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Carbon Footprint Analysis of the Freight Transport Sector Using a Multi-Region Input–Output Model (MRIO) from 2000 to 2014: Evidence from Industrial Countries

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Abstract: Freight transportation performs a critical role in the supply networks of the global economy and is heavily influenced by the activities of the industrial and manufacturing sectors, contributing significantly to their global carbon footprint (CFP). This research evaluates the lifecycle-based CFP emissions of freight transport activities in seven selected countries (China, Japan, the United States, Canada, Brazil, Great Britain, and Germany) over fifteen years, considering international trade linkages with the rest of the world. In the literature, most researchers have investigated the CFP of the transportation sector in general or analyzed the CFP of two or three countries, such as the USA and China. However, this research is novel in that it examines the CFP of the freight transport sectors of the seven biggest industrial countries. In addition, a positive relationship was found between the CFP and the gross domestic product (GDP), population, level of urbanization, and area of these countries. Therefore, this study investigates the relationship between global CFP, GDP, population, level of urbanization, and country area. A total of 15 stochastic model-based multi-regional input–output lifecycle assessments were built for each country, comprising 35 key industries. Statistical modeling tools were used to assess carbon emissions. The results show that China is the largest contributor to the freight-related CFP, while the U.S. is the second largest. The manufacture of coke and refined petroleum products represents the dominant sector. In contrast, warehousing and support activities have the most significant contributions in Germany and Great Britain. Land transport and transport via pipelines contribute the most to Canada's CFP. The results of the regression analysis show that there is a positive relationship between the investigated variables.

Keywords: carbon footprint; life cycle assessment; multi-region input–output model; sustainability; freight transport

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1. Introduction

Freight transportation refers to the movement of products from one location to another, enabling production and consumption to occur in different locations. Transportation is an essential component in the development of economic specialization: firms can (1) specialize in producing the items for which they are most equipped and (2) trade with other firms to obtain products that can be created more effectively by other companies. These opportunities are facilitated via freight transportation. Freight transportation operations can be analyzed from an industry's supply or demand side. Demand originates from companies requiring urgent transport of raw materials, and intermediate and final products. Businesses that purchase freight transportation services are known as shippers. A freight transportation chain comprises of two components, the infrastructure (e.g., roads, railways, airports, seaports, locks, dams on rivers, and pipelines) and the carriers, which deliver products. Shippers use freight carriers to deliver their goods with trucks, trains, ships, or airplanes [1], depending on their needs and preferences (see Figure 1).

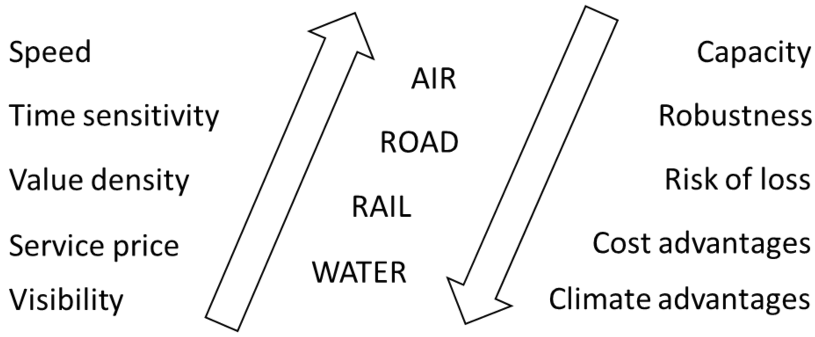


Figure 1. Characteristics of freight service across modes [1].

Due to the nature of waterways and sea routes, carriers often do not need to invest in infrastructure. Major private carriers fight for a worldwide market share in the maritime sector, while smaller companies compete in the short-sea and inland waterway sectors. However, waterborne carriers have a low per-unit cost and limited operational speed, making them ideal for the long-distance transportation of low-value commodities. Road, rail, and short-sea shipping compete with inland waterways transportation. Maritime transport holds a significant portion of the market share based on the moved volume of goods.

International aviation accounts for a disproportionately large share of total economic output. Air freight transport through dedicated freight carriers is rising alongside the continued usage of passenger planes for carrying belly freight. The variable costs of air transport are significantly higher than the fixed costs. Although the unit costs are much higher for large volumes compared to alternative techniques, air transport is the most efficient way to travel great distances, outpacing all other options. Pipeline transportation is mainly limited to liquid petroleum and natural gas transport. Due to its high fixed cost share, the network cost is relatively high when carrying small volumes, but the price decreases as the quantity increases. Pipeline networks offer slow transport and are often located in sparsely populated areas [2].

Over the past decade, the importance of sustainability has become more widely recognized; strict governmental sustainability regulations and increased social pressure have pushed companies to include sustainability as a factor in their operations. Sustainability has three pillars: environmental, economic, and social. The transportation sector used for industrial operations also serves as the primary means of carrying people and commodities. These systems can be considered as a bridge that connects the production stages to the ultimate consumption in national economies. By 2050, global freight demand is predicted to rise to 45 trillion ton km [3]. From this perspective, achieving long-term sustainability in delivering services and products is a crucial goal in the broader mission of transport planning and policymaking worldwide. The transportation industry represents a significant part of countries' GDP and the global economy as a whole [4]. Transportation is the most significant economic sector, directly employing roughly 10 million people and contributing around 5% of the European Union's (EU) GDP. According to statistics, the transportation sector is responsible for various environmental impacts, such as energy usage and greenhouse gas (GHG) emissions. However, transportation also performs an essential role in the growth of national economies; specifically, economic activities related to industrial and manufacturing sectors are freight transportation's primary drivers and represent an essential factor of national supply chains [4].

The emissions caused by transportation make up around 27% of the United States' total GHG emissions, making the sector the highest contributor. The transportation sector's emissions rose faster than any other industry between 1990 and 2020 [5]. At the same time, there has been an increased worldwide awareness of GHG emissions and their role in climate change. According to the World Resources Institute, 58% of the GHGs produced are carbon dioxide (CO_2) emissions from burning fossil fuels. As transportation is a significant sector in social development and economic growth, it is responsible for consuming a significant amount of energy worldwide. In 2019, transportation contributed 8.22 billion tons of the world's carbon emissions, as reported by Our World in Data based on Climate Analysis Indicators Tool (CAIT) [6]. As of 2018, China's transportation sector accounted for 9.17% of the country's total carbon emissions. Such developments have highlighted the importance of limiting the CO_2 emissions of the transportation sector to reduce total worldwide emissions [7]. Consistently rising GHG emissions from transportation in the E.U. between 2013 and 2019 differ significantly from emissions from other sectors during the same time. An 0.8% rise in E.U. domestic transportation emissions between 2018 and 2019 was reported. Since the COVID-19 epidemic, early predictions show a reduction of 12.7% in 2020 due to a sharp fall in transportation activities. In comparison, emissions declined only by 1–3% yearly during the economic crisis in the previous decade. According to forecasts made at the national level, the member states anticipate a substantial increase in transportation emissions after 2020, and the rise may be seen until 2025 if additional steps are not implemented [8]. However, researchers have not analyzed the freight sector's environmental impacts in an in-depth way. In addition, existing works only studied environmental effects of one of the two countries. On the other hand, this paper studied the carbon footprint (CFP) of the freight transport sector over 15 years in seven industrial nations.

Considering such trends, this study's primary goal is to assess the environmental impact of freight transportation and investigate the relationships among factors, such as CFP, GDP, urbanization, population, and area, in the seven countries, with significant relationships hypothesized among them. There were only 83 cities with more than a million people in 1950; by 2008, the total had risen to 400. Globally, 512 cities had a population of at least 1 million people in 2016. A predicted 662 cities will have at least 1 million citizens by 2030 [9]. By 2050, the share of worldwide urban inhabitants is predicted to climb to 67%. Rapid urbanization will also significantly boost carbon emissions [10]. According to the International Energy Agency (IEA), urbanization accounts for around 70% of worldwide energy-related carbon emissions; this is anticipated to rise to 76% by 2030. As a result, academics and policymakers have continued to pay attention to the link between urbanization and carbon emissions [11]. Many studies have shown the negative relationship between urbanization and CFP. For instance, Wang et al. [11] believe that the link between urbanization and carbon emissions is negative. They found that for every percentage point increase in the size of a city's population, carbon emissions rise by 0.20%. In the present study, manufacturing industries that makeup supply chains and the individual relationships between different manufacturing industries and transportation modes are examined. The direct and indirect CFP impacts of the industrial economic transactions of seven countries are the primary focus of this investigation. These impacts take into consideration the supply chain industries that support production and supply chain industries in other nations that export to the national markets in question [11].

The above method provides a comprehensive understanding of the CFP impacts on the freight transport sector in the seven examined countries. Additionally, the analysis shows which sector contributes the most to the overall CFP, considering the freight transport sector. These findings can help decision-makers better understand trends in the CFP of the sector and how it correlates with the urbanization, population, GDP, and area of the given country. In contrast, this study's scope is limited as it depends on the world input–output database (WIOD), which provides data until 2014. The main objective of this study was to provide a comprehensive analysis of the CFP of the freight transport sectors of the seven countries.

Additionally, the hypothesis analysis shows a significant correlation between the CFP and the GDP, urbanization, population, and area of each country in the corresponding period. The paper is organized as follows: in Section 2, a review of the related literature is presented, and in Section 3, details of the proposed method are provided. Section 4 contains the results and discussions, and Section 5 highlights the conclusion of this study and future directions for research.

2. Literature Review

Many studies have identified the environmental impacts of industries using the lifecycle assessment (LCA) method. The literature is replete with studies that used the LCA method to trace the environmental effects of different regions over various periods. The LCA method is suitable for analyzing environmental impacts from the extraction of raw materials up until the final stages of production. Although studying a product's lifecycle can be beneficial, it is critical to consider and assess the economic, social, and environmental implications on larger scales, such as the city, regional, or country level, or even for the entire global economy. In order to carry out an environmental assessment, studies focusing on regional or national economies, input–output economic tables are utilized in combination with environmental effect multipliers, which are the foundation of input–output analysis (IOA). IOA research can be classified into two types: single-region IOA and multiregional IOA (MRIO analysis). Single-region IOA focuses on examining the sustainability implications of a specific region (e.g., a nation, city, state, etc.) with the assumption of local technology. MRIO methods, conversely, consider international monetary flows more deeply [12].

The environmental and economic impacts of different industries were identified using MRIO and IOA. For instance, industrial sectors in the United States (USA) were analyzed by integrating a linear programming-based method called Data Envelopment Analysis (DEA) and Economic Input–output Life Cycle Assessment (EIO-LCA). To achieve this integration, different environmental constraints were aggregated into a single eco-efficiency score. Initially, the EIO-LCA model calculated each industry's GHG emissions, energy and water use, hazardous waste production, and toxic discharges. Second, an input-oriented DEA multiplier model was created. Third, each environmental area's objective and performance improvement values were specified, along with eco-efficiency ratings and rankings [13]. In addition, Abbood et al. assessed the carbon and energy footprints of US industrial operations considering the country's worldwide trading linkages. MRIO lifecycle assessment frameworks were used to evaluate global energy and CFP effects for over 40 major economies, including China, Russia, the USA, and the rest of the world (RoW) [14]. Jiang et al. carried out a study in which input–output analysis, energy consumption, and structural decomposition models were applied to study the carbon emissions of China's construction sector [15]. Wang et al. calculated and assessed China's industrial carbon emissions efficiency and evolution features from 2002 to 2015 using energy consumption and input–output methods [11]. Elagouz et al. [16] measured and assessed the environmental, social, and economic effects of alternative fuel buses across all of their lifecycle phases to inform sustainable transportation practices in hosting mega-events. Thus, a hybrid, MRIO-based lifecycle sustainability assessment (LCSA) model was built to assess three bus types: compressed natural gas (CNG) based, electric, and diesel buses. The water-PM2.5 nexus is investigated in a study [17] using an Environmentally Extended MRIO model combined with an Integrated Nexus Strength measure and linkage analysis.

