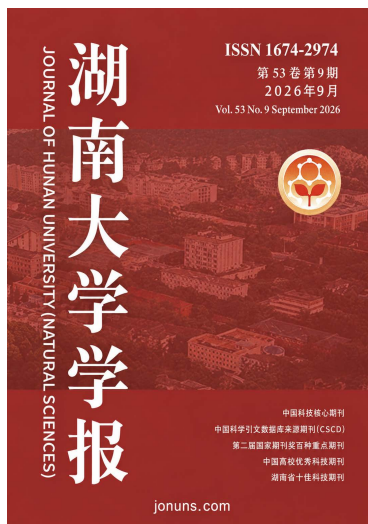




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Green Port Management Strategies for Decarbonizing Sea Transportation and Improving Maritime Logistics Resilience

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Abstract: Maritime transportation faces increasing pressure to reduce greenhouse gas emissions while maintaining the continuity and resilience of logistics operations amid environmental, geopolitical, and supply chain disruptions. This study examines green port management strategies for decarbonizing maritime transportation and strengthening maritime logistics resilience. A qualitative literature-based research approach was employed through the review of relevant academic books, peer-reviewed journal articles, institutional reports, policy documents, and other credible scientific sources. The collected literature was analyzed using qualitative content analysis to identify recurring themes, strategic measures, relationships, and theoretical insights related to green port management, maritime decarbonization, and logistics resilience. The findings indicate that renewable energy integration, port electrification, alternative low- and zero-carbon fuels, energy-efficiency measures, digitalization, green infrastructure, environmental monitoring, and stakeholder collaboration can contribute to reducing maritime emissions while strengthening operational continuity and adaptive capacity. The study develops an integrated framework that conceptualizes green port management as a strategic link between maritime decarbonization and logistics resilience. The framework integrates technological, operational, organizational, governance, and environmental dimensions and demonstrates that effective green port transformation requires coordinated rather than isolated interventions. Overall, the findings suggest that green port management can support both long-term emission reduction and the development of more adaptive and resilient maritime logistics systems.

Keywords: green port management; maritime decarbonization; maritime logistics resilience; port electrification; sustainable maritime transportation; green ports.



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绿色港口管理战略：推动海上运输脱碳与提升海事物流韧性

摘要：海上运输正面临日益增加的温室气体减排压力，同时还需要在环境、地缘政治和供应链中断的背景下维持物流运营的连续性与韧性。本研究旨在探讨绿色港口管理战略在推动海上运输脱碳和增强海事物流韧性方面的作用。研究采用基于文献的定性研究方法，对相关学术专著、同行评议期刊论文、机构报告、政策文件及其他可信的科学资料进行系统审阅。所收集的文献采用定性内容分析法进行分析，以识别与绿色港口管理、海事脱碳和物流韧性相关的重复性主题、战略措施、相互关系及理论观点。研究结果表明，可再生能源整合、港口电气化、低碳和零碳替代燃料、能源效率提升、数字化、绿色基础设施、环境监测以及利益相关者协作，能够在降低海运排放的同时，增强运营连续性和适应能力。本研究构建了一个综合性框架，将绿色港口管理概念化为连接海事脱碳与物流韧性的战略纽带。该框架整合了技术、运营、组织、治理和环境等多个维度，并表明，有效的绿色港口转型需要采取协调一致的综合措施，而非孤立实施单一干预。总体而言，研究结果表明，绿色港口管理不仅有助于实现长期减排目标，也有助于构建更加灵活、适应性更强且更具韧性的海事物流系统。

关键词：绿色港口管理；海事脱碳；海事物流韧性；港口电气化；可持续海上运输；绿色港口。

1. Introduction

Maritime transportation is a fundamental component of global trade, carrying more than 80% of the volume of world trade and connecting production, consumption, and distribution networks across countries. However, the continued dependence of maritime transportation on fossil fuels has created a significant environmental challenge through greenhouse gas emissions, air pollution, and energy-intensive port and shipping operations. At the same time, maritime logistics systems are increasingly exposed to disruptions arising from geopolitical tensions, extreme weather events, climate change, congestion, and vulnerabilities at major maritime chokepoints. Recent disruptions around the Panama and Suez Canals demonstrate how environmental and geopolitical pressures can extend shipping routes, increase transportation costs, create delays, and weaken supply-chain reliability. These conditions indicate that maritime sustainability can no longer be addressed solely through emission reduction; ports must simultaneously enhance their capacity to absorb, adapt to, and recover from disruptions. Consequently, green port management has become increasingly important as a strategic approach for integrating environmental performance, operational efficiency, and resilience within maritime transportation[1].

