Green Ports A New Direction for Achieving Sustainable Development

الموانئ الخضراء كتوجه جديد لتحقيق التنمية المستدامة

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Abstract

This research aims to explore green logistics and study it as one of the maritime transport approaches that can be relied upon to achieve sustainability.

The key findings indicate that green logistics services, in their essence, reflect a sustainable approach to supply chain management. To prevent environmental pollution caused by port operations, the concept of sustainable development and green operations has become an essential solution. Adopting the concept of green ports is crucial, especially in light of the global trend towards sustainability, environmental preservation, reducing energy and resource waste, and protecting the planet. Green ports are those that prioritize environmental conservation and the sustainability of maritime operations. Their principles are based on practices aimed at minimizing negative environmental impacts while ensuring the sustainable use of resources and energy. Additionally, green ports seek to enhance environmental protection and preserve marine and coastal ecosystems.

Keywords: Green logistics**;** green ports**;** smart green port**;** Ecosystems**;** sustainable development.

الملخص

يهدف هذا البحث إلى تسليط الضوء على الموانئ الخضراء ودراستها كأحد مناهج النقل البحري التي يمكن الاعتماد عليها لتحقيق التنمية المستدامة.

تشير النتائج الرئيسية إلى أن الخدمات اللوجستية الخضراء، في جوهرها، تعكس نهجًا مستدامًا لإدارة سلسلة التوريد. ولمنع التلوث البيئي الناجم عن عمليات الموانئ، أصبح مفهوم التنمية المستدامة والعمليات الخضراء حلاً أساسيًا. ويعد تبني مفهوم الموانئ الخضراء أمرًا بالغ الأهمية، خاصة في ظل الاتجاه العالمي نحو الاستدامة والحفاظ على البيئة وتقليل هدر الطاقة والموارد

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وحماية الكوكب. والموانئ الخضراء هي تلك التي تعطي الأولوية للحفاظ على البيئة واستدامة العمليات البحرية. وتستند مبادئها إلى ممارسات تهدف إلى تقليل التأثيرات البيئية السلبية مع ضمان الاستخدام المستدام للموارد والطاقة. بالإضافة إلى ذلك، تسعى الموانئ الخضراء إلى تعزيز حماية البيئة والحفاظ على النظم البيئية البحرية والساحلية.

الكلمات المفتاحية: اللوجستيك الاخضر؛ الموانئ الخضراء؛ الموانئ الخضراء الذكية، النظم البيئية، التنمية المستدامة.

Introduction

Ports are the backbone of international trade, but they are also responsible for environmental pollution through maritime transport activities. Studies indicate that over 80% of global trade is conducted via seas and that ports continue to be a significant source of environmental pollution and carbon emissions. This is due to their high consumption of energy and fuel, as well as the storage and supply of fossil fuels to ships. The challenge lies in finding suitable alternatives to reduce these emissions without compromising the competitiveness of ports while ensuring they continue to provide high-standard services at reasonable costs. Additionally, there is a need to rethink all aspects of port operations and infrastructure to leverage technology and keep pace with advancements in various shipping and transportation sectors.

- **Problem Statement:**

The concept of sustainable mobility first emerged in Europe in 1992 within the "Green Paper," which highlighted the impact of transportation on the environment and explored a common strategy to mitigate the sector's negative effects on the economic and social life of member states. The ambitious plan to achieve climate neutrality by 2050 aims to reduce emissions from the transport sector by 90% by that date. In recent years, port emissions have significantly increased. Based on this, our study focuses on the strategy envisioning the future of ports while integrating four key elements: port operations, the environment, energy, and safety & security. This integration will enable the creation of more efficient and sustainable ports. Given the growing concerns about global environmental changes, green port practices have become increasingly important worldwide. To prevent environmental pollution from port operations, ports are adopting and implementing green port policies. Thus, this research paper seeks to answer the following key question:

What is the international strategy for achieving sustainable green ports, and what are its social, economic, and environmental implications?

