Assessing the Impact of Implementing Green Sustainability Practices in Ports on Environmental and Economic Performance

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المستخلص:
الهدف من هذه الورقة هو تقييم فوائد اعتماد الممارسات الخضراء في إدارة الموانئ، مع التركيز على مساهمتها في الاستدامة البيئية والاقتصادية. من خلال تعزيز الأساليب الواعية بيئيًا، يمكن للموانئ تقليل بصمتها البيئية وأيضًا تحسين كفاءتها التشغيلية، مما يخلق توازنًا بين الأهداف البيئية والاقتصادية.

تم استخدام نهج منهجي لجمع وتحليل البيانات ذات الصلة. تم تصميم استبيان شامل وتوزيعه على خبراء متخصصين في إدارة الموانئ المستدامة لتحديد العوامل الأكثر تأثيرًا في التنفيذ الناجح، تم تطبيق عملية التحليل الهرمي(AHP) مع التركيز على الخصائص الرئيسية المرتبطة عادةً بعمليات الموانئ المستدامة.

نتائج الدراسة توضح أولوية واضحة لعوامل رئيسية في تقييم تأثير الممارسات الخضراء داخل الموانئ. البنية التحتية التكنولوجية ظهرت كأهم عامل، نظرًا لدورها في تمكين الابتكارات المستدامة وعمليات الموانئ الفعالة. ثم، جاهزية المؤسسات في المرتبة الثانية، مع التأكيد على ضرورة وجود سياسات داعمة وثقافة تنظيمية ملتزمة. وأخيرًا، تم اعتبار التأثير البيئي، مع تسليط الضوء على أهمية متابعة والتخفيف من الآثار البيئية كجزء من تبني الممارسات الخضراء.

هذه الأفكار تبرز ضرورة وجود نهج شامل، يدمج بين التكنولوجيا، جاهزية السياسات، ومراقبة البيئة لتحقيق أهداف التنمية المستدامة.

الكلمات المفتاحية: الاستدامة البيئية - الممارسات الخضراء - الموانئ - البنية التحتية التكنولوجية.

Abstract:
The purpose of this paper is to evaluate the benefits of adopting green practices in port management, specifically examining their contribution to environmental and economic sustainability. By promoting environmentally conscious approaches, ports can not only reduce their environmental footprint but also enhance their operational efficiency, and creating a balance between environmental and economic goals.

It employed a systematic approach to collecting and analyzing relevant data. A comprehensive questionnaire was designed and distributed to experts specializing in sustainable port management. To identify the most influential factors for successful implementation, the Analytic Hierarchy Process (AHP) was applied, focusing on key characteristics commonly associated with sustainable port operations.

The findings of this study reveal a clear prioritization of key factors in evaluating the impact of green practices within ports. Technological infrastructure emerged as the most important factor, given its role in enabling sustainable innovations and efficient port operations. This is followed by institutional readiness, emphasizing the need for supportive policies and a committed organizational culture. Finally, environmental impact was considered, highlighting the importance of monitoring and mitigating environmental effects as part of adopting green practices. These insights underscore the necessity of a comprehensive approach, integrating technology, policy readiness, and environmental monitoring to achieve sustainable development goals.

Keywords: Environmental Sustainability - Green Practices - Ports - Technological Infrastructure

1- INTRODUCTION

In the face of rapid technological advancements and digitalization, ports are under increasing pressure to modernize their operations and adopt more sustainable practices to protect the environment and achieve economic development. Green ports are a crucial part of these efforts, playing a key role in reducing the environmental impact of the maritime industry. However, ports face multiple challenges in effectively implementing their green initiatives, such as the high cost of eco-friendly technology, resistance to change, lack of technical expertise, and insufficient infrastructure necessary for these updates.

Green ports have seen significant improvements, leading to essential changes in the management of maritime operations and the reduction of harmful emissions. Technologies such as renewable energy systems, process automation, and big data analytics have become vital tools in achieving environmental sustainability in ports, enabling substantial enhancements in operational efficiency and reducing the environmental impact of maritime activities.