Existing literature has established several important approaches for reducing emissions in ports and maritime transportation, including renewable energy adoption, alternative fuels, electrification, energy-efficiency improvements, smart energy systems,

emission monitoring, and operational optimization. Reviews of green ports and maritime logistics demonstrate that technological and operational measures have become central to port sustainability, while recent research emphasizes the importance of combining clean energy, operational measures, energy systems, regulatory frameworks, and stakeholder collaboration rather than relying on a single decarbonization intervention. Nevertheless, the existing literature remains relatively fragmented between maritime decarbonization and port resilience. Research on decarbonization tends to prioritize emission reduction, energy systems, and technological solutions, whereas resilience studies increasingly focus on infrastructure, organizational adaptation, disruption management, and supply-chain continuity. This separation limits the ability of existing theoretical perspectives to explain how environmental strategies can simultaneously strengthen the resilience of maritime logistics. Moreover, previous research indicates that existing sustainability studies provide insufficient support for port-level decision making because empirical evidence, integrated assessment, and consideration of different port contexts remain limited. Therefore, a more integrated perspective is required to explain how green port management strategies can reconcile the potentially competing objectives of decarbonization, operational efficiency, and logistics resilience[2].

This study examines green port management strategies for decarbonizing maritime transport and strengthening logistics resilience through clean energy,

low-carbon fuels, port electrification, digitalization, operational efficiency, environmental governance, and stakeholder collaboration. It aims to develop an integrated understanding of how green port management can support both maritime decarbonization and resilient logistics while aligning with the IMO's 2023 net-zero ambitions[3].

The central argument of this study is that green port management should not be viewed merely as an environmental compliance mechanism but as a strategic capability capable of simultaneously supporting maritime decarbonization and logistics resilience. The integration of clean energy, low-carbon technologies, intelligent operational systems, environmental governance, and collaborative stakeholder mechanisms can reduce emissions while improving resource efficiency, operational flexibility, preparedness, and the capacity of maritime logistics systems to respond to disruptions. This argument is consistent with recent literature indicating that port decarbonization requires combinations of technological, operational, regulatory, and collaborative measures, while contemporary resilience research increasingly recognizes that resilient ports require organizational, technological, and environmental capabilities rather than infrastructure protection alone. Accordingly, investigating the intersection between green port management and maritime logistics resilience is important both theoretically and practically because it can provide a more integrated framework for understanding sustainable maritime transformation. The study therefore argues that strategically designed green port management can become a critical mechanism for achieving a dual transition: reducing the carbon intensity of sea transportation while strengthening the resilience, continuity, and adaptability of maritime logistics systems.

2. Methods

The object of this study is the phenomenon of green port management in the context of maritime transportation decarbonization and maritime logistics resilience[4]. The study focuses on the increasing pressure on ports and maritime transportation systems to reduce greenhouse gas emissions while maintaining operational continuity and responding effectively to disruptions affecting maritime logistics and global supply chains. The phenomenon encompasses the implementation of environmentally sustainable port management strategies, including the adoption of renewable and clean energy, alternative low- and zero-carbon fuels, port electrification, energy-efficiency measures, digital technologies, environmental monitoring, and collaborative governance. At the same time, the study considers the resilience dimension of maritime logistics, particularly the capacity of ports and related transportation systems to anticipate, absorb,

adapt to, and recover from operational, environmental, technological, geopolitical, and supply-chain disruptions. Therefore, the object of analysis is not limited to individual port technologies but encompasses the strategic relationship between green port management, maritime decarbonization, and the resilience of maritime logistics systems[5].