- **Sub-questions:**

To further explore this issue, the study addresses the following sub-questions:

- What are green logistics services?
- What are the differences between a green port and a conventional port?
- What are the driving factors behind the transition to environmentally friendly green ports?

- **Hypotheses:**

To complete this study, we propose the following hypotheses:

- Environmental logistics services aim to shift towards the green concept of logistics.
- The green port is a relatively new approach and differs entirely from conventional ports in terms of construction and operation mechanisms.
- Green ports have emerged to reduce the negative environmental impact of ports while ensuring economic returns.

- **Objective:**

This research aims to:

- Study the concept of green logistics services and their role in achieving sustainability.
- Explore the concept, objectives, and requirements of green ports in their transition towards sustainability.
- Examine key international measures taken to prevent pollution caused by ships.

- **Methodology:** The study adopts a descriptive-analytical approach, focusing on identifying and analyzing the problem.

1. Green Logistics and Sustainabilit:

1.1 The Concept of Green Logistics:

The concept of green logistics emerged in the 1980s as a solution to environmental crises caused by logistics-related activities, such as carbon emissions and noise pollution. It also aimed to achieve an environmental balance for logistics support companies while meeting institutional and social objectives. Green logistics is considered a system responsible for managing transportation and supply in an environmentally friendly manner. It encompasses not only forward logistics operations, including raw material acquisition, production, packaging, transportation, storage, and delivery to consumers, but also reverse logistics, which involves waste recycling and disposal. Logistics services are the lifeline of international trade. Establishing policies targeting transportation infrastructure, including ports, airports, and multimodal facilities, can help enhance the reliability and efficiency of services. These policies promote environmentally sustainable logistics, encouraging the use of low-carbon shipping modes and energy-efficient storage solutions. The 2023 World Bank Logistics Performance Index Report highlighted the sector’s global economic significance, alongside its growing strategic importance in addressing emerging climate challenges. Green logistics represents a sustainable approach to supply chain management, aiming to enhance the environmental efficiency of logistics operations while fostering a balance between sustainability and economic prosperity. (Malak Abu Diya, 2024, p. 345)

Several definitions have been proposed for green logistics, with scholars generally agreeing on the following:

- "Efforts to measure and reduce the environmental impact of logistics activities and services, incorporating proactive design strategies for all elements of the logistics process."

- "Green logistics revolves around the efficient and effective environmental management of logistics activities, covering both forward and reverse flows of products and information from origin to consumption to meet customer requirements. It is also defined as a system that integrates advanced technologies and equipment to minimize environmental damage during logistics operations."
- "Green logistics refers to the planning, control, management, and execution of transport and supply systems using advanced logistics technologies to reduce resource consumption and pollutant emissions, ultimately protecting the environment and achieving sustainable development." (Dina Saleh Sayed Abdelaziz, Basant Hisham Ahmed Youssef, and Mohamed Reda Haggag, Volume 58, Issue 02, 2019, pp. 08-09)

1.2 Advantages of Green Logistics:

Adopting green supply chain management is a promising strategy for companies, especially as global consumption is expected to increase by 75% by 2025. Additionally, global per capita income and spending on consumer goods are anticipated to rise. Companies seeking to expand their customer base must adhere to sustainability standards that enhance operational performance. The key benefits of green logistics include: (Source: https://arabic.fourwinds-ksa.com/, 2024)

- ✓ **Reducing Emissions:** One of the most significant advantages of green logistics is its role in reducing greenhouse gas emissions. This approach incorporates eco-friendly best practices to minimize the carbon footprint in supply chains. Key strategies include reducing energy consumption, optimizing logistics operations for efficiency, and establishing delivery hubs closer to customer bases. Since transportation is the largest contributor to greenhouse gas emissions, companies that establish storage warehouses near target markets can significantly reduce both emissions and transportation-related costs.
- ✓ **Waste Reduction:** Most companies are transitioning to digital documentation and integrating operational data into online systems instead of relying on physical paperwork. This shift drastically reduces paper waste, simplifies processes, and centralizes access to customer insights, inventory management, and order processing. Additionally, green logistics strategies help minimize plastic waste associated with packaging. By adopting renewable resources and implementing recycling best practices, companies can significantly reduce the amount of plastic used in deliveries.
- ✓ Increasing Customer Awareness Consumers today are more conscious of their carbon footprint and seek brands that align with their values and environmental concerns. When companies integrate green logistics into their operations and communicate these efforts to their customers, they not only enhance awareness but also guide consumers on how to participate in sustainability initiatives.
- ✓ Enhancing Brand Reputation and Competitiveness Taking tangible steps to improve green logistics in supply chain management strengthens brand