Transport is the most dependent on fossil fuels of any sector, accounting for 37% of CO_2 emissions from end-use sectors. While it was one of the sectors most impacted by the COVID-19 outbreak, emissions are likely to rise again as demand rises and the use of alternative fuels remains restricted. This expansion is especially likely in developing and emerging economies [18]. In light of this, Park et al. [19] investigated the link between the manufacturing and transportation sectors in the United States from economic and environmental long-term viability perspectives. Quantifying the lifecycle impacts of the national freight transportation operations of U.S. manufacturing industries and supply networks (the manufacturing transportation nexus) was one of the primary objectives, alongside examining the eco-efficient transportation performance of different manufacturing sectors. GHGs, energy utilization, and water withdrawals were also studied in addition to economic outcomes. EIO-LCA and Principal Components Analysis were used to achieve the study's aims. The economic and environmental impacts of four means of transportation (air, rail, road, and water) were also examined as part of the scope of the study. EIO-LCA data showed that the food industry has the most significant influence, accounting for nearly 20% of GHG emissions, energy use, and water withdrawals, and 12% of the total economic output. The second and third effects and outputs were attributed to automobiles and the manufacturing of their parts. Eco-efficiency ratings for the operations of iron and steel mills and the production of agricultural chemicals were the lowest for ordinance and accessories (0.719) [19]. Egilmez et al. [4] conducted a lifecycle study of cradle-to-gate freight transportation effects linked with US industries. The extent of the problem was determined by considering the effects that the 276 manufacturing sectors in the USA have on four modes of transportation (air, rail, road, and water). The results were compiled into 53 different major manufacturing sectors. DEA was used to quantify the eco-efficiency of each mode after the lifecycle impacts had been determined, and GHG emissions, energy, and water use were shown to be the three most important factors. According to the findings, truck transportation accounted for 48–60% of all environmental impacts of the industrial sector when looking at all four modes of transportation. Depending on the impact category, rail and air transport made up between 20% and 21% of the total effect of the four modes of transportation [4].

To reduce the use of public resources and increase service quality, Dolinayova et al. [20] provided methods for establishing open and unhindered competition in freight transportation which consider complex features, such as traffic flows, demand on logistics systems, multimodal chains, business circumstances in transportation markets, and the role of railway infrastructure managers regarding railway markets, railway charge systems in terms of minimum access packages and extra services in selected EU countries, and social costs. The authors discussed research approaches for deregulating the rail freight sector in a sustainable transportation system. In addition, the study examined rail infrastructure costs by comparing models of train prices in the V4 countries and Austria [20].

Agbo and Zhang [21] developed and utilized a mathematical model in an experiment investigating the viability of synchro-modality in Ghana. Data for the numerical analysis of the transportation corridor was gathered from web resources, direct interviews with specialists, and the researchers' informed and knowledgeable judgment. According to the findings, using fewer vehicles, the synchro-modal service design reduced costs by 22% compared to the unimodal service. To ensure long-term financial sustainability, maritime-inner-region freight transportation requires an improved modal split and parallel use of different modes. In addition, the study's findings indicated that synchro-modality increases the overall consumption of transportation services. Environmental sustainability is accomplished by using fewer trucks; in addition, pollution, traffic congestion, and noise also decrease [21].

Seaport and city operations are greatly affected by the mismatch between various vehicle flows (e.g., commodities, people, cruises, and private vehicles) and the creation of bottlenecks. Therefore, data from port authorities, major terminal operators, and logistics services were taken into account using the eastern Sicilian port system as a case study [22] to determine the three pillars of sustainability: environmental, economic, and social impacts. The authors stated that previous research provided valuable information about the efficiency of freight transportation. However, there are advantages and drawbacks to previous and current research, and data on terminal efficiency has been obtained from port authorities, key terminals, and logistics companies. The study investigated the benefits and disadvantages of plans for the two ports (Catania and Augusta) that affect the whole system and provided a clear outline of how the ports demonstrate efficiency [22].

Bagoulla and Guillotreau analyzed the influence of maritime transportation on the French economy. The authors applied a similar approach to other studies focusing on countries with sizeable maritime sectors (e.g., Korea, Ireland, China, and Spain) to allow for comparisons. The assessment of the environmental impact of shipping on air pollution through emissions of GHGs (i.e., SO_2, NO_x, CO_2, $PM_{2.5}$, and PM_{10}) provided a novel contribution to the literature. Evaluating direct and indirect maritime transport emissions is crucial, considering the introduction of stricter regulations by the International Maritime

Organization and the EU (inside and outside Sulphur Emission Control Area limits) to decrease sulfur emissions from ships [23].

As energy consumption for transportation is a major contributor to GHG emissions, increased attention has been placed on efforts to reduce the CFP of the sector. Yu et al. [7] utilized IOA and an enhanced structural decomposition analysis model to identify ways to structurally reduce transportation-related emissions in China. According to the findings, the energy intensity effect significantly decreased the carbon emissions of the Chinese transportation sector, developments that are driven by improvements in energy efficiency. The final demand effect performs a major role in determining increases in carbon emissions for the transportation sector. Furthermore, it was discovered that increasing the proportion of low-carbon and high-carbon energy consumption structures on the energy supply side of the transportation sector contributes to limiting increases in carbon emissions [7]. Using China's MRIO table from 2007, 2010, and 2012, Liu et al. [24] assessed road freight emissions from the point of view of the supply chain. The authors quantified the road freight emissions in China for the first time.

Wang et al. [25] examined the relationships between urbanization, energy usage, and carbon emissions in a group of Association of Southeast Asian States (ASEAN) nations from 1980 to 2009. The study adds to the growing body of empirical literature by studying the consequences of urbanization and identifying causal linkages between variables. The results of the Pedroni panel cointegration tests indicate the presence of a long-term equilibrium link between urbanization, energy usage, and carbon emissions among ASEAN countries. The influence of urbanization on carbon emissions is further demonstrated using the panel completely modified ordinary least squares approach; a 1% increase in urban population results in a 0.20% increase in carbon emissions. Granger causality tests uncovered unilateral short-run causal links between urbanization and energy usage, and urbanization and carbon emissions.

Earlier research assumed a unitary elasticity of emissions concerning population change, implying that a 1% increase in population resulted in a 1% rise in emissions.

This study found that worldwide population changes over the previous two decades have been more than proportionately related to increases in carbon dioxide emissions and that the influence of population change on emissions is far more prominent in developing nations than in affluent countries [26].

Shi [27] investigated feedback or endogenous effects between energy consumption, transportation, and main macroeconomic factors, and the resulting CO_2 emission levels resulting from fiscal policy, monetary policy, inflationary pressure, and economic activity in China. The fundamental concept was to establish a hybrid technique to uncover endogeneity in China's transportation footprint, which is primarily influenced by the energy consumption and the CO_2 emission levels of various transportation modes and important macroeconomic issues, while also investigating the epistemic uncertainty that surrounds this issue as expressed by Information Entropy, the Variance Inflation Factor, and a Covariance matrix. It can be stated that road transportation has performed a leading role in reducing the overall sustainability level, which is primarily driven by trade and fixed-asset investment, and monetary and fiscal policy. However, consumer expectations and cornerstone economic pricing have marginally influenced the transportation footprint.

Using the Scopus database to search for previous studies that have identified the CFP of the transportation sector, it was found that the existing literature is limited in that it only includes a single-year study based on ECO-LCA models. Furthermore, analyzing a single region is inefficient in calculating and understanding the potential impacts of the CFP globally. The current studies investigate the environmental effects of the transportation sector in general or as a part of certain industrial sectors. In addition, a recent study investigated US and Chinese manufacturing industries to determine the economic and mid- and end-point environmental impacts over a 20-year study period. Saber et al. [11] highlighted that the previous study focused on one or two countries and only accounted for a single year in analyzing the CPF in their studies. This study enhances the state-of-the-art by expanding the time scope to 20 years and focusing on the global economy (40 nations and the rest of the world). To the best of our knowledge, no study has compared the effects related to the CFP of the freight transport sectors of the main industrial countries as a time-series fulfillment or investigated the correlation among the CFP and the GDP, population, urbanization, and area of each country. Therefore, the aims of this study are as follows: (1) create longitudinal multi-region input–output (MRIO) models to analyze the economic output and the CFP of the freight transport sector activities of the US, China, Canada, Japan, Germany, Brazil, and Great Britain over the longest available period (according to the WIOD database), taking into account economic outputs associated with onsite and supply chains (local and global); and (2) apply a linear regression model to test the sensitivity relationship among the CFP and the GDP, population, urbanization, and area of each country.

CFP labeling for products and services is considered a simple and effective technique for decreasing GHG emissions. Life cycle analysis (LCA) is a valuable method for evaluating the CFP of relevant goods and services. However, the related criteria for the CFP of products and services are unlikely to be applied properly. Thus, a hybrid LCA and multi-criteria decision analysis (MCDA) technique was presented in a study [28] to assist in the evaluation of the CFP of products and services using numerous environmental indicators. The findings revealed that air pollution caused by coal consumption was the main environmental effect of China's paper production business [28].

3. Materials and Methods

The following are the scientific questions addressed in this study: (1) How did the freight transportation activities versus environmental impacts (the life cycle inventory of GHGs) of the seven countries change over the study period? (2) How has the stock (cumulative) and flow (annual rate) of GHG emissions evolved? (3) How sensitive are the environmental and economic outputs of the freight transport sector to the urbanization level, area, population, and GDP for each country? Previous studies have examined manufacturing activities in individual countries and have limited their scope to a single year or a short time period. This study is novel in that it identifies the CFP of the freight transport sector over fifteen years. Furthermore, the seven biggest industrial countries in the world are investigated. As such, the present study investigates the environmental impacts of the freight transportation sector in seven countries: the USA, Canada, China, Japan, Germany, Great Britain, and Brazil. Fifteen MRIO models were created for each country from 2000 to 2014. The MRIO model consists of 40 countries with the largest economies and the RoW, with 35 sectors for each country. Next, deterministic and stochastic MRIO models were initiated using data from each country, including the 35 main sectors. Uncertainty in the input–output data were identified through 30 replications using the Monte Carlo simulation method. Moreover, three phases (see below) of the comparison method were applied after calculating the total impacts of the CFP. Finally, a linear regression analysis was used to identify positive or negative relationships between GDP, CFP, population, area, and urbanization effects for each country. The analysis distinguishes two types of impact: onsite and supply chain impact. The phrase "onsite impacts" focuses solely on the local implications of the manufacturing industries of the seven chosen countries. However, indirect effects and supply chain impacts refer to the impacts of the freight transport sector outside the domestic manufacturing of the seven chosen countries.

