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Benchmarking Efficiency, Sustainability, and Corporate Responsibility in Maritime Logistics: An Entropy-GRA Model with Sensitivity Analysis

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Abstract: As global awareness of sustainability and corporate social responsibility (CSR) intensifies, container shipping lines (CSLs) face growing pressure to align their operations with stakeholder expectations. However, existing studies in maritime logistics often examine CSR and environmental performance separately, rely on qualitative methods, or focus on broader shipping contexts without targeting CSLs specifically. Moreover, few studies provide data-driven benchmarking tools to evaluate performance across multiple sustainability dimensions. This study addresses these gaps by developing a quantitative benchmarking model that integrates entropy weighting and the grey relational analysis (GRA) to assess the performance of ten major CSLs using real-world data from 2022. The model incorporates operational, environmental, and social indicators, with entropy weighting objectively capturing the relative importance of each criterion. The GRA method is applied to rank CSLs based on their closeness to an ideal performer. A sensitivity analysis is then conducted by varying the distinguishing coefficient to test the robustness of the results. The findings reveal that cost-related criteria, such as the number of employees, energy consumption, and greenhouse gas emissions, carry the most weight. CSLs that perform consistently across multiple indicators tend to outperform peers that show inconsistency or rely heavily on a narrow set of strengths. This study contributes to the literature by offering an integrated, replicable approach for efficiency, sustainability, and CSR performance benchmarking in maritime logistics and by providing practical insights for policymakers, industry managers, and researchers.

Keywords: container shipping lines; grey relational analysis (GRA); entropy; corporate social responsibility (CSR); sustainability; efficiency

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1. Introduction

Nowadays, evaluating the performance of a logistics company requires a holistic approach that covers more aspects than just financial outcomes. Indeed, there has recently been a strong rise in customers' awareness and demand in the sustainability of logistics operations. Facing this pressure, the retailers, on the one hand, announced their strategy to net zero, and on the other hand, pushed their major logistics providers, that is, the world's leading container shipping lines (CSLs), to also make commitments towards decarbonizing themselves [1]. The benefit of satisfying customer demands in this regard was reported by Shin, Y. et al. (2017) in a study using empirical evidence from more

than 1000 freight forwarders, shippers, shipping practitioners, and container shipping service users to analyze the influence of sustainable management practices on customer satisfaction, word of mouth intention, and purchase intention. The study found that companies' sustainable management activities and customer satisfaction are positively associated, and thus, customer perception of sustainability is important and has direct consequences in the valuation of the shipping company [2].

Reducing greenhouse gases (GHGs) is not the only topic that came under the public's increased scrutiny. The plea for regulating the shipping sector has, in addition, spread to areas of society and governance. To respond to these new markets and customer dynamics, the world's key players in maritime shipping have come up with their own agenda towards net zero by 2050, with detailed actions and roadmaps. In fact, over the years, major CSLs such as Maersk, Hapag-Lloyd, Evergreen, CMA CGM, Yang Ming, Wan Hai, etc., have started to evaluate their sustainability and corporate social responsibility (CSR) performances for years, which are meticulously detailed and published in their sustainability and CSR reports on an annual basis. For example, as can be found on their websites, Maersk had sustainability publications dated back to as early as 2011, Hapag-Lloyd introduced a code of ethics as part of responsible corporate governance in 2010, Evergreen started publishing corporate social responsibility reports in 2014, Yang Ming commenced the activity in 2012, etc. In these reports, a wide range of topics is covered, which can mostly be grouped under categories of environment (e.g., GHG emissions, marine life protection, air quality, climate change, etc.), human resources (e.g., education and training, diversity and inclusion, human rights, etc.), and governance (e.g., compliance, ethics, health, and safety, etc.). For each category, the reporting details include specific data and figures related to each topic, action plans to be carried out, and targets to achieve in both the short and long terms.

As revealed in these companies' reports, even though sustainability and CSR are treated distinctly, they are often combined in the company efforts. The shipping lines' sustainability targets are set up based on the long-term balance of environmental, social, and economic factors. To achieve them, the CSL's operations are geared toward the long-term strategic planning of supply chains, product design, and especially energy use (for example, green energy, decarbonization, etc.) that serve the sustainability purpose. The targets are often reviewed and updated in compliance with regulatory bodies and global frameworks such as the UN Sustainable Development Goals (SDGs). In contrast, their CSR initiatives may be short term and externally focused, remaining largely voluntary and based on goodwill and reputation management. Many of the world's top CSLs have voluntary commitments to ethical practices and social impact, often through philanthropy, employee engagement, and community initiatives. For example, over the years, CMA CGM, Maersk, Yang Ming, COSCO, etc., have donated to environmental causes or support local charities, built classes in remote areas, and provided education and training to children and young women.

Given the fact that the maritime shipping landscape today often integrates CSR into sustainability strategies to align ethical responsibility with business goals, it is essential to revisit the literature to see how the treatment of these phenomena in academia has been progressing. It turns out that much research has been devoted to these topics, but surprisingly, they are addressed separately for the most part. Regarding sustainability, numerous books and articles have discussed aspects ranging from general to specific. From the general point of view, the following areas have been covered: conceptualization, adoption, and implications of green shipping [3]; current strategic planning for sustainability in international shipping [4]; the transition towards sustainability in the shipping industry [5]; the communications to public and social media regarding shipping industry's sustainabil-

ity [6]; maritime industry environmental impacts and sustainability challenges [7]; and discerning sustainability approaches in shipping [8]. In more specific analyses, the subjects below have been discussed: green shipping technologies, ship recycling, and green liner network design [9]; the correlation between green shipping management capability and firm performance [10]; etc.

In terms of CSR, a wide range of aspects have also been explored. For example, the impact of corporate governance in the operational and financial performance of maritime business [11–13]; the framework, reasons, and drivers for maritime logistics companies to adopt and implement a CSR strategy [14]; the importance of customer expectations in container shipping [15]; the link between CSR and organizational performance in container shipping [16]; the current challenges and future directions of CSR in the international shipping industry [17]; the role of CSR in supporting the welfare of seafarers [18]; the barriers to the implementation of strategic CSR in shipping [19]; etc.

Despite the abundance of research being devoted separately to sustainability and CSR as discussed above, only a much smaller research body has incorporated both features in a single study, and in instances where such an integration was attempted, it was either only qualitatively or was not specifically about container shipping at all. For example, the integration of CSR and sustainability was qualitatively examined in a case study at a company that manages oil tanker and dry bulker vessels [20]. In another study, perceptions and attitudes towards CSR and sustainability developments were investigated, even though in a quantitative manner, the context of this study also revolved around international oil tanker and dry bulker carrier operators [21].

Because studies that include both of these features were limited to only a few articles, and little to no research has been conducted in the context of container shipping, there exists an absence of literature that reflects the latest developments in this aspect of the industry, preventing it from being a source of fresh discussion and undermining its capacity in providing a holistic perspective to academics, practitioners, and others interested in the field. Thus, it is necessary that this combination be examined under a single quantitative model to obtain a result decision-makers can rely on to gain an overview of the topic as well as to understand the direction in which the industry might be heading in the near future.

Stemming from this necessity, this paper sets out to contribute to the current literature by proposing a model to benchmark shipping lines under the combined metrics of sustainability, CSR, and efficiency. The purpose of this is fourfold. First, it can assist decision-makers, customers, or investors to select top-performing shippers, those that demonstrate the ability to align well with stakeholder values, for business and investment purposes. Second, the benchmarking result would serve as a motivation for the shipping lines that are outperformed by their peers to reevaluate and reformulate their current strategies in operations, technology, and environment protection to better meet customer demands. Third, the approach makes a significant contribution to the existing literature by introducing a comprehensive framework integrating the entropy weighting method with grey relational analysis (GRA) for container shipping line selection using a pre-defined set of variables tailored specifically for sustainability, CSR, and efficiency metrics. On the one hand, the simplicity and user-friendly nature of GRA offers a time-saving and accessible method for various stakeholders, including customers, investors, and managers, to conduct analyses with ease. On the other hand, the pre-defined variables used in the study were meticulously curated based on not only their relevance to industry standards, societal impact, and user requirements, but also on previous works from other authors to cover critical domains of sustainability, CSR, and efficiency. Fourth, even though entropy and GRA have been used in numerous studies across various domains, for example, in

manufacturing systems [22], healthcare performance [23], the energy sector [24], information technology [25], air pollution [26], city evaluation [27], supply chain resiliency [28], and air travel [29], to the best of the authors' knowledge, they have yet to be employed in the analysis of maritime logistics in this specific setting. Thus, the proposed framework combining an entropy-based GRA with this pre-defined set of variables would constitute a convenient and practical tool for users interested in the field.