credibility and market positioning. Research indicates that customers are willing to pay a premium for products from brands that embrace sustainable practices.

1.3 Green Logistics Measures:

To transition toward eco-friendly logistics, companies can take several key steps: (Source: https://www.logos3pl.com/ar, 2024)

- Systematic Travel Route Optimization traditionally, route optimization was a manual process, often resulting in excessive paper waste and high fuel costs. Inefficient routes increased travel distances and fuel consumption. By implementing automated route planning tools, companies can optimize delivery routes, minimize fuel use, and reduce carbon emissions by mapping out the shortest and most efficient paths.
- Promoting Environmentally Responsible Transportation On-demand and same-day delivery services can hinder sustainability efforts, as delivery trucks often operate below full capacity, leading to higher operational costs and increased emissions. Companies should implement batch delivery strategies and explore eco-friendly transportation alternatives to reduce waste.
- Reducing Carbon Footprint and Operating Costs A primary advantage of green logistics is its ability to lower greenhouse gas emissions. By assessing a company's energy consumption and fuel usage in transporting goods, businesses can measure their carbon footprint and compare it to global and industry benchmarks. This analysis helps in implementing strategies to cut emissions, such as switching from road transport to rail freight, which is significantly more sustainable. Additionally, choosing fuel-efficient vehicles and alternative energy sources helps reduce operational costs related to fuel consumption and vehicle maintenance.
- Commitment to Sustainability Adopting green logistics signals a company’s genuine commitment to environmental responsibility, fostering customer trust and brand loyalty. Research suggests that 42% of consumers are willing to pay more for eco-friendly products and services. By embracing sustainability, companies enhance their brand image, attract environmentally conscious customers, and ultimately drive sales growth and business expansion.

1.4 Green Logistics Management Activities:

Key green logistics management activities include: (Source: Akram Ahmed Al-Tawil, Ahmed Abdul Sattar, and Abdul Mohsen Al-Talibi, 2024)

- ✓ Green Procurement One of the most critical aspects of green logistics, green procurement involves selecting materials and products based on environmental standards to minimize their negative impact throughout their lifecycle.
- ✓ Green Transportation Aims to maximize the volume of transported goods while minimizing environmental harm by optimizing traffic flow and transportation routes. This contributes to reducing CO_2 emissions and improving overall sustainability.

- ✓ Green Storage Also known as sustainable warehousing, this involves designing storage facilities and strategies to lower logistics costs while minimizing environmental pollution.
- ✓ Green Manufacturing A production approach focused on efficient resource use, reducing waste and greenhouse gas emissions, and lowering the health risks for workers due to environmental pollution.
- ✓ Green Packaging With growing global concern over packaging waste, governments and companies are increasingly investing in eco-friendly packaging solutions. These initiatives help cut costs, improve competitiveness, and enhance sustainability in product packaging.
- ✓ Reverse Logistics Involves recycling, remanufacturing, and reprocessing surplus or outdated materials. Reverse logistics is crucial for environmental conservation and helps businesses manage returned products, defects, and excess inventory more efficiently.