The first phase of the comparison involves the investigation of the total CFP impacts for each year during the study period for each country. This phase allows for an understanding of each country's sustainability performance over time. The second phase compares the onsite CFP impacts for each country to their areas to determine whether larger countries require longer distances and more time needed to deliver goods. Third, the sector with the highest CFP is identified for each country. This step clearly explains which sectors require more efforts toward decreasing environmental impacts and operating more efficiently. The scope of the study includes both onsite and supply chain CFP impacts of the chosen countries' industrial–economic transactions. The national and foreign supply chain industries that support manufacturing and the national market impact the economy indirectly. Figure 2 below explains the five steps of the methodology.

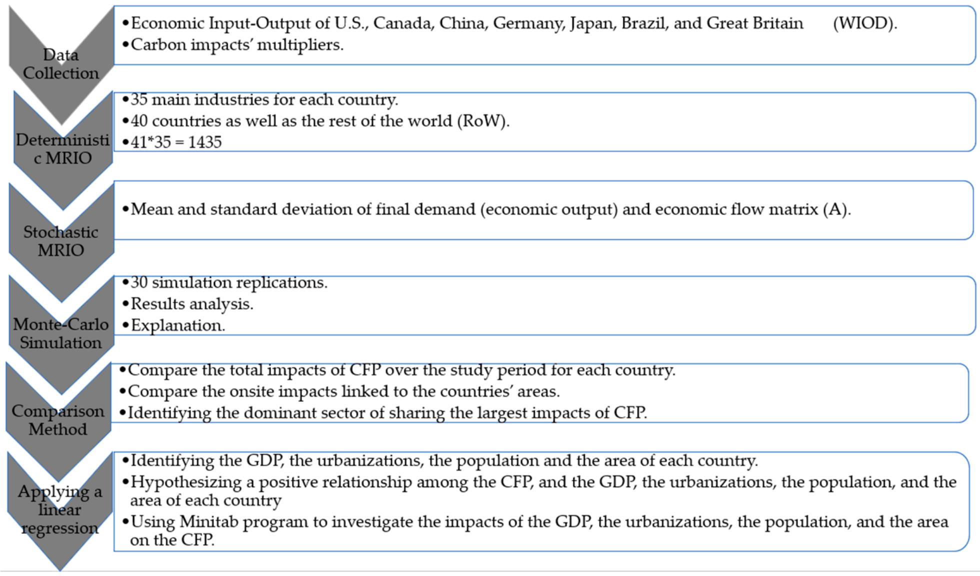


Figure 2. The five steps of the research methodology.

3.1. Data Collection

The data set was obtained from an input–output table time series collected between 2000 and 2014 for the USA, Canada, China, Japan, Germany, Great Britain, and Brazil, provided by the WIOD. The database contains extensive information on each country's output and export, including tables showing 59 items produced and utilized by 35 industries. The data set is estimated by matching these tables to market data. The WIOD provided this data for 40 countries, including all 27 EU member states and 13 large countries outside the EU and the RoW; the data in the tables are classified according to the International Standard Industrial Classification Rev. 3 (ISIC Rev. 3). According to the National Accounts, the WIOD is based on official national statistics [29]. In addition, the World Bank open database was utilized to collect each country's GDP and urbanization ratio data over the study period. Finally, the Our World in Data website was used to obtain population and area data for each country.

3.2. Mathematical Background

The mathematical background involves the building of two models: one deterministic and one stochastic. Seven steps are involved in the construction of each model. The two models are explained in detail below.

3.2.1. Building the Deterministic Model

Each row in the A_{ij}^{rs} matrix indicates input from another sector (domestic or international) to create a unit of output in our model. This matrix A_{ij}^{rs} likewise demonstrates the input of sector I from nation r into industry j in country s as an element. There are 35 sectors in each country, meaning that I and j in this matrix equal the total number of sectors. Furthermore, the sum of r and s equals 41, the total number of countries and the RoW. Utilizing the MRIO framework's fundamental linearity assumption, total output is determined for the provided economic output by Equation (1):

$$x_t^r = (I - (A_{ij}^{rs})_t)^{-1} (f_i^r)_t \quad (1)$$

where f_i^r is a vector containing a dollar output from the industrial sector I in region r and zero production everywhere. A final output change in country r accounts for the total output vector x_t^r and I is the identity matrix, with all elements being 0 except for the diagonal entries, which are equal to one. The total requirement matrix (also known as the Leontief Inverse) is Equation (1) $(\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1}$. Once the overall output vector has been approximated, the total CFP can be calculated by multiplying the output from each sector by its carbon effect per dollar of production, as shown in Equation (2) [30].

$$\mathrm{C_t} = \mathrm{B_t}\,(\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1}\,(\mathrm{f}_i^r)_t \quad (2)$$

$\mathrm{C_t}$ represents total GHG emissions for all 40 major countries and the RoW, while $\mathrm{B_t}$ is a matrix with diagonal components showing the GWP per $M output for each sector [29].

The deterministic model's steps are shown in Figure 3.

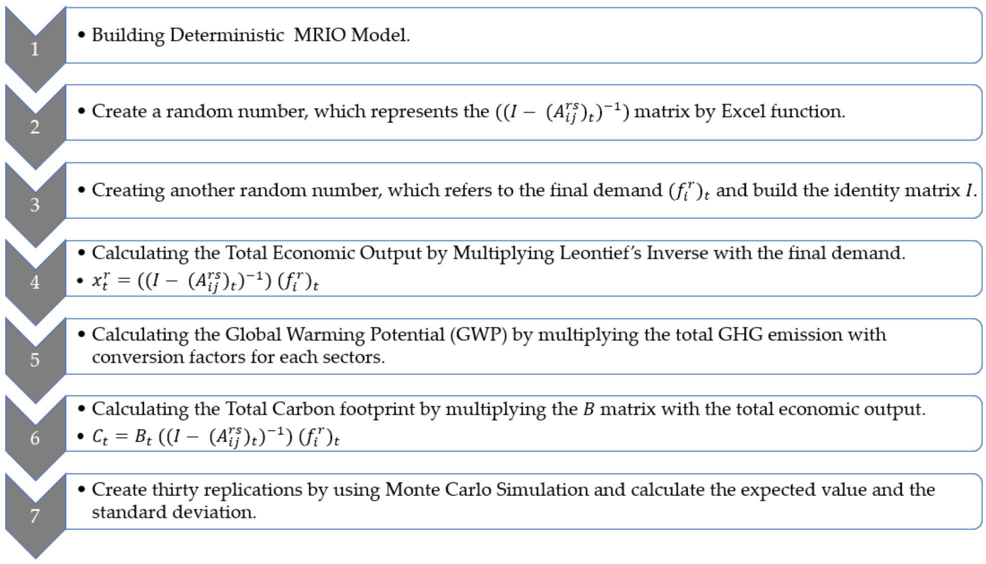


Figure 3. Steps involved in building the deterministic model.

3.2.2. Building the Stochastic Model

The stochastic MRIO models assume that the final demand $(\mathrm{f}_i^r)_t{}'$ and the total requirement matrix $(\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1})'$ are random variables with a mean and standard deviation. Data points from the WIOD are used to determine the mean values. Furthermore, standard deviations are calculated by multiplying the mean by a factor k, which is considered 10%, as assumed by [31]. As a result of this procedure, the economic output of each manufacturing industry was defined as the final demand. The total requirement matrix $(\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1})'$ and final demand $(\mathrm{f}_i^r)_t{}'$ are noted as follows, where $\mathrm{x}_t^{r\prime}$ is estimated as the stochastic total economic output (onsite + supply chain).

$$\mathrm{x}_t^{r\prime} = ((\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1})'\,(\mathrm{f}_i^r)_t{}' \quad (3)$$

After calculating the stochastic total economic production $\mathrm{x}_t^{r\prime}$, it is possible to calculate the total CFP $(\mathrm{C_t}')$ of all sectors in 41 countries as well. Economic output and $\mathrm{B_t}$ (a matrix with diagonal entries that reflect GWP per million dollars of economic activity) were multiplied to obtain the total CFP estimated in the deterministic model [30]. Since both variables are random, a Monte Carlo simulation is utilized in a stochastic context to estimate the overall mean and standard deviation of GWP impacts.

$$\mathrm{C_t}' = \mathrm{B_t}\,((\mathrm{I}-(\mathrm{A}_{ij}^{rs})_t)^{-1})'\,(\mathrm{f}_i^r)_t{}' \quad (4)$$

Figure 4 summarizes the steps of the stochastic model.

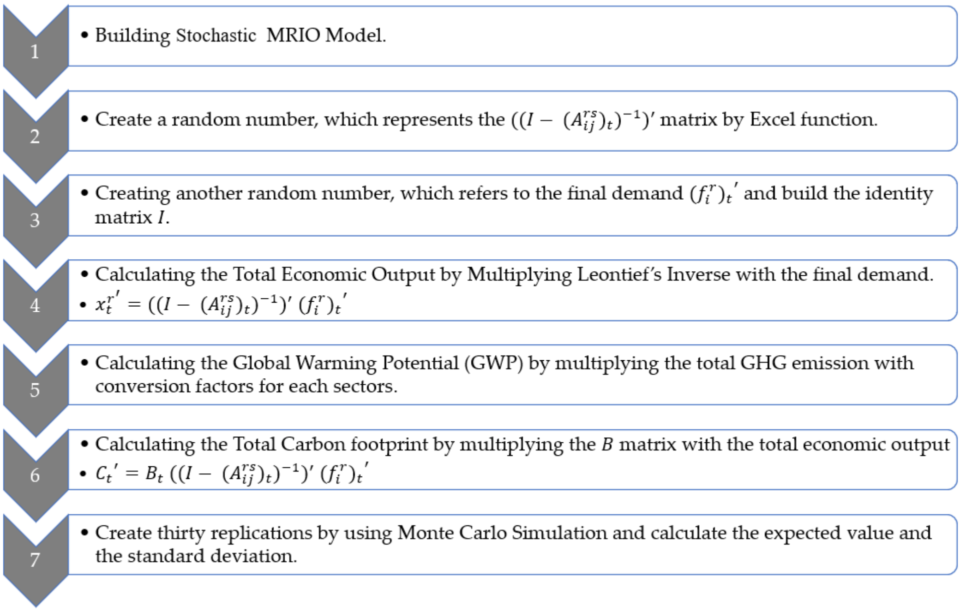


Figure 4. Building the stochastic model.