2. Literature Review

2.1. Sustainability in the Shipping Industry

As the concept of sustainable development was introduced in the Report of the World Commission on Environment and Development in 1987, achieving sustainability has become an issue that attracts full attention from global communities [30]. McGuire, C. et al. (2011) raised the concern that international maritime shipping practices are still far from sustainable, and the international community and government entities have not fully realized the true costs of shipping [31]. Similarly, Monios, J. (2020) argued that where regulations and jurisdictions can be observed from different institutions and governing bodies in the shipping industry, these regulations and jurisdictions are usually overlapped, leading to certain challenges ranging from emissions to noise and climate change adaptation being under-addressed [32]. In line with this, a systematic review by Lee, P. et al. (2019) revealed that even though industries, governments, and international organizations have dealt with sustainability issues in transportation and economic studies, its research significance and scope were fragmentary in those research domains [33]. Nonetheless, despite fewer developments being seen in the shipping industry than in other types of transportation [34], it is inaccurate to state that no progress has been achieved thus far in the transition towards a greener and cleaner seaborne shipping industry. Regarding efficiency, Qahtan, S. et al. (2023) used a q-rung ortho pair fuzzy rough sets-based decision-making framework to assess the performance of 62 ship energy systems and proposed that choosing the most efficient among them would help achieve a sustainable transportation environment, maximum economic performance, and energy consumption reduction [35]. Bernacki, D. (2021) proposed a cost model to assess the link between the vessel size and sustainable performance of dry bulkers and container ships to estimate the savings in shipping costs incurred from operating large vessels at seaports [36]. In terms of operations planning, Parthibaraj, C. et al. (2018) developed a sustainable decision model for allocating ship capacity to satisfy shipping demand and to generate a route plan [37]. As for state-of-the-art technology applications, Oloruntobi, O. et al. (2023), also in a systematic approach, reviewed 88 documents relating to the development of technology in the maritime industry and revealed that simulated training, augmented reality, remote vessels operations, unmanned autonomous vessels, drones, 5G networks, etc., are among those expected to soon be used prevalently in the field [38]. Relating to the human facet, Di Vaio, A. et al. (2023), in a systematic review of 114 articles published in the ISI Web of Science and Scopus databases from 1990 to 2022, investigated the relationship between responsible innovation obtained from green technology adoption and gender equality to understand how decarbonization technology relates to gender mainstreaming [39]. The study pointed out that women should be trained on technology adoption in decarbonization operational processes to support gender equality and technological development. Other studies are concerned with the emission reduction aspect of container shipping. Cariou, P. (2011) examined the long-term strategy of cutting CO_2 emissions by slow steaming and estimated the bunker breakeven price at which this strategy is sustainable [40]. Czermański, E. (2021) used an energy consumption approach to estimate the reduction of SO_x, NO_x, particulate matter, and CO_2 to facilitate the early detection of environmental impacts and determine the areas with the greatest potential for

emissions reduction in container shipping [41]. Some other studies addressed sustainability disclosure from the management and even social media perspectives. Zhou, Y. et al. (2021), via a hierarchical unsupervised text-mining method, extracted information from container shipping companies' sustainability reports to evaluate their sustainability performance in three dimensions: employee training and management, sustainable business management, and sustainable shipping operation [42]. Zhou, Y. et al. (2022) examined stakeholders' perceived importance of sustainability development goals based on their reaction and sentiment toward container shipping companies' sustainability disclosure on Twitter and Facebook [43]. Despite an abundance of research that has addressed an extensive array of aspects on sustainability as discussed above, little has specifically examined this topic in the context of container shipping sustainability performance. With the growing momentum of containerized trade volume across the globe creating ever-pressing impacts on the environment, this area not only inevitably but also urgently requires further rigorous analysis to provide stakeholders with vital information for reference and decision-making when needed.

2.2. CSR in the Container Shipping Industry

CSR has become a central consideration for container shipping lines in the past decade, evolving from a voluntary add-on to a standard business practice. All major container carriers now publicly report on CSR efforts covering a broad spectrum of issues, ranging from occupational health and safety to community welfare and labor rights [15]. This reflects growing stakeholder scrutiny and expectations: regulators, investors, and especially customers increasingly demand that carriers minimize negative social and environmental externalities. According to Oikonomou, I. (2018), there is a need for CSR strategies in shipping to fulfill various objectives both for the employees working offshore and on-board vessels in the areas of environmental protection, safety, wellbeing, and relations with customers, suppliers, investors, and communities [44]. Grewal, D (2018), by inspecting the growth of CSR and its acceptance in the maritime industry, concluded that together with the basis of efficiency and service characteristics, CSR provides a novel niche for companies to differentiate themselves in the increasing competition among major global shipping lines [45]. A study on the interaction impacts of CSR and service quality on shipping companies' performance by Yuen, K. et al. (2018) showed that CSR and service quality complement each other in driving job and customer satisfaction, and the link between them produces synergistic and compensatory effects on customer satisfaction and job satisfaction, respectively [46]. Evident in leading container shipping lines' annual reports, the CSR comprehensive stakeholder strategy typically follows frameworks such as the Global Reporting Initiative or ISO 26000. For instance, one industry study formulated a multi-dimensional CSR index based on ISO 26000 to benchmark shipping companies, illustrating the trend toward formalized CSR metrics in the sector [12]. Such CSR metrics frameworks help carriers measure performance across environmental and social dimensions and set targets (for example, carbon intensity, safety incidents, and community investment), enabling more objective benchmarking of CSR progress. Still, implementation in container shipping is often tailored—companies prioritize the CSR facets that align with their corporate values and stakeholder priorities. As Tang and Gekara (2020) observed, some carriers concentrate on certain CSR elements over others, reflecting what they believe customers value most [15]. Parviainen, T. (2018) underlined that multi-stakeholder pressure and action can promote the adoption of CSR activities in the shipping industry and push towards improved overall regulations [47]. Their study indicated that shipping companies need to satisfy multi-stakeholders' demands, considering the growing importance of maritime governance in the future.

Despite widespread acknowledgment of CSR's importance, container shipping companies face notable challenges in executing CSR policies effectively. A major barrier is the resource constraint—implementing meaningful CSR programs requires financial investment, specialized knowledge, and human capital, which can be difficult to allocate in an industry often operating on thin margins [19]. Relatedly, some firms lack a clear strategic vision for CSR; without top management commitment and long-term planning, CSR efforts can remain ad hoc or superficial. Another hurdle is the measurement of CSR outcomes. Shipping lines have historically focused on easily quantifiable operational metrics; therefore, developing robust indicators for social performance or ethical conduct is challenging. Yuen and Lim's (2017) survey of shipping firms revealed that the absence of standardized measurement systems hinders the integration of CSR into strategic decision-making [19]. There is also evidence of a mismatch between costs and customer willingness to pay. While big customers increasingly demand sustainable practices, not all are willing to pay a premium for "green" or socially responsible services. This can make it difficult for carriers to justify large CSR expenditures purely on commercial grounds. Additionally, compliance with high regulatory standards—for example, new emissions rules or labor regulations—can strain companies, leaving fewer resources for voluntary CSR initiatives.

In light of these insights, CSR has firmly taken root in the container shipping industry as both an ethical imperative and a strategic asset. Ongoing research is now focusing on how to benchmark and improve CSR performance among carriers, integrating it with broader sustainability goals. The challenge ahead lies in standardizing metrics and sharing best practices so that all container lines can effectively balance profitability with social responsibility in a highly competitive global shipping arena [12,15,48].

