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# Measuring Eco-Efficiency of the Global Shipping Sector Based on an Energy and Environmental Approach: A Dynamic Slack-Based Measure Non-Oriented Model

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**Abstract:** The compatibility of shipping with environmental protection is a subject that the international community is becoming increasingly concerned about, considering the threat of climate change. The current study aims to assess the worldwide shipping sector's eco-efficiency performance for the first time using the Dynamic Slack-Based assess non-oriented Data Envelopment Analysis methodology, while the visualization of the results has been made with the geographic information system of ArcGIS. The findings show that the most vibrant shipping sectors in the world, such as the Marshall Islands, present the lowest eco-efficiency levels due to the nations' roles as tax havens for shipowners. Furthermore, traditional maritime economies such as the Chinese one show a great growth in the eco-efficiency score due to the strategies of the shipping companies that are headquartered in the region to invest and adopt Environmental, Social, and Governance principles, which help them to achieve high scores in eco-efficiency. Finally, nations with small fleets have the greatest eco-efficiency score, as local governments have engaged in sustainable activities and initiatives over the previous four to five years to enable their marine industry to thrive and dominate the market.

**Keywords:** environmental efficiency; energy; dynamic slack based model; sustainability; ESG

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## 1. Introduction

Maritime transportation is one of the world's most significant forms of transportation and freight [1,2]. It has been operating for a long time, assisting individuals with their commercial and travel needs. Shipping travel is still necessary, despite the emergence of new kinds of transportation. Maritime transportation has evolved over time. Distance and time limits have been eliminated by the most modern ships, and technological improvements have resulted in a wider spectrum of maritime transportation [3,4]. In addition, the construction of new ships has increased the efficiency and safety of maritime traffic.

However, the shipping industry has an environmental effect since it contributes to air pollution, noise pollution, vessel discharges, port congestion, and marine species invasion [5]. Specifically, shipping delivers around 90% of global trade and contributes to 3% of global greenhouse gas (GHG) emissions from fossil fuel burning. Emissions may grow by 130% by 2050 [1]. Therefore, to achieve an ambitious zero-emission trajectory associated with 1.5 °C, international shipping must move away from utilizing fossil fuels, backed by the requisite technology and infrastructure to create safe and scalable zero-emission fuels (SZEF), including distribution, storage, and bunkering. Significant adoption of SZEF will be required for shipping to continue toward this path [6]. A general fuel transition may be divided into three stages: (i) emergence, (ii) diffusion, and (iii) reconfiguration. In the first phase, research via pilots and innovation begins to encourage acceptance of a novel fuel, which then rapidly gains in competitiveness during the 'diffusion' phase to become the new dominant fuel in the reconfiguration phase [7,8]. However, shipping is still in the emerging phase of the transition, and by 2030, at least 5% of SZEF must be achieved to enable rapid scaling and broad acceptance in the diffusion phase. This equates to 29.8 million metric tons of ammonia or 28.1 million metric tons of methanol, depending on the green hydrogen generated by SZEF [6,9].

Furthermore, the maritime sector can easily achieve energy transition and efficiency by following and integrating Environmental, Social, and Governance (ESG) principles into their business [10]. ESG is required for a sustainable global economy, and these elements can provide an overview of carbon emissions and assist the shipping industry in managing emissions through ESG reports [1]. Companies in the sector are now focusing on green energy, net zero emissions, and a low-carbon future, while their investments in renewable energy generation progress and can be characterized as a critical step toward climate action in the sector. Some of the hazardous gases produced into the atmosphere by ships include methane ($CH_4$), carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), and ozone ($O_3$) [7]. These emissions are the outcome of the Industrial Revolution, which began in the 1700s, and GHG emissions are the primary driver of the rise in global temperatures. GHG emissions are classified into three categories: Scope 1, Scope 2, and Scope 3. Among the above categories, emissions related to Scope 3 are the most difficult to address and quantify. Although the inclusion of ESG frameworks helps businesses in the shipping sector make better decisions by helping them understand and identify the risks associated with the energy transition and efficiency [11].

Though businesses in the maritime sector can better control their emissions and apply ESG principles by measuring their eco-efficiency score, eco-efficiency may play a critical role in assisting the shipping industry in meeting its zero net emissions objective and being less detrimental to the environment [12]. Till today, the issue of measuring the eco-efficiency of the global shipping sector has not been thoroughly investigated by experts in the field. Thus, the novelty of our research work is to use the Data Envelopment Analysis (DEA) to measure the eco-efficiency score in the maritime sector per country and highlight those with the highest and lowest performance. Additionally, the use of the geographic information software ArcGIS will help with the visualization of the results.

The manuscript is broken down into the following sections: Section 2 introduces the concept of green shipping in the global community and presents the importance of the energy transition of the sector, the challenges, and the contribution of eco-efficiency to the enhancement of the actions of the sector to meet its environmental goals and to be energetically upgraded. Section 3 illustrates the materials and methods used. Section 4 indicates the findings of the research work. Section 5 discusses the results of the current research, and Section 6 presents the limitations of the research, proposes future directions for further research in the studied field, and concludes the manuscript.

## 2. Green Shipping: The Energy Transition, the Challenges Facing the Sector, and the Role of Eco-Efficiency

Sustainable shipping, as it has evolved in recent years, is projected to affect the global shipping sector while also reinforcing the need for sustainable management of our society's technical resources [1–15]. Energy resources are at the heart of human activity, and global trade is on the mend. Climate change has driven global trade to evolve in an environmentally friendly way. The sustainability of shipping activities today appears to be a requirement for the preservation of the planet. As a result, renewable energy sources can help boost the power of ships and marine transport [16–18].

Green shipping is the environmental vision of the future, and it refers to the modernization of shipping on a sustainable path [19]. Green shipping comprises pollution-reduction methods that are directly linked to innovation and the utilization of renewable energy sources [15,20]. The ecological concerns of society, along with the many crisis periods of the time, force the major transportation sector to move to more efficient types of energy. The use of renewable energy sources is an innovative approach that stresses the use of limitless energy resources and is related to all the global maritime fleet's activities, such as the international and domestic movement of products, people, and services [21,22].

The use of renewable energy has the potential to totally transform the world's maritime fleet at all scales and to varying degrees, while simultaneously boosting the global economy and influencing future ship designs [23,24]. Ships of different sizes have different propulsion systems, including primary, hybrid, and/or auxiliary, as well as on-board and shore-side energy use. Wave energy, biofuels, wind energy, photovoltaic solar power, and the use of renewable supercapacitors are all potential renewable energy sources for nautical applications [25]. With a limited number of new ships aiming for entirely renewable energy or zero-emissions technologies for primary power, these sustainable energy solutions may be used in both current fleet retrofits and new construction and design [14,22,25]. To transition to a clean-energy marine industry, a significant shift from fossil fuel-powered transport to energy-efficient designs and renewable energy technologies must begin immediately. Under ideal conditions, renewables' contribution to the maritime industry's energy mix is limited in the short and medium term. Despite this, ship designers continue to improve their designs, and proof-of-concept flights demonstrate considerable cost savings in a variety of applications. The current surplus of fossil fuel-powered transportation, as well as the resulting reduced investment market, has impeded the development of renewable energy solutions for shipping [22].

