

The Logistic Carbon Footprint: A Dynamic Calculation Tool for an Indicator of the Sustainability of Logistic Processes with a Case Study on the Port of Trieste

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Abstract. Quantifying the emissions produced along different supply chains is an extremely difficult challenge. However, carbon-based emissions generated by the transport sector have an extremely significant impact on environmental sustainability.

To address these issues, we propose a method for estimating the carbon footprint as an indicator of the environmental sustainability of processes as it represents the total emissions produced within a given process.

Therefore, the first problem we come across is developing a tool for calculating the logistic carbon footprint, which clearly defines the boundaries of application of the model and its scope of application. For this reason, the proposed tool will follow a standardized and uniform approach in order to streamline the calculation processes and make it even more efficient: the sources of emissions related to a supply chain are innumerable, so depending on the different approaches to calculating emissions, they can lead to extremely different results. In order to streamline the calculation process, the main sources of primary emissions and indirect emissions due to the supply of fuel oil have been used in a preponderant manner, and then an adjustment factor that takes into account all factors omitted from the model has been introduced. In this way, the calculation of the carbon footprint has been made uniform, homogeneous, and comparable as well as quantitatively reliable.

Once the method of elaboration of the carbon footprint is framed, we will proceed to use this synthetic indicator for the analysis of environmental sustainability for different logistic processes that consider the Port of Trieste as an intermodal exchange hub for intra-Mediterranean traffic and with destination the main markets of continental Europe, taking into account different modes of transport: road, rail, and maritime transport.

Keywords: Carbon footprint · Logistics · Maritime transport · Sustainability

1 Introduction

The World System is a complex set of delicate balances in relation to each other within which fall the geographical, social, and economic dynamic aspects. The network of

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increasingly dense interconnections on a global scale involves a reduction of physical distances, which is reflected on the intensification of the flow of people, goods, knowledge and capital, through processes and innovations faster and faster.

It is therefore clear that the environmental aspects closely linked to the relationship between human activity and geography, take on an increasingly central role. The two lines that traveled on parallel tracks in terms of economic activity and environmental sustainability, have begun to diverge over the last decades. Hence the need for a careful and concrete assessment of pollutant emissions produced by economic activity, focusing in this case on pollutant emissions from logistics processes.

We can therefore introduce the concept of Carbon Footprint as a synthetic indicator of greenhouse gas emissions generated by a given process, expressed in terms of equivalent CO_2 [1]. This paper proposes to concretely define an approach to the calculation of the logistic carbon footprint, following an innovative approach that is both quantitatively correct and follows a standardized approach, aimed at obtaining comparable estimates of the pollutant emissions [2]. The proposal presented in the following article stems from the ambitious desire not to limit oneself to quantifying the emissions produced in the context of a supply chain, but to define a standardized and uniform calculation tool that can be used regarding two different targets: the first relates to the numerical quantification obtained through an estimate as accurate as possible, and the second relates to the criterion of comparability, using a standardized criterion of evaluation of the greenhouse gases emission as a parameter to take strategical choice [3].

To this aim, the emission factors deriving from intermodal transport will be accurately outlined, then moving on to a concrete evaluation of the pollutants produced by the movement of goods, highlighting not only a quantitative evaluation but also the uniform approach to calculation adopted for an evaluation of the Carbon Footprint to make the proposed effective standardize and comparable.

Calculating the Carbon Footprint is therefore equivalent to carrying out a single issue of the life cycle of a process, that is developing a life cycle study for a single impact category [4]. Every change in the logistics sector of the production chain has a direct effect on greenhouse gas emissions. GHG emissions mainly depend on the energy produced by the combustion of hydrocarbons, which are used in heat engines for various purposes. It is estimated that the logistics sector of transport generates approximately 28% of total greenhouse emissions each year, so in this context the study of the emissions produced by the logistics chain and the policies to limit some of them represent an extremely topical and debated issue [5].

2 Materials and Methods

The Carbon Footprint is a measure to quantify the total greenhouse gas emissions directly associated with a product, an organization, or a service. It represents an indicator for monitoring the effectiveness of environmental management policies through the preparation of what is known as an "emission inventory" [6].