2.3. Sustainability and CSR in the Container Shipping Industry

Despite numerous aspects of sustainability and CSR having been explored in the literature of international shipping business, there are still mismatches with reality and practices. First, research so far has tended to approach this matter on a more macro scale. The aims of those articles were either to provide a general view on maritime laws that were governing these issues, to analyze the attitude and the awareness of shipping companies towards CSR and sustainability, or to examine how some shipping lines were applying these concepts in their operations. Oftentimes, a clear distinction in research targets is not mentioned in these articles as they include both bulker and container vessel operating companies. Thus, these studies' main concerns are sustainability and CSR in general rather than how the two concepts are being implemented specifically in container shipping. Second, most studies are either qualitative or have a qualitative base to it, that is, approaching the topics of sustainability and CSR from a qualitative angle using surveys and questionnaires and then converting the information collected into some form of calculable figures. There is a consistent lack of research that purposefully positions itself to tackle these problems in a quantitative manner using numerical data obtained directly from container shipping lines. As most research so far gravitates towards the qualitative side, the current literature has yet to sufficiently cover the quantitative side of these topics. Third, little research has touched on the combination of both sustainability and CSR in a single study. A large majority of articles isolate their own scope of analysis into either sustainability or CSR, while both of them have been growing in significance and receiving a lot of attention worldwide and are megatrends at the moment. Hence, analyzing them in the same study would bring about a comprehensive holistic view to address the contemporary concerns of the industry's operations. Fourth, and perhaps also the most profound gap between academia and reality, is that the combination of sustainability and CSR is even more understudied in the context of container shipping. As these two areas become central to business

practices globally, the container shipping industry is no exception to being operated under these principles. Hence, as a whole, they deserve their own holistic examination. Without proper analysis to serve as reference, shipping lines would be uncertain about their position in competition with others. Those that are outperformed by their peers would not know what part or extent their strategy and direction do not align with customers' expectations, or if their efforts in these areas were devoted to the right place. Thus, the question of who is performing best has become perhaps not only beneficial for insiders, such as related stakeholders and these shipping lines themselves, but also for outsiders, that is, end consumers, who are increasingly showing a preference for business with sustainability- and CSR-oriented companies.

This paper aims to address the challenges above by benchmarking top global container shipping lines in the metrics of sustainability, CSR, and efficiency performance. To accomplish this, this article collects quantitative data from these shipping companies, including variables in these three categories. These variables are then processed under a grey relational benchmarking model at different stringent levels to observe how results would vary given the same dataset; after that, the result consistency is analyzed and evaluated through a sensitivity analysis. This paper then discusses the performance of the chosen shipping lines and assess related managerial implications. This article's goal is to provide stakeholders, particularly customers and practitioners in the field, with a reference point for decision-making. This evaluation aids in the selection of shipping lines that align with stakeholders' sustainability and CSR values while also guiding companies towards improved performance in these areas.

3. Methodology

This article's objective is to use a quantitative approach to benchmark the performance of container shipping lines in terms of sustainability, CSR, and efficiency. Among the many decision-making models available in the literature, some of the most widely used are AHP, ANP, TOPSIS, DEA, ELECTRE, PROMETHEE, etc. Some models were devised to tackle qualitative or fuzzy problems via tools like surveys, questionnaires, or expert opinions such as AHP and ANP. Other methods are designed to directly deal with quantitative data such as DEA, SAW, or GRA. The grey relational analysis (GRA) is one multi-attribute decision-making model (MADM) that has been proven to have potential in the ranking and benchmarking of entities [49]. It is a method with straightforward calculation that offers flexibility for various scenarios, accommodating decision-makers' preferences for either stringent or lenient evaluations. Furthermore, unlike DEA, which empirically requires at least twice as many alternatives as inputs and outputs combined for the model to function well, GRA is not restricted by this condition. As the number of conglomerates dominating the global maritime shipping business is limited to only around 10, it is not twice the number of inputs and outputs incorporated in the model as presented in part 4 or this study. Therefore, GRA is an apt model to use for this purpose. Hence, this study adopts GRA to benchmark the chosen CSLs.

3.1. Grey Relational Analysis (GRA)

The GRA, invented by Deng (1982), is part of grey system theory dedicated to solving problems relating to trade-offs among multiple factors and variables intricately related to each other. By converting values of each alternative's performance attributes into a single value, the GRA ranks these values against each other, producing the final benchmarking result of all alternatives in the set. This means the original MADM problem is now turned into a single-attribute decision-making problem, allowing for an easy comparison among multiple-attribute alternatives.

The GRA procedure consists of four steps, as presented in Figure 1 below:

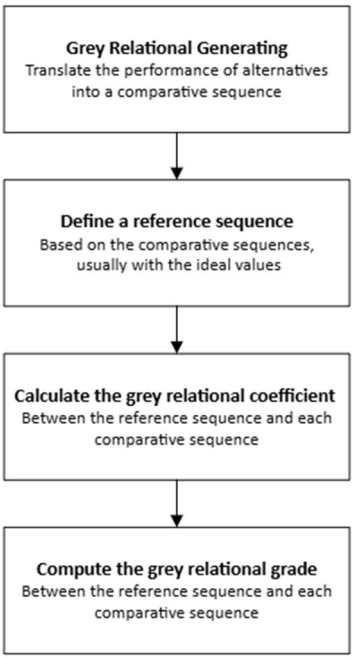

Figure 1. Grey relational analysis procedure.

The best choice among the alternatives is the one whose comparative sequence yields the highest grey relational grade compared with the reference sequence.

3.1.1. Grey Relational Generation

For a set of m alternatives, where each has n attributes, the ith alternative can be written as a vector with n dimensions $\beta_i = (\mathcal{b}_{i1}, \mathcal{b}_{i2}, \ldots, \mathcal{b}_{ij}, \ldots, \mathcal{b}_{in})$, $1 \le i \le m$, where $\mathcal{b}_{ij}$ represents the performance value of attribute j of alternative i, with $1 \le j \le n$. To generate a comparative sequence, the term β_i is then translated into $\vartheta_i = (\theta_{i1}, \theta_{i2}, \ldots, \theta_{ij}, \ldots, \theta_{in})$, where θ_{ij} is a normalized value from $\mathcal{b}_{ij}$ based on the characteristic of the jth attribute. There are three cases for the normalization of θ_{ij} as follows:

- J is an attribute whose value is expected to be the larger the better:

$$\theta_{ij} = \frac{\mathcal{b}_{ij} - Min\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\}}{Max\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\} - Min\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\}} \quad 1 \le i \le m,\ 1 \le j \le n \tag{1}$$

- J is an attribute whose value is expected to be the smaller the better:

$$\theta_{ij} = \frac{Max\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\} - \mathcal{b}_{ij}}{Max\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\} - Min\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\}} \quad 1 \le i \le m,\ 1 \le j \le n \tag{2}$$

- J is an attribute whose value is expected to be as close to the desired value $\mathcal{b}_j^*$ as possible:

$$\theta_{ij} = 1 - \frac{\left|\mathcal{b}_{ij} - \mathcal{b}_j^*\right|}{Max\left\{Max\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\} - \mathcal{b}_j^*,\ \mathcal{b}_j^* - Min\left\{\mathcal{b}_{ij},\ i = 1,\ 2,\ \ldots,\ m\right\}\right\}} \quad 1 \le i \le m,\ 1 \le j \le n \tag{3}$$

3.1.2. Reference Sequence Definition

The reference sequence is defined as the sequence having ideal attribute values, against which other comparative sequences are benchmarked to find the one closest to it. The value for the reference sequence can be derived from the grey relational generating procedure of

either Equations (1)–(3) depending on the characteristic of attribute j. These normalization processes will scale the performance value for each attribute of the alternatives to [0, 1], and the one with value equal to 1 or closest to 1 would be the best choice as it is closest to the ideal value. Hence, the alternative with the most attribute values equal to or closest to 1 would be the best alternative. From this logic, this article defines an ideal sequence with all attributes having maximum value $\vartheta_0 = (\theta_{01}, \theta_{02}, \ldots, \theta_{0j}, \ldots, \theta_{0n})$, = (1, 1, …, 1, …, 1) as the reference sequence.