2. Green Ports:

Since the rise of maritime trade, ports have played a vital role in economic and social development. More than 80% of global trade (by volume) is transported via sea routes, with containerized goods accounting for 35% of total cargo volume and over 60% of total trade value. (Source: https://blogs.worldbank.org/, 2024) When it comes to green transportation, 80-90% of global goods are shipped by sea. However, container ships emit nearly 1 billion metric tons of CO_2 annually, contributing to about 3% of all greenhouse gas emissions while also releasing tons of toxic waste into the oceans. Recognizing these environmental challenges, the International Maritime Organization (IMO), in September 2021, set an ambitious goal to cut carbon emissions by 50% by 2050, compared to 2008 levels. This initiative, backed by 150 industry leaders, is a significant step toward decarbonizing the shipping industry and promoting sustainable maritime trade. (Source: https://www.sap.com/mena-ar/insights/green-logistics.html, 2024)

2.1 The Concept and Importance of Green Ports:

In recent years, port authorities have increasingly focused on developing measures that ensure the technical and regulatory conditions for future port operations. These measures also encompass various social and environmental aspects necessary to maintain and enhance service quality, making them particularly important for the port industry. This concept is referred to as the Green Port, which signifies the implementation of specific strategies to ensure that port development efforts—across economic, regulatory, and environmental domains—lead to enhanced efficiency, effectiveness, and optimal operations. The Green Seaport (GS) concept, which primarily aims to maximize economic benefits while minimizing the environmental impact of ports on their surrounding areas, is a relatively recent trend in the maritime industry. The more environmental conservation is prioritized, eco-friendly development is achieved, and energy and economic resources are preserved, the more a green port succeeds in establishing the required balance between economy and nature.

Green sustainable ports should not only be evaluated in terms of cost but also based on the benefits they generate, their sustainability, economic savings, and optimal use of available resources. Therefore, the primary goal of green ports is to implement environmental protection policies, adopt eco-friendly development practices, replace non-renewable energy sources with renewable alternatives, and incorporate environmentally driven management approaches within port operations. Ultimately, this leads to ports that foster a sustainable relationship between the economy and nature—a factor that requires significant attention. (Aminuddin Md Arof, Amayrol Zakaria, & Noorul Shaiful Fitri Abdul Rahman, 2024)

Thus, green ports are those that prioritize environmental conservation and sustainable maritime operations. Their principles are based on practices aimed at reducing negative environmental impacts, ensuring sustainable use of resources and energy, and enhancing environmental protection while preserving marine and coastal ecosystems. Adopting the green port concept is crucial, especially amid the global push for sustainability, environmental preservation, energy efficiency, and resource conservation to safeguard the planet. (Ezzeldeen Elfarsi, Amr Ekram, Wesam Elkwafi, & Ahmed Ismail, June 2022, p. 33)

Green ports play a significant role in reducing environmental pollution, enhancing operational and economic performance, and improving port competitiveness. However, the extent of transformation into green ports varies from country to country and port to port due to differences in port functions, geography, economic and political systems, and port infrastructure, including management, buildings, equipment, storage facilities, workforce, and additional activities.

To achieve or fully implement the sustainable green port concept, ports must consider several key factors that facilitate its successful application. Achieving a balance between social, economic, and environmental dimensions requires careful study of these factors, as they are applicable to almost all ports, regardless of their country's economic status. These factors include: (Sobhy Mostafa Mohamed & May Salah Eldine, January 2020, pp. 240-241)

Sediment buildup at port entrances and coastal erosion.

- Overall impact on the local community.
- Cargo spills from chemical tankers and bulk carriers.
- Air pollution from bulk cargo handling.
- Oil leaks during pipeline disconnection.
- Interference with recreational and fishing boats.
- Marine life impact from ship navigation, operations, and docking.
- Pipeline networks and their effect on local property values.
- Declining marine life populations near ports due to port infrastructure.
- Disruptions during port construction or renovation.
- Marine biodiversity protection.
- Waste disposal into water bodies.
- Oil spills.
- Ballast water impact on plankton.

- Noise and vibrations from cargo handling.