Each of the greenhouse gases considered is weighted for its specific contribution to the increase in the greenhouse effect relative to that of CO_2. We can then define the Global Warming Potential - GWP of greenhouse gas, where GWP indicates the peculiar

characteristic of a gas such as the warming power of the atmosphere compared to that of carbon dioxide, which by definition is set equal to 1. The climate-changing power of gas is expressed in terms of equivalent carbon dioxide. The Carbon Footprint is the environmental indicator expressed in terms of equivalent CO_2 that allows measuring the emissions of Greenhouse Gases - GHG associated directly or indirectly with a process, a product, or a service. In particular, the Carbon Footprint is a measure of how much CO_2 a given production and consumption system emits in its entirety. It is therefore a quantitative definition of greenhouse gas emissions and is an increasingly central tool in the management of corporate strategies on the environment and sustainability of economic processes and, in this case, logistics [7].

The normative notions that regulate the Carbon Footprint and allow its reporting are, at an international level, the standards ISO 14064:2006, later updated in 2019 with regard to the Carbon Footprint of a process, and the GHG Protocols proposed by the World Resources Institute (WRI). The objective of these normative references is to create common standards for the measurement and comparable quantification of product or process greenhouse gas emissions.

The ISO 14064 standard divides emission sources into three different categories (Table 1):

Table 1. Emission sources categories – Source: Personal Elaboration, [8]

Direct GHG emissions	This category includes all emissions generated directly by production activities, which are therefore strictly related to the use of fossil fuels: all activities that require thermal or electrical energy are therefore included in this category
Indirect GHG emissions	Emissions deriving from energy consumption: in this case, emissions produced during the production process, but deriving from third-party energy sources that are not relevant, are considered
Other indirect emissions	Includes all emissions not categorized in the two previous areas

The GHG Protocols follow hand in hand what is expressed by the ISO 14064 standard, outlining the three previous different profiles of emissions that will be called 'scope': scope 1: direct emissions, scope 2: indirect emissions, scope 3: other indirect emissions.

Moreover, it is important to underline that in the GHG Protocol emission reports and for the Standards ISO 14064 the drafting of scopes 1 and 2 are mandatory, while scope 3 is optional and not binding [8–10].

2.1 The Logistic Carbon Footprint

We will now introduce the Carbon Footprint for logistic processes: all those operations directly related to the movement of goods from the place of production to the final destination. The idea is to formalize a model capable of defining a standardized approach to calculating the carbon footprint of a logistics chain, articulated through various modal

shifts. The core of the logistic chain is represented by maritime transport, the leading sector of international trade, while at the top and the bottom of this process the movement of goods takes place by different means of transport: rail and road. Ports represent the fundamental connection points for these processes [11]. Every year, the logistics sector is responsible for 27% of total greenhouse gas emissions: the study of the carbon footprint of these processes is of primary importance in the reduction of emissions, especially considering the current macroeconomic scenario, increasingly globalized and interconnected [12].

To evaluate the GHG emissions of a logistic chain, we will have to carry out a preliminary analysis of the main ways of transport used, starting from the different categories of ships used in the shipping sector and then focusing our attention on road and rail traffic. We are not going to consider air freight because it is a relative niche sector in terms of volume. After an initial overview of the vehicles, it will be essential to study the heat engine and the energy required in order to define the number of emissions produced. From here, we can proceed to calculate the direct emissions resulting from a logistic process that includes the three modes of transport mentioned above: road, rail, and ship. In this context, we will then go on to calculate the direct and indirect emissions attributable to Scope 1 and Scope 2 of the GHG Protocol for activities carried out in a port environment [6].

The calculation model presented will take into account the main elements of the logistic chain related to the different transport modes. However, to follow a standardized approach to calculation, an adjustment factor of 5% attributable to direct emissions and 2% attributable to indirect emissions will be introduced, taking into account all exogenous factors such as tides, traffic conditions, adverse sea currents, tire wear, etc., as well as relatively negligible emission factors and, also, relatively negligible emission factors such as handling operations in the various intermodal hubs as these operations will be considered within the adjustment factor. It is clear that in the quantification of the logistic carbon footprint many factors can have a slight impact on the quantification of emissions: it is, therefore, necessary to clearly define the boundaries of the model within which to calculate the carbon footprint in order to obtain a model that is qualitatively correct and at the same time applicable to different realities.

