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A MULTICRITERIA DECISION MODEL FOR SUSTAINABLE PORT FUNCTIONS IN ENVIRONMENTAL PERSPECTIVES

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ABSTRACT

Port operations, while critical to global trade and economic growth, contribute significantly to environmental pressures through activities such as vessel traffic, cargo handling, dredging, and on-dock transportation, leading to emissions of greenhouse gases and other pollutants. Hence, it is of priority to have a systematic evaluation and prioritization of sustainability measures across port functions. This study employs a multi-criteria decision-making (MCDM) approach, the Analytic Hierarchy Process (AHP), to evaluate and prioritize key functional roles and subfunctions that contribute to port sustainability performance. By engaging expert judgment from two leading ports in Malaysia, the analysis identifies stakeholder priorities on the emphasis among landlord, operational, regulatory and community functions in sustainable port management. The structured AHP framework ensures transparency and reproducibility of the weighting process while remaining adaptable to incorporate emerging sustainability measures, such as green hydrogen bunkering. The results show that the experts from two major ports expressed differing perspectives on the highest priority function with the Landlord function (at 0.370) being the top priority for Northport and the Regulatory Function (at 0.664) to be ranked highest for Johor Port. Details analysis indicates that the difference is not significant. The findings may offer useful insights for guiding resource allocation, encouraging consensus-building workshops to align stakeholder perspectives, and providing a preliminary foundation for future research on sustainability frameworks. Moreover, this study can contribute to supporting policymakers, port practitioners, and researchers in making more informed and balanced decisions toward advancing environmentally sustainable port operations.

Keywords: *Analytical Hierarchy Process, Maritime logistics, Sustainable Port, Port Functions.*

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1. Introduction

Port sustainability has emerged as an essential field of research and practice, focusing on balancing economic growth, environmental stewardship, and social responsibility. Scholars have developed diverse frameworks and methodologies to identify and measure port sustainability indicators (PSIs). For instance, Shiau & Chuang (2015) proposed a linkage-based framework to generate initial PSIs, refined through rough sets theory, and validated by diverse stakeholder groups. Other studies have emphasized systematic reviews and meta-analyses to map trends and gaps in the literature (Vega-Muñoz et al., 2021; Styliadis et al., 2022), revealing the dominance of environmental performance measures shaped by the number of initiatives taken by the ports. Meanwhile, Kim et al. (2021) advanced the discourse by conceptualizing port resilience as a multi-dimensional construct that supports sustainability, underscoring factors such as flexibility and collaboration. Malaysian ports have begun developing a Green Port Policy to promote environmentally friendly and commercially viable operations, announced by Transport Minister Datuk Seri Liow Tiong Lai at the 2016 UNESCAP Ministerial Conference on Transport in Moscow (The Star, 2016). Centered on environment, community engagement, and sustainability, the policy introduces initiatives such as ballast water management, fuel quality studies, and energy-saving measures. Alongside enhancing safety, security, connectivity, and infrastructure, the policy aims to position Malaysia as a competitive regional transport hub while supporting the UNESCAP 2030 Agenda and Sustainable Development Goals. Therefore, it is necessary to establish a framework that systematically integrates key stakeholders while incorporating existing initiatives, with specific consideration of the Malaysian context.

Ports play a pivotal role in facilitating global trade and, increasingly, in advancing environmental sustainability. While port activities such as cargo handling, vessel traffic, dredging, and on-dock transportation have traditionally exerted significant environmental pressure, the sector is now actively embracing sustainable practices. By integrating measures such as shore power, cleaner fuels, and real-time monitoring of emissions, ports are striving to reduce their ecological footprint and contribute meaningfully to broader environmental sustainability goals and provide the evidence needed to inform policy decisions, protect communities, preserve ecosystems, and build a sustainable future for generations (Solomon et al., 2024; Mohd Yazid et al., 2025).