3.1.3. Grey Relational Coefficient Calculation

The distance between θ_{ij} and θ_{0j} and the maximum and minimum values for all alternatives and attributes are defined as follows, respectively:

$$\begin{aligned}\phi_{ij} &= \left|\theta_{0j} - \theta_{ij}\right| \\ \phi_{min} &= \mathrm{Min}\left\{\phi_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\right\} \\ \phi_{max} &= \mathrm{Max}\left\{\phi_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\right\}\end{aligned}$$

The grey relational coefficient measures how close attribute j of alternative i, compared with that of other alternatives, is to the ideal attribute of the reference sequence, and it is calculated as:

$$\Psi(\theta_{0j},\ \theta_{ij}) = \frac{\phi_{min} + \mu\ \phi_{max}}{\phi_{ij} + \mu\ \phi_{max}} \quad 1 \le i \le m,\ 1 \le j \le n \tag{4}$$

where μ is the distinguishing coefficient, $\mu \in [0, 1]$.

The presence of μ in Equation (4) allows for flexibility in the decision-making process. While $\mu \in [0, 1]$, setting it to a high value will make the GRA focus on major differences in the data sequences and be less sensitive to small changes among them. Therefore, the differences it highlights between the data sequences are not as distinctive as when μ is low, and the evaluation of alternatives appears to be more lenient overall. When μ is set to a low value, the GRA will become sensitive to even a small difference in the data sequences, hence contrasting the difference in the sequences' values in a bolder way. Thus, a small μ will give a more stringent evaluation in ranking the alternatives. The choice of μ will, therefore, affect the final outcome of the decision-making process.

The advantage of the GRA, as can be seen from Equation (4), is that it offers decision-makers the freedom to explore different levels of distinction by adjusting μ to observe how consistent the result is before deciding which value would best suit the decision-makers' need. This is especially helpful as in many cases, decision-makers in a company or an organization have to factor in various options and trade-offs before concluding the final decision. To exploit this advantage of the GRA, this article will explore varying levels of μ in the increasing order of 0.1, 0.3, 0.5, 0.7, and 0.9 to observe the consistency of the results as well as to examine how sensitive they are to the changing μ values.

3.1.4. Grey Relational Grade Calculation

Using grey relational coefficients calculated from Equation (4) as inputs, the grey relational grade between the comparative sequence ϑ_i and the reference sequence ϑ_0 is computed as:

$$\xi(\vartheta_0, \vartheta_i) = \sum_{j=1}^{n} w_j \psi(\theta_{0j}, \theta_{ij}) \quad 1 \le i \le m \tag{5}$$

where w_j is the weight of attribute j. The value of w_j is decided by the decision-makers, either through their own preference or through other dynamic weighted mechanisms that consider expert opinions such as AHP or ANP. For objectivity, this study adopts the entropy weighting method to derive w_j as presented in Section 3.2, and $\sum_{j=1}^{n} w_j = 1$.

The grey relational grade measures the extent to which a comparative sequence ϑ_i is similar to or correlates to the reference sequence ϑ_0. Thus, the higher ξ is, the more ϑ_i

resembles ϑ_0. As a result, the comparative sequence that yields the highest ξ with ϑ_0 is chosen as the best alternative. The grey relational grade and rank for each CSL will also be calculated as per each corresponding μ.

Finally, a sensitivity analysis is performed to evaluate the robustness and reliability of the ranking outcomes produced by the GRA framework. By systematically varying the distinguishing coefficient, the analysis assesses whether the relative performance of the DMUs remains stable under different evaluation intensities. A high degree of rank stability across μ levels reinforces the credibility of the findings and indicates that the results are not unduly influenced by minor shifts in model assumptions or parameter settings. Conversely, substantial rank fluctuations may highlight the presence of borderline performance cases or criteria imbalances, signaling the need for further scrutiny.

3.2. Entropy Weighting Method

The entropy method is an objective weighting technique used in multi-criteria decision-making (MCDM) to determine the relative importance of evaluation criteria based on the inherent information provided by the data. Unlike subjective weighting methods, which rely on expert judgment, the entropy method derives weights from the degree of variability or disorder in the data across alternatives. The underlying principle is that criteria exhibiting greater variation among alternatives contain more useful information for discrimination and should therefore be assigned higher weights.

The entropy method involves the following steps:

3.2.1. Normalization of the Decision Matrix:

Given a decision matrix X = $[x_{ij}]$ with m alternatives and n criteria, the raw data are first normalized to obtain r_{ij} to demonstrate the performance of alternative ith on the jth criterion:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \text{ for } x_{ij} \geq 0 \tag{6}$$

3.2.2. Entropy Calculation:

The entropy value e_j for each criterion j is calculated using the normalized values:

$$e_j = -k\sum_{i=1}^{m} r_{ij} ln\left(r_{ij}\right) \tag{7}$$

where $k = \frac{1}{\ln(m)}$ is a constant ensuring that $0 \leq e_j \leq 1$, and $r_{ij} \in [0,\ 1]$.

3.2.3. Degree of Diversification:

The degree of divergence (or information utility) d_j for each criterion is calculated as:

$$d_j = 1 - e_j \tag{8}$$

A higher d_j indicates greater variation and thus more discriminatory power.

3.2.4. Weight Calculation:

Finally, the weight w_j for each criterion is computed as:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{9}$$

The entropy method ensures that criteria with low variation (and thus limited discriminative value) are assigned lower weights, while those with high variability are considered more important in distinguishing between alternatives.

4. Data Collection and Variable Selection

4.1. Data Collection

This study aims to benchmark the efficiency, sustainability, and CSR performance of the top international CSLs to find out the high and low performers in the industry. For an objective evaluation, this article collects quantitative data directly from these shipping companies. The main source of information comes from their official publications, which consist of two major types: annual reports in which variables such as revenue, workforce, operating costs, fleet capacity, etc., can be found; and CSR reports where variables such as energy consumption, GHG emissions, gender equality, etc., are found. In many instances, data for variables are scattered in different types of reports, such as financial statements, consolidated audit reports, earnings releases, stakeholder announcements, or investor conferences. As there is not a single unified reporting structure among the companies, data for the same information must oftentimes be extracted from different sections. In addition, each shipping line establishes its own agenda with specific goals and targets to achieve; thus, each company has numerous different key performance indicators under the operations, sustainability, and CSR categories. As a result, many of the variables being reported are unique from company to company, and it was challenging to find a common ground among them. For a practitioner to successfully benchmark these shipping lines, it is necessary that a common set of variables across the shipping lines is found.

To overcome the challenge above, the article's data collection procedure meticulously underwent numerous steps to ensure that maximum usability of data is obtained. First, all possible data under each category are collected. As at this stage it was not immediately clear which variable is usable, that is, being commonly reported by all companies, all variables quantitatively reported by each company are documented. Second, the collected variables are compared, and those bearing no common ground across shipping lines are filtered out, leaving only those that are usable in the study. This is the step that decides whether a shipping line is eligible to proceed to the next step in the benchmarking process, ensuring that they have the same variables as their peers. Third, different measurements for the same variables are then converted to the same unit, because it is often the case that a company reports a similar variable but reports it in a different measurement system. This was performed for the purpose of calculation under the grey relational analysis (GRA) model. After these three steps, ten global shipping lines were included in the list, including CMA CGM (France), COSCO (China), Evergreen (Taiwan), Hapag-Lloyd (Germany), HMM (Korea), Maersk (Denmark), Wan Hai (Taiwan), Yang Ming (Taiwan), ZIM (Israel), and ONE (Japan). Together, these ten companies represent 70% of the world's entire shipping industry; thus, their collective operational practices would dictate the direction of the whole industry.