This study employs a qualitative library research approach, in which the research data are obtained and interpreted through systematic examination of relevant written sources rather than through field surveys, interviews, or experimental procedures. The primary data consist of relevant scholarly literature that directly discusses the phenomenon of green port management, maritime decarbonization, sustainable maritime transportation, and maritime logistics resilience. These sources are selected based on their relevance to the research problem, theoretical contribution, and ability to provide substantive evidence concerning the relationships among the main concepts examined in this study. Secondary data are obtained from supporting literature covering the three principal dimensions of the research, namely green port management, maritime decarbonization, and logistics resilience, as well as related issues concerning sustainable transportation, port sustainability, supply-chain resilience, energy transition, digitalization, and environmental governance. The secondary sources include academic books, peer-reviewed journal articles, previous research findings, institutional reports, policy documents, conference papers, and other credible scientific publications. The selection of literature is directed toward identifying recurring arguments, empirical findings, theoretical perspectives, strategic practices, and research gaps relevant to the development of an integrated understanding of sustainable and resilient maritime logistics[6].

The theoretical foundation of this study integrates three complementary perspectives. First, the Natural-Resource-Based View (NRBV) proposed by Hart (1995) extends the resource-based view of the firm by emphasizing that organizational competitive advantage can be developed through capabilities related to pollution prevention, product stewardship, and sustainable development. This perspective provides a foundation for understanding green port management as a strategic capability rather than merely an environmental obligation. Second, resilience theory, initially conceptualized by Holling (1973), emphasizes the capacity of systems to absorb disturbances while maintaining their essential structures and functions and subsequently adapting to changing conditions. This perspective is used to explain how maritime ports and logistics networks can develop capabilities to withstand disruptions and maintain operational continuity. Third, the Triple Bottom Line (TBL) framework introduced by Elkington (1997) emphasizes the simultaneous

consideration of economic, environmental, and social dimensions in organizational and sustainability performance. The framework supports the assumption that port sustainability should not be assessed solely through emission reduction but should also consider operational and economic continuity as well as broader social and environmental consequences. The integration of these theoretical perspectives provides the analytical foundation for examining green port management as a strategic mechanism that can connect environmental sustainability, organizational capability, and maritime logistics resilience[7].

The research process is conducted through several systematic stages of literature collection and examination. The first stage involves identifying the research problem and determining the main concepts represented by the keywords of green port management, maritime decarbonization, and logistics resilience. The second stage involves searching for and collecting relevant written sources, including academic books, peer-reviewed journal articles, previous studies, scientific papers, institutional reports, policy documents, articles, and other credible publications related to the research topic. The third stage consists of screening the collected literature based on relevance, scientific credibility, thematic alignment, and contribution to the research objectives. The fourth stage involves intensive reading and extraction of information from selected sources to identify theoretical arguments, empirical findings, strategic approaches, implementation challenges, and relationships among the concepts under investigation. The final stage involves organizing the extracted information thematically so that evidence concerning green port management strategies, maritime emission reduction, and logistics resilience can be compared and synthesized. Through this process, the literature is treated as the primary source of research information, enabling the study to develop a comprehensive interpretation without relying on primary field observations[8].

The collected data are analyzed using qualitative content analysis, which involves systematically examining, organizing, interpreting, and synthesizing information contained in the selected literature. The analysis begins with identifying meaningful statements, concepts, arguments, and findings associated with green port management, maritime decarbonization, and logistics resilience. Relevant information is then coded and categorized into thematic groups representing major strategic dimensions, such as clean energy adoption, alternative fuels, electrification, energy efficiency, digitalization, environmental governance, operational optimization, stakeholder collaboration, emission reduction, and resilience capabilities. The subsequent analysis examines patterns, similarities, differences, relationships, and recurring arguments across the selected literature. Particular attention is given to

identifying how specific green port management strategies contribute not only to reducing maritime emissions but also to enhancing the ability of maritime logistics systems to anticipate, absorb, adapt to, and recover from disruptions[9]. The final analytical stage involves synthesizing the identified themes and theoretical insights into an integrated interpretation of the relationship between green port management, maritime decarbonization, and logistics resilience. This content analysis enables the study to identify significant patterns and research gaps while constructing a theoretically grounded understanding of how sustainable port management can support both environmental objectives and the resilience of maritime logistics[10].

3. Result and Discussion

3.1 Green Port Management as an Integrated Maritime Sustainability Strategy

The literature analysis indicates that green port management has evolved from a relatively narrow environmental management concept into a broader strategic approach that integrates environmental performance, operational efficiency, technological innovation, and supply-chain considerations. Earlier research on green ports and maritime logistics identified the rapid development of research streams concerning port emissions, energy efficiency, sustainable operations, and environmental management, while subsequent studies have increasingly emphasized the interaction between technological and managerial interventions. This development suggests that the transformation of conventional ports into green ports cannot be achieved through isolated environmental initiatives. Instead, green port management requires coordinated strategies that influence energy consumption, vessel operations, cargo handling, infrastructure, digital information systems, and relationships among port stakeholders[11].