Additionally, smart systems and data analytics contribute to improving the financial efficiency of ports by enhancing resource management and reducing operational costs. These technologies have also become a key element in improving the ability to make informed decisions based on real-time data. The spread of technology in port operations has also facilitated the adoption of best practices on an international scale, contributing to the enhancement of efficiency and sustainability in maritime operations.

By leveraging these modern technologies, ports have become more capable of effectively addressing contemporary environmental and economic challenges, contributing to the achievement of sustainable development goals and ensuring the long-term sustainability of maritime operations.

However, despite the potential benefits of adopting new technologies and digitalization in green ports, they often face difficulties in effectively implementing these innovations. These challenges may result in a failure to achieve the desired improvements in efficiency and performance, hindering the development of the essential capacities needed to enhance sustainability in this sector.

2- Study Objectives:

- To examine how environmental and economic sustainability can be enhanced through the implementation of green practices in ports.
- To assess improvements in operational and economic efficiency through the application of renewable energy technologies and automation in ports.
- To measure the level of satisfaction among employees and beneficiaries regarding their experience in green ports through the adoption of digital transformation.

3- Research Hypotheses

- There is a strong relationship between improving green port operations and
- There is a correlation between the adoption of digital transformation in green ports and the increase in satisfaction among port personnel and service beneficiaries.

4- LITERATURE REVIEW

4-1 Theoretical Background "Green Ports: Definition and Concept"

- **Definition of Green Ports:** Green ports are those that adopt practices aimed at reducing harmful emissions, enhancing the efficiency of natural resource utilization, and minimizing waste and byproducts from port operations. These ports focus on using environmentally friendly technologies such as renewable energy, organic water treatment, and advanced waste management systems. The goal of these ports is to serve as models for how to reduce environmental impact while maintaining economic performance and competitiveness (Ortega-Sanchez et al., 2018).
- **The Concept of Green Ports:** The concept of green ports relies on a set of environmental principles based on developing technologies and operational methods that contribute to reducing the negative environmental effects of port activities (Munino et al., 2018). This concept can be divided into several key components:

  - **Emission Management:** Green ports' efforts include reducing carbon dioxide emissions and other pollutants through the use of renewable energy sources, such as solar and wind power, and adopting clean fuel technologies (Bergillos et al., 2018).
  - **Waste Management:** Green ports strive to improve waste management through recycling practices, safe handling of hazardous waste, and reducing waste generated from port operations (Magana et al., 2018).
  - **Energy Efficiency Improvement:** This involves reducing energy consumption by improving operational efficiency and using modern technologies such as smart lighting systems and more efficient electrical equipment (Clavero et al., 2018).
  - **Natural Resource Conservation:** Green ports aim to reduce the use of natural resources such as water and land by adopting water conservation technologies and managing land sustainably (Diez-Minguito et al., 2018).
  - **Collaboration with the Local Community:** Green ports are committed to collaborating with local communities to promote sustainable development and achieve mutual environmental and economic benefits (Paquiero et al., 2018).

- **Environmental Innovations in Green Ports:** Green ports depend on several environmental innovations that help enhance overall environmental performance, including the use of smart transportation systems to reduce traffic congestion and related emissions, and the application of strict standards for monitoring and evaluating environmental performance (Ortega-Sanchez et al., 2018).

4-2 The Role of Green Ports in Enhancing Environmental and Economic Sustainability