3.3. Monte Carlo Simulation

Based on basic object-object or object-environment relationships, the Monte Carlo method addresses a numerical issue representing object interactions. The method improves comprehension of natural phenomena by directly recreating their essential processes. This is accomplished by modeling a system's micro-interactions to solve at the macroscopic level. A random sampling of the relationships or microscopic interactions is used to arrive at a solution, meaning that the mechanics of implementing a solution necessitates repeated calculation. Computers can perform the repetitions if numerous tiny interactions are mathematically modeled. Although the Monte Carlo approach predates computers (more on this later), and they are not required to arrive at a solution, computers make finding a solution considerably faster in most cases [32]. The present study uses Monte Carlo simulations to determine the overall effect of CFP on the confidence intervals of the freight transport sector of seven countries. The stochastic MRIO model is replicated 30 times, 1 for each country and year, between 2000 and 2014. Furthermore, after running all 15 years 30 times, 450 experiments are carried out. The mean and standard deviation of the 30 CFP samples for each year are subsequently calculated.

3.4. Multiple Linear Regression Analysis

The Minitab program was used to run two multiple linear regression equations to examine the impacts of the variables, (1) the GDP and urbanization ratio and (2) the population of each country and its given area, on the freight sector's CFP in the selected countries. The null hypothesis is H_0: the variables are insignificant, and the alternative hypothesis is H_1: the variables are significant. The value of p for each dependent variable is compared with the significance level (i.e., alpha value). The null hypothesis is rejected if the p-value is less than the alpha value, confirming that the variables are significant. However, the null hypothesis is accepted if the p-value exceeds the alpha value, confirming that the variables are insignificant.

3.5. Testing the Null Hypothesis and the Alternative Hypothesis

Figures 5 and 6 show the GDPs and urbanization of the seven countries over the period of study, respectively. All countries increased their GDP rapidly, with the exception of Brazil and Canada, which showed slower increases in GDP. Urbanization rose more or less equally in all countries except Great Britain, where urbanization is much more developed than in the other countries examined.

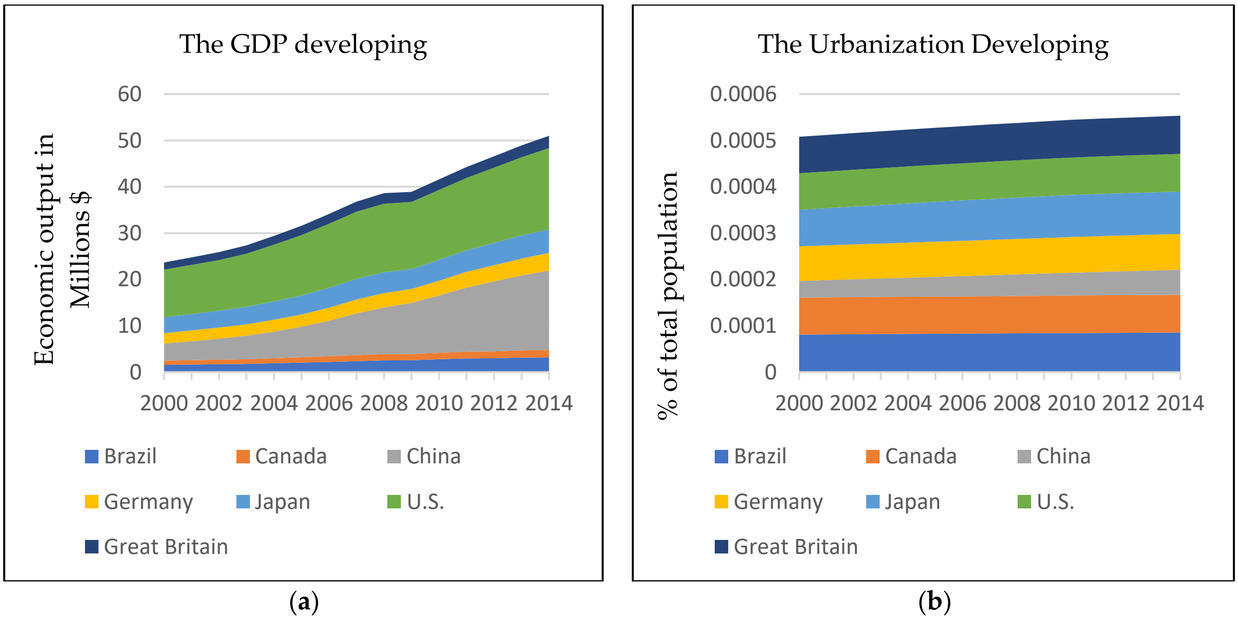


Figure 5. (**a**) The GDP of the seven countries from 2000–2014, (**b**) the urbanization of the seven countries from 2000–2014.

It is essential to analyze the relationships between CFP, GDP, and urbanization to draw the impacts of these last two variables on the CFP of the freight transport sector. The multiple linear regression analysis was carried out using the Minitab program. The null hypothesis in this test is that variables are stable at a significance level of 5%. Equations (5) to (11) explain the relationships among the three variables of the selected countries, where the increase in one or both of the variables leads to an increase in the CFP. Table 1 presents the findings of the regression analysis with CFP versus GDP and urbanization. The *p*-values for GDP and urbanization are 0.000 and 0.027, respectively. The null hypothesis for the two variables is rejected because the *p*-value is less than the significance level, which is 0.05 for all countries. Hence, based on the linear regression test, both variables are significant and have a positive relationship with the CFP of the freight transport sector of the seven countries.

$$\text{CFP of Brazil} = 149{,}983{,}283{,}204 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (5)$$

$$\text{CFP of Canada} = 156{,}018{,}236{,}730 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (6)$$

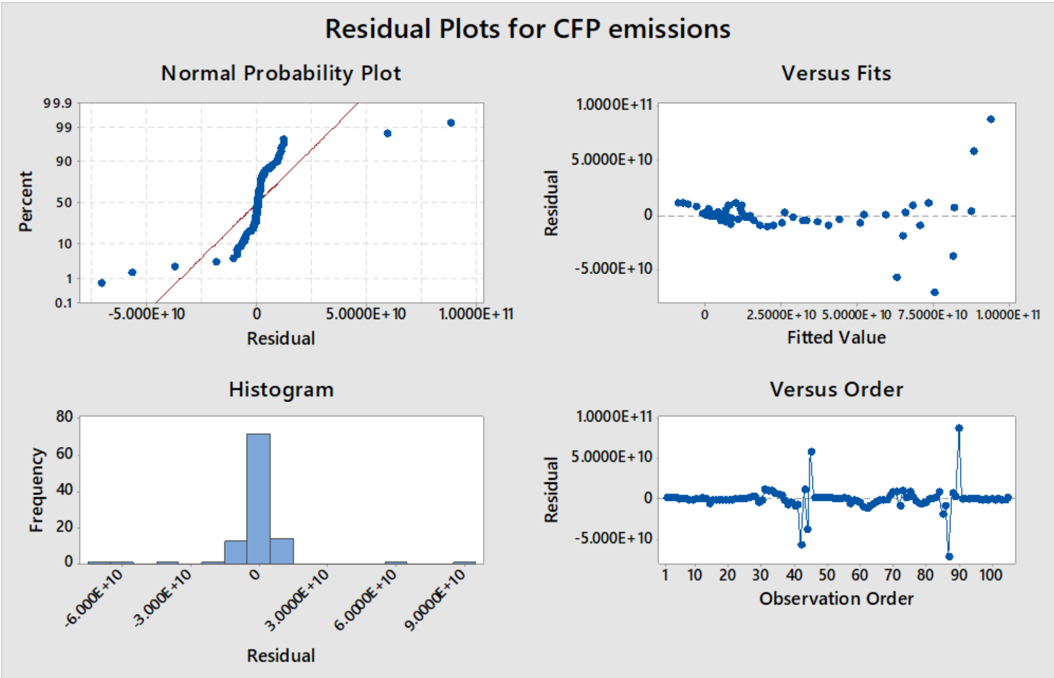
$$\text{CFP of China} = 27{,}571{,}494{,}453 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (7)$$

$$\text{CFP of Germany} = 130{,}645{,}076{,}789 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (8)$$

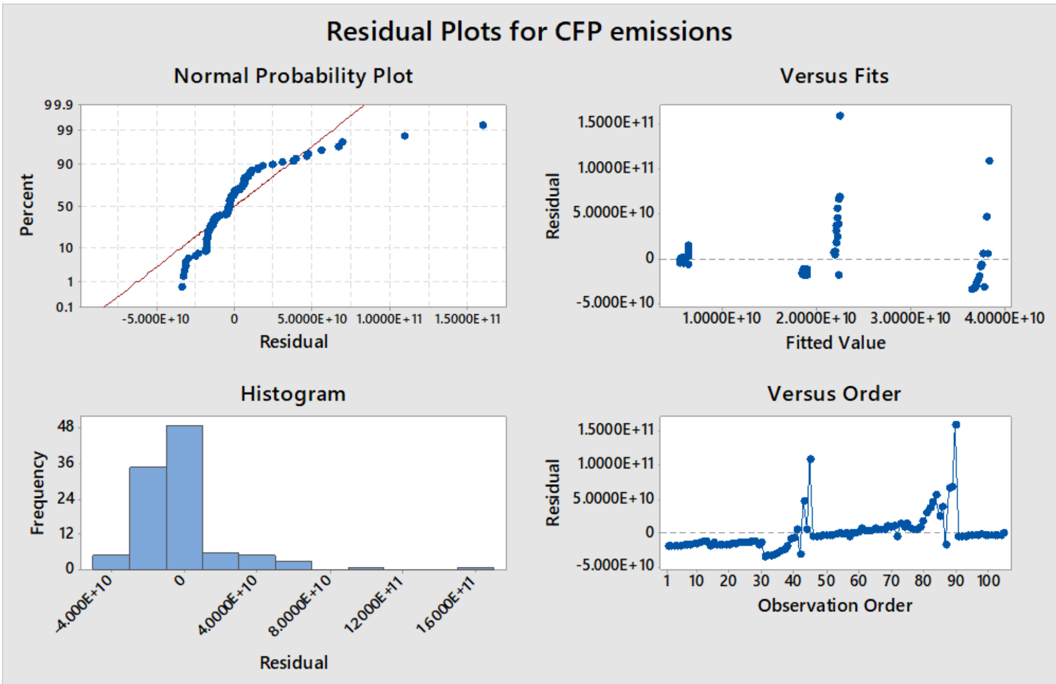
$$\text{CFP of Great Britain} = 146{,}321{,}193{,}231 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (9)$$

$$\text{CFP of Japan} = 148{,}829{,}223{,}580 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (10)$$

$$\text{CFP of U.S.} = 84{,}977{,}410{,}546 + 10{,}062\ \text{GDP} - 2{,}054{,}356{,}692\ \text{urbanization} \quad (11)$$



(**a**)



(**b**)

Figure 6. (**a**) Residual plots for the CFP share versus the GDP and urbanization; (**b**) Residual plots for the CFP share versus the population and country size.

Table 1. Regression analysis findings: CFP emissions versus GDP and urbanization.