Even though renewable energy sources have a significant impact on the maritime transport sector and its future development, the shift to green shipping may be tough [26,27]. Major barriers to a wider use of renewable energy options for shipping include the following: Due to (i) the lack of financial feasibility of such systems and (ii) the availability of separate incentives for ship owners and operators, the adoption of clean energy technologies in this industry has been slow. Finally, market forces functioning under a stricter regulatory framework will decide the rate of adoption of renewable energy technologies for shipping, although this will be tempered by infrastructure lock-in and other non-market factors. As a result, a number of organizational, structural, behavioral, market, and non-market hurdles need to be removed before renewables can meaningfully contribute to the maritime industry's energy requirements. The use of renewable energy for shipping must be properly managed as we move away from fossil fuels [28].

To demonstrate and grow the role of renewables in shipping, significant efforts and support measures are required immediately [25,29]. To achieve commercial viability, renewable energy shipping systems require supportive policies and incentives to stimulate research, innovation, and proof-of-concept tests. Furthermore, assistance should be concentrated mostly on small ships (less than 10,000 deadweight tons), which are more frequent globally and transport a smaller proportion of total cargo yet emit more greenhouse gases per unit of cargo and distance traveled than larger ships. Additionally, according to the majority of shipping companies, additional incentives that can aid in the installation of environmentally friendly applications on ships include increased energy savings, international and national tax exemptions in different ports, adherence to national and international regulations, marine environment protection, the advancement of knowledge in maritime transport of passengers and cargo, and the provision of services [30].

However, eco-efficiency is another option to support the energy transition and produce greater value through technology and process innovations while lowering resource usage and the shipping sector's environmental effects. In the early 1990s, the World Business Council for Sustainable Development (WBCSD) introduced for the first time the concept of eco-efficiency, which is based on the idea of using fewer resources to produce more products and services while reducing waste and pollution levels [31–36]. Also, eco-efficiency may be applied to all aspects of businesses in the maritime sector and is ranked among the most important methods that help businesses in the sector meet environmental goals [37,38]. One of the most powerful components of eco-efficiency is the relationship between environmental and economic performance. Therefore, the scope of the current research is to calculate the eco-efficiency score of the most dominant countries in the shipping industry globally by considering the environmental and economic aspects of the sector per country as well.

## 3. Materials and Methods

Charnes, Cooper, and Rhodes (the CCR model) have developed the Data Envelopement Analysis (DEA), while Banker, Charnes, and Cooper (the BCC model) have refined it later. Since then, the DEA approach has established itself as one of the main techniques for evaluating the efficacy and efficiency of decreasing environmental pollution from a macroeconomic perspective [39]. The comparison decision-making units (DMUs) with different inputs but the same outputs are evaluated using linear mathematical programming in this approach to determining relative eco-efficiency. The DEA approach investigates DMU efficiency levels in terms of productivity and degree of inefficiency when compared to each DMUs inputs and outputs [39–41].

### *3.1. Sample, Data and Variables*

This study makes use of panel data from the shipping industry of ninety-three (93) global shipping companies. Each of the selected companies represents a DMU in this research. This study lasted five (5) years to understand the consequences of the marine sector's efforts per company to raise their eco-efficiency. The data available was retrieved from the database of Refinitv Eikon, which is powered by Thomson Reuters. As mentioned above, the SBM DEA was used to determine the efficiency levels of each of the selected shipping companies. The selection of the companies is based on their size according to the number of their employees. Specifically, the authors excluded from the sample small and medium enterprises, and they considered only the large companies of the global sector (with more than 250 employees). The main criterion for the selection of the largest companies is the high level of their emissions. Precisely the largest global cargo shipping companies are those that are responsible for 3% of global greenhouse gas emissions.

Moreover, the selection of the variables is another critical issue for any DEA model since failing to pick the appropriate inputs and outputs might result in misleading results [41–48]. Table 1 presents the selected variables, which have been employed as inputs and outputs in the current study.

**Table 1.** The inputs and outputs for the eco-efficiency index structure with SBM DEA.

| Type | Variable | Definition | Units of Measurement |
|---|---|---|---|
| Inputs | Full-time employees | This metric denotes the total count of both full-time workers and the equivalent number of full-time employees derived from part-time or temporary employees, as reported and recorded at the conclusion of the fiscal period. | Metric employees |
| | Energy Use Total | The aggregate utilization of both direct and indirect energy in terms of gigajoules. | Metric tonnes |
| | Fixed Assets | A durable asset or piece of machinery that is owned and utilized by a firm for the purpose of generating revenue in its operational activities. | Metric dollars |
| | Revenue | Net operating revenue is the financial metric that encompasses the total revenue generated by a company's operational endeavors, accounting for any deductions made for sales adjustments and their corresponding counterparts. | Metric dollars |
| Output | $CO_2$ emissions | The emissions discussed below are a direct consequence of energy utilization within the transportation industry. These encompass emissions arising from the burning of fossil fuels as well as carbon dioxide emissions resulting from the combustion of solid, liquid, and gaseous fuels. | Metric tonnes |

### 3.2. The Estimation of Data Envelopment Analsysis

There is a wide range of methods that can be applied by experts in the field to calculate the efficiency of DMUs. Figure 1 describes the different practices that can be adopted by both academics and practitioners.

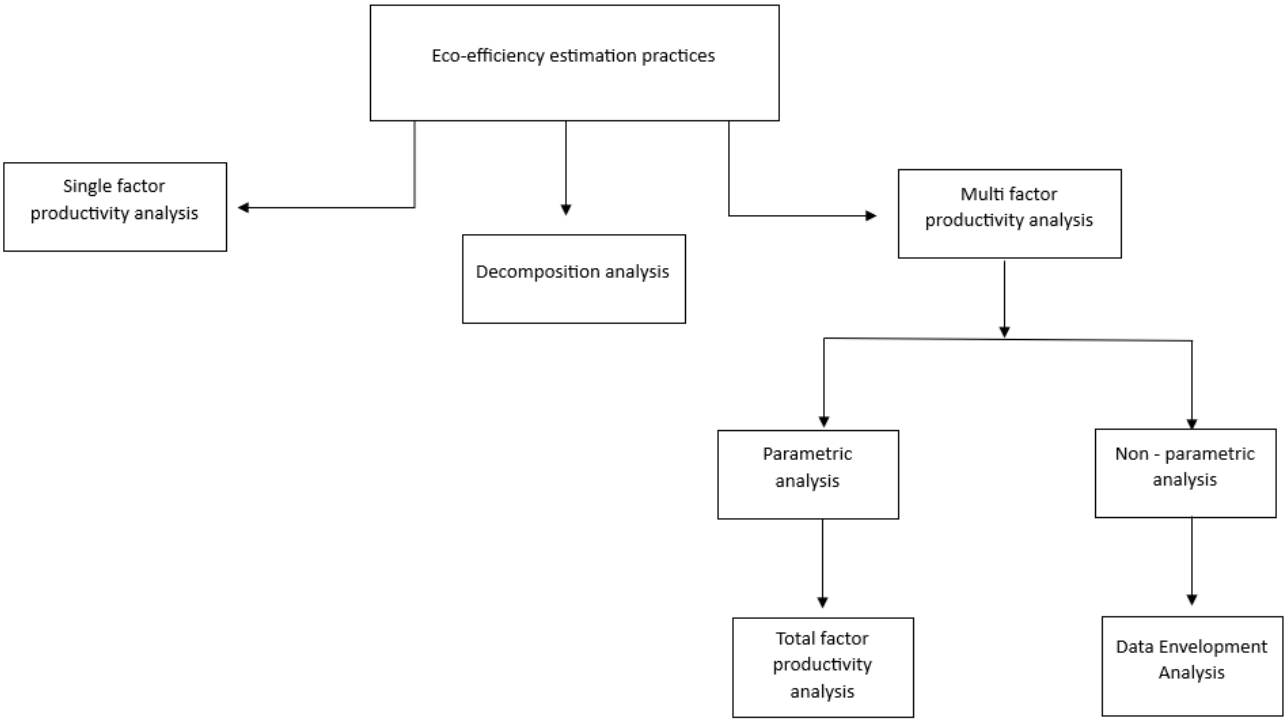



**Figure 1.** Models for the measurement of eco-efficiency. Source: Own elaboration.

The Constant Return to Size (CRS) approach and overall technical efficiency of the CCR model imply that there is no statistically significant relationship between DMU efficiency and operation size. On the other side, the BCC method uses the Variable Return Scale (VRS) to evaluate the technological efficacy of DMUs. Since it assumes that all DMUs function at a perfect scale, which may not be possible given that enterprises profit from economies of scale, the CCRs CRS assumption is acceptable to some extent. Therefore, any researcher who exclusively uses CRS to quantify DMU-scale efficiency risks having their results biased [39,40].