Beyond indicator development, researchers have focused on the integration and institutionalization of sustainability practices within port operations. Canadian ports' participation in the Green Marine program illustrates how standardized indicators and proactive strategies improve environmental performance and competitiveness (Hossain et al., 2019). Similarly, frameworks like those proposed by Serra et al. (2023) and the indicator frequency analysis by Özispa & Arabelen (2018) underscore the need for a coherent set of PSIs covering economic, social, and environmental aspects. Collectively, these studies highlighted a growing recognition of the importance of stakeholder engagement, namely port authority functions in advancing sustainable ports, while identifying critical gaps and the uneven application of indicators across ports worldwide.

Achieving environmental sustainability in port operations requires coordinated efforts from multiple stakeholders (Shiau & Chuang, 2015; Serra et al., 2023). Port authorities hold a pivotal role by establishing and enforcing environmental standards, investing in green infrastructure, and promoting cleaner technologies such as shore power systems and electric cargo-handling equipment (Hossain et al., 2019). Shipping companies contribute by adopting low-emission vessels and complying with international regulations, including the use of cleaner alternative fuels (Vega-Muñoz et al., 2021). Terminal operators and logistics providers can enhance sustainability by implementing energy-efficient operational practices and comprehensive waste reduction measures (Özispa & Arabelen, 2018). Meanwhile, government agencies play a critical role in shaping supportive regulatory frameworks, offering financial incentives, and fostering research and innovation aimed at reducing port-related environmental externalities (Styliadis et al., 2022). Furthermore, engagement with local communities and environmental organizations ensures transparency, accountability, and alignment with broader societal expectations (Kim et al., 2021). Acciaro et al. (2014) identified four (4) core port functions from past studies: landlord, regulatory, operator, and community to be collectively essential for transitioning ports toward environmentally sustainable and resilient operations in their InnoSuTra EU FP7 project. Hence, the four core port functions are considered in this study.

To guide decision-makers in selecting the most effective mitigation measures, expert judgment must be systematically elicited and synthesized. The increasing complexity of assessing port sustainability performance, which must balance economic efficiency, environmental stewardship, and social responsibility, has driven researchers to adopt multi-criteria decision-making (MCDM) methods (Shiau & Chuang, 2015; Serra et al., 2023). MCDM provides a systematic and transparent framework to structure decision problems, compare alternatives, and incorporate the diverse perspectives of stakeholders (Tarmudi et al., 2024; Yazid et al., 2023). Among these, the Analytic Hierarchy Process (AHP) and its extensions, such as Fuzzy AHP, have been widely applied to prioritize sustainability indicators and weigh the relative importance of conflicting objectives (Prajapati et al., 2020; Tseng & Yip, 2021). For instance, Shiau & Chuang (2015) combined an indicator generator framework with rough sets theory (RST) to refine and validate port sustainability indicators (PSIs) through both expert judgement and stakeholder input, highlighting the practical use of hybrid MCDM approaches. Similarly, Tseng & Yip (2021) applied Fuzzy AHP to evaluate cruise port performance, accommodating the vagueness and subjectivity inherent in expert assessments.

Beyond AHP-based methods, other MCDM techniques have been employed to provide richer comparative analysis. Techniques like the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) allow researchers to rank ports or sustainability strategies based on their proximity to ideal performance benchmarks or stakeholder preferences (Prajapati et al., 2020). TOPSIS, for example, has been used to evaluate port competitiveness by integrating economic, environmental, and operational criteria, offering a clear ranking of alternatives (Styliadis et al., 2022). PROMETHEE, on the other hand, provides flexibility in handling qualitative and quantitative criteria and has been applied in sustainability contexts to capture stakeholder priorities more dynamically (Kabir & Sadiq, 2016). These MCDM tools have been praised for their ability to navigate trade-offs, ensure transparency, and systematically incorporate diverse views, which is essential given the multi-stakeholder environment of port governance (Vega-Muñoz et al., 2021). Collectively, recent studies highlight that integrating MCDM method, especially hybrid or fuzzy approaches with participatory frameworks offers a robust pathway for ports to monitor, benchmark, and enhance their sustainability performance in line with global and local sustainability goals (Kim et al., 2021; Serra et al., 2023).