To capture the latest development, this article collected data from 2022, which were the latest data published at the time the research was conducted. Because the article's objective is to investigate the most up-to-date development of the global shipping industry in terms of efficiency, sustainability, and CSR, as well as to reflect the most recent awareness, preferences, and practices of related stakeholders in the field, it is essential that the article uses the latest data available at the time. Such data would also ensure that the approach the article took is objective and realistic, aligning with the novel nature of discussions occurring both within and outside academia on these topics. Additionally, it is often in the latest reports or announcements that shipping lines reveal their next directions, strategies,

and plans toward achieving sustainable development goals, further underscoring the importance of using up-to-date information. Practitioners and other interested parties can adopt a similar approach when evaluating shipping companies, using the article's methodology as a reference for their own research endeavors.

4.2. Variable Selection

As each CSL pursues their own agenda and operations activities, they report a wide range of variables under each of the sustainability, CSR, and efficiency metrics. It is only possible to benchmark these CSLs against each other if shared characteristics are found among them. Therefore, it is necessary to identify the common factors that provide a basis for evaluating and ranking these companies. To accomplish this, the variable selection process adopts a funnel approach. First, all possible variables from each CSL are considered. As the process continues, they are narrowed down to only a few variables under each category that are reported by all CSLs. Finally, the filtered variables are then selected based on their relevance to the existing literature, standards of the industry, impact on society, and concerns of stakeholders. As a result of the process, the following variables in each category are chosen:

Sustainability

- CO_2 (in '000 tons): The main GHG that is responsible for global warming, emitted from shipping activities [40,41].
- SO_x (in '000 tons) + SO_x scrubber (in % of vessels): Sulfur dioxide (SO_2) and sulfur trioxide (SO_3), also emitted from shipping activities, can cause acid rains that destroy vegetation and buildings and have a negative impact on human health [41]. As IMO's regulation on sulfur limits went into effect in 2020, shipping lines have to fit their vessels with exhaust gas cleaning systems (also known as "scrubbers") for compliance [50].
- NO_x (in '000 tons): Nitrogen oxide (NO) and nitrogen dioxide (NO_2), produced by fossil fuel combustion, are responsible for ozone thinning, photochemical smog, and acid rain. Excessive NO_2 in residential areas is also linked to respiratory and cardiovascular diseases and mortality [51].
- Ballast water treatment technology (in % of vessels): Ballast water is the water pumped into a ship's ballast tanks at the initial port to provide stability and maneuverability during voyage. As part of operations, it can be released at the next port-of-call and introduce non-native organisms that may contain bio-invaders to the water bodies there. Thus, ballast water poses significant environmental threats and was required to be strictly managed by IMO since 2017 [52].

CSR

- Training hours per employee: Training days (or hours) per officer is a human resources KPI that represents the shipping line's commitment to the continuous maintenance and improvement of employee abilities. The commitment extends to incorporating new skills into the team, increasing staff motivation, promoting awareness of CSR, and elevating the overall quality of work within the organization [53,54]. This KPI is usually reported across CSLs in number of training hours per year.
- Schedule reliability (on-time rate, %): Punctual delivery is essential in creating a positive experience for customers and is an important characteristic for a CSL to be recognized as a reliable logistics provider. As on-time delivery cultivates higher customer satisfaction through fulfilling the CSL's responsibility to customers' needs, it crucially affects the growth of the CSL's customer base and is an all-time important index all CSLs strive for.

- Female employee in management (%): Previous studies indicated that a higher percentage of women in the board can have a positive impact on company performance, which is explained by diversity being introduced to the team and decreased level of conflict [55–57]. Nonetheless, women in management is still notably an underrepresented group, despite several calls for maritime companies to increase their presence in the board of management [58,59]. To solve this, in recent years, major CSLs have been implementing numerous actions to raise the proportion of women in their management, and some even plan to accelerate this dynamic up to the top level [60]. This remains an important KPI and an on-going initiative for CSLs until they reach a desired equality and inclusiveness target committed to stakeholders.
- Total services (number of routes): Owning a large global network is an indicator of a CSL's high serving capacity to satisfy customers' needs. The high number of shipping lanes, coupled with high reliability, facilitates timely and efficient transportation solutions, adding up to customer's trust and confidence in the CSL's ability to provide them with comprehensive, reliable, and adaptable services. In addition, a well-established global network aids the CSL in reaching its CSR goals through improved routing optimization and vessel utilization, resulting in the reduction of fuel consumption, total emissions, and other environmental impacts per unit of cargo transported. As customers are looking to conduct business with CSR-minded companies, this variable contributes directly to CSR objectives, and therefore, it is a must-have in this article's benchmarking model.

Efficiency

On the notion of measuring operational efficiency based on the relationship between inputs and outputs, numerous papers have used the following variables in their models [61–65]:

- Total fleet capacity—TEUs in '000 (input): the sum of both chartered and owned in-fleet capacity, representing the shipping line's total shipping ability.
- Total energy consumption—tetra Joules (input): fuel for vessel operations from different sources, all converted to Joules and added up.
- Number of employees (input): full-time employees directly working in shipping operations are counted. Those who work part-time or indirectly at other inland ports, warehouses, distribution centers, or in other logistics services are not included.
- Operating cost—USD million (input).
- Revenue—USD million (output).
- Transported volume—TEUs in '000 (output).

5. Empirical Study

5.1. Entropy Weight and Grey Relational Grade Calculations

Table 1 represents the data collected for the sustainability, CSR, and efficiency variables. The first eight criteria are beneficial, and the next six are unbeneficial. Table 2 shows the results of normalized values and criteria weights derived from the entropy method. These weights are then arranged in a descending order. It can be seen that the six heaviest weights are all unbeneficial criteria. Together, they account for 71.6% of the total weights. Thus, it is predicted that a CSL's performance in these criteria will decide the outcome of its rank.

To generate a comparative sequence in the first step of the GRA procedure, the variable values of each shipping line are normalized based on one of the three cases in Section 3.1.1. Specifically, in the sustainability category, data for CO_2, SO_x, and NO_x are the smaller the better, while ballast water treatment and SO_x scrubber are the larger the better attributes. For CSR, the training hours per employee, female in leadership, and total services attributes are the larger the better, while schedule reliability is the closer to the desired value the

better, with the ideal value being one. Regarding efficiency, data for total fleet capacity, revenue, and transport volume are the larger the better, while total energy consumption, number of employees, and operating cost are the smaller the better attributes. As such, each of these variables will adopt their corresponding equation in Section 3.1.1. Table 3 shows the results of grey relational generation for all variables.

In the last step of the GRA procedure, the variables in each category are assigned the corresponding entropy weights from Table 2. The grey relational grade for each CSL is calculated using Equation (5), and their results and corresponding ranks in the GRA are shown in Table 4, which are illustrated in Figure 2.

Figure 2 shows the rankings of CSLs in the GRA at varying μ levels (0.1–0.9) under the criteria weights derived from the entropy weighting method. As seen in Figure 2, the CSLs' relative ranks exhibit a remarkable degree of consistency across μ values, indicating the robustness of the entropy-based GRA framework under varying degrees of discrimination. Specifically, Yang Ming is consistently identified as the top performer across μ levels, while HMM and ZIM persist in the second and fifth places, respectively, suggesting stability and robustness of the ranking results. Similarly, Wan Hai and Evergreen remain in the third and fourth places over most of the μ spectrum (0.1–0.7), with their ranks only shifting by one at $\mu = 0.9$. Apart from this, no other change occurs in the top 50% of the CSLs. In the lower half of the list, the ranks of several other CSLs display a low degree of variation as μ increases. The most noticeable changes occur when μ increases from 0.1 to 0.3. Within this range, COSCO and ONE are seen to have the same pattern, where both CSLs' ranks increase by one and remain the same afterwards. Hapag-Lloyd's rank decreases from sixth to seventh, and Maersk's rank, in particular, decreases by two to bottom the list from μ = 0.5 and upwards. It is noticed, however, that after these changes, these CSLs' positions remain stable despite μ increasing to the highest value.

Overall, the ranking trajectories of the CSLs in Figure 2 show that the upper half of the CSLs appear to be more stable while those in the lower half are more sensitive to the degree of differentiation applied in the model. This potentially reflects uneven performance across evaluation criteria and serves as a prelude to the detailed sensitivity analysis presented in the following section.