Throughout the years, Data Envelopment Analysis (DEA) has been utilized to assess and analyze efficiency by several experts in the field. On the other hand, conventional DEA models are continuously created to statistically measure the technical efficacy and specialized productivity of the understudied decision-making units (DMUs). The production efficiency of DMUs that use both desired and undesirable outputs has been the subject of several studies over the past 20 years. Numerous studies in numerous sectors have combined advantageous findings, such as GDP and GNP, with unfavorable ones, such as $CO_2$ emission estimates and DMU energy efficiency [39–41]. Despite the lack of data for the variables under examination, the authors of the current study will consider fuel consumption and fleet size, depending on the number of ships, as acceptable inputs. On the other hand, acceptable production will be deemed GDP, while unwanted output will be $CO_2$ emissions [49–54].

Figure 1 illustrates the several stages of DEA usage. While there are six steps in total, the first is to program articulation in computing the DEA of the given DMUs eco-efficiency inputs and outputs. This study assumes that there will be n DMUs to be examined, each of which will represent a nation internationally in the shipping industry. The second phase entails the following: Each DMU uses many *i* inputs and r desirable and undesirable outputs; $DMU_j$ uses $x_{ij}$ amounts of input to generate $y_{rj}$ amounts of output. The energy inputs, $x_{ij}$, and outputs, $y_{rj}$, are assumed to have non-negative values. The third step assumes that each DMU has at least positive input and output utility and significance [55–58]. The eco-efficiency of the worldwide shipping industry for DMUs will be measured using a mathematical technique to assess DMU production:

$$h_j = \frac{\sum_{r=1}^{93} u_r y_{rj}}{\sum_{i=1}^{m} v_r x_{ij}} \tag{1}$$

In the fourth phase of the DEA approach, inputs and outputs of eco-efficiency were assigned weight vectors, $u$ and $v$, based on the above-mentioned Equation (1). The mathematical technique for assessing eco-efficiency is based on the limitation that no DMU has a higher efficiency level than one and that each DMU has the same weight. This indicates that if a DMUs ratio value is one, it is deemed efficient [39,41,59–61]. The final step (step 6) highlighted that the function may be approximated as the ratio of total weighted output divided by total weighted input:

$$max\ h_0(u, v) = \frac{\sum_{r=1}^{93} u_r y_{r0}}{\sum_{i=1}^{m} v_r x_{i0}} \tag{2}$$

$$\text{Subject to,} \quad \frac{\sum_{r=1}^{93} u_r y_{rj}}{\sum_{i=1}^{m} v_r x_{ij}} \leq 1,\ j = 1, 2, \ldots, jo, \ldots, n, \tag{3}$$

$$u \geq 0,\ r = 1, 2, \ldots, s, \tag{4}$$

$$u \geq 0,\ i = 1, 2, \ldots, m, \tag{5}$$

The technical effectiveness of a DMU is represented in the equation by ho, whereas the predicted weights of upgraded DMUs are represented by $u_r$ and $v_i$. The variables $y_{rj}$ and $x_{ij}$ display, respectively, the observed quantities of the $r_{\text{th}}$ type output for the $j_{\text{th}}$ DMU and the observed quantities of the $i_{\text{th}}$ type of input for the $j$ DMU. The equation's $r$ also defines the $s$ number of outputs for that efficiency estimation of $i$ various inputs and $j$, indicating the $n$ different DMUs [39,62,63].

### 3.3. The Dynamic Slack-Based Measure (SBM) DEA Non-Oriented Model Method

The SBM model is yet another tool for monitoring production efficiency over time [39,64]. To assess DMU performance in relation to the range's furthest frontier point, Tone created this idea in 2001. Among the several models used to assess production efficiency, the SBM DEA model seems to be the one that is most frequently employed by research [65]. To avoid data loss, the SBM model requires the use of software with high-precision arithmetic. Input, output, and non-oriented versions of the SBM model are available. The output-oriented and input-oriented models were combined to create the non-oriented model, which was employed in this study [66]. The model directly addresses slack while considering how output and input assumptions will vary proportionately. To depict a non-radial DEA model, the SBM is frequently employed. Eco-efficiency is thoroughly examined using the SBM-DEA model [67]. The model was guided by the equations mentioned below:

Firstly, let $j$ = 1, 2, ... $n$ be the number of DMUs, with each DMU having m inputs and $s$ outputs. In addition, the vectors of inputs and outputs for $DMU_j$ b will be as follows:

$$x_j = x_{1j}, x_{2j, \ldots,} x_{mj} \text{ and } y_j = (y_{1j}, y_{2j, \ldots,} y_{sj}) \text{ respectively} \tag{6}$$

Then, input and output vectors are defined as follows:

$$X \text{ and } Y \text{ by } X = (x_1, x_2 \ldots x_n) \in R^{mxn} \text{ and } Y = (y_1, y_2 \ldots y_n) \in R^{sxn} \tag{7}$$

In the following step, we assume that all the data are positive and that $X > 0$ and $Y > 0$.

$$[SBM - Min]\rho_0^{min} = min_{\lambda,s-,s} + \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1 - \frac{1}{m}\sum_{r=1}^{m} \frac{s_i^-}{y_{r0}}}$$

$$\text{Subject to } x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- (i = 1, \ldots, m)$$

$$y_{r0} = \sum_{j=1}^{n} y_{ij}\lambda_j + S_i^+ (r = 1, \ldots, s)$$

where, $\lambda_j \geq 0(\forall_j), s_i^- \geq 0(\forall_{jr} \geq 0(\forall_r)$.

The last part is to examine that SBM is thought to be effective at: $DMU_0 = (x_0, y_0) if \rho_0^{min} = 1$ exists. The above condition means that $S^- = 0$ and $S^+ = 0$, in other words, all of the input and output constraints are zero [64–67]. It is crucial to apply the dynamic DEA framework to measure energy efficiency. It enables experts and researchers in the field to examine how efficiency evolves over time. Economic success requires strategic eco-efficiency, planning, and investment. Efficiency ratings are frequently exaggerated by disregarding the dynamic nature of carryover activities and undesired output. When data are available, dynamic analysis is performed.