The findings further demonstrate that green port management can be understood through the Natural-Resource-Based View (NRBV) proposed by[12]. The NRBV identifies pollution prevention, product stewardship, and sustainable development as interconnected strategic capabilities through which organizations can respond to environmental constraints. In the port context, pollution prevention can be reflected through reductions in vessel, cargo-handling, and terminal emissions; product stewardship can be translated into responsible management of port services, energy systems, and environmental impacts across the maritime logistics chain; while sustainable development can be represented by investments in renewable energy, green infrastructure, clean technologies, and long-term stakeholder collaboration. Thus, the green port should not be viewed simply as a port with lower emissions but

as an organizational and operational system capable of embedding environmental considerations into strategic decision-making[13].

The literature also reveals that port sustainability performance depends on the interaction between technological capabilities and institutional arrangements. A systematic review of port sustainability found that stakeholder involvement remains an important factor in implementing sustainable port

strategies, while recent research on port decarbonization emphasizes the need to combine technological innovations, regulatory frameworks, and stakeholder collaboration. Consequently, the effectiveness of green port management depends not only on the availability of technologies but also on governance mechanisms capable of coordinating port authorities, shipping companies, terminal operators, logistics providers, energy suppliers, regulators, and local communities.

Table 1. Major Dimensions of Green Port Management

Dimension	Main Strategic Measures	Environmental Contribution	Management Contribution
Clean energy	Renewable electricity, solar energy, wind energy, clean energy procurement	Reduces dependence on fossil fuels and associated emissions	Improves long-term energy sustainability
Port electrification	Electric cargo-handling equipment, electric vehicles, shore-side electricity	Reduces local and operational emissions	Improves energy efficiency and operational control
Alternative fuels	Green methanol, ammonia, hydrogen and other low- or zero-carbon fuels	Supports maritime fuel transition	Creates new strategic energy capabilities
Energy efficiency	Energy management systems, efficient equipment, optimized operations	Reduces energy consumption and carbon intensity	Reduces operating costs and resource waste
Digitalization	IoT, AI, digital twins, real-time monitoring and data analytics	Enables emission and energy monitoring	Improves decision-making, visibility and operational coordination
Green infrastructure	Sustainable terminal design, energy-efficient buildings and infrastructure	Reduces lifecycle environmental impacts	Strengthens long-term port competitiveness
Environmental governance	Environmental standards, monitoring, reporting and compliance	Controls environmental impacts	Establishes accountability and strategic coordination
Stakeholder collaboration	Port authorities, shipping lines, terminal operators, logistics firms and government	Facilitates collective environmental action	Improves coordination and implementation capacity

The synthesis in Table 1 indicates that green port management is multidimensional. No single intervention is sufficient to achieve comprehensive decarbonization. This finding is consistent with the systematic review of 124 studies on port decarbonization, which categorized measures into clean energy sources, operational measures, energy systems, and conservative measures and emphasized the importance of combining multiple interventions according to the context of individual ports[14].

3.2 Green Port Strategies for Maritime Decarbonization

One of the strongest findings from the literature is that port decarbonization requires a combination of technological, operational, and managerial strategies. Maritime ports function as interfaces between vessels,

cargo-handling systems, land transportation, energy infrastructure, and logistics networks. Therefore, emissions generated within and around ports cannot be addressed exclusively through improvements to ships. Decarbonization must also involve port-side energy consumption, terminal equipment, cargo-handling processes, vessel-at-berth activities, and coordination between maritime and land-based transportation.

The first major strategy is the transition toward clean and renewable energy. Renewable electricity, solar power, wind energy, and other low-carbon energy sources can reduce the dependence of port operations on fossil-fuel-based electricity and conventional fuels. Existing research on seaport decarbonization identifies renewable energy integration, distributed energy resources, smart energy systems, and energy management as important components of the transition

toward smart and green ports. The importance of this strategy is amplified by the increasing international pressure to reduce emissions throughout the maritime transportation system[15].