Coefficients					
Term	**Coef**	**S.E. Coef**	**T-Value**	***p*-Value**	**VIF**
Constant	1.49983 + 11	74,092,237,835	2.02	0.046	
The GDP	10,062	1342	7.50	0.000	17.42
The urbanization	−2,054,356,692	917,359,364	−2.24	0.027	64.12
Model Summary					
S	**R-sq**	**R-sq (adj)**	**R-sq (pred)**		
1.56248×10^{10}	73.57%	71.37%	64.39%		

In addition, another analysis was conducted using the Minitab program to investigate the relationship between the CFP and the given country's area and population. The significance level was again set at 0.05 to test the null hypothesis of these variables. The results of this regression analysis are presented in Equation (12) and Table 2. The *p*-values for population and country size are less than the significance levels of 0.033 and 0.035, respectively. Therefore, the null hypothesis for the two variables is rejected; these variables are significant and have a positive relationship with the CFP of the freight transport sector of the seven countries examined.

$$\text{CFP of all countries} = 2,085,835,580 + 15.12\ \text{Population} + 2,085,835,580\ \text{Area} \quad (12)$$

Table 2. Regression analysis findings: the CFP emissions versus the country's size and population.

Term	**Coef**	**S.E. Coef**	**T-Value**	***p*-Value**	**VIF**
Constant	3,978,812,113	4,248,915,534	0.94	0.351	
Country area from the earth	15.12	6.98	2.17	0.033	1.23
Population in Millions	14,208,583,558,085	977,295,142	2.13	0.035	1.23
Model Summary					
S	**R-sq**	**R-sq (adj)**	**R-sq (pred)**		
2.73688×10^{10}	13.85%	12.16%	7.55%		

Understanding the link between CO_2 emissions and national urbanization has long been a priority for environmental scientists [33]. Using the Autoregressive Distributed Lag (ARDL) approach, Saeed Solaymani evaluated the link between CO_2 emissions from transportation and their primary factors. The findings indicate that, in the long term, urbanization is the primary contributor to the growth of CO_2 emissions, followed by the carbon intensity of energy. Carbon intensity of energy, GDP per transport worker, and urbanization considerably contribute to short- and long-term increases in transportation CO_2 emissions [34]. Solarin and Lean [35] studied the influence of natural gas use, output, and urbanization on CO_2 emissions in China and India from 1965 to 2013. The results indicate that the variables have a long-run connection and that natural gas, real GDP, and urbanization have a long-run positive effect on emissions in both countries [35]. Abbasi et al. [36] investigated the influence of urbanization and energy consumption on CO_2 emissions for a panel of eight Asian nations from 1982 to 2017 (i.e., Bangladesh, China, India, Indonesia, Malaysia, Nepal, Pakistan, and Sri Lanka). Panel co-integration results show a long-run link between urbanization, energy consumption, and CO_2 emissions. Panel co-integration and Granger causality approaches were also used in the analysis; the findings showed that urbanization and energy consumption significantly and positively influence CO_2 emissions, suggesting that urban growth and high energy consumption are long-term impediments to improving environmental quality [36]. The results of this study align with those of the abovementioned papers. Therefore, this is considered evidence of a positive correlation between these variables and the CFP of the freight transport sector.

4. Results and Discussion

The results of the current study differ from previous studies. This study comprehensively investigated the freight transport sector's environmental impacts and CFP through an examination of the seven largest industrial countries. This study focused on the freight sector's CFP impacts as data from fifteen years of study was available for the chosen countries. The findings of this study provide researchers and decision-makers with a clear idea of the CFP of this sector. In contrast, previous studies included the freight transport sector as a part of other industries and analyzed only one or two countries over the period of a single year. Moreover, the present study showed the relationships between the CFP of the freight transport sector and different variables, such as the level of urbanization, population, GDP, and area of each country. As such, this study revealed how sensitive the CFP of the freight transport sector is to different variables. Existing studies have only examined one of these four variables in regard to the environmental impacts of this sector. The results of the current study can provide insights for the field of environmental protection and can guide companies in improving the sustainability of this sector through choosing means of moving products that are more friendly to the environment. Finally, this study determined which sectors have the highest CFP regarding their use in the freight transport sector.

The current study used the EIO database collected from the WIOD. In addition, the accuracy of the results depends on the degree to which the EIO tables reflect the reality of each country. In addition, thirty replications were generated using Monte Carlo Simulations to validate the final CFP impacts. Therefore, the results addressed in the analysis did not have outliers. The selected industrial countries provide accurate data. Table 3 introduces the selected investigated sectors.

4.1. Total Impacts (Onsite + Supply)

The term "total impacts" refers to each country's onsite and supply impacts. The impacts are explained in detail for each country below.

4.1.1. The United States

According to the USA Environmental Protection Agency, the CFP of the transport sector represents 27% of the total carbon footprint [5]. The US has the largest CFP share, with 91% of the total impact caused by freight transport activities linked to US industries. The rest of the nation's carbon footprint was measured from 2.53% to 0.02%. Furthermore, 98.21% of global carbon emissions are attributed to the top 10 carbon-emitting countries (see Table 4).

The manufacturing of coke and refined petroleum products represents the dominant sector in terms of the CFP share with 34.28% of the total share. In addition, wholesale trade, excluding that of motor vehicles, contributes considerably to the total CFP (10.36%), as shown in Figure 7a. Ten critical industries are responsible for 84.76% of the overall CFP. The CFPs of other industries ranged from 9.36% to 1.73%.

4.1.2. Canada

Canada has the highest CFP share, with 92.17% of the total impacts in the country. The USA is the second largest contributor, with 4.38% of the overall impacts. The top ten carbon-emitting countries account for 99.27% of the total CFP in Canada, as shown in Table 4.

Regarding the total CFP share by industry for Canada, Figure 7b shows that land transport and transport via pipelines represent the dominant sector, with 60.95% of the total share. In addition, the manufacture of coke and refined petroleum products is the second largest contributor, with 11.87% of the total impact. A total of 93.68% of the overall CFP is accounts for the top 10 carbon-emitting industries. The remaining industries account for 9.28% to 1.02% of CFP emissions.

Table 3. The selected investigated sectors.

Sectors	
Coke and refined petroleum products Mfg.	Accommodation and food service activities
Land transport and transport via pipelines	Manufacture of machinery and equipment n.e.c.
Warehousing and support activities for transportation	Manufacture of textiles, wearing apparel and leather products
Retail trade, except of motor vehicles and motorcycles	Air transport
Wholesale and retail trade and repair of motor vehicles	Manufacture of paper and paper products
Rubber and plastic products Mfg.	Manufacture of food products, beverages, and tobacco products
Wholesale trade, except of motor vehicles and motorcycles	Manufacture of fabricated metal products, except machinery and equipment
Manufacture of chemicals and chemical products	Manufacture of basic metals
Electricity, gas, steam, and air conditioning supply	Manufacture of computer, electronic and optical products
Real estate activities	Repair and installation of machinery and equipment
Telecommunications	Manufacture of other non-metallic mineral products
Water transport	Human health and social work activities
Education	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Public administration and defense; compulsory social security	Crop and animal production, hunting and related service activities
Manufacture of other transport equipment	Activities auxiliary to financial services and insurance activities
Other service activities	Postal and courier activities
Construction	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
Mining and quarrying	

Table 4. The CFP shares of the top ten nations for each examined country.

Country	The Top Ten Nations	% of The Total Impacts of CFP
USA	USA, The RoW, Canada, Mexico, Great Britain, Republic of Korea, Russia, China, France, Spain	98.21
Canada	Canada, USA, The RoW, China, Greta Britain, Japan, Spain, The Netherlands, Germany, France	99.27
China	China, The RoW, Republic of Korea, USA, Japan, Taiwan, Germany, France, Indonesia, Russia	99.58
Japan	Japan, The RoW, USA, Republic of Korea, China, Indonesia, Germany, Taiwan, Denmark, Great Britain	99.12
Germany	Germany, The Netherlands, The RoW, Belgium, USA, France, Great Britain, Austria, Poland, Italy	95.97
Great Britain	Great Britain, The RoW, USA, Germany, France, The Netherlands, Sweden, Belgium, Spain, Russia	95.5
Brazil	Brazil, The RoW, USA, India, China, Republic of Korea, Germany, Taiwan, The Netherlands, Spain	99.08

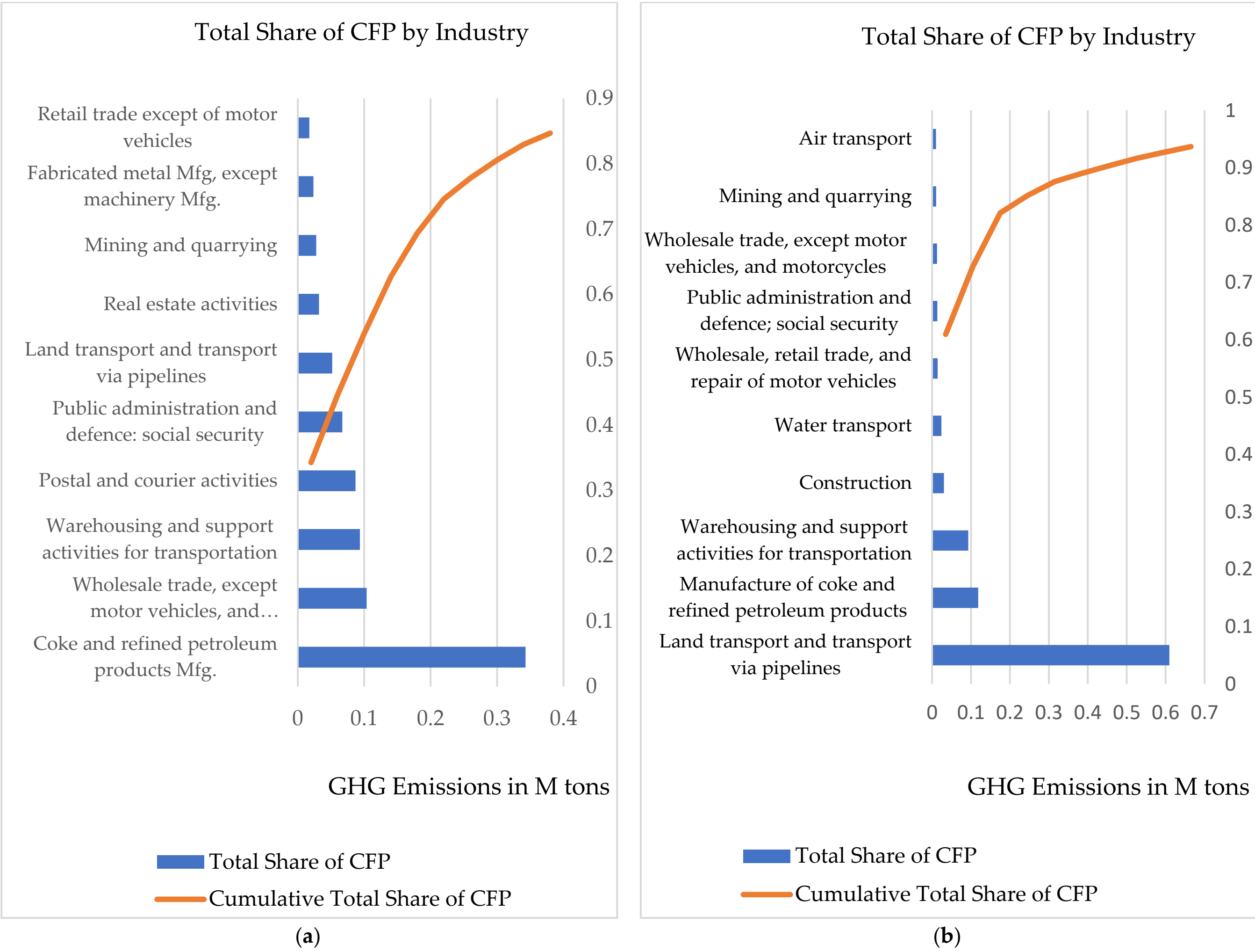


Figure 7. (**a**) Industry shares in the total US CFP impact; (**b**) industry shares in Canada's total CFP impact.