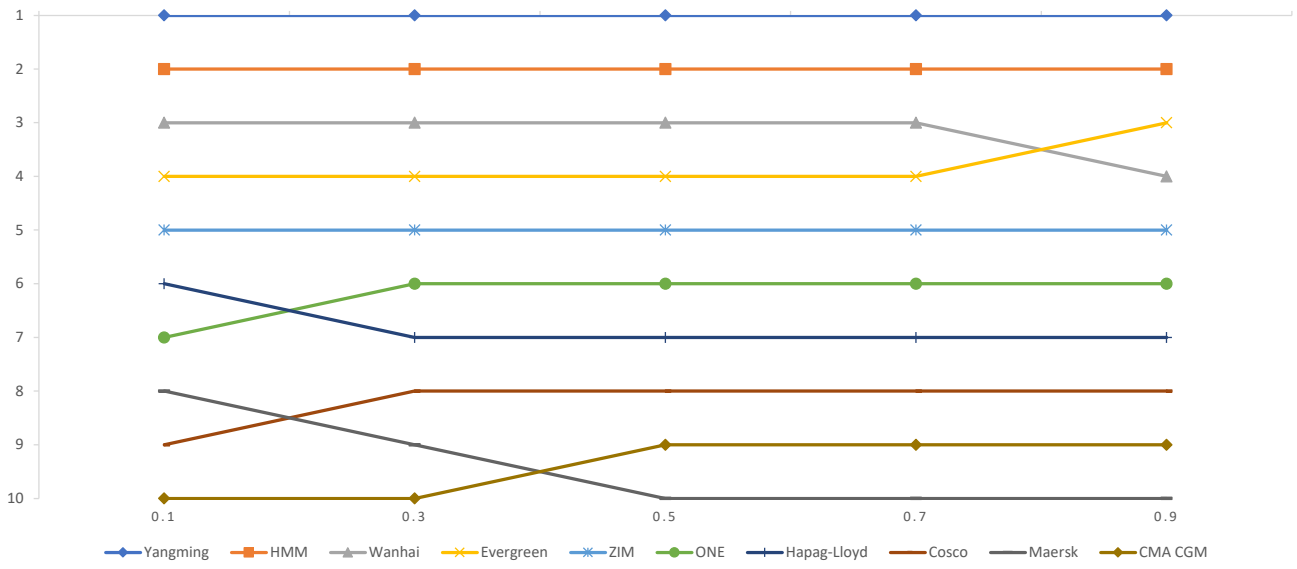

Figure 2. Sensitivity of the CSLs' rankings under an entropy-based GRA at varying μ levels.

Table 1. Quantitative values for the sustainability, CSR, and efficiency variables of shipping lines.

Shipping Line	Total Fleet Capacity (TEUs in '000)	No. of Training Hours per Employee	Transported Volume (TEUs in '000)	Revenue (USD Million)	International Routes (Total Services)	Ratio of Female Employees in Management	(%) Vessels with Ballast Water Treatment + SO_x Rubber	On-Time Rate	No. of Employees (Shipping Lines)	Total Energy Consumption (TJ)	Operating Cost (USD Million)	tCO_2e (in '000 tons)	SO_2 (in '000 tons)	NO_2 (in '000 tons)
CMA CGM	3186	35	21,740	58,950	333	32%	79%	67.3%	87,714	320,549	27,310	30,110	71	575
COSCO	2890	31	24,410	58,150	287	38%	39%	65.8%	31,510	259,785	32,415	20,778	242	496
Evergreen	1663	49	7646	21,076	150	20%	60%	68.2%	3121	106,288	7689	8144	18	121
Hapag-Lloyd	1797	20	11,843	36,401	119	17%	73%	61.0%	4106	166,408	18,441	15,676	31	176
HMM	816	34	3679	13,844	60	6%	90%	52.6%	1785	65,934	5954	5348	10	92
Maersk	4221	37	23,848	64,299	343	26%	73%	73.5%	104,260	447,345	30,589	77,957	99	604
Wan Hai	440	12	4460	8700	80	37%	91%	70.9%	4989	73,214	4452	5372	15	97
Yang Ming	731	33	4510	12,630	101	45%	86%	54.0%	3186	51,639	4895	4693	11	110
ZIM	549	41	3379	12,740	95	40%	77%	59.0%	4830	75,170	5999	7572	21	138
ONE	1548	12	11,081	29,282	166	35%	73%	57.1%	8816	121,128	14,285	9389	26	221

Table 2. Entropy normalization and weight.

Shipping Line	Total Fleet Capacity (TEUs in '000)	No. of Training Hours per Employee	Transported Volume (TEUs in '000)	Revenue (USD Million)	International Routes (Total Services)	Ratio of Female Employees in Management	(%) Vessels with Ballast Water Treatment + SO_x Rubber	On-Time Rate	No. of Employees (Shipping Lines)	Total Energy Consumption (TJ)	Operating Cost (USD Million)	tCO_2e (in '000 tons)	SO_2 (in '000 tons)	NO_2 (in '000 tons)
CMA CGM	−0.3076	−0.2474	−0.3132	−0.3132	−0.3169	−0.2404	−0.2391	−0.2391	−0.3671	−0.3155	−0.3084	−0.2955	−0.2656	−0.3324
COSCO	−0.2949	−0.2330	−0.3274	−0.3115	−0.2977	−0.2634	−0.1561	−0.2361	−0.2587	−0.2881	−0.3295	−0.2455	−0.3604	−0.3146
Evergreen	−0.2212	−0.2944	−0.1787	−0.1806	−0.2117	−0.1819	−0.2034	−0.2409	−0.0540	−0.1741	−0.1509	−0.1375	−0.1127	−0.1417
Hapag-Lloyd	−0.2312	−0.1792	−0.2323	−0.2489	−0.1839	−0.1640	−0.2282	−0.2261	−0.0666	−0.2284	−0.2559	−0.2091	−0.1647	−0.1810
HMM	−0.1411	−0.2452	−0.1091	−0.1370	−0.1164	−0.0790	−0.2559	−0.2074	−0.0348	−0.1267	−0.1269	−0.1024	−0.0734	−0.1173
Maersk	−0.3410	−0.2565	−0.3246	−0.3239	−0.3205	−0.2135	−0.2282	−0.2508	−0.3656	−0.3520	−0.3226	−0.3642	−0.3100	−0.3379
Wan Hai	−0.0913	−0.1277	−0.1248	−0.0989	−0.1419	−0.2598	−0.2574	−0.2461	−0.0771	−0.1361	−0.1034	−0.1028	−0.0990	−0.1217
Yang Ming	−0.1309	−0.2412	−0.1258	−0.1287	−0.1656	−0.2872	−0.2498	−0.2107	−0.0549	−0.1067	−0.1106	−0.0932	−0.0788	−0.1328
ZIM	−0.1071	−0.2704	−0.1026	−0.1294	−0.1591	−0.2703	−0.2351	−0.2218	−0.0753	−0.1386	−0.1276	−0.1308	−0.1256	−0.1547
ONE	−0.2121	−0.1277	−0.2237	−0.2204	−0.2246	−0.2523	−0.2282	−0.2177	−0.1165	−0.1891	−0.2222	−0.1513	−0.1453	−0.2081
$\Sigma r_{ij} lnr_{ij}$	−2.0784	−2.2228	−2.0621	−2.0925	−2.1384	−2.2117	−2.2813	−2.2966	−1.4707	−2.0553	−2.0580	−1.8322	−1.7355	−2.0420
e_j	0.9027	0.9653	0.8956	0.9088	0.9287	0.9605	0.9908	0.9974	0.6387	0.8926	0.8938	0.7957	0.7537	0.8868
$d_j = 1 - e_j$	0.0973	0.0347	0.1044	0.0912	0.0713	0.0395	0.0092	0.0026	0.3613	0.1074	0.1062	0.2043	0.2463	0.1132
w_j	0.0613	0.0218	0.0657	0.0574	0.0449	0.0248	0.0058	0.0016	0.2274	0.0676	0.0668	0.1286	0.1550	0.0712
Rank of importance	8	12	7	9	10	11	13	14	1	5	6	3	2	4

Table 3. Results of grey relational generating.