Maritime transport is the most important channel for international trade: it is estimated that more than 80% of the global volume of goods, including food, fuel, construction materials, chemicals, and household goods, is transported by sea, with more than 90,000 commercial vessels plying the world's oceans [13, 14].

We will then proceed to analyze the different types of ships categorized based on their cargo capacity to initially analyze consumption and then climate-altering gas emissions [15].

In order to quantify the emissions of the naval segment, we will start from the different types of vessels, taking into account the engine power (expressed in kWh) and assuming an energy efficiency of 70% of the main engines during navigation, while for roadstead and dockside operations the exclusive use of auxiliary engines at 100% energy efficiency is foreseen. This hypothesis will allow us to quantify the average hourly consumption of the different types of ships. Once the consumption produced by the fleet

under analysis has been evaluated, it will be possible to convert consumption into the volume of greenhouse gases produced [14].

To calculate the greenhouse gas emissions produced by the maritime segment we will use two different approaches: the first based on the energy used in terms of kWh, able to express the emissions in terms of *g pollutant* /kWh and a second referred to the effective fuel consumption [1].

In order to elaborate a carbon footprint covering the whole logistic chain, the analysis of emissions from road freight transport is essential. In this section, we will define the essential tools for the calculation of greenhouse gas emissions from combustion of heavy-duty trucks. For this reason, estimates will be made on an average sample, considering the most used vehicles for this application [17].

In order to evaluate the diesel consumption of the circulating vehicle fleet, we have used the "Handbook emission factor for road transport (HBEFA)" [15], a Microsoft Access database that shows the emissions and fuel consumption for all categories of circulating vehicles, based on a sample of over 50 thousand different vehicles.

From an elaboration of this information provided the table has been created about the volumes of emissions and average consumption for the circulating fleet, divided by weight [3]. The information provided therefore allows us to calculate in an extremely simple and direct manner the fuel consumption and GHG emissions for each route depending on the type of vehicle used [15].

Concerning the information obtained from the "Handbook emission factor for road transport (HBEFA)", the official estimates made by Isprambiente (Institute for environmental protection and research) report that for every gram of diesel consumed, an average of 3.16 g of carbon dioxide are produced. We can then compare the emission estimates obtained from the HBEFA database against the CO_2 average emissions for the trucks under analysis [1].

The third mode of transport that we will consider for the calculation of emissions from the supply chain is rail transport [26]. The main indicator for calculating energy and emissions from rail transport comes from the energy consumed based on the net weight of the train. For this analysis, the basic assumption is that in almost all situations, locomotives powered by electric motors are used to move goods by rail. As a consequence, direct emissions of greenhouse gases will be insignificant [19].

For this analysis, we will consider different categories of trains, defined according to their load capacity. The average size of freight trains in Europe is 1,000 tons. Freight trains can therefore be divided into different categories according to their maximum load volume.

For the calculation of emissions from the railway sector, we will therefore have to analyze the indirect emissions. This is the set of emissions falls into the producing of energy used to power the electric motors of locomotives [20, 26]. For the railway sector, it is, therefore, possible to estimate the energy consumption in terms of *kWh/t-km* and consequently, the carbon dioxide emissions produced expressed in *kg* CO_2*/t-km*. It, therefore, becomes necessary to further emphasize how greenhouse gas emissions from locomotives powered by an electric engine are indirect emissions resulting from the "well to wheel" process, thus generated indirectly for the supply of electricity consumed. For

the rail transport we will take into account both the direct and indirect factor of adjustment of 5 and 2%, due to reach a more precise estimation [21].

In addition to the direct emissions produced by the engines, the calculation of the Carbon Footprint for the logistics chain also includes indirect emissions: the class of emissions that cannot be directly attributed to the production process under analysis, but which derive from activities connected to it: in particular, for the logistics chain that is the subject of this study, emissions deriving from the production of electrical energy and the supply of essential fuel oil within the transport chain fall within this scope [1]. Generally, these emissions fall within scope 2 of the GHG Protocol, but it is worth remembering that an increasingly significant percentage of the electricity produced and used in the port comes from renewable sources [20].