2.2 Features of Eco-Friendly Green Ports:

To prevent environmental pollution from port operations, the concept of sustainable development and green operations has emerged as an effective solution. The green approach integrates three key aspects in port operations: energy conservation, environmental protection, and ecological care. Modern research on the economic and social impacts of ports (e.g., studies by the National Bank and others) highlights the increasing significance of geographic distribution in addressing the negative effects of port activities. This has become a critical factor for port authorities and policymakers, particularly in attracting global investments and partnerships.

- Green ports must comply with environmental regulations during loading, unloading, ship refueling, and the safe disposal of marine pollutants.
- They distinguish themselves through the application of advanced technologies that reduce pollution levels, improving environmental performance and mitigating ecological risks.
- They represent innovative solutions to environmental challenges.
- They position countries on the global map of eco-friendly ports.
- Green ports serve as the primary gateways for international trade, acting as critical hubs in the global maritime transport industry.
- Key Role of Green Ports in Sustainable Transport and Economic Development
- Green ports serve as a crucial link in the sustainable transport chain and play a vital role in driving economic development.
- They are part of the green economy, which includes sectors such as transportation, housing, agriculture, industry, energy, and infrastructure.
- The widespread adoption of green ports is based on several key specifications, the most important of which is achieving zero pollution. This involves preventing oil tankers from discharging water containing oil residues, ensuring clean vessel operations and fuel changes without environmental contamination, recycling solid waste, containers, and packaging, and implementing a structured recycling system for liquid waste, including chemicals and other hazardous substances.
- Green ports must be environmentally friendly, covering ship engines, onboard equipment, and all energy sources used, which must be clean and efficiently controlled. This extends to docks, buildings, facilities, drainage, electricity, waste collection, storage areas, parking zones, passenger terminals, administrative buildings, and all port-related services and infrastructure. (Youm7, 2024)

2.3 Goals of Green Ports:

The International Association of Ports and Harbors (IAPH) launched a Port Sustainability Program, based on the United Nations' 17 Sustainable Development Goals (SDGs), to enhance and coordinate sustainability efforts across global ports. This initiative also promotes international collaboration within the supply chain. The Global Ports Sustainability Program builds upon the IAPH’s 2008 Global Climate Initiative and extends to other areas of sustainable development.

Six key operational objectives were defined to help ensure sustainable maritime ports and harbors: (Aref Hassan Abdullah Al-Shaabi, 2023, pp. 980-981)

✓ Clean Water and Sanitation:

- Ensuring sustainable water management and sanitation.
- Guaranteeing access to clean drinking water and protecting water-dependent ecosystems.

✓ Industry, Innovation, and Infrastructure:

- Building resilient infrastructure and achieving sustainable industrialization.
- Promoting technological advancements to enhance port efficiency.

✓ Sustainable Cities and Communities:

- Supporting safer urban areas and human settlements.
- Reducing poverty and environmental pollution by improving air quality, waste management, and marine conservation.

✓ Climate Action:

- Raising awareness about climate change and its impacts.
- Enhancing climate-related disaster preparedness and air quality monitoring.

✓ Life Below Water:

- Protecting ocean ecosystems and promoting sustainable marine resource utilization.
- Preventing pollution, reducing ocean acidification, and conserving coastal and marine biodiversity.

✓ Partnerships for Sustainable Development:

- Encouraging global cooperation among governments, private sectors, and civil society.
- Strengthening commitment to achieving SDGs through strategic partnerships.

2.4 Digital Transformation and the Smart Green Port:

The term "Smart Port" has gained significant attention in recent years, both in practice and in efforts to develop a clear and consistent definition. One of the earliest attempts to define smart ports was by Yang et al., who described them as fully automated ports where devices are interconnected via the Internet of Things (IoT). A network of smart sensors, actuators, wireless devices, and data centers enables port authorities to deliver essential services more efficiently. According to the authors, the main drivers of smart ports are increased productivity and efficiency. (Silvia Battino & Mariadel Mar Muñoz Leonisio, 2024, pp. 186-187). Yau et al. combine the smart port and smart city concepts, defining a smart port as an integral part of a smart city, utilizing technological innovation to enhance port operations and services. When integrated with a smart city, a smart port boosts trade competitiveness while reducing energy consumption and traffic congestion. They identify five key characteristics of smart ports: (Adrianna Karaś, 2022, pp. 521-522)

- Smart port services and applications, including ship and container management.
- Technological infrastructure, such as data centers, networks, communication systems, and automation.