- **Technologies Used in Green Ports:** Green ports rely on modern and innovative technologies to achieve sustainability goals. These technologies include the use of renewable energy sources such as solar and wind power to operate port systems and facilities. Sustainable heating and cooling technologies are also employed to reduce energy consumption. Additionally, water treatment and reuse technologies are used in cleaning and maintenance processes, reducing the consumption of fresh water and minimizing pollution from contaminated discharges (Bergillos et al., 2018).
- **Waste Management and Reducing Environmental Impact:** Waste management plays a crucial role in achieving environmental sustainability in green ports. Strict waste management practices are adopted, including reducing the amount of waste generated, recycling, and using organic decomposition methods for organic waste. Hazardous waste is handled safely in accordance with international environmental standards. These measures help to minimize the environmental impact of port activities and enhance the protection of the surrounding environment (Magana et al., 2018).
- **Reducing Carbon Emissions:** Ports are significant sources of carbon emissions due to ship traffic and heavy equipment operations. To mitigate these emissions, green ports utilize advanced technologies such as clean fuels for ships, sustainable transportation systems within the port, and electric vehicles instead of traditional fossil fuel-powered vehicles. Additionally, measures are adopted to reduce vessel waiting times at the port, which decreases fuel consumption and carbon emissions (Clavero et al., 2018).
- **Economic Sustainability: Costs and Benefits:** Although transitioning to green ports may require substantial initial investments in infrastructure and modern technologies, the long-term economic benefits can be significant. These benefits include savings on energy costs through the use of renewable energy, reduced waste management costs through recycling, and improved operational efficiency leading to lower operational expenses. Furthermore, green ports may attract more businesses that prioritize sustainability, thereby increasing revenue and enhancing the port's reputation as an environmentally friendly trade hub (Diez-Minguito et al., 2018).

5- Challenges and Obstacles to Transitioning to Green Ports

- **High Costs of Infrastructure Investment:** One of the maximum huge demanding situations in transitioning to inexperienced ports is the excessive charges associated with investing in cutting-edge infrastructure and technologies. The shift to environmentally pleasant practices calls for enormous investments in renewable energy structures, waste management

technologies, and upgrading the device and equipment utilized in port operations. These preliminary fees can be a tremendous burden on ports, specifically in growing international locations with restricted economic resources (Bergillos et al., 2018).

- **Technical Challenges and Innovation:** the technologies needed for the transition to green ports are nonetheless in the developmental tiers in some cases, meaning that ports may additionally face technical challenges in adopting those innovations. For instance, implementing clever transportation structures and easy gas technologies calls for superior technologies that might not be effortlessly to be had or can be pricey. Moreover, working those systems requires professional personnel and excessive technical know-how, adding complexity to the transition (Magana et al., 2018).
- **Resistance to Change and Work Culture:** Resistance to trade is one of the limitations facing the transition to inexperienced ports, as port control may face challenges in converting the institutional subculture that is based on vintage and unsustainable practices. Port people might also display resistance to adopting new technology or converting conventional paintings methods, requiring additional efforts in training and elevating cognizance approximately the significance of environmental sustainability (Clavero et al., 2018).
- **Lack of a Supporting Regulatory and Legal Framework:** the absence of a clean regulatory and prison framework supporting the transition to green ports may be a large barrier. In some countries, there may be no criminal guidelines or guidelines encouraging the adoption of environmentally pleasant practices or providing the essential economic incentives for ports to make this transition. This lack of law can result in delays or the vain implementation of inexperienced port tasks (Diez-Minguito et al., 2018).
- **Environmental and Geographical Challenges:** Environmental and geographical conditions can pose obstacles to the implementation of green port technology. For instance, coastal areas liable to herbal disasters which include hurricanes and floods may be wrong for long-term investments in green infrastructure. Additionally, weather change can affect the effectiveness of technology which includes sun and wind power, including an additional layer of complexity to the transition system (Ortega-Sanchez et al., 2018).
- **Funding and Financial Support:** the loss of important funding and monetary help is one in all the most important barriers facing ports attempting to find to transition to green ports. These ports require big financing to cover the costs of latest infrastructure and technology, further to monetary help for training and retraining personnel to deal with modern-day technologies (Paquiero et al., 2018).

6- The Future of Green Ports in Global Sustainability

- In line with the global shift towards sustainability goals, green ports play a crucial role in transitioning to clean energy sources. These ports rely on renewable energy, including solar and wind, to power their infrastructure, thereby reducing dependence on fossil fuels. This shift significantly contributes to reducing greenhouse gas emissions, a critical step in meeting climate change goals outlined in the Paris Agreement. According to López and Guerrero

(2020), green ports serve as models for promoting clean energy use and minimizing the environmental impact of maritime activities.