4.1.3. China

Looking at the CFP share by country, the findings show that China is the most significant contributor, with 96.05% of the total impacts. The RoW is the second contributor, with 1.61% of the total impacts. The top ten carbon-emitting nations account for 99.58% of the overall CFP, as shown in Table 4.

Both the manufacturing of coke and refined petroleum products, and warehousing and support activities for transportation sectors are responsible for the most significant portions of the CFP in the country, with 33% and 11.70%, respectively. The CFP of the remaining industries ranges from 8.48% to 2.53%. A total of 82.21% of the overall Chinese CFP is generated solely by the top 10 carbon-producing industries (see Figure 8a).

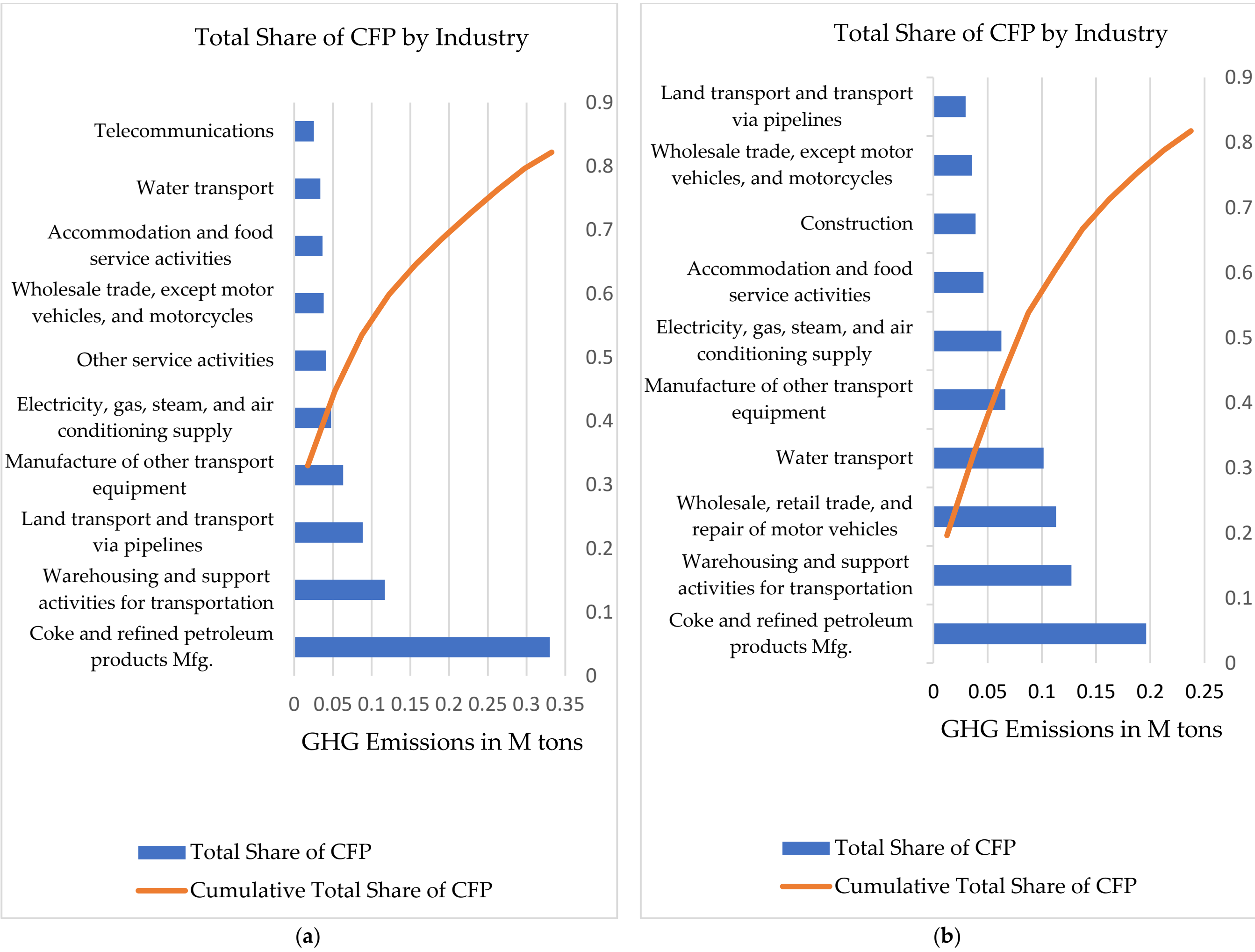


Figure 8. (**a**) The industries' shares in China's total CFP impact, (**b**) the industries' shares in Japan's total CFP impact.

4.1.4. Japan

In terms of Japan's CFP share by country, the findings show that Japan is the most significant contributor, with 90.26% of the total impacts. The RoW is the second largest, contributing 4.25% of overall effects. The top 10 carbon-emitting countries contribute 99.12% to the overall CFP (see Table 4).

The manufacturing of coke and refined petroleum products and the warehousing and support activities for transportation sectors are responsible for the largest CFP share in Japan, with 19.62% and 12.73%, respectively. Between 11.31% and 2.96% of the remaining industries represent the remaining CFP share. The CFP of the top 10 carbon-producing industries is 81.78%. Figure 8b summarizes the results.

4.1.5. Germany

The results show the overall mean share for each country in the total German CFP, with Germany making up the majority (84.75%) of the total effect. The CFP impacts from other countries range from 2.9% to 0.5%. A total of 95.97% of the country's total emissions come from the top 10 carbon-emitting countries, as shown in Table 4.

Warehousing and support activities for the transportation sector account for 42.9% of the overall CFP in Germany. According to Figure 9a, 12.03% of the CFP is attributed to land and pipeline transportation. The CFP of the top 10 carbon-emitting industries is 85.76% of the overall German footprint. The remaining industries have CFPs ranging from 11.05% to 1.88%, respectively.

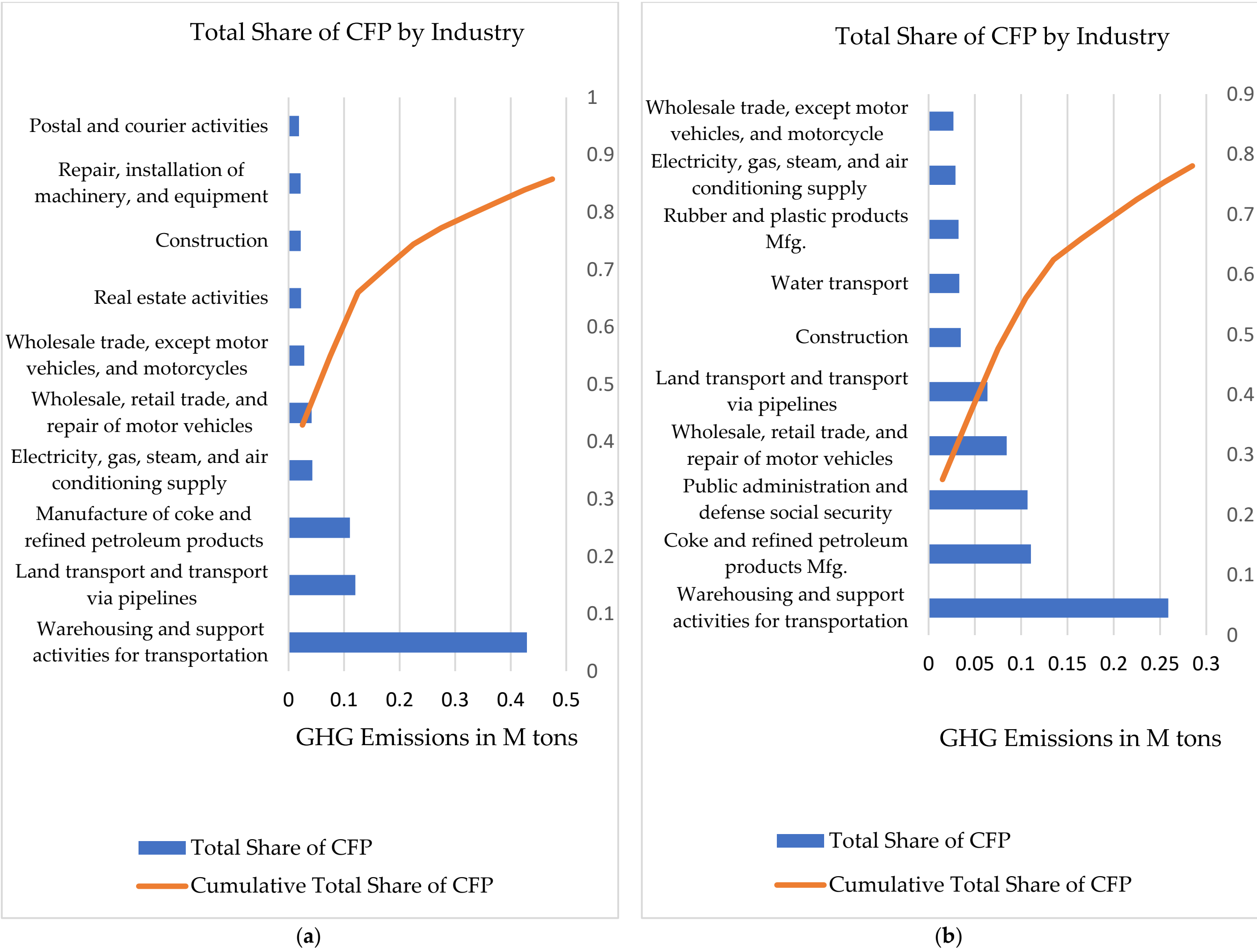


Figure 9. (**a**) Industry shares in Germany's total CFP impact, (**b**) industry shares in Great Britain's total CFP impact.

4.1.6. Great Britain

The findings show that Great Britain itself has the highest CFP share, with 82.56% of the total impacts in the country. In addition, the RoW is the second largest contributor, with 4.61% of the overall impact. The top 10 carbon-emitting countries generate 95.5% of the total CFP (see Table 4).

Warehousing and transportation support operations and the manufacturing of coke and refined petroleum products account for 25.89% and 11.05% of the country's CFP, respectively. CFP impacts were between 1.06% and 2.67% for the remaining industries. More than 78% of the country's CFP comes from the top 10 carbon-emitting industries (see Figure 9b).

4.1.7. Brazil

According to the results, Brazil accounts for 92.5% of Brazil's overall total CFP. The carbon impact of the remaining countries ranged from 2.87% to 0.15%. The top 10 nations accounted for 99.08% of the overall CFP in the country, as shown in Table 4.

The manufacturing of coke and refined petroleum products has the most significant CFP in Brazil, accounting for 40.22% of the total. Land and pipeline transportation also contributed significantly to the CFP, with a combined contribution of 22.62% (see Figure 10).

