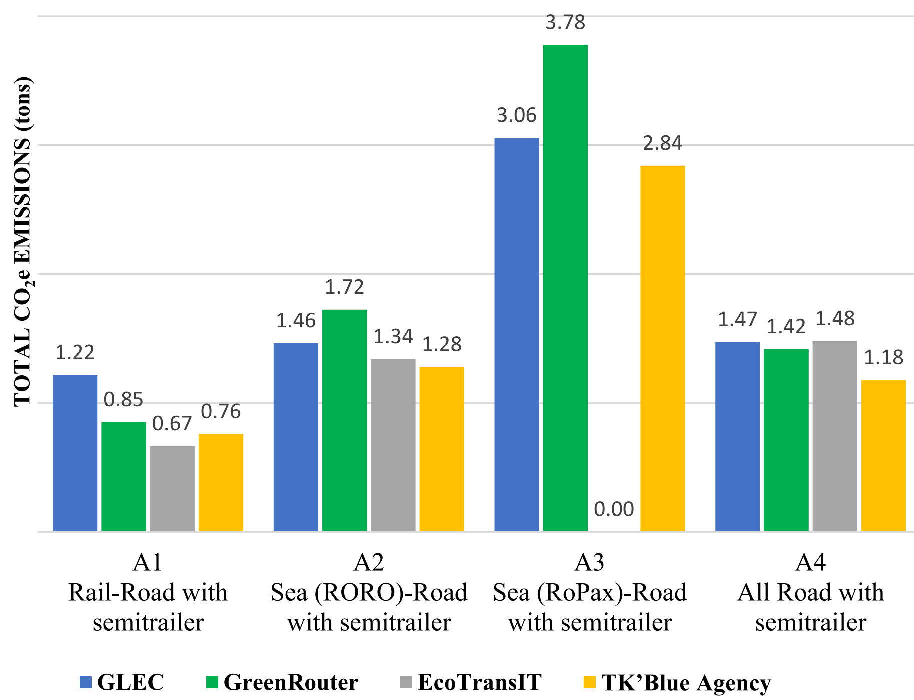


Fig. 5. Total CO_2e emissions for case study A.

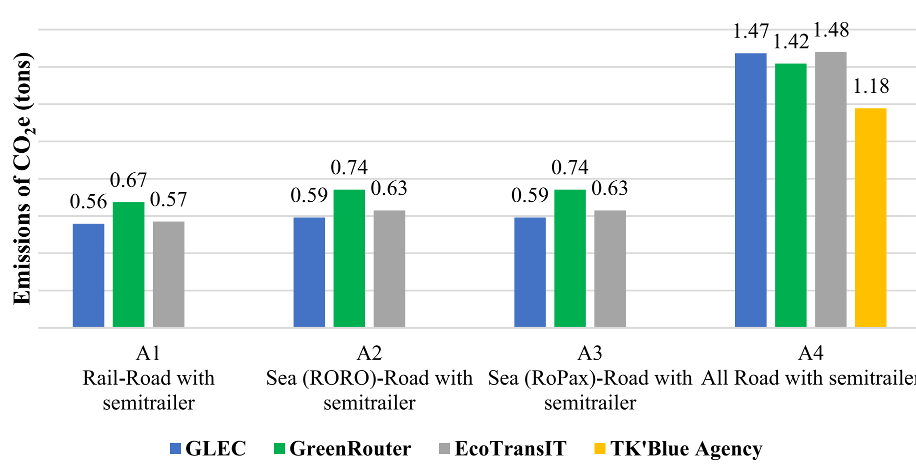


Fig. 6. CO_2e emissions for the road transport leg.