It will be essential to study the entire life cycle of diesel fuel, from the processes of extraction, processing, refining, storage, and final distribution of the fuel, to evaluate the indirect emissions of a logistics chain, in which the movement of heavy vehicles and therefore the use of fuel oil is of primary importance. Generally, this process is called "From Well to Tank" (WTT) [22]. Focusing on the "Well to Tank" process, the diesel production chain must be considered. The problem to be faced now is to calculate the energy used starting from the extraction of the primary source, oil from the oil well, up to making it available as fuel for the thermal engines used within the supply chain. The emissions of the WTT process will be 645.17 g CO_2 eq/kg of fuel [15].

3 Data

In the previous paragraph, the calculation methodology for structuring the carbon footprint analysis for a chain was proposed.

Therefore, starting from the naval segment, it will be fundamental to subdivide the maritime transport segment starting from the different types of ships used and then quantify consumption as shown in the following tables [14] (Tables 2 and 3):

Table 2. Ships types by category – Soruce: Personal Elaboration, [14]

Ship by category	Class by size	Unit of measurement	Gross weight average (in tons)	Average engine power (in kW)	Average speed (in knots)
Bulk carrier	0–9.999	DWT	3.313	1.687	9,9
	10.000–34.999		28.455	7.112	11,6
	35.000–59.999		54.546	9.548	12,2
	60.000–99.999		81.713	10.989	12,3
	100.000–199.999		198.060	18.997	12,7
	200.000–+		284.595	22.740	12,8

(*continued*)

Table 2. (*continued*)

Ship by category	Class by size	Unit of measurement	Gross weight average (in tons)	Average engine power (in kW)	Average speed (in knots)
Container	0–999	Teus	9.080	6.182	12,7
	1.000–1.999		21.520	13.152	14,5
	2.000–2.9999		37.478	22.640	16,2
	3.000–4.999		58.072	39.328	17,2
	5.000–7.999		81.168	52.556	17,5
	8.0000–11.999		119.058	57.901	17,9
	12.000–14.500		149.023	61.231	17
	14.500–19.9999		178.871	60.202	16,4
	20.000–+		195.615	60.241	16,3
General cargo	0–4.999	DWT	1.913	1.107	8,8
	5.000–9.999		7.534	3.471	10,4
	10.000–+		23.156	7.910	12,2
Oil tankers	0–4.999	DWT	2.781	1.414	8,9
	5.000–9.999		9.005	3.134	9,3
	10.000–19.999		20.338	5.169	9,8
	20.000–59.999		43.467	8.570	11,9
	60.000–79.999		72.401	12.091	12,4
	80.000–119.999		106.477	13.518	11,9
	120.000–199.999		154.878	17.849	12,5
	200.000–+		304.656	26.710	12,9
Ro-Ro	0–4.999	DWT	1.930	1.751	9,2
	5.000–+		11.286	11.526	14,4

Table 3. Ships emission by category – Source: Personal Elaboration, [14]

Ship by category	Class by size	Unit of measurement	Average consumption (tons per day)	
			Main engine consumption	Auxiliary engine consumption
Bulk carrier	0–9.999	DWT	5,5	0,5
	10.000–34.999		17,6	0,5
	35.000–59.999		23,4	0,7

(*continued*)

Table 3. (*continued*)

Ship by category	Class by size	Unit of measurement	Average consumption (tons per day)	
			Main engine consumption	Auxiliary engine consumption
	60.000–99.999		28,8	1,1
	100.000–199.999		42,3	1,1
	200.000–+		56,3	1,1
Container	0–999	Teus	14,4	0,8
	1.000–1.999		26	2,1
	2.000–2.9999		38,5	3
	3.000–4.999		58,7	3,7
	5.000–7.999		79,3	4
	8.0000–11.999		95,6	4,2
	12.000–14.500		107,8	4,2
	14.500–19.9999		109,4	3,9
	20.000–+		108,6	3,7
General cargo	0–4.999	DWT	0,6	0,1
	5.000–9.999		1,7	0,4
	10.000–+		3,6	1,2
Oil tankers	0–4.999	DWT	4,3	0,6
	5.000–9.999		7,1	1
	10.000–19.999		10,8	1,6
	20.000–59.999		22,2	2
	60.000–79.999		31,4	1,9
	80.000–119.999		31,5	2,6
	120.000–199.999		39,4	3,1
	200.000–+		65,2	3,7
Ro-Ro	0–4.999	DWT	3,2	2,4
	5.000–+		7,2	3,7