The CFP of the top 10 carbon-emitting industries represents 93.20% of the total. The CFPs of the remaining industries ranged from 6.89% to 0.980%.

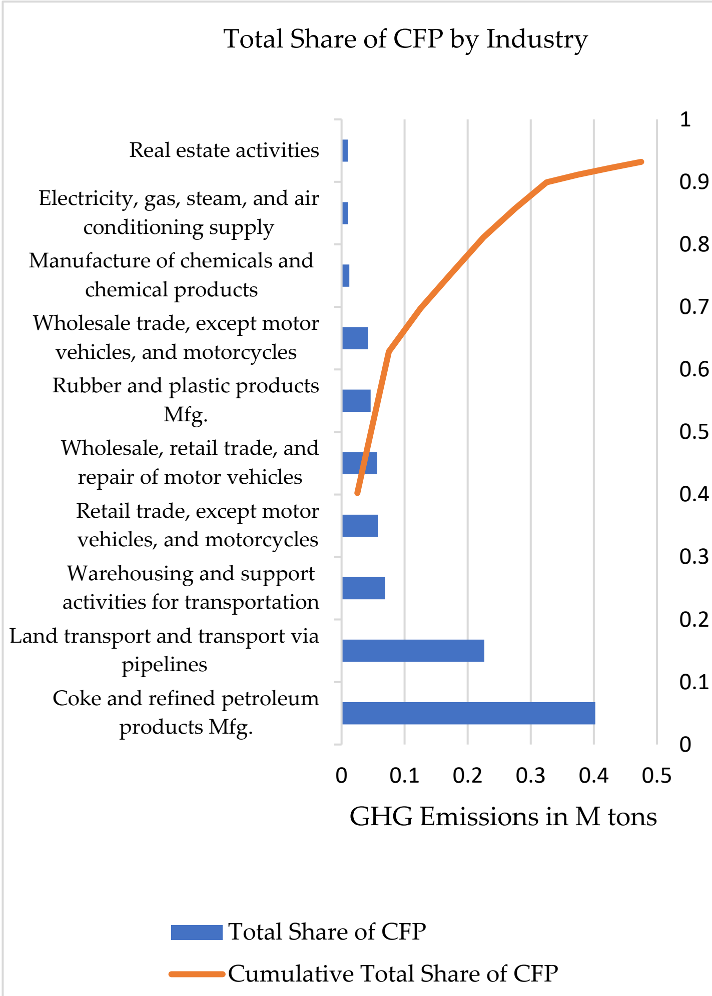


Figure 10. Industry shares in Brazil's total CFP impact.

Table 4 illustrates the CFP shares from the top 10 importing and exporting countries for each country examined, including the country in question (i.e., the domestic transport of products). Moving products inside the country contributed the highest share of the CFP compared with the impacts of other countries, as this includes the import and export of products from all countries.

4.2. Onsite Impacts

The manufacturing of coke and refined petroleum products sector has the highest share of the CFP of the USA, China, Brazil, and Japan. On the other hand, warehousing and transportation support operations have the most significant onsite carbon impacts in Great Britain and Germany. Meanwhile, the land and pipeline transportation sectors are the biggest contributors to Canada's onsite CFP (see Table 5). In addition, the warehousing and transportation support operations sector is considered the second largest contributor to the CFPs of both China and Japan. The land and pipeline transportation sector are the second largest contributor to the CFPs of Germany and Brazil. Finally, wholesale trade, except for motor vehicles and motorcycles, the manufacturing coke and refined petroleum products, public administration, defense, and obligatory social security sectors are the second largest contributors in the USA, Canada, and Great Britain, respectively.

Table 5. The onsite impacts of the seven countries.

Onsite Impacts of the Seven Countries			
Country	**Dominant Sector**	**% Of the Dominant Sector from the Total Impacts**	**The Aggregated Impacts of the Top Ten Sectors**
USA	The manufacturing of coke and refined petroleum products	31.58%	84.98%
Canada	Land transportation and pipeline transportation	63.83%	94.82%
China	The manufacturing coke and refined petroleum products	32.65%	82.81%
Brazil	The manufacturing coke and refined petroleum products	38.31%	93.88%
Germany	Warehousing and support activities for transportation	46.70%	88.26%
Great Britain	Warehousing and transportation support operations	30.47%	80.10%
Japan	The manufacturing coke and refined petroleum products	18.12%	81.03%

The authors conclude that Canada, China, the USA, and Brazil have the highest onsite share of the total CFP, as these countries are considered the largest countries in the world and their areas represent 6.73%, 6.54%, 6.31%, and 5.74% of dry earth area, respectively [37]. In addition, the nature of geography shapes these countries in that they require long fleets to deliver goods to their cities. On the other hand, Japan, Germany, and Great Britain are considered more negligible than other countries in terms of area, and thus contribute less to the onsite share of the total CFP than the rest.

4.3. Supply Chain Impacts

The analysis of the supply chain impacts of the seven countries is comprised of two phases: impacts by country and impacts by industry. Table 6 presents the country out of the seven examined with the highest contribution to the CFP. The RoW is the most significant contributor in these countries with the exception of Canada and Germany. The USA and The Netherlands are the largest contributors to the CFP in Canada and Germany, respectively. On the other hand, the US is considered the second largest contributor to the CFPs of Japan, Great Britain, and Brazil. The RoW is the second largest contributor to the CFPs of Canada and Germany. Finally, Republic of Korea and Canada are considered the second largest contributor to the CFPs of China and the USA, respectively.

Table 6. The supply chain impacts of the seven countries by country.

Supply Chain Impacts of the Seven Countries by Country			
Country	**Dominant Country**	**% Of the Dominant Country from the Total Impacts**	**The Aggregated Impacts of the Top Ten Countries**
USA	The Rest of World (RoW)	30.83%	81.34%
Canada	US	60.22%	91.10%
China	The Rest of World (RoW)	40.48%	91.03%
Brazil	The Rest of World (RoW)	38.30%	89.68%
Germany	The Netherlands	19.04%	77.15%
Great Britain	The Rest of World (RoW)	26.44%	77.74%
Japan	The Rest of World (RoW)	43.63%	92.65%

Table 7 shows the supply chain impacts of the seven countries by industry. The manufacturing of the coke and refined petroleum products sector is the dominant contributor to the CFP in all of the countries examined except for Japan, where the water transport sector is the biggest contributor to the CFP. The manufacture of other transportation equipment sector is considered the second largest contributor in Brazil and China. The mining and quarrying industry, transport via land and pipelines, manufacturing of coke and refined petroleum products, transportation industry warehousing and support operations, and water transport sectors are the second biggest contributors in the USA, Canada, Japan, Germany, and Great Britain, respectively.

Table 7. The supply chain impacts of the seven countries by industry.

Supply Chain Impacts of the Seven Countries by Industry			
Country	**Dominant Industry**	**% Of the Dominant Industry from the Total Impacts**	**The Aggregated Impacts of the Top Ten Industries**
USA	The manufacturing of coke and refined petroleum products	63.68%	91.56%
Canada	The manufacturing of coke and refined petroleum products	42.81%	93.58%
China	The manufacturing of coke and refined petroleum products	41.57%	86.24%
Brazil	The manufacturing of coke and refined petroleum products	63.87%	92%
Germany	The manufacturing of coke and refined petroleum products	35.08%	88.54%
Great Britain	The manufacturing of coke and refined petroleum products	45.46%	85.02%
Japan	The water transport sector	33.97%	95.17%

Due to the lack of comparable studies quantifying the freight sector's CFP in the literature, this study can be considered the first analysis of the CFP of the freight transport sector. However, some studies have analyzed the CFP of manufacturing in general, including the freight transport sector. For instance, Saber et al. [12] studied the CFP of manufacturing activities in the USA and China. The results showed that China had the largest contributions to the CFP of manufacturing globally, with 91%. US manufacturing was the second largest contributor to the CFP, with 84% globally. In addition, Abbood et al. [14] investigated the energy and carbon footprint of US manufacturing. The results showed that the CFP of US manufacturing was 82% globally. These two studies conclude that the USA and China are the largest contributors to the global CFP. Therefore, the results of the current study could be validated and calibrated by comparing them with the results of these studies. Consequently, the freight transport sectors of the USA and China are the largest contributors to CFP globally.

4.4. Comparison

Figure 11 shows the total impacts for each country over the studied period. The figure explains the total CFP share of the freight transport sector for each year from 2000–2014 for the seven countries. It can be seen that China had a high CFP share in the years 2000 and 2002. In addition, the highest levels were in 2014, when it contributed 97.07% of the total CFP impacts. In addition, although the freight transport sector's emissions account for 9.17% of the total CFP emission in China [7], the Chinese freight transport sector contributes the highest CFP among the seven countries. The figure also shows that all countries except China were affected by the financial crisis in 2008, which significantly impacted their economic output and thus performed a crucial role in their CFP shares. However, China continued its freight transport activities and produced additional GHG emissions. This shows that China's freight transport sector is inefficient and is responsible for a major CFP. Even though the transport sector's emissions account for 27% of the total carbon emissions in the USA, the US has a lower CFP share than China, with the highest share of CFP between 2000 and 2004. Subsequently, the financial crisis affected the total economic output of the USA, leading to a CFP reduction. In addition, there was a slight increase in the emissions from the freight transport sector after the 2008 crisis until 2014. Based on this, it can be concluded that the freight transport sector in the USA is more efficient than that in China.

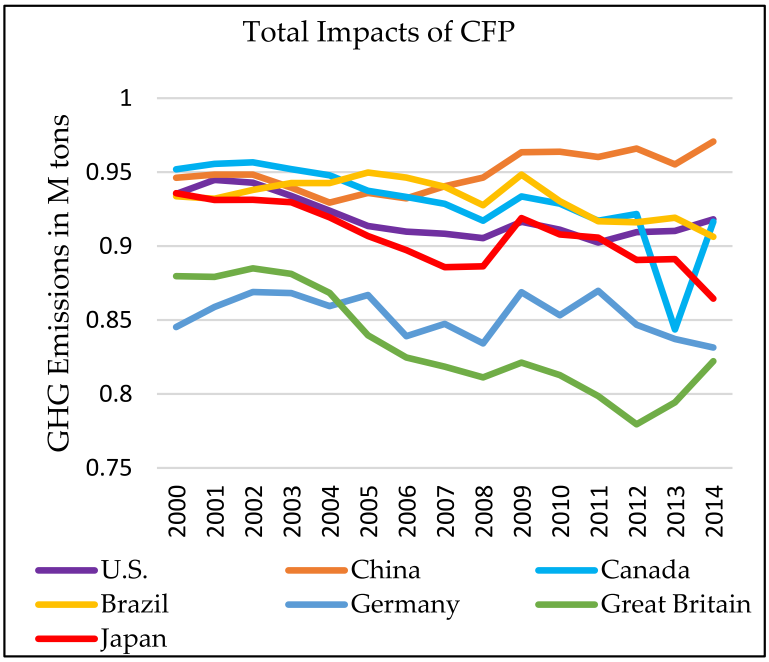


Figure 11. The total CFP impacts for all countries from 2000 to 2014.