The second strategy involves port electrification. Electrification can be applied to cargo-handling equipment, terminal vehicles, port service equipment, and shore-side electricity systems. Shore-side electricity allows vessels to connect to electricity while at berth and reduce the need to operate auxiliary engines. This strategy can therefore reduce emissions in port areas while also improving local air quality. However, electrification requires sufficient electricity generation capacity, grid infrastructure, charging facilities, technological compatibility, and substantial investment. Consequently, electrification should be integrated with renewable energy and smart energy management rather than treated as an independent intervention[16].

The third strategy concerns alternative maritime fuels. The transition toward low- and zero-carbon fuels is increasingly important because some maritime activities are difficult to fully electrify. Green methanol,

green ammonia, hydrogen-based fuels, and other emerging alternatives can contribute to long-term maritime decarbonization. Nevertheless, alternative fuels introduce new management challenges related to fuel availability, infrastructure, safety, storage, transportation, cost, and regulatory requirements. Therefore, ports are required to develop energy ecosystems capable of supporting both current and future fuel technologies.

The fourth strategy involves operational optimization. Port congestion, inefficient vessel scheduling, unnecessary equipment movement, extended vessel waiting times, and inefficient cargo-handling processes can increase fuel consumption and emissions. Digital technologies can contribute to addressing these problems through real-time monitoring, predictive analytics, intelligent scheduling, and improved coordination among port stakeholders. Recent research indicates that higher levels of digitalization can contribute to lower costs and energy consumption while enabling real-time monitoring, early warning, and intelligent management.

Table 2. Green Port Strategies and Their Decarbonization Mechanisms

Strategy	Decarbonization Mechanism	Expected Outcome	Main Implementation Challenge
Renewable energy integration	Replaces fossil-based energy	Lower port carbon intensity	Intermittency and infrastructure requirements
Shore-side electricity	Reduces vessel auxiliary-engine use at berth	Lower berth emissions	Grid capacity and compatibility
Electrification	Replaces fossil-fuel equipment	Lower terminal emissions	High capital expenditure and charging infrastructure
Alternative fuels	Replaces conventional marine fuels	Long-term shipping decarbonization	Availability, safety and cost
Energy management systems	Optimizes energy consumption	Higher energy efficiency	Data and system integration
AI and digitalization	Optimizes scheduling and resource use	Reduced idle time and energy waste	Digital infrastructure and skills
Green cargo handling	Reduces fuel consumption in terminal operations	Lower operational emissions	Equipment modernization
Green shipping corridors	Coordinates low-carbon maritime routes and ports	System-level emission reduction	Cross-border coordination
Environmental monitoring	Measures and controls emissions	Improved accountability	Data quality and standardization

The findings suggest that the most effective decarbonization approach is therefore portfolio-based rather than technology-specific. A port that installs renewable energy but maintains inefficient cargo-handling operations may achieve only partial environmental improvement. Similarly, electrifying equipment without increasing the availability of clean electricity may shift rather than fully eliminate emissions. The literature consequently supports an integrated strategy in which energy systems, operational measures, digital technologies, infrastructure, and

governance are developed simultaneously. This conclusion is particularly consistent with recent research emphasizing that ports require context-specific combinations of decarbonization measures rather than a universal single solution.

3.3 Digitalization as an Enabler of Green Port Management

Digitalization emerges as a cross-cutting capability connecting green port management with both decarbonization and logistics resilience. The literature

indicates that technologies such as the Internet of Things, artificial intelligence, digital twins, big-data analytics, automated systems, and real-time monitoring can improve visibility over port activities and energy consumption. This is particularly important because effective environmental management requires accurate information about where, when, and how energy and emissions are generated[17].

Digital technologies can support decarbonization by optimizing vessel arrival times, berth allocation, cargo-handling operations, equipment utilization, and energy consumption. For example, improved vessel scheduling can reduce unnecessary waiting and engine use, while intelligent equipment management can minimize idle operation and energy waste. Digital twins can also provide simulations of alternative operational scenarios, allowing port managers to evaluate potential environmental and operational consequences before implementing changes[18].

The resilience implications of digitalization are equally significant. Real-time information systems can provide early warnings of congestion, extreme weather, infrastructure failures, supply-chain disruptions, and changes in vessel movements. This enables port managers to adjust schedules, redirect resources, communicate with stakeholders, and implement contingency plans. Recent resilience literature indicates that the field has increasingly shifted from a narrow infrastructure perspective toward a broader approach involving organizational, technological, and environmental dimensions. Digitalization therefore functions as an enabling capability that supports both environmental efficiency and adaptive capacity[19].