Shipping Line	Total Fleet Capacity (TEUs in '000)	No. of Training Hours per Employee	Transported Volume (TEUs in '000)	Revenue (USD Million)	International Routes (Total Services)	Ratio of Female Employees in Management	(%) Vessels with Ballast Water Treatment + SO_x Rubber	On-Time Rate	No. of Employees (Shipping Lines)	Total Energy Consumption (TJ)	Operating Cost (USD Million)	tCO_2e (in '000 tons)	SO_2 (in '000 tons)	NO_2 (in '000 tons)
CMA CGM	0.7263	0.6097	0.8730	0.9038	0.9647	0.6612	0.7744	0.3103	0.1615	0.3204	0.1826	0.6531	0.7371	0.0566
COSCO	0.6480	0.5135	1.0000	0.8894	0.8021	0.8138	0.0000	0.2785	0.7099	0.4740	0.0000	0.7805	0.0000	0.2109
Evergreen	0.3235	1.0000	0.2029	0.2226	0.3180	0.3560	0.3984	0.3297	0.9870	0.8619	0.8843	0.9529	0.9655	0.9434
Hapag-Lloyd	0.3589	0.2162	0.4025	0.4982	0.2085	0.2797	0.6507	0.1769	0.9774	0.7100	0.4997	0.8501	0.9075	0.8359
HMM	0.0994	0.5946	0.0143	0.0925	0.0000	0.0000	0.9806	0.0000	1.0000	0.9639	0.9463	0.9911	1.0000	1.0000
Maersk	1.0000	0.6757	0.9733	1.0000	1.0000	0.5086	0.6507	0.4406	0.0000	0.0000	0.0653	0.0000	0.6164	0.0000
Wan Hai	0.0000	0.0000	0.0514	0.0000	0.0707	0.7884	1.0000	0.3874	0.9687	0.9455	1.0000	0.9907	0.9784	0.9902
Yang Ming	0.0770	0.5676	0.0538	0.0707	0.1449	1.0000	0.9030	0.0304	0.9863	1.0000	0.9842	1.0000	0.9957	0.9648
ZIM	0.0288	0.7838	0.0000	0.0726	0.1237	0.8647	0.7283	0.1347	0.9703	0.9405	0.9447	0.9607	0.9526	0.9102
ONE	0.2930	0.0000	0.3662	0.3702	0.3746	0.7375	0.6507	0.0946	0.9314	0.8244	0.6484	0.9359	0.9310	0.7480

Table 4. Results of the grey relational grade calculation and rank comparison of entropy-based GRA (μ = 0.1–0.9).

	μ = 0.1		μ = 0.3		μ = 0.5		μ = 0.7		μ = 0.9	
	Grade	**Rank**	**Grade**	**Rank**	**Grade**	**Rank**	**Grade**	**Rank**	**Grade**	**Rank**
CMA CGM	0.2384	10	0.4448	10	0.5550	9	0.6264	9	0.6773	9
COSCO Shipping Lines	0.2722	9	0.4736	8	0.5804	8	0.6488	8	0.6971	8
Evergreen	0.5623	4	0.7211	4	0.7842	4	0.8216	4	0.8473	3
Hapag-Lloyd	0.4120	6	0.6129	7	0.7026	7	0.7566	7	0.7934	7
HMM	0.6983	2	0.7716	2	0.8091	2	0.8348	2	0.8541	2
Maersk	0.3098	8	0.4455	9	0.5318	10	0.5937	10	0.6405	10
Wan Hai	0.6313	3	0.7483	3	0.7957	3	0.8255	3	0.8469	4
Yang Ming	0.7098	1	0.7887	1	0.8253	1	0.8498	1	0.8678	1
ZIM	0.5367	5	0.7104	5	0.7747	5	0.8121	5	0.8378	5
ONE	0.4054	7	0.6230	6	0.7140	6	0.7674	6	0.8032	6

5.2. Sensitivity Analysis

To assess the robustness of the entropy-based GRA results, a sensitivity analysis was conducted by examining the variation in the CSL rankings across five levels of the distinguishing coefficients (μ = 0.1, 0.3, 0.5, 0.7, and 0.9). As stated in 3.1.3, μ controls the GRA model's ability to differentiate between alternatives. Lower μ values enhance sensitivity by magnifying differences among CSLs, thus emphasizing performance contrasts while higher μ values compress score differences, hence reducing discrimination. To quantify sensitivity, both the range, that is, maximum rank minus minimum rank, and the standard deviation of rankings across μ levels were calculated for each CSL. These two metrics provide a clear indication of each CSL's ranking volatility or consistency.

As seen from the results in Table 5, the CSLs can be categorized into three groups. The first are the stable performers. CSLs in this group include Yang Ming, HMM, and ZIM; all exhibit zero-rank ranges and a standard deviation of zero, indicating that their relative position is entirely unaffected by changes in μ. This remarkable stability reflects performance that is both balanced and resilient, regardless of how sharply differences between alternatives are emphasized in the model.

Table 5. Summary of rankings across μ levels.

CSL	μ = 0.1	μ = 0.3	μ = 0.5	μ = 0.7	μ = 0.9	**Range**	**Stdv.**
Yang Ming	1	1	1	1	1	0	0.00
HMM	2	2	2	2	2	0	0.00
Wan Hai	3	3	3	3	4	1	0.45
Evergreen	4	4	4	4	3	1	0.45
ZIM	5	5	5	5	5	0	0.00
ONE	7	6	6	6	6	1	0.45
Hapag-Lloyd	6	7	7	7	7	1	0.45
COSCO	9	8	8	8	8	1	0.45
Maersk	8	9	10	10	10	2	0.89
CMA CGM	10	10	9	9	9	1	0.55

The second group includes Wan Hai, Evergreen, ONE, Hapag-Lloyd, COSCO, and CMA CGM. This group exhibits relatively consistent performance but shows minor sensitivity as μ increases, having a rank range of one and a moderate standard deviation (~0.45). Their rankings shifted slightly but remained within a narrow band.

The last group contains Maersk, the only CSL that exhibited a rank range of two and a higher standard deviation of 0.89, indicating a relatively high level of sensitivity to the changing μ value. Its rank dropped from 8th at μ = 0.1 to 10th at higher μ values. This pattern suggests that Maersk performs strongly in certain high-contrast criteria, which

gives it an advantage when the model emphasizes variation (low μ). However, as the evaluation becomes more balanced (μ = 0.3 and upwards), its relative weaknesses in other areas reduce its overall standing.

Overall, the sensitivity analysis using both the range and standard deviation of rankings confirms that the model yields stable and reliable results for most CSLs. At the same time, it also provides useful insight into which firms show more balanced performance and which ones may have inconsistencies. For those with higher sensitivity, this can point out where improvement is needed to achieve better overall performance. In this sense, the distinguishing coefficient μ is not only a parameter that adjusts the level of discrimination but also acts as a stress test that helps uncover hidden weaknesses in performance.

6. Managerial Implications and Research Limitations

6.1. Managerial Implications

This paper aims to address the growing importance of selecting container shipping lines that prioritize sustainability and CSR, a trend increasingly observed among stakeholders. Through empirical analysis, several key insights can be pointed out regarding the performance analysis of major global shipping lines in relation to the sustainability, CSR, and efficiency metrics.

First, CSLs that consistently rank highly across all μ levels demonstrate strong, balanced performances across a broad set of criteria. Yang Ming and HMM are representative of this. Yang Ming maintained first place across all μ values, reflecting excellence in both sustainability and CSR indicators; for example, there was strong compliance with environmental regulations (86%) and low sulfur oxide (SO_2) and nitrogen oxide (NO_2) emissions. Similarly, HMM consistently ranked second, supported by outstanding environmental indicators (lowest emissions in the group), a relatively small fleet, and the second highest compliance (90% vessels with ballast water treatment). Notably, HMM and Yang Ming are among the top three CSLs having the least number of employees, and this criterion holds the heaviest weight as derived from the entropy analysis. This helps explain the result of their overall performance.