- Use of sustainable technologies to enhance energy efficiency and reduce greenhouse gas emissions.
- Port clusters, consisting of shipping companies and stakeholders concentrated in a specific geographic area.
- Infrastructure development, fostering collaboration among different ports.

As the global shipping industry moves toward greater efficiency, cost-effectiveness, and sustainability, digital transformation in ports has become increasingly important. It contributes to cost reduction, safety improvements, and enhanced operational efficiency. Additionally, digital transformation helps in:

- Enhancing customer service and reducing paperwork.
- Providing better data access and improving decision-making.
- Minimizing emissions and improving environmental quality.

Since seaports play a crucial role in sustainable coastal development, transforming them into smart port ecosystems is essential.

The first three generations of ports primarily focused on port services and production. However, the fourth generation prioritized information services, integrating ports within global supply chains. The fifth generation of ports builds upon these advancements, incorporating green and smart technologies, emphasizing environmental protection, sustainability, and innovation.

Unlike previous port generations, which failed to achieve low-carbon growth or address climate change and pollution, the smart port concept focuses on:

- Enhancing logistics integration through new technologies.
- Optimizing the supply and demand of logistics services.
- Improving resource allocation within transport and distribution systems.

This has led to the rise of automated ports since the early 21st century, driven by the rapid development of advanced communication, networking, and smart technologies. Furthermore, geospatial technology tools play a vital role in the development and management of smart green ports, offering valuable insights into port operations, environmental impacts, and areas for improvement.

2.5 The Role of Geospatial Technology in Smart Green Ports:

As technology continues to advance, it is likely that more innovative solutions will emerge, enhancing the sustainability and efficiency of smart green ports. The digitization of shipping is moving towards fully autonomous, yet safe and reliable, vessels that target smart green ports. Geospatial technology tools can be used in smart green ports in various ways to improve efficiency, safety, and sustainability. Below are some of the ways in which geospatial technology tools can be utilized in a smart green port: (Mohamed Elhussieny, Ola Arafat, & Ahmed El Kassar, 2–7 September 2023, pp. 414-415)

- Real-time Ship Tracking: Geospatial technology tools such as the Automatic Identification System (AIS) can be used to track ships in real-time. This helps optimize vessel traffic management and reduce ship waiting times, thereby minimizing fuel consumption and emissions.

- Berth Allocation Optimization: Geospatial technology tools can analyze berth availability, water depths, and other factors to enhance berth allocation. This helps reduce vessel turnaround times and improve port efficiency.
- Air Quality Monitoring: Geospatial technology tools can be used to monitor air quality within and around the port. This helps identify areas with high pollution levels and implement corrective measures to reduce emissions.
- Waste Management: Geospatial technology tools can assist in managing waste generated in the port. This includes identifying waste generation areas, tracking waste movement, and managing its disposal.
- Water Quality Monitoring: Geospatial technology tools can be used to monitor water quality within and around the port. This helps detect areas with high pollution levels and take corrective actions to mitigate contamination.
- Predictive Maintenance: Geospatial technology tools can predict maintenance requirements for port infrastructure such as cranes, quay walls, and other equipment. This helps minimize downtime and enhance port efficiency.
- Emergency Response: Geospatial technology tools can be used to plan emergency response actions in case of accidents or natural disasters. This includes identifying evacuation routes, emergency shelters, and other resources needed for emergency response.

Geospatial technology tools can be utilized in multiple ways to enhance the efficiency, safety, and sustainability of smart green ports. By leveraging these tools, ports can reduce their environmental impact and improve overall performance. The use of geospatial technology tools has been increasingly adopted in the development and management of smart green ports. These tools offer various benefits, including improved efficiency, cost savings, and environmental sustainability. This literature review explores the application of geospatial technology tools in smart green ports.