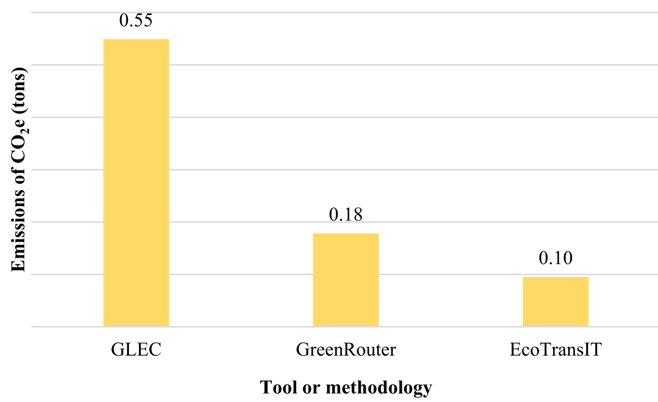


Fig. 7. CO_2e emissions for the rail transport leg (case A1-Rail-Road with semitrailer).

Emissions related to logistics hub activities are not always included in the calculations provided by the selected tools despite the fact that the ISO 14083 standard requires them. This can lead to underestimated emissions since transshipment activities are the source of a non-negligible share of emissions and other negative externalities.

It is also important to consider how the distances traveled are calculated, as this is a key parameter. As mentioned in the previous paragraphs, for road transport, routing systems normally provide the minimum distance traveled given a starting point and a destination point. However, it may happen that for various reasons road transport follows a different route or has some restrictions: providing the actual data would help to be more accurate.

Regarding the input dataset (Section 2.2), data required to calculate emissions should be collected as accurately and reliably as possible, but this is not always a simple process. When the transportation of goods is insourced, primary data are used, i.e. the amount and typology of fuel. A vehicle's fuel consumption is influenced not only by the route and weight carried but also by the general condition of the vehicle itself, driving style, traffic levels, and other external factors. In order to calculate emissions, it is also essential to be aware of the fuel mixture that was used on the different legs of the route. In addition, if the WTT emissions are to be calculated, it must be aware of how that fuel was produced and transported, i.e., the source of energy used.

When the transport is outsourced, i.e., performed by a third party, it is necessary to use secondary data, which makes the calculation of the total emissions of the transport less precise. To reach a good accuracy of the calculation, it is necessary to have access to: the distances travelled, the weight of the goods transported, the type of the vehicle used, routing and condition of the vehicle.

6. Conclusions

Considering the increasing attention on environmental sustainability and decarbonization aspects, it is nowadays crucial for companies and organizations to measure and declare CO2e emissions coming from logistic chains ("Corporate sustainability reporting – European Commission," n.d.).

Calculations by the current available tools are made in a way that facilitates reporting of CO2e emissions and, secondly, verification by certification bodies. When primary data are not available, secondary data (modeled or standard) have to be used: in this case, online tools can of help in calculating CO2e transport and logistics emissions.

The goal of the present research was to compare the most commonly used online tools to assess CO_{2e} transport emissions, according to the GLEC methodology, with the final aim of providing a support to companies which need to assess CO_2e emissions related to transport and logistics services.

The results obtained show slight differences between the selected tools and highlight that the final figures primarily depend on the quality of the data provided for the calculation.

Based on the research conducted, there is no one tool that is clearly superior to the others, so the choice of tool may vary depending on the specific needs of the user.

Further research could be devoted to comparing commercial versions of the selected tools, including newly available online instruments such as Pledge ("Sustainability solutions built for freight forwarders," n.d.).

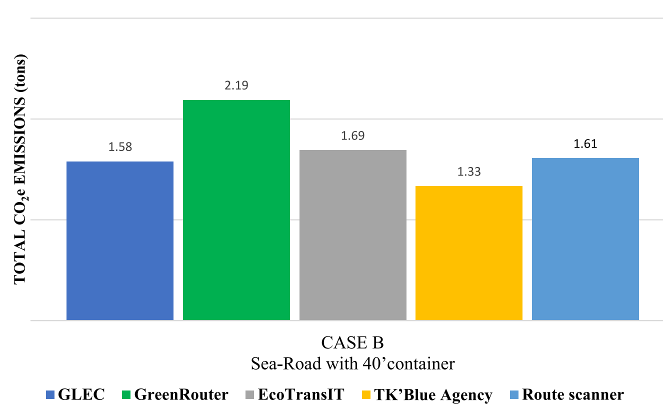


Fig. 9. Total CO_2e emissions for case study B- Sea-Road with 40′container.