Based on the information given in the previous tables, we will then consider the emission factors associated with consumption and power demand using the following emissions conversion table [2, 18] (Table 4):

Table 4. Different emission factors for shipping sector - Source: Personal Elaboration, [1, 14]

Emission factor:		gpollutant/gfuel	GWP-100
CO_2	Carbon dioxide	3,114	1
SO_2	Sulfur sulfide	0,05	-
Emission factor:		g/kWh	
N_2O	Nitrogen oxide	0,03	298
CH_4	Methane	0,2	25
CO	Carbon monoxide	1,04	1,8
PM10	Particulate matter	0,01	-

Using this information, it will therefore be possible to quantify the emissions of the shipping segment.

Also, for road transport, we will define an average estimate of consumption and emissions starting from the different categories of vehicles used according to their average weight and taking into analysis only articulated trucks of EURO 4 category or higher, that is meeting certain minimum standards in terms of energy efficiency. In this case, it will be possible to determine the emissions and consumption as follows [16] (Table 5):

Table 5. Rail transport consumption and emissions – Source: Personal Elaboration, [16]

Category	Average speed	Consumption. average		Emission factors				
				CO_2	CH_4	N_20	NOx	PM
Dimension	km/h	g/km	km/l	g/km				
<7,5	64,74	127,02	6,56	408,6	0,01	0,35	2,15	0,13
7.5–14	64,73	154,14	5,41	494,1	0,01	0,41	3,02	0,13
14–20	64,65	185,66	4,49	559,0	0,01	0,53	3,44	0,13
20–28	64,72	221,46	3,76	691,0	0,01	0,59	3,71	0,13
28–34	64,67	257,56	3,24	795,7	0,01	0,68	4,03	0,13
34–40	64,64	271,32	3,07	808,9	0,01	0,77	4,51	0,14
40–50	64,58	302,93	2,75	953,6	0,01	0,91	5,27	0,14
50–60	64,64	378,01	2,20	1183,2	0,01	1,29	6,58	0,14

Finally, the quantification of emissions about rail transport, which we recall falling into the category of indirect emissions, will be elaborated starting from the following estimates [19, 20, 26] (Table 6):

Table 6. Emissions per rail freight transport – Source: Personal Elaboration, [20, 26]

Type of train	Gross tonne weight train	Energetic consumption (kWh/t-km)	Energetic consumption (kWh/km)	Emissions (gCO_2/t-km)	Emissions (kg CO_2/km)
Light	500 t	1,1	701,8	22,8	14,5464
Average	1.000 t		1251,8		25,9464
Large	1.500 t		1801,8		37,3464
Extralarge	2.000 t		2351,8		48,7464
Heavy	5.000 t		5651,8		117,1464

Also, for rail transport different types of trainsets will be considered depending on their weight, where it will be possible to quantify the energy consumption in terms of *kWh-t-km* and emissions expressed in *kg* CO_2*-km.*

4 The Case Study: Carbon Footprint Estimate Through the Port of Trieste

In this case study, we are going to quantify the carbon footprint for the handling of a single TEU coming from the Far East, and more specifically from Shanghai with final destination at the Duisburg Freight Village, with a modal shift foreseen in the Port of Trieste where the container will leave for Frankfurt on a freight train, and then face the last step Frankfurt-Duinsburg by road [23].

To evaluate the Carbon Footprint deriving from these processes, we will have to segment the logistic process into three articulated phases:

- First phase: Ship transport from Shanghai to the Port of Trieste, handled through a large container ship, with a maximum capacity of 15,000 Teus and a load factor of 80%, with an average cruising speed of 16.4 knots per hour.
- Second Phase: Transport by rail with origin at the Port of Trieste and with a destination at the railway terminal of Frankfurt am Main, operated by means of a convoy assembled within the boundaries of the Port of Trieste, with a maximum length of 480 m, for a total of 24 wagons capable of carrying up to 48 Teus, with a load factor of 90%.
- Third Phase: Final handling of the container by road, leaving Frankfurt and with final destination Duisburg. We will have to consider in the basic assumptions the use of standard 20 feet containers with an average weight of 20 tons. In this case study we consider the freight village of Duinsburg as final destination by virtue of the agreements between the Trieste and Duisburg freight villages.