- Green ports are experiencing significant advancements in waste management, adopting advanced recycling technologies and waste-to-energy conversion systems. These innovations help reduce the amount of waste sent to landfills, conserving natural resources and minimizing environmental impact. Additionally, these technologies contribute to public health improvements by reducing environmental risks associated with marine waste. According to a study published in Maritime Policy & Management, these advancements play a pivotal role in enhancing waste management practices in green ports. (Ortega-Sanchez et al., 2018).
- Green ports aim to enhance their operational performance through the adoption of automation and digitization technologies. Automated systems for unloading and loading ships, inventory management, and vessel movement tracking contribute to reducing port operation time and lowering operational costs. Furthermore, these technologies help mitigate emissions resulting from delays in port operations, improving resource efficiency and minimizing environmental impact. In this context, Jones (2021) highlighted the benefits of automation in optimizing port operations.
- International partnerships and the standardization of environmental practices among ports worldwide are vital for achieving sustainability. By adopting global environmental standards and sharing expertise, green ports can strengthen their role in the international arena and achieve more effective results. These partnerships foster innovation and technology transfer among countries, helping ports adapt to future environmental challenges. A study by Global Environmental Change Journal emphasizes the importance of international collaboration in advancing environmental sustainability and driving innovation in green ports.
- Green ports directly contribute to achieving the United Nations Sustainable Development Goals (SDGs), particularly those related to climate action, clean energy, and marine life conservation. By reducing emissions and enhancing resource efficiency, these ports support these global goals, reinforcing the international community's commitment to transitioning towards a more sustainable economy. According to Port Technology International, green ports are crucial tools for achieving sustainable development on a global scale.
- Green ports are expected to continue evolving in the future, focusing on advancing technological innovations and increasing reliance on artificial intelligence and big data to enhance performance. These advancements will contribute to improving the global competitiveness of ports while achieving a balance between economic growth and environmental protection. Future investments in green infrastructure will be a priority for promoting sustainability. According to Smith (2022), the ongoing development of green ports will be essential in advancing the global sustainability agenda.

7- Research Methodology

This study employs a descriptive-analytical approach, determined as the most appropriate methodology following a review of relevant literature and discussions with field experts. This approach was chosen to systematically gather field data on the phenomenon under study using a

comprehensive questionnaire. The questionnaire was carefully developed and distributed to a purposive sample of fifty students, allowing for an in-depth understanding of their characteristics, attitudes, perspectives, and usage behaviors related to the study topic.

Upon retrieval, the questionnaires were subjected to rigorous testing through statistical validation techniques to ensure reliability and validity. The most common responses were identified, and the key criteria agreed upon were subsequently selected. To prioritize these key factors, the Analytic Hierarchy Process (AHP) technique was applied, a decision-making tool effective in multi-dimensional and complex contexts. In this study, AHP facilitated the selection and prioritization of critical elements, based on input from experts and study participants, by assessing the relative importance of each factor.

Through AHP, the research identified the most significant factors impacting the quality of maritime learning, which are essential to emphasize within the current study. This systematic prioritization ensures that the study focuses on the elements that will have the greatest influence on enhancing the quality of maritime education and training.