According to Tone and Tsut-sui, the four categories of correlates in dynamic DEA models are fixed, free, good, and bad. As a result, real GDP is the only connecting statistic that displays the profit component linking the two consecutive production years [64,65]. The primary goal of the current research is for the 93 larger shipping companies to improve the environmental performance of their maritime industries and lower $CO_2$ emissions.

$$E_{ot} = \frac{1 - \frac{1}{m+nbad}\left(\sum_{i=1}^{m} \frac{w_i^- s_i^{-*}}{x_{iot}} + \sum_{i=1}^{nbad} \frac{s_{iot}^{bad*}}{Z_{iot}^{bad}}\right)}{1 - \frac{1}{m+ngood}\left(\sum_{i=1}^{m} \frac{w_i^+ s_i^{+*}}{y_{iot}} + \sum_{i=1}^{ngood} \frac{s_{iot}^{good*}}{Z_{iot}^{good}}\right)} (i = 1, \ldots T)$$

This research anticipates that ninety-three separate companies will be thoroughly examined. For the *j*-th country, throughout the two following time periods (*t* = 1, ... *T*), *j* = 1, ..., *n* Each DMU under consideration has m inputs, with *i* = 1, *k*, and *m*.

## 4. Results

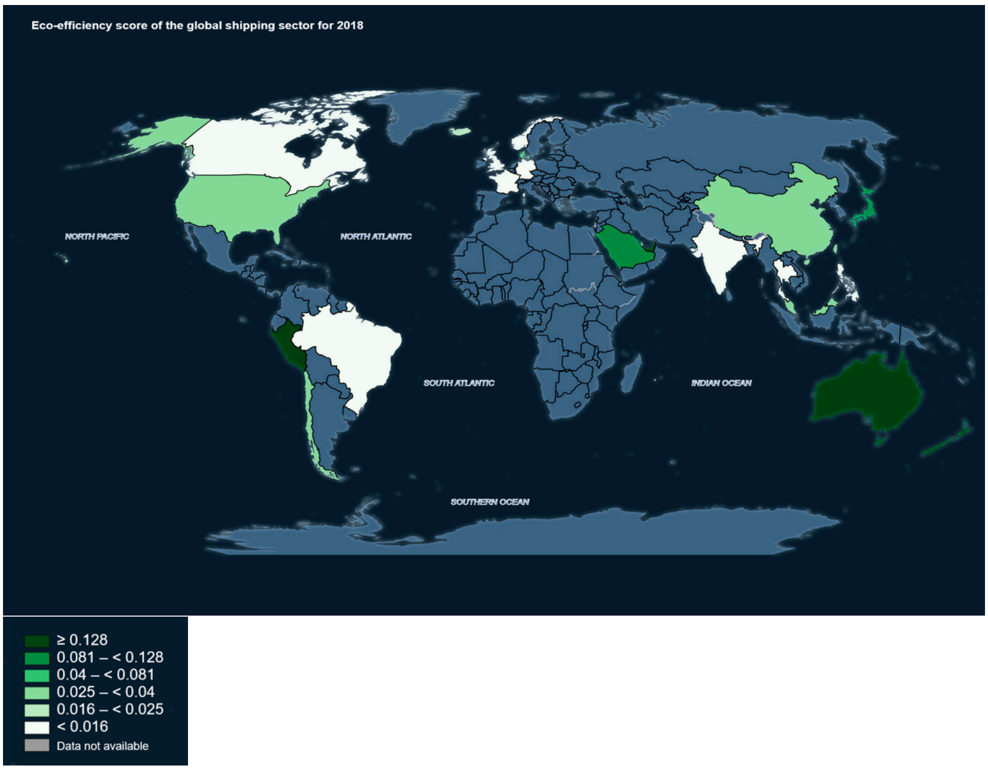
As it has been described above, this study uses the SBM non-oriented model for the measurement of eco-efficiency in the global shipping sector with the use of MaxDEA 8 Ultra software.

The results for eco-efficiency, obtained through the application of the dynamic slack-based measure non-oriented model, are shown in Table A1 (Appendix A). These results pertain to the 93 worldwide shipping businesses that were selected for analysis. Furthermore, the utilization of ArcGIS software has facilitated the depiction of the computed eco-efficiency values for each of the years under investigation. This aids in comprehending the variations in eco-efficiency outcomes across the selected shipping companies over time (refer to Figure 2a–d).

This study found that eco-efficiency in the shipping sector presents fluctuation among the examined years. Eco-efficiency was at 0.565 in 2018, while a year later (2019), the index presents a decrease of about 14 percentage points. However, eco-efficiency indicated an important increase (21%) among the years 2019–2020. Moreover, in the following studied years, 2021 to 2022, the eco-efficiency score was higher.

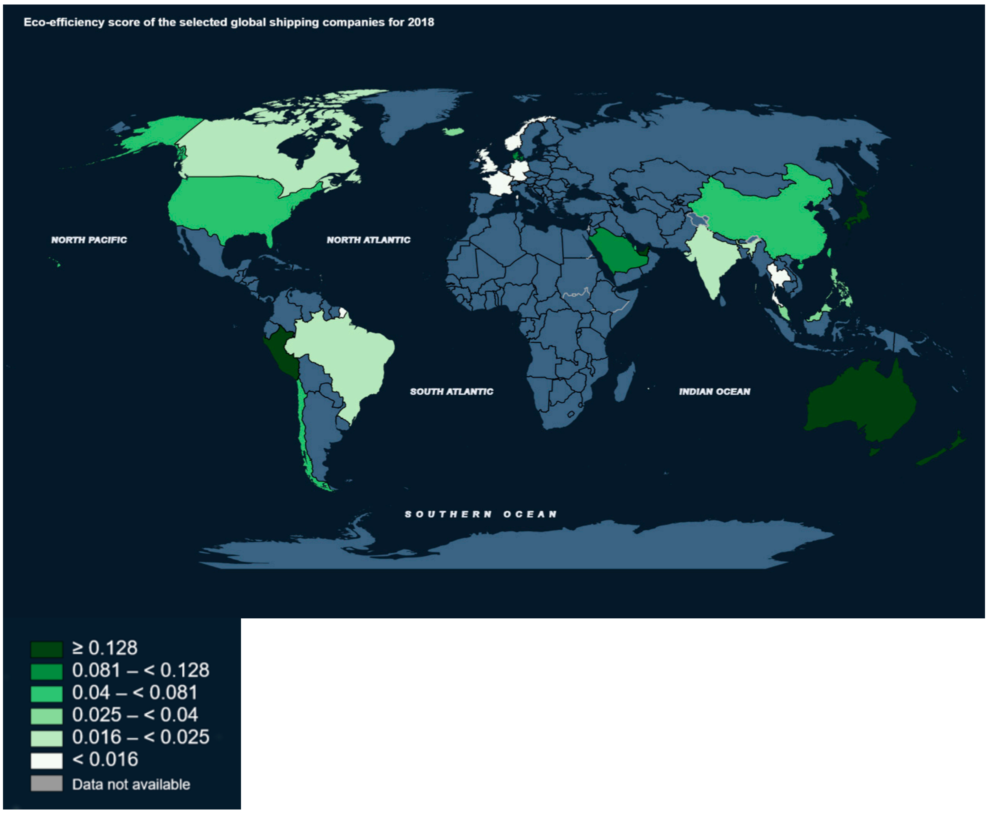
Canadian shipping companies seem to score among the highest levels of eco-efficiency. Despite Canada having one of the smallest shipping sectors in the world, based on the size of the fleet, shipping is critical to maintaining the Canadian economy, working for everyone, and producing excellent employment for the country [68]. The Government of Canada is also dedicated to taking real steps to accomplish its climate goals and provide Canadians with an efficient and ecologically friendly shipping system. Therefore, Canada's government has formulated the Canadian Green Shipping Corridors Framework and Canada's participation in the Zero-Emission Shipping Mission [69]. Both projects aim to assist all parties interested in developing a green shipping corridor by: (i) establishing a common Canadian vision to ensure that green shipping corridors are consistently implemented; and (ii) empowering all parties to collaborate to eliminate emissions and address the climate crisis. In addition, the government's statement is that by being at the vanguard of decreasing marine emissions, the country will create new opportunities for Canadian clean tech and clean fuel entrepreneurs, as well as contribute to Canada's economic development and prosperity [68–72].