Analytic Hierarchy Process (AHP) offers a transparent, quantitative way to rank and weight environmental measures according to multiple criteria drawn from port functions. Extensive adaptation of AHP can be seen in constructing the performance evaluation metrics within various organisations. Although a variety of environmental mitigation measures exist, port authorities lack a clear, consensus-driven ranking of which measures yield greatest overall sustainability benefits given their specific functional context. Ad hoc decision-making can lead to sub-optimal investments or overlooked high-impact measures. The objective of this research is to identify key environmental sustainability measures relevant to major port functions through elicit expert judgments on the relative importance of these measures.

2. Methodology

In this study, the major port functions are considered and analysed using AHP for their priorities. Table 1 shows the main port functions considered as the main factors that will have greater impact in the port sustainability performance. Each of the port functions has the sub factors that indicate the potential environment sustainable initiatives under their function that are perceived to have most impact: Landlord Function (6 sub factors), Regulatory Function (5 sub factors), Operator Function (3 sub factors) and Community function (6 sub factors).

Table 1. Adapted Factors for Two level dimensions (Acciaro et al, 2014; Bahri et al., 2025)

Goal Indicator	Main Factors	Sub Factors
To identify and rank port function that impacts the performance of Environmentally Sustainable Ports in Malaysia	Landlord Function	Protect the port ecosystems (LF_1)
		Create optimal space allocation and green recreation areas (LF_2)
		Provide adequate waste reception facilities (LF_3)
		Ensure the use of space is optimized in master planning (LF_4)
		Include environmental considerations in the planning and execution of connectivity policy and infrastructure (LF_5)
		Adapt to climate change (LF_6)
	Regulatory Function	Regulate environmental matters within the port (RF_1)
		Monitor pollution, including noise and emissions (RF_2)
		Allow/prohibit activities within the port (RF_3)
		Reward/punish port operators over/under performing against specific environmental goals (RF_4)
		Share information with reference to environmental compliance (RF_5)
	Operator Function	Minimize impacts from operations(OF_1)
		Improve energy efficiency and energy conservation within the port (OF_2)
		Ensure operators include environmental considerations in the selection and management of subcontractors (OF_3)
	Community Function	Share information/ increase visibility of green activities(CF_1)
		Ensure coordination of environmental activities (CF_2)
		Market the port as green(CF_3)
		Ensure environmental awareness among employees of both the port authority and the port operators(CF_4)
		Stimulate and facilitate port users in adopting green practices (CF_5)
		Facilitate sustainable resource management (CF_6)

Data setting

A close-structured questionnaire was distributed to port personnel at managerial levels in several ports in Malaysia so as to gain their feedback regarding the research. The purposive sampling technique is applied in order to focus on the selection of a group of qualified decision-makers, based on their experience and expertise within the scope of this study.

Northport (Malaysia) Bhd (Northport), located in Port Klang, is one of the largest multi-purpose gateway ports in Malaysia's national ports system. Northport is part of MMC Port Holdings Berhad (MMC Ports), Malaysia's largest port group. Northport offers dedicated facilities and services to handle a wide variety of cargoes ranging from containers to cars to break bulk, liquid and dry bulk cargoes of all types and shipment sizes. Seizing the opportunities from growing global trade, driven by globalisation and trade liberalisation, Northport has moved up the value chain by broadening its product base, including through 'logistical integration' and increasing its attractiveness to a wider range of shippers and shipping lines. The central role played by Northport has been strengthened by its ability to offer an extensive global shipping connectivity. The premier world-class port is now linked to many ports worldwide, offering one of the most comprehensive ranges of shipping services in the region. As one of Malaysia's major port operators, Northport (Malaysia) Bhd ("Northport") plays an important role in facilitating the movement of goods, including electric vehicles (EVs) and their batteries. With the rapid rise in EV adoption, ports have become the first point of contact for these sensitive and high-value products, making their role critical in ensuring safe, secure and sustainable handling practices (Northport website, 2025).