We will now go on to quantify the greenhouse gas emissions for each of these phases, starting with shipping [23].

To quantify the emissions deriving from the use of a large container ship for an extremely long route, it will be necessary to first analyze the route followed by the relative transit times and then evaluate the consumption [24, 25] (Table 7).

Table 7. Route Shanghai-Trieste, distance and transit time – Source: Personal Elaboration, [24]

Route Tianjin Xingang - Trieste			
Origin	Destination	Transit Time (hours)	Distance (NM)
Shanghai	Shekou	41	672
Shekou	Singapore	98	1.602
Singapore	Salalah	182	2.985
Salalah	King Abdoullah	72	1.183
King Abdoullah	Port Said	47	771
Port Said	Rjieka	83	1.364
Rjieka	Koper	8	127
Koper	Trieste	1	12
		Transit Time (in hours): 531	Total Distance (in NM) 8.716

To evaluate the emissions produced, it will be necessary to consider the consumption for a container ship with a capacity of 15,000 Teus. Referring to the tables above, the hourly consumption is equal to 4.56 tons of diesel fuel, and at an energy efficiency of 80%, the engines will be able to deliver 48,162 kW/h [14, 15]. Once we know the fuel consumption for the maritime segment of the logistic value chain is close to 2421,36 tons of oil.

The auxiliary engines will be used at 60% of their power for quayside operations: it is assumed that the consumption of auxiliary engines is equal to 0,0978 tons per hour, therefore, assuming that for each port of call 10 h will be necessary to carry out all land-based activities, the consumption at the quay will be equal to 0,978 tons of fuel for each port of call. Considering, therefore, the proposed ocean route from Shanghai to Trieste, we can directly evaluate the total emissions produced by the roadstead activities for the ship under analysis equal to 8,802 tons of diesel fuel, deriving from the unit consumption of 0,978 tons per port of call multiplied by the 9 port calls foreseen by the route in analysis.

Based on this calculation approach, the estimated emissions will be 8301,7 tons of equivalent carbon dioxide, where assuming an 80% load factor, each individual container will be responsible for 691,8 kg of CO_2 equivalent. At this point it will be necessary to consider the adjustment factor of 5% to include in the calculation the neglected factors and the exogenous factors of the process, equal to 34,6 kg. The total emissions produced

by the single container for the Shanghai-Trieste route will be equal to 726,4 kg CO_2 equivalent.

We will now calculate the indirect component of emissions from the "from well to the tank" process, where we know that for every kg of diesel consumed, 645.17 g of CO_2 equivalent will be produced, subsequently corrected by an adjustment factor of 2%. Based on this information we can then define the indirect emissions as 158,35 kg of CO_2 equivalent per TEU.

Once the modal shift has been carried out, the container is expected to leave the Port of Trieste by rail with destination Frankfurt. The train assembled in Trieste will have a capacity of 1.018 tons, divided into 48 teus of 20 tons and an electric locomotive weighing 138 tons. This information will be useful to evaluate the estimated consumption of electricity, equal to 1,1 kWh/t-km, and the emissions in terms of CO_2 equivalent equal to 22,8 g CO_2/t-km. This information will be crucial for the evaluation of emissions from rail transport, but first it will be essential to quantify the distance traveled, which for this particular destination is 842 km. Based on the information previously provided, the energy consumption in terms of kilowatt-hours is a total of 942,871.6 or 19,643.16 kWh per single container. At this point it is possible to estimate the emissions based on the emission factor equal to 22.8 g CO_2 equivalent per tonne per kilometer: with this calculation then the consumption in term of kilograms of CO_2 equivalent is 19,543.16, which per single container reaches 407.15 kg of $CO2$ equivalent. Now, we are going to consider the 7% overall adjustment factor for the rail sector as well. The evaluation of this adjustment factor considering all the factors not calculable and considered that are part of this quantification is equal to 28.50, in conclusion, we can therefore state that the emissions for rail transport are equal to 435.65 kg of CO_2 equivalent [19, 20].