Moreover, Chinese shipping companies seem to invest a lot in eco-efficiency. Chinese maritime corporations have initiated significant efforts in the areas of decarbonization, emission reduction, and the use of alternative energy sources. The primary impetus behind this initiative stems from the International Maritime Organization's (IMO) dedication to achieving decarbonization in the realm of global shipping. The objective is to diminish carbon dioxide ($CO_2$) emissions per unit of transport work, considering international shipping as a whole. The target is to achieve a minimum reduction of 40% by the year 2030, with ongoing endeavors aimed at attaining a 70% reduction by 2050, relative to the emissions recorded in 2008. Given that China is a member state of the International Maritime Organization (IMO), it follows that the required procedures prescribed by the IMO are applicable to all maritime firms operating inside China. Furthermore, the establishment of domestic carbon neutrality objectives in China, along with the implementation of green financing frameworks by international ship financing institutions, has played a significant role in facilitating this phenomenon.

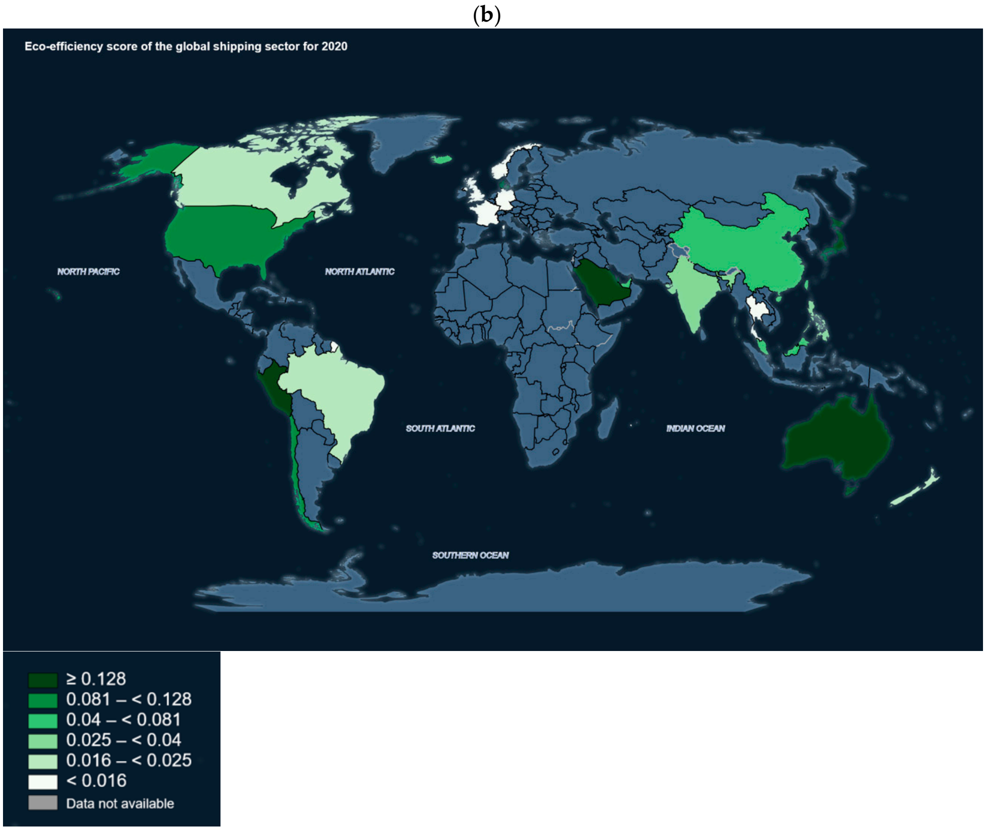



(**a**)

**Figure 2.** *Cont.*

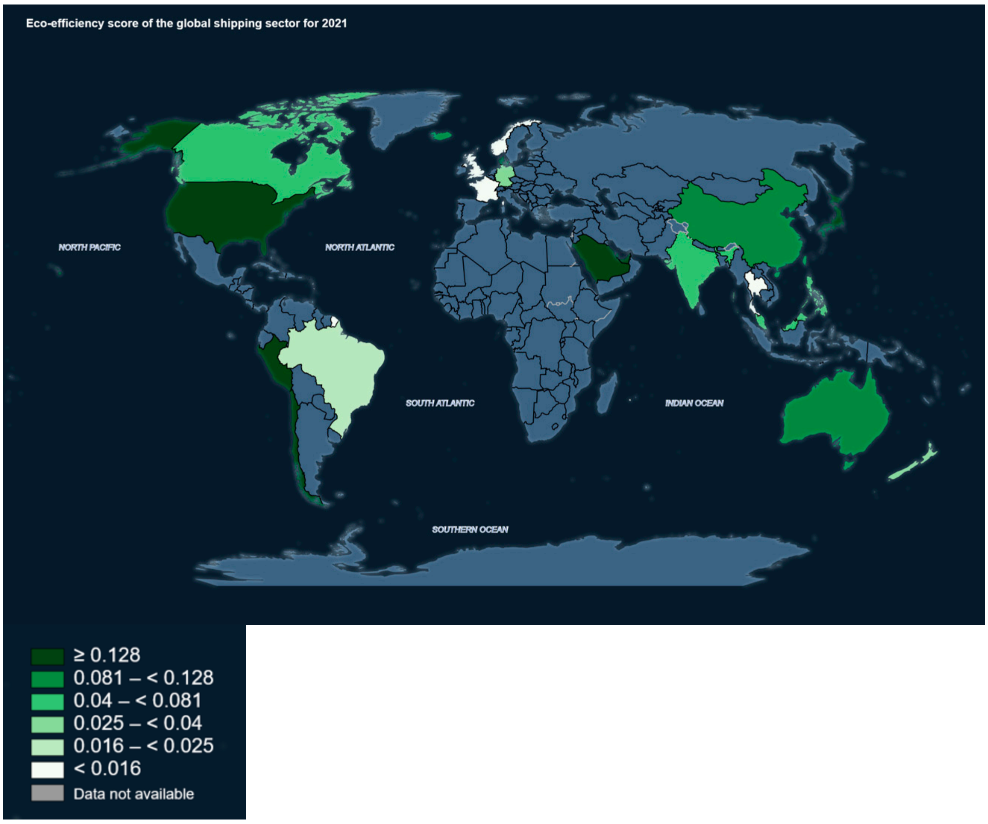



(**b**)