Another major port in Malaysia is Johor Port Berhad. The port has been committed to environmental responsibility and sustainable practices through its operations and achievements (Johor Port, 2025). Several initiatives were done in ensuring its environmental performance, noting that Johor Port has successfully reduced its carbon footprint, expanded the use of cleaner Biodiesel, and electrified its internal mobility fleet of motorcycles. Furthermore, the Company has transitioned to LED lighting and implemented a 2.1 megawatt-peak solar system which now powers 12% of Johor Port's energy needs. This progress brings Johor Port closer to achieving 15% renewable energy by 2030, with ongoing efforts directed towards a 30% target of carbon emission reduction by the same year. In this study, selected personnel from both North Port and Johor Port were requested to provide their perceptions and feedback through a survey.

In this study, there are two parts of the questionnaire: Part A and Part B. The objective of Part A of this questionnaire is to determine the port functions that are perceived to have the highest impact in ensuring the sustainability performance of the ports based on their expertise. The respondents are asked to rank the importance of each factor and its sub-factors. The responses are tabulated and examined for their consistency and validity. In Part B, the objective of this questionnaire is to determine the weightage of the indicator of the performance evaluation index. The respondents were asked to compare the importance of each sub-element based on Saaty's level of importance, based on Table 2.

Table 2. Saaty's level of importance (Saaty, 1990)

Scale	Meaning	Explanation
1	Equally important	Two criteria have equal important
3	Weakly important	Experience and judgement slightly favour one criterion over another
5	Strongly important	Experience and judgement strongly favour one criterion over another
7	Very strongly important	A criterion is favoured very strongly over another
9	Extremely important	The evidence favouring one criterion over another is of the highest possible affirmative
2,4,6,8	Intermediate value between adjacent scales	When there is a compromise between the judgment

The final responses were finalized to five (5) experts, who are the top managers in Malaysian ports. Those experts came from the sustainability departments of the two ports, who have more than 10 years of working experience and hold decision-making positions. Table 3 summarizes the profile of experts.

Table 3. Details of selected experts

Respondent	Organisation	Department	Position	Working years
R1	North Port	-	Group Managing Partner	30
R2	Johor Port Berhad	Operations	Group Managing Container	27
R3	North Port	Operations	Chief of Operation	24
R4	North Port	Quality	Assistant Group Managing	19
R5	Johor Port Berhad	Special Project	Senior Manager	14

Methods of data Analysis using Analytic Hierarchy Process (AHP)

There are five steps in using the AHP approach.

Step 1: Define hierarchy

In this step, the goal of the study is described together with the criteria and their alternatives. However, for this study, the criteria are the main functions, and the alternatives are the sub-factors.

i. Goal: Rank environmental measures.
ii. Criteria: Port functions (Landlord Function, Regulatory, Operational Function and Community Function).
iii. Alternatives: Sub function (List of mitigation measures/or sustainable initiatives).

Step 2: Pairwise comparisons

iv. For each criterion, experts compare measures two-by-two on a 1–9 scale.

$$A = [a_{ij}],\ a_{ij} = \frac{importance\ of\ i}{importance\ of\ j}\ ,\ Aw = \lambda_{max} w \qquad \text{(Eq. 1)}$$

Where A denotes the relative importance of the decision elements. For example, a_{ij} has a relative importance in the decision element over the decision element *j*, and vice versa.