However, digitalization itself introduces risks. Dependence on interconnected digital systems increases exposure to cybersecurity threats, system failures, data-quality problems, and technological inequalities between ports. Consequently, digital transformation should be accompanied by cybersecurity, data governance, interoperability standards, employee training, and organizational preparedness. The result is a strategic paradox: digitalization can increase resilience

only when the digital infrastructure itself is sufficiently robust and adaptable[20].

3.4 Green Port Management and Maritime Logistics Resilience

The literature analysis demonstrates that maritime logistics resilience is closely connected to the ability of ports to maintain continuity under changing and disruptive conditions. Recent research on port resilience identifies a shift from an infrastructure-centered understanding toward a more holistic strategy involving organizational, technical, and environmental aspects. This finding is important because maritime disruptions increasingly arise from interacting risks rather than isolated physical failures[21].

Recent disruptions affecting major maritime chokepoints illustrate this vulnerability. UN Trade and Development reported substantial reductions in Suez Canal and Gulf of Aden traffic during the 2024 disruptions, accompanied by major increases in Cape of Good Hope routing and longer vessel distances. Longer routes increased fuel consumption, costs, and emissions while placing additional pressure on maritime supply chains. These developments demonstrate that resilience and decarbonization are interconnected. A disruption that forces vessels to travel longer distances may simultaneously increase supply-chain vulnerability and greenhouse gas emissions.

Green port management can strengthen resilience through several mechanisms. First, renewable energy and distributed energy systems can reduce dependence on centralized energy sources and provide alternative sources of power during disruptions. Second, digital monitoring can improve situational awareness and accelerate decision-making. Third, diversified fuel and energy systems can reduce dependence on a single energy source. Fourth, efficient operations and improved cargo visibility can reduce congestion and enable ports to recover more rapidly after disruptions. Fifth, stakeholder collaboration can improve coordination during emergencies and facilitate rapid reconfiguration of logistics activities.

Table 3. Relationship Between Green Port Strategies and Logistics Resilience

Green Port Strategy	Resilience Capability	Mechanism	Expected Resilience Benefit
Renewable energy	Absorptive capacity	Diversifies energy sources	Reduced energy disruption vulnerability
Energy storage	Response capacity	Provides backup energy	Continuity during energy interruptions
Digital monitoring	Anticipatory capacity	Detects disruptions early	Faster response
AI-based planning	Adaptive capacity	Reconfigures operations	Greater operational flexibility
Alternative fuels	Adaptive capacity	Diversifies fuel supply	Lower dependence on conventional fuels

Electrified equipment	Operational capacity	Reduces dependence on fossil-fuel equipment	More efficient operations
Stakeholder collaboration	Coordinative capacity	Improves information and resource sharing	Faster collective response
Green infrastructure	Recovery capacity	Improves infrastructure efficiency and robustness	Faster recovery
Green shipping corridors	Network capacity	Coordinates ports and shipping routes	Greater supply-chain continuity

The relationship summarized in Table 3 indicates that green port management should not be interpreted solely as an environmental agenda. It also creates capabilities that are relevant to resilience. This is an important theoretical finding because it connects the environmental perspective of the NRBV with the resilience perspective. Green investments can become strategic resources when they simultaneously reduce environmental impacts and increase the ability of ports to manage uncertainty.

3.5 The Complementarity Between Decarbonization and Resilience

A major finding of the analysis is that maritime decarbonization and logistics resilience should not necessarily be treated as competing objectives. In certain circumstances, green strategies can produce complementary benefits. Energy efficiency, for example, reduces emissions while simultaneously reducing energy dependence and operating costs. Renewable energy can reduce carbon intensity while

diversifying energy sources. Digitalization can optimize resource consumption while improving visibility and responsiveness. Alternative fuels can reduce carbon emissions while diversifying the maritime energy portfolio. However, the relationship is not automatically positive. Some green technologies require significant capital investment, specialized infrastructure, new skills, and new supply chains. If these requirements are not properly managed, the transition itself may create new vulnerabilities. For example, dependence on a limited supply of a new alternative fuel could create a new form of energy dependency. Similarly, excessive dependence on complex digital systems can expose ports to cyber risks. Therefore, green port management should be designed according to a principle of resilient decarbonization, whereby environmental technologies are evaluated not only according to their emission-reduction potential but also according to their effects on operational continuity, adaptability, cost, security, and supply-chain dependence.