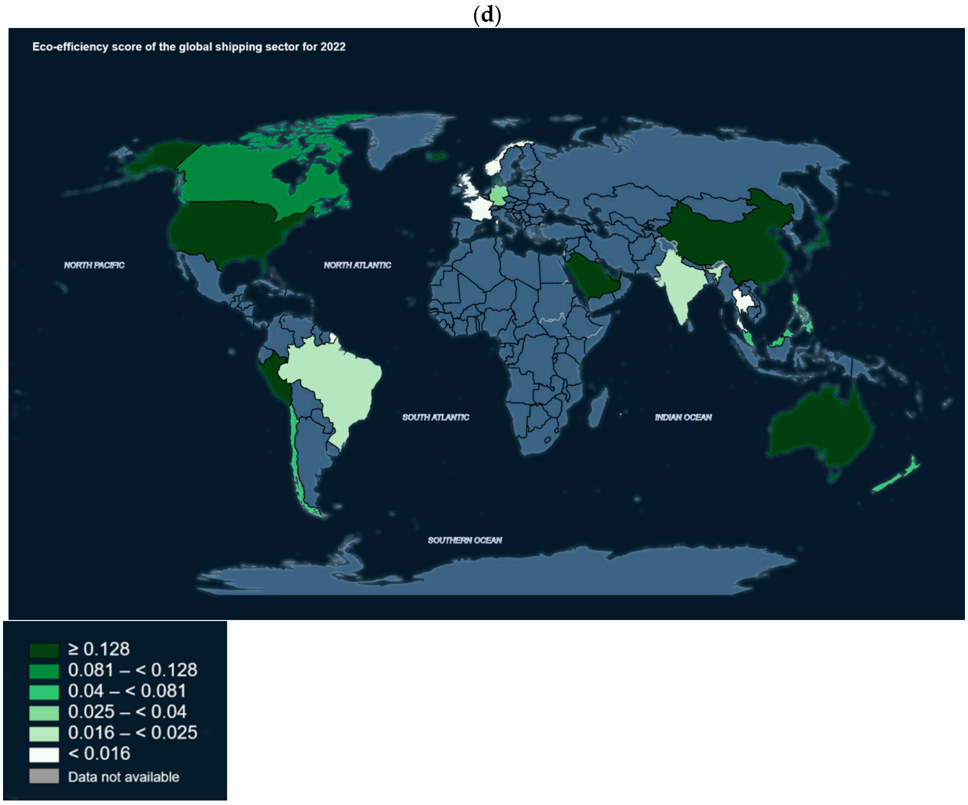



(**c**)

**Figure 2.** *Cont*.




(**d**)




(**e**)

**Figure 2.** (**a**). Eco-efficiency score of the selected global shipping companies for 2018. (**b**). Eco-efficiency score of the global shipping sector for 2019. (**c**). Eco-efficiency score of the global shipping sector for 2020. (**d**). Eco-efficiency score of the global shipping sector for 2021. (**e**). Eco-efficiency score of the global shipping sector for 2021.

Furthermore, in recent years, China has made significant strides in the promotion of environmentally sustainable shipping practices. The greater implementation of Environmental, Social, and Governance (ESG) principles is expected to be essential in driving this progress forward. The prioritization of a cleaner environment is a key aspect within China's overarching objective of achieving "common prosperity" in the long run. The implementation of the concept of "common prosperity" has resulted in the initiation of regulatory changes and stringent measures targeting several industries, such as private education and technology. Considering the pivotal position that shipping will assume in the transition towards a more sustainable economy, it is quite probable that this sector will see significant regulatory transformations in the future.

Although among the examined shipping companies that prove limited efforts to achieve higher eco-efficiency levels are those that are headquartered in the Marshall Islands [12,56,73,74]. Shipping companies in the above country can be characterized as some of the most dynamic in the global shipping sector; however, it is quite an oxymoron that companies in this country present the lowest eco-efficient levels in the industry. However, there is an explanation for the reasons why this may happen. The region of the Marshal Islands is well known as a tax haven on a global scale. By analyzing the term "tax haven," this refers to just a country that allows corporations to pay little or no taxes, while a pure tax haven is a country that levies no taxes at all. For example, the Marshal Islands, due to a strong law that closely oversees the country's offshore jurisdiction and financial services, can be regarded as one of the most well-established pure tax havens globally [75–77]. Moreover, studies have shown that the use of tax havens poses not just a sociopolitical and economic dilemma but also an environmental one. However, financial opacity in the shipping sector makes it difficult to assess how money flows affect economic activity in the ocean and their environmental consequences [75,77].

Finally, among the countries with higher and lower eco-efficient performance, there are those that reveal a slight improvement in it. Qatar is among those countries that shows an important improvement related to the eco-efficient performance of the shipping sector [78]. The country's marine economy will gain speed as Qatar opens new trade lines and diversifies its supply sources. Following the unfair siege, the government launched many steps to improve marine trade and assure a steady supply of commodities for people, such as the goal to formulate and achieve a sustainable maritime sector. Under the country's National Vision 2030, Qatar is rapidly establishing a sustainable transportation system, and several initiatives taken in recent years have already created a firm foundation for the government to go ahead in attaining its goals within established time periods. A variety of government agencies, including the Ministry of Transport, the Public Works Authority, and others, are working together to realize the country's objective of ecologically friendly transportation systems [78]. In addition, through the years, the maritime sector of Qatar went paperless in transactions via the Mwanina port community system of Mwani Qatar, which kept sustainability at the heart of its ecosystem because it believes the world relies heavily on sea freight for its efficiency and low costs, and now is the time to adopt new technologies for a greener, more sustainable shipping industry [79].

## 5. Discussion

The compatibility of shipping with environmental protection is an issue that concerns the international community more and more under the threat of climate change. Legislative and institutional initiatives for sustainable development in shipping set a strict regulatory framework to reduce pollution from shipping activities but also look more long-term towards the development of innovative technologies with higher energy efficiency [1,2,8,27,80].

Shipping has long been a key engine of global trade and innovation. However, although maritime operations contribute to growth and development, they also damage the environment. With environmental protection and sustainability playing a significant role in UN policies, shipping's link with sustainability and measures to minimize pollution from marine operations are likely to be at the forefront of discussion [71,72,81]. The threats to the environment posed by the transportation of people and, more importantly, products are diverse and have varying degrees of influence. The most common kind of pollution is operational pollution, which results from routine ship operations and extends both to water with fuel spills and possibly cargo leaks and to air with atmospheric pollution from sulfur dioxide and carbon dioxide emissions from fuel carbon. Other types of pollution include pollution from ship building, maintenance, and disassembly, as well as pollution from ship accidents such as sinking, grounding, collisions, and fire [3,82,83].

As a result, the challenge is how shipping can keep up with sustainable development while being environmentally friendly. The measurement of eco-efficiency is one method that can assist the global shipping sector in achieving this goal. Schaltegger and Sturm coined the phrase "eco-efficiency" in 1990. However, the World Business Council for Sustainable Development (WBCSD) was responsible for developing one of the world's key eco-efficiency principles in 1991. The term was defined as the provision of economically competitive goods and services that meet societal needs in terms of quality of life and that the entire process of manufacturing and availability for consumption, that is, throughout its life cycle, should have the least possible environmental impact [12,56,74,84].

Today, eco-efficiency has become the buzzword for most sectors globally. However, in the shipping sector, the measurement of eco-efficiency has not yet been examined thoroughly. Therefore, the novelty of this research is the construction and measurement of the eco-efficiency index and the highlights of those countries with the highest and lowest eco-efficiency levels. To approach the research question, we have developed and applied the Dynamic Slack-Based Measure non-oriented model in the shipping sector, which is considered one of the 93 largest shipping companies globally [65–67]. The formulation of the index was based on two input and two output variables, while the MaxDEA software was used for the calculation of the index. Furthermore, the results have been visualized in maps with the use of the geographic information system ArcGIS.