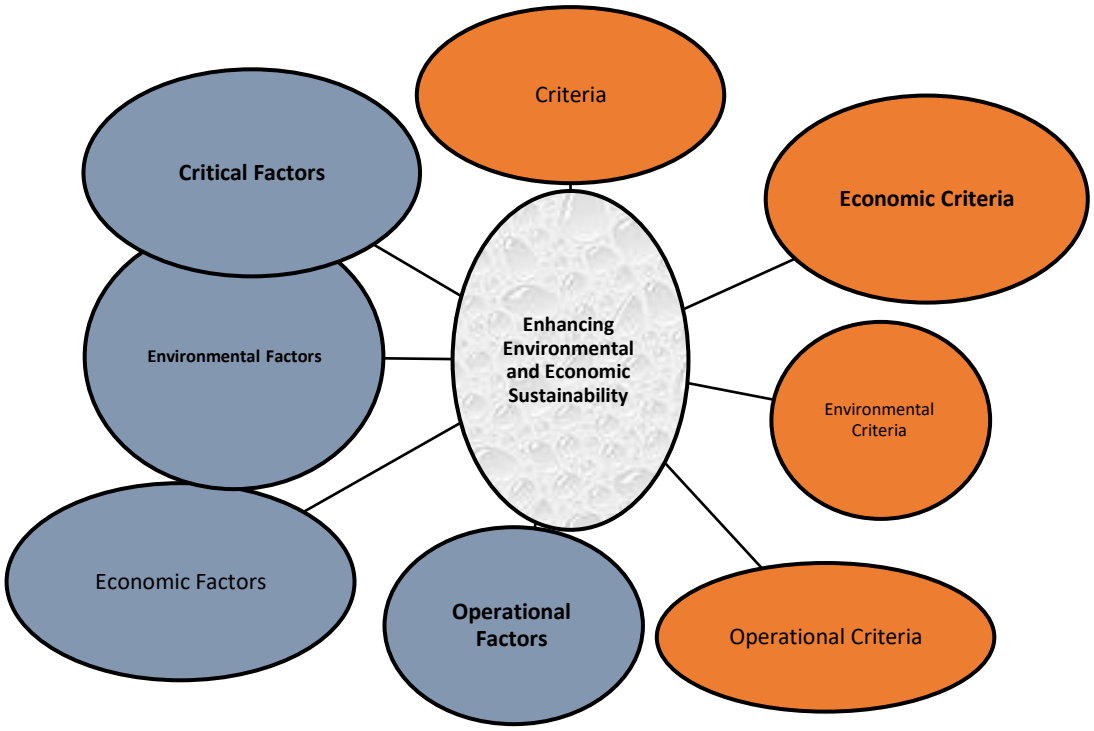

Figure (1): Hierarchical Diagram of the Analytic Hierarchy Process (AHP)

Explanation of the Diagram: -

1. **Main Objective:**

- **Enhancing Environmental and Economic Sustainability**

  The predominant objective is to decorate environmental and economic sustainability via the implementation of inexperienced port standards. This goal is located on the top of the diagram in a square.

2. **Criteria:**

- Environmental Criteria: Includes key environmental elements consisting of energy performance, waste management, and pollution reduction.
- Economic Criteria: Includes financial elements consisting of value discount and efficiency development.
- Operational Criteria: Includes operational factors which include progressed logistics and innovation in sustainable answers.

3. **Critical Factors:**

- Environmental Factors: Such as power efficiency, waste management, and pollutants reduction, linked to the environmental criteria.
- Economic Factors: Such as price discount and performance development, related to the economic criteria.
- Operational Factors: Such as stepped forward logistics and innovation in sustainable answers, connected to the operational criteria.

7-1 AHP Methodology:

The AHP methodology employs a natural, pairwise approach to compare criteria or alternatives in relation to a criterion. The process consists of three main parts:

1. **Identifying Obstacles and Designing a Hierarchy Prioritization Model:** This involves defining the criteria and structuring them into a hierarchical model to prioritize and address obstacles.
2. **Creating a Questionnaire and Gathering Data:** Developing a detailed questionnaire to collect data through pairwise comparisons, allowing for the evaluation of different factors based on expert judgment or stakeholder input.
3. **Determining Normalized Weights:** Calculating the normalized weights for each category of barriers and each individual barrier based on the collected data, which helps in assessing the relative importance of each factor.

8- DATA ANALYSIS

In this section, the software of the AHP method can be clarified to evaluate the effectiveness of implementing inexperienced practices in ports and their impact on achieving environmental and monetary sustainability. AHP changed into adopted as an analytical device to assess the effectiveness of these practices in promoting sustainability through focusing on 3 predominant criteria: (1) Environmental Impact (EI); (2) Technical Infrastructure (TI); and (3) Institutional Readiness (IR).