As no previous study has analyzed more than two countries, the authors compare this study's results with studies focusing on China and the USA, as their economies generate one-third of the world's economic production. For instance, a recent paper [12] analyzed the manufacturing industries of the United States and China to determine the economic implications and the mid- and endpoint environmental impacts throughout a 20-year study period from 1995 to 2014. The results showed that the GHG emissions of US industries were at their highest in 2000 and 2001 before the financial crisis and were followed by a drop in 2009. Following this drop, GHG emissions increased slightly until 2014. In contrast, China's GHG emissions rose continuously from 2000 to 2014. The highest CFP share was in 2014 and was three times greater than the CFP share in 2000 [10]. The results of the current paper provide additional evidence regarding the total impacts of the Chinese transport sector. In addition, Canada, Japan, and Brazil also show various values for their total CFP impacts over the studied period. The highest CFP share for Canada was from 2000 to 2004, followed by a decrease from 2005 to 2011. GHG emissions increased slightly until 2014. Japan had the highest level of CFP emissions between 2000 and 2003; after a decrease that lasted until 2009, Japan saw a boost from 2009 to 2011, followed by a slight drop from 2011 to 2014. Brazil contributed the most to the CFP from 2003 to 2007, but a decrease could be seen up until 2014.

In a comparison of the five previously mentioned countries with Germany and Great Britain, both Germany and Great Britain had the lowest levels of CFP emissions. Therefore, they can be considered the countries with the most efficient freight transport sectors. Great Britain started from a peak value in 2000 and decreased until 2012, representing the lowest CFP share. Afterward, its CFP increased slightly until 2014. Germany had its highest share of CFP emissions from 2000 to 2005 and from 2009 to 2012 and showed a slight decrease until 2014. Based on this, the authors conclude that Great Britain is the country with the most sustainable freight transport sector.

The second phase of the comparison examines onsite CFP share relative to the area of the seven countries. Canada is the largest country among the seven countries chosen for investigation, as shown in Figure 12. However, China is considered the dominant contributor to the onsite CFP. Even though it is not the largest country, China is responsible for a considerable CFP. Figure 12 shows that Canada, China, Brazil, and the USA have the most extensive areas and the largest onsite CFP shares. In addition, Japan had a high impact on the onsite CFP despite having the smallest area compared with other countries, showing that the freight transport sector in Japan is less efficient. Meanwhile, Great Britain and Germany share the lowest CFPs, suggesting that their freight transport sectors can be considered more efficient than those in other countries; this is especially true for Great Britain, which has the most efficient freight transport sector.

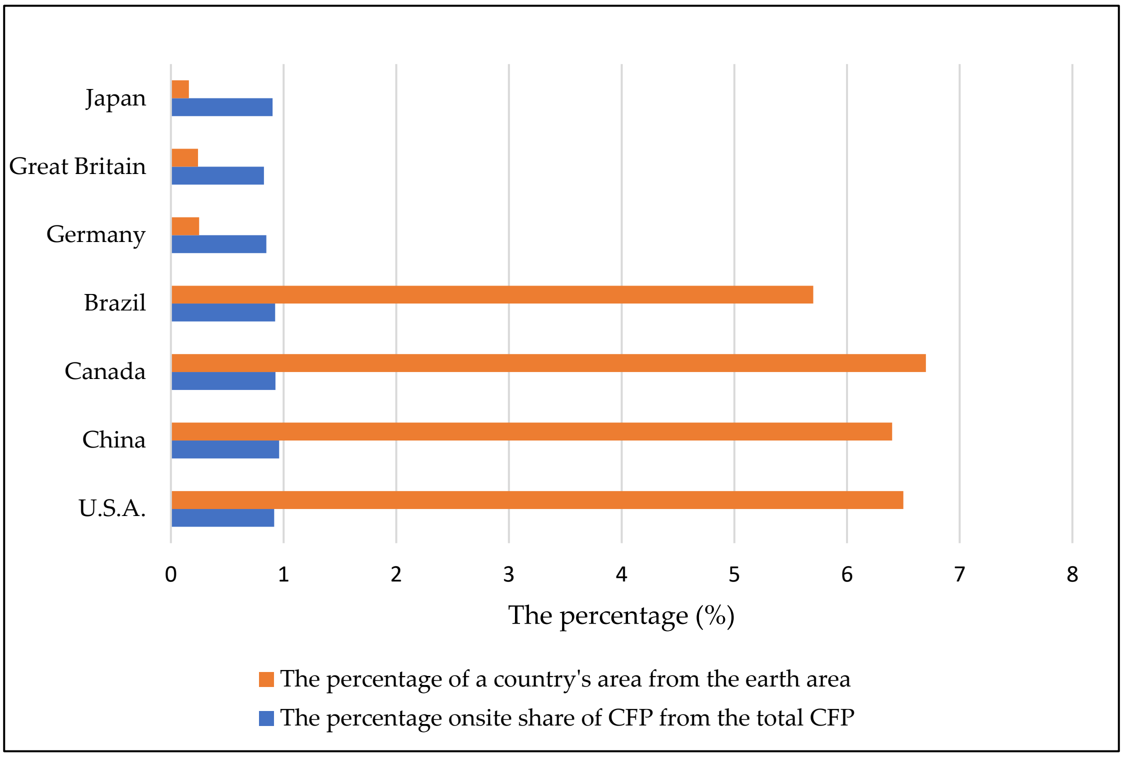


Figure 12. Onsite shares and country areas.

The final step in the comparison identifies the dominant sector in regard to CFP share (see Table 8). The manufacturing of coke and refined petroleum products sector is the largest contributor to the CFP in the USA, China, Japan, and Brazil. This sector contributes the most significant CFP in Brazil. In China and the USA, this sector produces almost the same amount of carbon emissions. Japan, however, is comparatively the smallest contributor to CFP emissions in this sector, suggesting that it is the most efficient country among the seven concerning its dominant sector. Canada is the largest contributor of carbon emissions from land transport and transport via pipelines in large part because Canada is the largest country investigated in this study. As such, delivering goods in Canada requires crossing long distances, which leads to more fuel consumption, the main source of GHG emissions. Warehousing and support activities for the transportation sector is the most significant contributor to the CFPs of Germany and Great Britain; however, Great Britain can be considered more efficient as its CFP is half the size of Germany's. One implication that can be drawn from the results is that the sectors mentioned above require more efforts to decrease their total impacts and effectively apply sustainable measures in the investigated countries.

Table 8. The CFP shares of the dominant sectors for each country.

Country	The Largest Contributing Sector of CFP	% of Total CFP Impacts
USA	Manufacture of coke and refined petroleum products	0.34
China	Manufacture of coke and refined petroleum products	0.33
Canada	Land transport and transport via pipelines	0.61
Great Britain	Warehousing and support activities for transportation	0.26
Japan	Manufacture of coke and refined petroleum products	0.20
Germany	Warehousing and support activities for transportation	0.43
Brazil	Manufacture of coke and refined petroleum products	0.40

5. Conclusions and Future Work

Since much of the literature on the subject focuses on evaluating public transportation systems at the national or municipal level, research on the sustainability of freight transportation has not been substantially examined by researchers despite its importance. There has been a lack of attention paid to the environmental and social aspects of sustainability in the current literature, as revealed by an extensive review of previous studies [3]. This study aimed to assess the CFP of the freight transport sector globally over fifteen years. Therefore, this study concentrated on establishing an analytical model (MRIO) to evaluate the global CFP of the freight transport sector in the seven largest industrial countries: the USA, Canada, China, Japan, Germany, and Great Britain. Analysis of the global CFPs of these countries, 40 major economies worldwide, and the RoW was carried out using MRIO modeling. A total of 15 MRIO models were built for each country from 2000 to 2014. Due to concerns about the uncertainty in assessing CFP impacts using input–output models, a stochastic MRIO framework was also developed. Final demand and Leontief's Inverse were randomized in Monte Carlo simulations to determine the standard deviation of CFP impacts for each country and industry. The CFP total was calculated by multiplying total economic output by a diagonal environmental damage multiplier, such as the Global Warming Potential (GWP) per million dollars of economic activity. After the total CFP for 15 years between 2000 and 2014 was calculated for all seven countries, the Monte Carlo Simulation technique was utilized to build 30 replications. For each year of CFP, we estimated the expected value and the standard deviation.

Moreover, three comparison phases were utilized to determine the efficiency of each country's freight transport sector. The total CFP impacts were analyzed in the study period for all countries and their areas, and their onsite impacts were considered as well. Finally, the largest contributing sector for each country was determined. The Minitab program was used to build a multiple linear regression equation to test whether the GDP, urbanization, area of, and population of each country impact the total emissions of the freight transport sector's CFP in each country over the study period. The null hypothesis of the impact was H_0: the variables are insignificant, and the alternative hypothesis was H_1: the variables are significant. The results showed that the total impacts (i.e., onsite + supply chain) for each country, which include the USA, Canada, China, Japan, Germany, Great Britain, and Brazil, are 91%, 92.17%, 96.26%, 84.75%, 82.56%, and 92.5%, respectively. China is the largest contributor to the CFP of the freight transport sector, while Great Britain has the most sustainable freight transport sector. In addition, the manufacture of coke and refined petroleum products sector has a dominant CFP share in the USA, China, Japan, and Brazil. However, warehousing and support activities for the transportation sector have the highest CFP share in Germany and Great Britain, while the land and pipeline transport sectors are dominant in Canada. The supply chain impacts consist of a country and a sector's supply chain impacts. The RoW is the biggest contributor to the CFPs of China, the USA, Brazil, Japan, and Great Britain. However, the USA and The Netherlands are dominant contributors to the CFP in Canada and Germany, respectively. On the other hand, the manufacturing of coke and refined petroleum products sector is the dominant contributor to the CFP in countries except for Japan, where the water transport sector is the biggest contributor to the CFP.

Canada, China, the U.S., and Brazil have the highest onsite CFP share; this is not surprising, considering that these countries are some of the largest in the world. The nature of geography shapes these countries in that long fleets are required to deliver goods across vast areas. On the other hand, Japan, Germany, and Great Britain are smaller countries and thus contribute less to the onsite CFP share. In addition, the results show that the null hypothesis was rejected; there is a positive relationship between CFP and the GDP, area, urbanization, and population of all of the countries examined over the study period. The *p*-values for the GDP, urbanization, population, and area of each country are 0.000, 0.027, 0.033, and 0.035, respectively. All of the *p*-values for the four variables are less than the significance level of 0.05. Therefore, the null hypothesis was rejected, suggesting a positive relationship between these variables and the share of the CFP of the freight transport sector. One of the most important limitations of this study is that it does not include recent data as the authors used the WIOD. The input–output tables that are available in the WIOD are available until 2014. In addition, this study focused on freight transportation and did not include other industries, representing another limitation. However, this study can be extended by analyzing all industrial sectors. Furthermore, future research can include additional countries to help those in the field develop a more complete understanding of global GHG emissions. Furthermore, energy footprint, water consumption, and other impacts of the freight transport sector can be studied using similar methods. Future research can also take advantage of recently available data to compare results and determine the sustainability performance of each country and sector. Finally, the research can be extended to analyze the social and economic impacts of the freight transport sectors of these countries.

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