Findings reveal that countries with the smallest fleet are those that present the most impressive eco-efficient performance, while the countries that dominate the field seem to invest less in adopting practices and decrease the environmental footprint of their shipping activities [3,41,48]. Specifically, the improvement of the Canadian and Taiwanese shipping sectors is awesome. Both governments try their best to achieve a carbon-neutral maritime sector by setting the appropriate regulations and offering initiatives to shipowners. Each of the two economies has developed strategies that encourage companies in the shipping sector to adopt sustainable practices and actions in order to decrease their environmental footprint. Although Brazil's shipping sector is another one that has presented an important performance in terms of eco-efficiency, Brazil has untapped potential to construct green corridor systems throughout its coast with the goal of optimizing waterway traffic, with a concentration on short-sea shipping (maritime transport on the Brazilian coast). The country's maritime sector has already rethought traditional transportation and innovated via the use of innovative alternatives such as hybrid systems, renewable energy, liquefied petroleum gas, biomethane, compressed natural gas, and so on [85–87]. Moreover, by heavily utilizing short-sea shipping, Brazil has already improved the logistical flow between the south and north of the country, which can enable the adoption of the green logistics corridor.

In addition, what is noteworthy from the results is that traditional economies in shipping are not included in those with the highest eco-efficiency. Greece leads world shipping in total fleet capacity [88,89]. Especially in the transportation of liquid fuels, the Greek-owned fleet transports more than 25% of the transportation of petroleum products internationally. However, while the world economy is struggling to disengage from the use and consumption of oil and its products due to the environmental burden of gaseous pollutants when burning conventional fuels and, above all, due to their impact on climate change, the Greek shipping industry has succeeded in progressing in this direction, but not to the desired extent [88,89]. The transition to the use of cleaner energy can create amazing opportunities for Greece and its shipping, which should not be missed under any circumstances. The requirement to use cleaner energy in all sectors creates the possibility for the Greek-owned fleet not only to transport clean fuels but for these fuels to be produced in the country and used by ships with an almost zero footprint on the environment.

Even though the dynamics offered by sustainable fuels are excellent and given, there are nevertheless several technical limitations. Difficulties in the handling, distribution, and storage of hydrogen are a negative factor in its wider application. Ammonia, although qualified as the most promising economic option, causes great uncertainty regarding the safety of its use, while methanol and biofuels, although flexible options, create correspondingly great uncertainty about their long-term competitiveness and availability [89]. Finally, it is underlined that the transition to the use of cleaner energy in Greek shipping can only be achieved through a combination of solutions and changes regarding not only the use of fuels but also investments and policies. Therefore, a systemic approach will be needed from the Greek government that will guide and support the shipping industry in finding long-term solutions compatible with the achievement of climate goals. In this direction, providing incentives for research and innovative solutions from academic and private bodies will play an important role [88].

In addition, according to the findings of the eco-efficiency measurement, the problem of tax-haven nations appears to be an impediment to the global shipping sector achieving eco-efficiency and sustainability goals. Firm tax evasion has received significant public attention in the research community. Despite enhancing the firm's revenues in the short run, tax evasion may decrease the firm's long-term sustainable business continuity. The results of the current study highlight the issue of tax evasion and its negative impact on eco-efficiency. Specifically, the eco-efficiency score in the countries of Panama, Singapore, Liberia, the Marshall Islands, and the Bahamas presents the lowest eco-efficiency performance score globally [75–77]. As we have mentioned in Section 4, these countries are among those that dominate the shipping sector. However, these countries have the role of a tax haven for the shipowners, and this represents their limited willingness to develop and adopt sustainable and eco-efficient practices in order to mitigate their environmental footprint. Therefore, it is vital for the global community to mitigate the above circumstances, as the effect of tax havens in the sector can be devastating for the environment and the sector as well. The governments of these countries should enhance their audit systems and develop regulations that cannot allow companies that are headquartered in these countries to ignore the environment and the impact of their activities on it.

## 6. Conclusions

Shipping has always been a central driver of trade and innovation in the global economy. However, as much as shipping activities contribute to progress and development, they also endanger the environment. With environmental protection and sustainability playing a leading role in shaping the policies of countries worldwide, shipping's relationship with sustainability and efforts to prevent pollution from marine activities are expected to be at the center of attention [3,13,80,85].

The risks to the environment from the shipping of people and, above all, goods are diverse and involve different levels of impact. The most widely known form of pollution is operational, which comes from the normal operation of ships and extends both to water with fuel spills and possible cargo leaks and to air with atmospheric pollution from sulfur dioxide and carbon dioxide emissions from fuel carbon. Other forms of pollution are pollution during the construction, maintenance, or dismantling of the ship, and pollution from accidents such as sinking, grounding, collisions, and fire on ships. Thus, the question that arises is how shipping can keep pace with sustainable development so that its global activity does not burden the environment [23,70].

Eco-efficiency is considered among the most important strategies for encouraging the transition from unsustainable to sustainable development in the shipping sector. The concept of eco-efficiency is centered in the shipping sector on the principle of producing more services with fewer resources while generating less waste and advertising [31,73]. Thus, the scope of the current study was to measure the eco-efficiency scores of the largest shipping companies in the global shipping sector and highlight those with the highest and lowest performance scores. To approach the research question of this study, an econometric model based on the Dynamic Slack-Based Measure non-oriented approach has been developed. Moreover, the performance score of the country in the sample has been mapped with the use of the ArcGIS software to be friendly for the reader.

The findings show that countries with the smallest fleets have the most spectacular eco-efficient performance, while countries that dominate the industry appear to invest less in adopting methods and reducing the environmental imprint of their shipping activities. Particularly impressive is the growth of the Canadian and Chinese shipping sectors [68,69]. Both governments make every effort to develop a carbon-neutral marine industry by enacting relevant rules and providing programs to shipowners. Each of the two economies has established policies to encourage shipping businesses to adopt sustainable practices and actions to reduce their environmental footprint. However, Brazil's maritime sector has also demonstrated significant eco-efficiency performance. Brazil has latent potential to build green corridor systems along its coast to optimize waterway traffic, with a focus on short-sea shipping (maritime transport along the Brazilian coast) [85]. The country's marine industry has already rethought old modes of transportation and innovated by utilizing novel alternatives such as hybrid systems, renewable energy, liquefied petroleum gas, biomethane, compressed natural gas, and so on.

Regarding the limitations of this research, they are mainly based on the unavailable data for the shipping sector in more countries. Moreover, our future research plans include the hierarchy of the eco-efficiency score based on the multicriteria analysis of entropy TOPSIS. Within this analysis, we are going to hierarchize the countries by considering and weighting specific criteria, such as the inputs and outputs of the current study, and then we are going to calculate the new eco-efficiency performance score. This method will help us in the decision-making process regarding the most sustainable country's shipping sector.