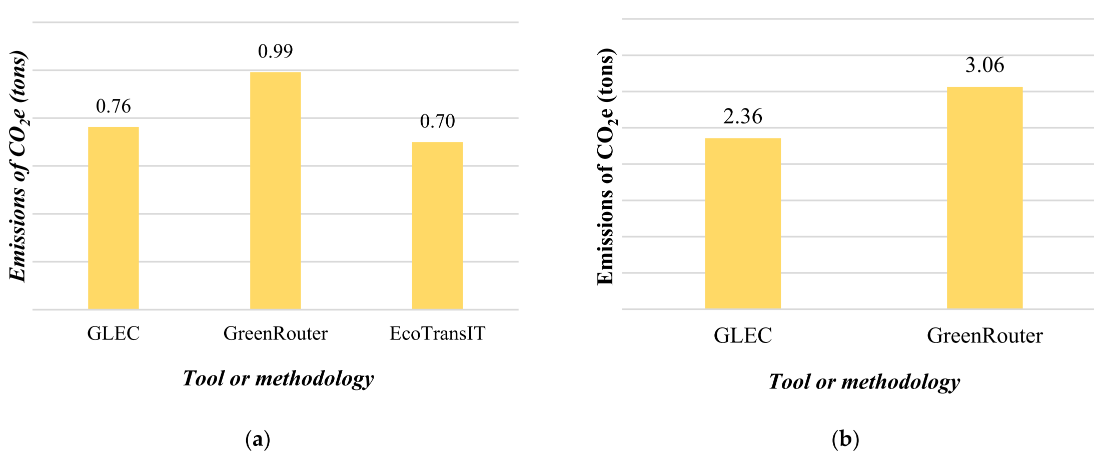
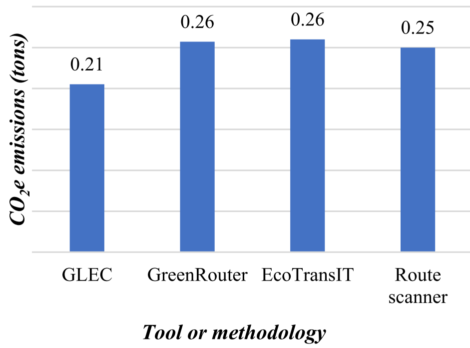
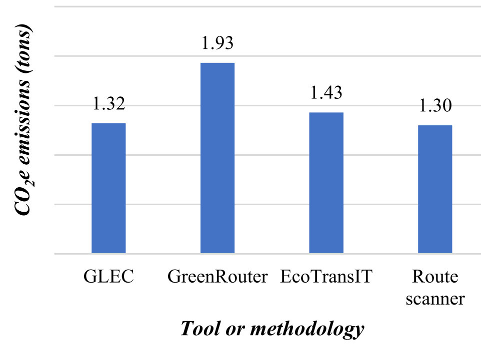


Fig. 8. CO_2e emissions for the sea transport leg using (a) a RoRo ship and (b) a RoPax ship.



(a)



(b)

Fig. 10. CO_2e emissions for (a) road transport and (b) sea transport leg using a containership.

Table 5
Comparison of the tools/methodologies selected in terms of flexibility, accuracy and degree of friendliness.

Characteristics	Tools			
	GreenRouter	EcoTransIT	TK'Blue	Route scanner
Flexibility	Medium (demo version)High (commercial version)	Medium (free version)High (commercial version)	Medium	Low
Accuracy	Medium (demo version)High (commercial version)	Medium (free version)High (commercial version)	Medium	High
Degree of user-friendliness	Medium	High	Medium	High

CRediT authorship contribution statement

Erika Olivari: Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Claudia Caballini:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Xavier Lluch:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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