For the last step, we will take into account the emissions deriving from the handling of a single container by road from the railway terminal of Frankfurt to the Duisburg Freight Village, for a total distance of 276 km, covered on average in 3 h and 3 min, considering a standard Teu weighing 20 tons handled by an articulated truck capable of carrying up to 40 tons, where the average consumption is estimated to be 221.46 g of diesel per kilometer [16]. We can then quantify with a simple arithmetic calculation the fuel consumption used equally to 60, 99 kg of diesel fuel and consequently direct emissions of 246.5 kg of $CO2$equivalent and indirect emissions of 39.35 kg of CO_2 equivalent. We will finally apply the adjustment factors by which the direct emissions will be 258.83 kg $CO2$ equivalent while the indirect emissions will be 40.13 kg CO_2 equivalent [22].

To conclude, it is, therefore, possible to quantify the total emissions generated by the entire logistics chain for the movement of a single container from Shanghai to Duisburg, evaluated as the sum of the different transport modes (Table 8):

Table 8. Emission for the route Shanghai-Duisburg – Source: Personal Elaboration

Way of transport	Direct emissions	Indirect emissions	Total emissions
Marine vessel	691,8 kg of CO_2	158,35 kg of CO_2	850,15 kg of CO_2
Rail transport	-	-	435,65 kg of CO_2
Road transport	258,83 kg of CO_2	40,13 kg of CO_2	298,96 kg of CO_2
Total emissions	950,6 kg of CO_2	198,48 kg of CO_2	1584,76 kg of CO_2

5 Discussion

The analysis of the carbon footprint cannot disregard two intrinsic components: the evaluation of emissions and their communication. Often, there is a tendency to give greater importance to the first of these two aspects, but it is precisely in the communication of the Carbon Footprint that the importance of defining uniform calculation criteria lies [17]: In fact, the emissions report must not be limited to quantifying in purely numerical terms the volumes of greenhouse gases produced within a process, but must be able to represent a starting point for the strategic and decision-making choices of business processes, thus declining as a comparative advantage, not only in terms of cost-effectiveness due to greater energy efficiency but concerning the reduction of harmful emissions produced [4].

Starting from an assessment of the sources of average emissions for each category of vehicle used in the context of modal transport, a calculation model has been developed that would be able to provide useful information in terms of absolute volumes of emissions and their intensity for each unit moved, following a standardized and uniform approach to quantification, [17] and trying to reduce part of the discretion resulting from the assessment of emissions [15].

It is necessary to point out that there is a problem in the discretionary nature of the quantification of the carbon footprint. In fact, in this sense, delineating the boundaries within which to elaborate a rational analysis of emissions appears extremely complex, and this is why it was decided to define limits for the model, on which to subsequently apply an adjustment factor that would include emissions neglected by the analysis and all exogenous influencing factors. This approach means that the analysis of the Carbon Footprint of the logistics chain includes only the most relevant elements and those closely related to the process. However, all other factors omitted within a single parameter are considered. Therefore, the proposed adjustment factor becomes fundamental in order to concretely define the boundaries of the calculation model for the evaluation of emissions deriving from a logistics chain and to pursue the criteria of comparability and transparency foreseen for the drafting of the Carbon Footprint, since it limits any discretion.

6 Conclusions

This paper aims to combine theoretical and practical information in terms of quantifying carbon footprint emissions for logistics processes. In order to take full advantage of this

indicator, it is essential to streamline calculation processes and smooth out the factors that can be included in the quantification of emissions. By defining standardized application criteria for the calculation of the Carbon Footprint, it will take on an even more central role in decision-making processes, allowing rational choices to be made in terms of economic and environmental efficiency and laying the foundations for sustainable development.

The introduction of an adjustment factor for direct and indirect emission sources will make it possible to quantify emissions by analyzing primary emission funds in detail, including exogenous and highly discretionary components in the calculation.[8] However, the importance of the carbon footprint must not be limited to the mere numerical value expressed in the quantity of GHGs produced in the context of a specific production process, but its intrinsic strength is based on the combination of quantification and communication [21]. Generally, the quantitative aspect is the one that catalyzes the attention, but the concept of communicability represents a point of central importance within the concept of Carbon Footprint: it is a clear and direct tool to highlight a specific component of the life cycle of a process, which can represent in a biunivocal way useful information in terms of environmental sustainability, [12] but above all, a performance indicator, thus representing a comparative advantage in terms of attention to environmental issues [2, 7].

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