Table (1) indicates the pairwise comparison matrix furnished through a specialized expert to evaluate the effectiveness of making use of green practices in ports. The highest weight became assigned to Environmental Impact, followed by Technical Infrastructure, and subsequently Institutional Readiness.

Table (1): the pairwise comparison matrix

Challenges	PI	TI	IR	CW	GM	W	WSV
Environmental Impact (EI)	1	1	0.5	1.83	1.83	9.56%	1.83
Technical Infrastructure (TI)	3.45	0.56	1	2.71	2.71	22.9%	2.71
Institutional Readiness (IR)	3.21	0.89	0.5	2.46	2.46	36.8%	2.46
Total	7.66	2	2.45	-	-	7	1

The following values are then calculated to confirm the consistency of the pairwise comparison matrix: -
Since the CR value < 0.1, the matrix is taken into consideration constant and dependable.

Table (2) shows the final decision matrix for evaluating the effectiveness of applying green practices in ports through the three main criteria:
Table (2): the final decision matrix

Criterion	CW	Rank
Environmental Impact (EI)	1.83	3
Technical Infrastructure (TI)	2.71	1
Institutional Readiness (IR)	2.46	2

Table (2) indicates that Technical Infrastructure (TI) ranks first in priority, followed by Institutional Readiness (IR), and then Environmental Impact (EI)

Results of the First Hypothesis Test: There is a significant relationship between the application of green practices in ports and the achievement of environmental and economic sustainability.

Table (3) shows a strong relationship between the application of green practices and the achievement of environmental and economic sustainability, with a correlation coefficient of 0.559 at a significance level of 0.00, indicating a significant statistical correlation.

Table (3): relationship between the application of green practices and the achievement of environmental and economic sustainability

Independent Variable	Dependent Variable	Correlation Coefficient (R)	Coefficient of Determination (R^2)	Significance Level
Application of Green Practices	Achievement of Environmental and Economic Sustainability	0.559	0.313	0.00

Results of the Second Hypothesis Test: There is a correlation between the application of green practices and the increase in operational efficiency in ports.

Table (4) suggests a robust correlation among the software of inexperienced practices and the increase in operational efficiency, with a Pearson correlation coefficient of 0.939 at a significance level of zero.00, confirming the correlation speculation.

Table (4): a robust correlation among the software of inexperienced practices and the increase in operational efficiency

Independent Variable	Dependent Variable	Pearson Correlation Coefficient (R)	Significance Level
Application of Green Practices	Operational Efficiency	0.939	0.00

Results of the Third Hypothesis Test: There is a correlation among the utility of green practices and the boom in pride among people and port provider beneficiaries.

Table (5) shows a strong correlation among the utility of green practices and the growth in pride among employees and beneficiaries, with a Pearson correlation coefficient of zero.918 at an importance degree of zero.00, confirming the validity of the 1/3 speculation.

Table (5): a strong correlation among the utility of green practices and the growth in pride among employees and beneficiaries

Independent Variable	Dependent Variable	Pearson Correlation Coefficient (R)	Significance Level
Application of Green Practices	Satisfaction of Workers and Beneficiaries	0.918	0.00

9- Conclusion and Discussion

In conclusion, the application of sustainable, eco-friendly practices in ports is a crucial step toward achieving both environmental and economic sustainability. These practices aim to enhance ports' environmental performance by reducing negative impacts on the environment and realizing financial benefits, such as cost reduction and improved operational efficiency.

Additionally, implementing green practices boosts the reputation of ports and increases the satisfaction of employees and stakeholders, positively impacting overall port performance and contributing to long-term sustainability. To maintain this progress, it is essential for ports to continuously monitor the implementation of these practices and regularly assess their effectiveness, ensuring ongoing improvement and the achievement of targeted sustainability goals.

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