Step 3: Priority vector calculation

v. Compute weights wi (principal eigenvector) from each comparison matrix.

$$Aw = \lambda_{max} w,\ \sum_{i=1}^{n} wi = 1 \qquad \text{(Eq. 2)}$$

Where λ the eigenvalue is associated with the eigenvector *w*. Saaty (1980) recommended using eigenvector, $w_{max} = [w_1, w_2, \ldots, w_n]^T$ corresponds to the maximum eigenvalue, λ_{max}, to represent the relative weight of each of these criteria.

Step 4: Consistency check

vi. Calculate Consistency Index (CI) and Consistency Ratio (CR).
Consistency Index (CI):

$$\mathrm{CI} = \frac{\lambda_{max}\ \ n}{n-1} \quad \text{(Eq. 3)}$$

where n is the matrix size.

Consistency Ratio (CR):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad \text{(Eq. 4)}$$

with Random Index (RI) is drawn from standard tables (e.g. RI = 1.12 for n=4). A CR < 0.10 is typically accepted.

Step 5: Aggregate

vii. Synthesize across criteria to obtain global weights.
Global weights aggregation:

$$W_{global,j} = \sum_{k=1}^{m} w_{criterion,k} \times w_{k,j} \quad \text{(Eq. 5)}$$

where $w_{k,j}$ is the local weight of alternative j under criterion k.

Comparing the opinions of both selected ports

To strengthen the results, a Spearman's Rank Correlation analysis was conducted to compare the rankings and quantify the correlation between this study's findings (Bahri et al., 2022). Spearman's rank correlation measures the strength and direction of the monotonic relationship between two ranked variables. The calculation and results are as follows:

$$\rho - 1 - \frac{6\sum d^2}{n(n^2-1)} \quad \text{(Eq. 6)}$$

Where:

ρ = Spearman's rank correlation coefficient

d = difference between the two ranks of each observation

n = number of observations (number of sub factors)

3. Results & Discussion

In this section, the ranking of each factor and its subfactors based on AHP approach is tabulated in Table 4 and 5. The feedback was checked for its consistency through the system (Goepel, 2018) and the CI values are well below 0.1.

The results in Table 4 illustrate the relative importance of four key port functions, Landlord, Regulatory, Operator, and Community, alongside their respective subfactors, as perceived by the experts' responses from Northport. The Landlord Function emerged as the most critical overall (weight = 0.370), driven mainly by *Landlord F1* (global weight = 0.133), reflecting the centrality of port infrastructure and asset management to sustainability which is to protect the port

ecosystems (LF_1). The Regulatory Function followed closely (weight = 0.297), with *Regulatory F1* (global weight = 0.134) emphasizing the importance of compliance and policy enforcement. The Operator Function (weight = 0.273) showed that *Operator F1* held the highest single global weight (0.159), highlighting the operational aspects of port management as pivotal for sustainable performance. In contrast, the Community Function had the lowest weight (0.061), with its leading subfactor (*Community F1*) contributing modestly (global weight = 0.019). Overall, the distribution of global weights underscores that while community considerations matter, operational efficiency, regulatory compliance, and strategic asset management are prioritized by stakeholders in assessing port sustainability performance.

Table 4. Results from Northport (global weights of port functions and subfactors (3 respondents)

Factor	Weights	Subfactor	Local Weights	Global Weights
Landlord Function	**0.370**	Landlord F1	**0.359**	**0.133**
		Landlord F2	0.205	0.076
		Landlord F3	0.139	0.051
		Landlord F4	0.123	0.046
		Landlord F5	0.099	0.037
		Landlord F6	0.075	0.028
Regulatory Function	0.297	Regulatory F1	**0.452**	**0.134**
		Regulatory F2	0.218	0.065
		Regulatory F3	0.17	0.050
		Regulatory F4	0.102	0.030
		Regulatory F5	0.057	0.017
Operator Function	0.273	Operator F1	**0.583**	**0.159**
		Operator F2	0.297	0.081
		Operator F3	0.12	0.033
Community Function	0.061	Community F1	**0.315**	0.019
		Community F2	0.206	0.013
		Community F3	0.15	0.009
		Community F4	0.136	0.008
		Community F5	0.098	0.006
		Community F6	0.096	0.006