One of the most commonly used geospatial technology tools in smart green ports is Geographic Information Systems (GIS). GIS enables the collection, analysis, and visualization of spatial data related to port operations. This includes data on vessel movements, cargo handling, and infrastructure. By utilizing GIS, port operators can identify areas for improvement to enhance efficiency and minimize environmental impact.

Another geospatial technology tool used in smart green ports is Remote Sensing (RS). Remote sensing involves using satellite imagery and other remote sensing techniques to collect data on port operations. This data can be used to monitor and manage environmental impacts, such as water quality and air pollution. Remote sensing can also be used to track vessel movements and cargo handling, providing valuable insights for port operators.

The Global Positioning System (GPS) is another geospatial technology tool used in smart green ports. GPS enables real-time tracking of ships and cargo movements. This information can be used to optimize shipping routes and reduce fuel consumption, leading to cost savings and emission reductions. In addition to these tools, emerging technologies are also being used in smart green ports. For example, Unmanned Aerial

Vehicles (UAVs) are being deployed to monitor port operations and collect data on environmental impacts. Augmented Reality (AR) is also being used to visualize port operations and identify areas for improvement.

2.6 The International Convention for the Prevention of Pollution from Ships:

The International Convention for the Prevention of Pollution from Ships is one of the most important legal instruments related to international maritime transport. Decarbonization remains a pressing priority, as international shipping is responsible for approximately 3% of global greenhouse gas emissions. Short-term decarbonization measures include the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) under Annex VI of the convention. These requirements have been in effect since 2023 and are expected to build upon previous regulations, including the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). During its 80th session, the International Maritime Organization's Marine Environment Protection Committee (MEPC) adopted the revised strategy for reducing greenhouse gases. Plans to limit these emissions are nearing completion, but before implementation, a comprehensive assessment of the impact of open measures is required as part of the impact assessment action plan for states.

Maritime transport is under pressure to reduce carbon emissions as soon as possible. However, the shipping industry faces uncertainty regarding the best strategy to achieve this. Panama, Liberia, and the Marshall Islands collectively account for the highest percentage of global CO_2 emissions due to their market share in ship tonnage. Between 2012 and 2022, the share of CO_2 emissions from the three largest ship-owning nations—China, Japan, and Greece—also increased. Therefore, assessing the digital footprint of the global fleet is crucial. One potential consequence of decarbonization is its impact on maritime logistics costs, which could have a ripple effect on trade and economic output, especially for developing nations. It may also drive increased investment in ship capacity, alternative fuels, and green technologies. The effects of decarbonizing maritime transport are likely to be more significant for small island developing states (SIDS) and least developed countries (LDCs).

Decarbonizing shipping by 2050 will require significant investments, with estimates suggesting $8 billion plus $28 billion annually. Expanding fuel production, distribution, and supply infrastructure to achieve 100% carbon-neutral fuel by 2050 will require annual investments ranging from $28 billion to $90 billion. Furthermore, full decarbonization could increase annual fuel costs by 70% to 100% compared to current levels. According to UNCTAD, maritime logistics costs are projected to rise by 2.7% in the medium term, with ship time at sea increasing by 2.8% and average maritime freight costs rising by 1.5% by 2030. Developing coastal nations, including small island states and least developed countries, are expected to experience greater GDP and trade flow declines than developed coastal nations. The widespread implementation of alternative fuels requires a major transformation of fuel production and distribution value chains. This also involves multiple stakeholders across maritime transport, ports, energy, and finance sectors. Decarbonization efforts must be collectively pursued by the wider industry, including shipping companies, ports, manufacturers, shippers, investors, energy producers, and distributors. Green corridors, which are collaborative shipping

routes between ports, play a crucial role in these efforts. (United Nations Conference on Trade and Development, 2024)