Second, some CSLs rank higher when μ is low, indicating that their strengths lie in criteria with high variability across the dataset. Wan Hai and Hapag-Lloyd fit this profile. Wan Hai in particular shows a strong ranking at lower μ values (0.1–0.7) due to its highest environmental compliance (91%), highest on-time delivery rate (70.9%), and lowest operating cost. It also reports very low emissions of CO_2, SO_2, and NO_2 combined. This advantage only diminishes when μ = 0.9, suggesting that at this total relaxing value of μ, the CSL's performance may not be as balanced across all dimensions, particularly in governance metrics such as training hours and efficiency metrics such as energy consumption per TEU. Hapag-Lloyd also shows stronger performance at a low μ, which may be attributed to relatively favorable sustainability performance. However, its governance indicators are weaker, for example, having the second lowest percentage of female managers, which likely impacts its score under more balanced assessment conditions at higher μ values.

Third, CSLs that show improvement or maintain stable rankings as μ increases are generally those with consistent, though not necessarily outstanding, performance across all criteria. Evergreen and ONE demonstrate this pattern. Evergreen does not dominate in any single indicator but performs steadily in environmental, operational, and governance areas, which explains its slight rise in ranking as the evaluation places more weight on overall balance. Similarly, ONE exhibits moderate to good performance across all dimensions, such as emissions, compliance, and employee training, and shows no major weaknesses. Its ranking improves at higher μ values, suggesting it benefits from having a uniform and well-rounded performance profile, even if it does not lead in any specific area.

Fourth, ZIM maintains a consistent middle tier ranking across all μ levels, indicating a relatively neutral performance profile. It does not excel dramatically in any single area but shows steady performance across the board, that is, moderate environmental compliance, acceptable emissions, and a fair on-time rate. The CSL's consistent performance suggests operational reliability but highlights the potential for strategic improvement in key differentiating areas.

Fifth, CMA CGM consistently ranks near the bottom, although it improves slightly as μ increases. While its environmental compliance (79%) and training hours (35) are respectable, its overall data profile suggests underperformance across several critical criteria, such as total energy consumption and CO_2, SO_2, and NO_2 emissions combined. CMA CGM's rank slightly improves when μ increases, which suggests that although its performance is not dominating in any particular area, it does not suffer from major weaknesses either. This implies that the company performs moderately across most indicators; hence, it tends to rank slightly better when the evaluation places more emphasis on overall balance rather than highlighting sharp differences. Similarly, COSCO remains within the lower end of the rankings, with minor improvement over the range of μ = 0.3–0.9. Despite its scale, the company reports high emissions, in which its SO_2 emissions are the highest, and the lowest environmental compliance (39% vessels with ballast water treatment). These results indicate that efforts to improve environmental and governance performance could significantly impact COSCO's ranking and its overall sustainability profile.

Lastly, Maersk displays a clear decline in rank as μ increases, indicating high sensitivity to the model's discriminatory power. This suggests that its strengths are concentrated in a few high-variance criteria, most notably scale-related metrics such as revenue, fleet size, and global reach. However, its efficiency, environmental, and governance performance lags compared with peers, with the highest emissions combined, highest energy consumption, highest number of employees, and average compliance—all of which are undesirable criteria. When the model begins to emphasize consistency across all indicators (at higher μ), these weaknesses lower its relative standing.

6.2. Research Limitations and Future Research Directions

This study provides a novel application of the entropy-based grey relational analysis (GRA) to benchmark container shipping lines (CSLs) based on sustainability, CSR, and operational performance. While the findings contribute valuable insights, several limitations must be acknowledged, and future research directions are proposed to address them.

First, this analysis was conducted based on data from the year 2022 only. Performance within a single year may be influenced by temporary factors such as market fluctuations, regulatory changes, or short-term strategic responses, which may not fully reflect the true capabilities of each CSL. As a result, the rankings and insights presented here, while informative, should be interpreted with caution. A more comprehensive understanding of each CSL's strengths and weaknesses would require a time series analysis using multi-year data. Such an approach would allow practitioners and decision-makers to observe long-term trends, consistency, and resilience in each CSL's performance. Future studies could extend this work by incorporating data over a longer period, which would contribute to more solid benchmarking practices and offer better support for decision-making in both industry and policy contexts.

Second, the analysis relies on publicly available quantitative data from sustainability and CSR reports. While this ensures objectivity, the lack of standardized reporting frameworks across CSLs can introduce inconsistencies in indicator definitions and data coverage. As noted by Tang and Gekara (2020), variability in CSR reporting practices can limit the comparability of performance evaluations [15]. While our study contributes

to this discussion by proposing a set of benchmarking variables specifically tailored to the container shipping sector, we acknowledge that these indicators, though grounded in industry practices and literature, represent only an initial step. To fully deal with the complexity of container shipping, including its global operational scope, environmental footprint, and regulatory diversity, a more comprehensive and standardized framework is needed. Therefore, scholars and industry bodies can collaborate to continue developing, from the groundwork laid by this paper, an industry-specific CSR benchmarking framework that captures the full range of the economic, environmental, and social impacts of maritime logistics. This would help standardize future benchmarking efforts.

Third, this study does not incorporate qualitative factors, such as stakeholder perceptions, customer satisfaction, or reputational risk, which are crucial dimensions of CSR performance [21]. The exclusion of these criteria may underrepresent the social and governance aspects of CSR. Future research should consider integrating qualitative assessments, for example, stakeholder surveys, interviews, or sentiment analysis from reports, with quantitative MCDM methods. This method could enhance the evaluation of the social and governance aspects of the study.

Lastly, while the entropy method provides an objective means of weighting criteria based on information dispersion, it may not always reflect stakeholder priorities, which are more often than not linked to profitability. As analyzed in Section 5.1, the six criteria that bear the heaviest weights derived from entropy are all unbeneficial criteria, while revenue—probably the variable that attracts the most attention from the majority of stakeholders—ranks ninth in order of importance. This might be met with mixed reactions from certain practitioners and stakeholders. It could also be the case that some critical sustainability, efficiency, or CSR dimensions exhibit low variance but remain highly important to industry stakeholders. Thus, a promising future direction is to test whether the top-ranked firms in these metrics also show stronger financial indicators or ESG scores from third-party rating agencies, thereby validating the practical relevance of the rankings.

7. Conclusions

With sustainability and CSR increasingly being high on the agenda of international forums, and customers showing a growing preference for businesses with sustainability and CSR mindsets, CSLs as a link in the global supply chain are facing mounting pressure to comply with ever stricter rules and regulations as well as to align with customer values. As each company is, on the one hand, racing against each other to meet customer demands, and on the other hand, trying to optimize their operational efficiency, which company manages this challenge best and the implications that this may bear become an inevitable question to which an adequate answer would benefit not only the CSLs themselves but also other related stakeholders. This paper was driven by the lack of integrated, quantitative approaches in previous studies, which often evaluated sustainability and CSR separately or relied on qualitative methods not tailored to the container shipping industry. This paper proposes a robust benchmarking model that integrates entropy weighting and the grey relational analysis to evaluate the performance of ten major global CSLs in terms of operational efficiency, environmental sustainability, and CSR. By incorporating objective entropy weights, the model prioritizes criteria based on their informational value, while the GRA enables comprehensive ranking based on the closeness of each CSL to an ideal performer. The evaluation, based on 2022 data, reveals that a few CSLs—such as Yang Ming, HMM, and Wan Hai—demonstrate strong and balanced performance across multiple indicators, while others show inconsistency or dependence on a narrow set of strengths.

A sensitivity analysis is conducted by varying the distinguishing coefficient μ to assess the stability of the rankings. The results confirmed that top-performing CSLs tend to

maintain their positions regardless of μ, indicating strategic coherence and operational robustness. In contrast, volatility in ranking suggests imbalances in performance or over-reliance on specific criteria. The findings aid in the selection of shipping lines and provide practical implications for these companies to align their operations with stakeholder expectations of sustainability and CSR.

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