Table 5 shows the results based on feedback from experts in Johor Port, which reveal a notable shift in priorities compared to the feedback from Northport. Note that the Regulatory Function dominates overall importance (weight = 0.664) and its leading subfactor, *Regulatory*

F1, which is to regulate environmental matters within the port (RF_1),contributing the highest global weight (0.347). This contrasts with the earlier findings, where the Landlord and Operator Functions held greater influence, highlighting a stakeholder emphasis now placed more heavily on compliance, governance, and policy enforcement for sustainability. The Landlord Function's overall weight has declined to 0.183, although *Landlord F1* still plays a key role (global weight = 0.078), reflecting the continued but secondary importance of port infrastructure and asset management. The Operator Function further decreased in prominence (weight = 0.100), with its top subfactors (*Operator F1* and *Operator F3*) each contributing only 0.039 to the global score, much lower than previously observed. Meanwhile, the Community Function remains the least prioritized (weight = 0.053), although *Community F4* shows slightly higher influence (global weight = 0.023) than other community-related subfactors. Overall, compared to the other port's results that balanced operational, landlord, and regulatory aspects, this distribution underscores a sharper, more regulatory-driven perspective in evaluating port sustainability performance, suggesting a shift in stakeholder expectations toward stricter governance and compliance as central pillars of sustainability.

Table 5. Results from Northport (global weights of port functions and subfactors (2 respondents)

Factor	Weights	Subfactor	Local Weights	Global Weights
Landlord Function	0.183	Landlord F1	**0.427**	0.078
		Landlord F2	0.13	0.024
		Landlord F3	0.112	0.020
		Landlord F4	0.125	0.023
		Landlord F5	0.109	0.020
		Landlord F6	0.097	0.018
Regulatory Function	**0.664**	Regulatory F1	**0.523**	**0.347**
		Regulatory F2	0.193	**0.128**
		Regulatory F3	0.07	0.046
		Regulatory F4	0.151	**0.100**
		Regulatory F5	0.064	0.042
Operator Function	0.100	Operator F1	**0.388**	0.039
		Operator F2	0.224	0.022
		Operator F3	**0.388**	0.039
Community Function	0.053	Community F1	0.064	0.003
		Community F2	0.131	0.007
		Community F3	0.17	0.009
		Community F4	**0.436**	0.023
		Community F5	0.086	0.005
		Community F6	0.114	0.006

Despite the distinct difference in the perception of importance of subfactors between the two port experts, the final output which is the ranking of the subfactors are tested for its significance. Table 6 shows the details differences between the two evaluations.

Table 6: Comparison of Ranking of sub factors between Two Ports

Subfactor	**Port 1**	**Port 2**	**Difference in values**	**Rank 1**	**Rank 2**	**Difference in rank**	**d^2**
CommunityF1	0.019	0.003	0.016	14	**20**	-6	36
CommunityF2	0.013	0.007	0.006	16	17	-1	1
CommunityF3	0.009	0.009	0.000	17	16	1	1
CommunityF4	0.008	0.023	-0.015	18	10	8	64
CommunityF5	0.006	0.005	0.001	**20**	19	1	1
CommunityF6	0.006	0.006	0.000	19	18	1	1
LandlordF1	**0.133**	0.078	0.055	3	4	-1	1
LandlordF2	0.076	0.024	0.052	5	9	-4	16
LandlordF3	0.051	0.02	0.031	7	14	-7	49
LandlordF4	0.046	0.023	0.023	9	11	-2	4
LandlordF5	0.037	0.02	0.017	10	13	-3	9
LandlordF6	0.028	0.018	0.010	13	15	-2	4
OperatorF1	0.159	0.039	0.120	1	8	-7	49
OperatorF2	0.081	0.022	0.059	4	12	-8	64
OperatorF3	0.033	0.039	-0.006	11	7	4	16
RegulatoryF1	0.134	0.347	-0.213	2	1	1	1
RegulatoryF2	0.065	0.128	-0.063	6	2	4	16
RegulatoryF3	0.05	0.046	0.004	8	5	3	9
RegulatoryF4	0.03	0.1	-0.070	12	3	9	81
RegulatoryF5	0.017	0.042	-0.025	15	6	9	81
			Total				504