2.7 European Green Ports: The European Green Deal:

At the end of 2019, the European Union's executive bodies approved a long-term climate transition strategy called the European Green Deal. The plan aims to make the European economy sustainable and turn the EU into a climate-neutral entity by 2050 by minimizing CO_2 emissions through a series of political initiatives and environmental regulations. (https://www.project-syndicate.org/, 2024). The European Green Deal is at the core of Europe's new growth strategy, focusing on sustainable economic development. It prioritizes green technologies, resource efficiency, and biodiversity while enforcing stricter health and environmental standards. (https://www.tatsachen-ueber-deutschland.de/ar/almanya-wawrwba/sfqt-awrwba-alkhdra, 2024). The EU aims to reduce emissions by 50% by 2030 compared to 1990 levels, with the maritime sector expected to cut 90% of transport emissions by 2050. (https://attaqa.net, 2024). Smart green port initiatives will include sustainable port design, green construction, optimized logistics, and circular economy practices.

Models of cooperation across multiple stakeholders from EU countries pave the way for the large-scale deployment of innovative supply chain solutions across European ports.

Developing integrated, low-emission energy supplies and production in ports (such as electricity, green hydrogen, and biofuels), along with supply, storage, distribution, and energy (recharging) systems. This includes sustainable alternative fuels and refueling infrastructure for ships and vehicles in ports, as well as for other uses (e.g., port equipment/machinery, onshore power supply systems for docked ships, etc.). Demonstrating sustainability and innovation beyond the supply and demand for energy in ports, particularly through integration with green and smart logistics services, port operations, energy-efficient buildings, and other sustainable initiatives. Showcasing seamless and highly efficient logistics processes that enhance the integration of maritime transport communications, leveraging digital technologies to optimize shipping operations in ports. This enables efficient and automated logistics chains, as well as data-sharing among stakeholders. Ensuring clear commitments and contributions across Europe to adopt technological, non-technological, and innovative solutions. These may be implemented through follow-up actions, such as those supported by the EU's Connecting Europe Facility or other funding programs.

Conclusion:

Logistics services are the lifeblood of international trade, and green logistics represent a sustainable approach to supply chain management. These services focus on improving the environmental efficiency of logistics operations, fostering an eco-friendly and sustainable environment. Adopting green supply chain management strategies offers a promising future for businesses. Since the inception of maritime trade, ports have played a pivotal role in the economic and social development of nations. More than 80% of global merchandise trade (by volume) is transported via maritime routes. A significant and growing portion of this volume—around 35% of total shipments and over 60% of trade value—is carried in containers.

The green port concept is a relatively new approach that fundamentally differs from conventional ports in terms of construction, operation, environmental impact, and economic returns. Green ports play a crucial role in boosting economic development in surrounding regions while minimizing environmental damage. In contrast, traditional seaports are major sources of environmental pollution—whether air, water, soil, or noise pollution—due to cargo transportation and port activities.

Maritime transport operations and port machinery, including ship engines and cargo handling equipment, contribute to harmful emissions, including carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), primary and secondary gases, and other air pollutants linked to port activities, such as smog and particulate matter pollution, which disrupt natural ecosystems. Additionally, water pollution results from oil spills, wastewater discharge, contaminated ballast water, and the destruction of marine biodiversity, including endangered species. The logistics of cargo handling also contribute to traffic congestion, soil contamination, and hazardous solid waste generation, especially when dealing with bulk cargo. The maritime industry and ports worldwide face increasing pressure to comply with stricter environmental regulations, while competition among seaports has become fiercer than ever. The 21st century has seen a growing awareness of environmental preservation and a stronger push toward implementing smart and sustainable green port concepts.

Smart green ports are part of the innovative solutions to environmental challenges. These ports must be environmentally friendly, integrating comprehensive control systems for emissions from dredging, buildings, facilities, sanitation, electricity, garbage collection, warehouses, and services. Other essential elements include parking areas, passenger terminals, administrative buildings, and port extensions, all designed with sustainability in mind. Geospatial data plays a crucial role in optimizing port operations, and artificial intelligence (AI) is increasingly becoming the key driver powered by data to accelerate the maritime industry toward a greener future.

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