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## Appendix A

**Table A1.** Dynamic Slack-Based Measure non-oriented results for the eco-efficiency index.

| DMUs | Eco Efficiency Score 2022 | Eco Efficiency Score 2021 | Eco Efficiency Score 2020 | Eco Efficiency Score 2019 | Eco Efficiency Score 2018 |
|---|---|---|---|---|---|
| 1 | 0.81 | 0.33 | 0.05 | 0.03 | 0.02 |
| 2 | 1.00 | 0.66 | 0.42 | 0.23 | 0.22 |
| 3 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 |
| 4 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 |
| 5 | 0.09 | 0.04 | 0.02 | 0.02 | 0.01 |
| 6 | 1.00 | 1.00 | 1.00 | 0.01 | 0.00 |

**Table A1.** *Cont.*

| DMUs | Eco Efficiency Score 2022 | Eco Efficiency Score 2021 | Eco Efficiency Score 2020 | Eco Efficiency Score 2019 | Eco Efficiency Score 2018 |
|---|---|---|---|---|---|
| 7 | 0.40 | 0.76 | 0.27 | 0.12 | 0.11 |
| 8 | 0.08 | 0.07 | 0.04 | 0.05 | 0.04 |
| 9 | 0.04 | 0.04 | 0.01 | 0.02 | 0.01 |
| 10 | 0.07 | 0.06 | 0.03 | 0.04 | 0.03 |
| 11 | 0.03 | 0.02 | 0.01 | 0.03 | 0.02 |
| 12 | 0.07 | 0.05 | 0.02 | 0.02 | 0.01 |
| 13 | 0.77 | 0.66 | 0.41 | 0.62 | 0.61 |
| 14 | 0.64 | 0.55 | 0.16 | 0.45 | 0.44 |
| 15 | 0.50 | 0.49 | 0.16 | 0.64 | 0.63 |
| 16 | 0.72 | 0.48 | 0.27 | 0.12 | 0.11 |
| 17 | 0.31 | 0.32 | 0.17 | 0.09 | 0.08 |
| 18 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| 19 | 0.66 | 0.58 | 0.16 | 0.32 | 0.31 |
| 20 | 0.03 | 0.03 | 0.01 | 0.02 | 0.01 |
| 21 | 0.09 | 0.09 | 0.06 | 0.03 | 0.02 |
| 22 | 1.00 | 1.00 | 0.37 | 0.09 | 0.08 |
| 23 | 0.55 | 0.33 | 0.20 | 0.07 | 0.06 |
| 24 | 0.15 | 0.09 | 0.05 | 0.02 | 0.01 |
| 25 | 0.60 | 0.51 | 0.43 | 0.25 | 0.24 |
| 26 | 0.96 | 0.98 | 0.79 | 0.72 | 0.71 |
| 27 | 0.88 | 0.56 | 0.06 | 0.03 | 0.02 |
| 28 | 0.08 | 0.07 | 0.04 | 0.04 | 0.03 |
| 29 | 0.40 | 0.36 | 0.12 | 0.18 | 0.17 |
| 30 | 0.43 | 0.33 | 0.26 | 0.15 | 0.14 |
| 31 | 0.16 | 0.16 | 0.04 | 0.03 | 0.02 |
| 32 | 0.50 | 0.92 | 0.22 | 0.07 | 0.06 |
| 33 | 0.49 | 0.65 | 0.26 | 0.09 | 0.08 |
| 34 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 |
| 35 | 0.69 | 1.00 | 0.46 | 0.13 | 0.12 |
| 36 | 0.69 | 0.56 | 0.19 | 0.30 | 0.29 |
| 37 | 0.48 | 0.43 | 0.16 | 0.22 | 0.21 |
| 38 | 1.00 | 0.44 | 0.18 | 0.13 | 0.12 |
| 39 | 0.99 | 0.88 | 0.20 | 0.10 | 0.09 |
| 40 | 0.94 | 1.00 | 0.29 | 0.12 | 0.11 |
| 41 | 0.26 | 0.26 | 0.10 | 0.06 | 0.05 |
| 42 | 0.58 | 0.14 | 0.07 | 0.03 | 0.02 |
| 43 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 |
| 44 | 0.52 | 0.47 | 0.25 | 0.36 | 0.35 |
| 45 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| 46 | 0.05 | 0.03 | 0.01 | 0.01 | 0.00 |
| 47 | 0.05 | 0.05 | 0.03 | 0.02 | 0.01 |
| 48 | 1.00 | 0.52 | 0.16 | 0.06 | 0.05 |
| 49 | 0.64 | 0.35 | 0.15 | 0.09 | 0.08 |
| 50 | 0.24 | 0.15 | 0.11 | 0.05 | 0.04 |
| 51 | 1.00 | 1.00 | 0.24 | 0.19 | 0.18 |
| 52 | 1.00 | 1.00 | 0.41 | 0.15 | 0.14 |
| 53 | 0.11 | 0.09 | 0.03 | 0.02 | 0.01 |
| 54 | 0.74 | 0.33 | 0.10 | 0.04 | 0.03 |
| 55 | 1.00 | 1.00 | 0.50 | 0.19 | 0.18 |
| 56 | 0.87 | 0.62 | 0.16 | 0.09 | 0.08 |
| 57 | 0.90 | 0.76 | 0.29 | 0.18 | 0.17 |
| 58 | 0.27 | 0.14 | 0.13 | 0.05 | 0.04 |
| 59 | 0.59 | 0.34 | 0.31 | 0.12 | 0.11 |
| 60 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| 61 | 0.07 | 0.05 | 0.03 | 0.02 | 0.01 |
| 62 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| 63 | 0.54 | 0.41 | 0.54 | 0.18 | 0.17 |
| 64 | 0.46 | 0.39 | 0.34 | 0.17 | 0.16 |

**Table A1.** *Cont.*

| DMUs | Eco Efficiency Score 2022 | Eco Efficiency Score 2021 | Eco Efficiency Score 2020 | Eco Efficiency Score 2019 | Eco Efficiency Score 2018 |
|---|---|---|---|---|---|
| 65 | 0.25 | 0.25 | 0.07 | 0.04 | 0.03 |
| 66 | 0.02 | 0.05 | 0.03 | 0.02 | 0.01 |
| 67 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| 68 | 1.00 | 1.00 | 1.00 | 1.01 | 1.00 |
| 69 | 0.04 | 0.04 | 0.02 | 0.02 | 0.01 |
| 70 | 1.00 | 1.00 | 0.75 | 0.26 | 0.25 |
| 71 | 0.26 | 0.17 | 0.02 | 0.02 | 0.01 |
| 72 | 1.00 | 0.16 | 0.13 | 0.06 | 0.05 |
| 73 | 0.07 | 0.05 | 0.02 | 0.02 | 0.01 |
| 74 | 0.57 | 0.50 | 0.30 | 0.20 | 0.19 |
| 75 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| 76 | 0.79 | 0.98 | 0.06 | 1.01 | 1.00 |
| 77 | 0.19 | 0.16 | 0.10 | 0.08 | 0.07 |
| 78 | 1.00 | 1.00 | 1.00 | 1.01 | 1.00 |
| 79 | 0.09 | 0.08 | 0.03 | 0.03 | 0.02 |
| 80 | 0.58 | 0.62 | 0.56 | 0.24 | 0.23 |
| 81 | 0.14 | 0.11 | 0.07 | 0.03 | 0.02 |
| 82 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 |
| 83 | 0.06 | 0.05 | 0.03 | 0.03 | 0.02 |
| 84 | 0.08 | 0.39 | 0.09 | 0.04 | 0.03 |
| 85 | 0.21 | 0.18 | 0.09 | 0.05 | 0.04 |
| 86 | 0.11 | 0.10 | 0.02 | 0.02 | 0.01 |
| 87 | 0.24 | 0.07 | 0.02 | 0.02 | 0.01 |
| 88 | 0.13 | 0.13 | 0.06 | 0.04 | 0.03 |
| 89 | 0.43 | 0.19 | 0.14 | 0.07 | 0.06 |
| 90 | 0.68 | 0.20 | 0.09 | 0.02 | 0.01 |
| 91 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| 92 | 0.06 | 0.03 | 0.02 | 0.34 | 0.33 |
| 93 | 0.26 | 0.11 | 1.00 | 0.58 | 0.57 |

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