Based on the *d* value from Table 6, the Spearman's rank correlation coefficient between the evaluation of two ports is calculated as follows:

$$= 1 - \frac{6 \times 504}{20(20^2 - 1)} = 0.981$$

A ρ value of 1 indicates a perfect positive correlation between the rankings of the two studies. This confirms that both studies rank the ports in the same order, reinforcing the robustness of the methodology. Next, the p-value is determined as it helps assess the statistical significance of the observed correlation. For Spearman's rank correlation, the test statistic t is calculated as follows:

$$t = \frac{\rho\sqrt{n-2}}{\sqrt{1-\rho^2}}$$

With $n = 20$ and $\rho = 0.981$;

$$t = \frac{0.981\sqrt{20-2}}{\sqrt{1-0.981^2}} = \frac{0.981\times\sqrt{18}}{0.000357} = \frac{4.162}{0.000357} = 11648.58 \sim \text{large number}$$

Since the t-statistic value is very large, it means that the p-value approaches zero. This suggests that the perfect correlation observed is highly statistically significant. The statistical results confirm that the ranking order remains consistent despite differences in absolute percentage values caused by variations in criteria selection and weighting.

4. Conclusion and Recommendations

The comparative analysis of the two sets of results highlights how expert-driven multi-criteria decision-making (MCDM) frameworks, such as AHP, reveal evolving stakeholder priorities in port sustainability. Initially, greater emphasis was placed on operational efficiency and landlord functions; however, the updated analysis shows a pronounced shift toward the Regulatory Function, reflecting a growing recognition of governance, compliance, and policy enforcement as critical drivers of sustainable port performance. The variation in priorities between Johor Port and Northport may stem from differences in their operational contexts, governance structures, and strategic focus. Johor Port, being a major gateway for bulk cargo and petroleum-related activities, is subject to stricter environmental oversight and international regulatory compliance, which could explain the higher emphasis placed on the Regulatory Function. In contrast, Northport, with its stronger role in containerized and general cargo operations, may prioritize the Landlord and Operator Functions to ensure efficient infrastructure management and operational performance. Furthermore, local stakeholder expectations, the degree of regulatory engagement, and port-specific sustainability initiatives could also influence the weightings, leading to the observed divergence in expert judgments.

For policymakers, this insight underscores the need to strengthen regulatory frameworks, enhance enforcement mechanisms, and allocate resources toward capacity-building in compliance and monitoring. For port practitioners and managers, the results serve as actionable guidance to invest in governance systems, transparent reporting, and continual improvement processes, without neglecting asset management and operational efficiency. The structured and transparent nature of the AHP methodology also ensures that these decisions are auditable and can be communicated clearly to stakeholders, fostering trust. For researchers, the adaptable framework offers a foundation for further study, including dynamic updates to incorporate emerging sustainability measures such as green hydrogen bunkering or digitalization initiatives. Finally, the observed divergence in weights across functions suggests opportunities for targeted stakeholder workshops to build consensus, aligning strategic plans more closely with shared sustainability objectives while remaining responsive to emerging environmental challenges.

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Author Contribution

Author 1 wrote the draft of the whole article under the supervision of Author 2 and Author 3. Authors 2 and 3 collaborated on crafting the literature review and supervising the article writing process. For the research methodology, Authors 2 and 4 contributed to the analysis and interpretation of results.

Conflict of Interest

The authors have no conflicts of interest to declare.

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