Table 4. Potential Synergies and Trade-Offs

Strategy	Decarbonization Effect	Resilience Effect	Potential Trade-Off
Renewable energy	High	High	Intermittency
Electrification	High	Moderate–High	Grid dependence
Alternative fuels	High	Moderate	Supply availability
Digitalization	Indirect–High	High	Cybersecurity risks
Energy efficiency	High	High	Initial investment
Automation	Indirect	High	Technology dependence and workforce transition
Green infrastructure	High	High	High capital requirements
Green shipping corridors	High	High	International coordination complexity

The implication is that port authorities should avoid evaluating green strategies using a single environmental indicator. Instead, investment decisions should consider a multidimensional set of indicators covering emissions, energy security, operational efficiency, adaptability, recovery capacity, financial feasibility, and stakeholder acceptance.

3.6 Stakeholder Collaboration and Green Port Governance

Another important finding concerns the governance dimension of green port management. Ports are complex ecosystems involving multiple actors with different interests, resources, responsibilities, and regulatory obligations. Consequently, the decarbonization of port operations cannot be achieved exclusively by port authorities. Shipping companies, terminal operators, logistics companies, energy providers, government agencies, technology firms,

cargo owners, and local communities must participate in the transition.

The literature on port sustainability emphasizes that stakeholder involvement is an important determinant of sustainable port development. Similarly, recent port decarbonization research emphasizes regulatory frameworks and stakeholder collaboration as necessary complements to technological measures. This suggests that green port governance should establish common environmental targets, shared performance indicators, data-sharing mechanisms, investment arrangements, and accountability structures.

Collaborative governance is also directly relevant to resilience. During disruptions, ports must coordinate vessel operators, cargo owners, terminal operators, transport providers, government authorities, and emergency services. The same institutional relationships established for environmental collaboration can therefore become valuable resilience resources. A port ecosystem characterized by strong communication and trust may be better positioned to coordinate responses when disruptions occur.

3.7 Integrated Green Port Management Framework

Based on the literature synthesis, this study proposes an integrated conceptual relationship in which green port management operates as the central strategic

mechanism connecting decarbonization and resilience. The framework consists of four interconnected layers.

The first layer is green resource transformation, involving renewable energy, electrification, alternative fuels, energy efficiency, and green infrastructure. This layer addresses the physical and technological foundations of decarbonization.

The second layer is smart operational management, involving digitalization, artificial intelligence, real-time monitoring, predictive analytics, automation, and intelligent scheduling. This layer converts green resources into operational improvements and provides information necessary for rapid decision-making.

The third layer is collaborative governance, involving port authorities, shipping companies, terminal operators, logistics providers, energy suppliers, regulators, and other stakeholders. This layer ensures that green transformation is coordinated across organizational boundaries.

The fourth layer is dual performance outcomes, consisting of maritime decarbonization and maritime logistics resilience. Decarbonization is reflected in lower emissions, greater energy efficiency, and increased use of low- or zero-carbon energy. Resilience is reflected in improved preparedness, response, adaptation, continuity, and recovery.

Table 5. Integrated Green Port Management Framework

Management Layer	Key Components	Primary Function	Decarbonization Outcome	Resilience Outcome
Green resource transformation	Renewable energy, electrification, alternative fuels	Transform energy systems	Lower carbon intensity	Energy diversification
Smart operations	AI, IoT, digital twins, analytics	Optimize operations	Lower energy consumption	Faster adaptation
Green infrastructure	Sustainable terminals and equipment	Improve physical efficiency	Lower lifecycle emissions	Greater infrastructure robustness
Collaborative governance	Stakeholder partnerships and regulation	Coordinate transformation	Collective emission reduction	Coordinated disruption response
Environmental monitoring	Carbon accounting and emission monitoring	Measure performance	Improved emission control	Better situational awareness
Integrated planning	Scenario analysis and contingency planning	Align sustainability and resilience	Long-term decarbonization	Improved preparedness
Performance management	Environmental, operational and resilience indicators	Evaluate outcomes	Continuous improvement	Continuous adaptation

The framework demonstrates that the relationship between green port management and logistics resilience is not linear. Instead, it is circular and mutually reinforcing. Green technologies improve efficiency; digital systems improve visibility; stakeholder collaboration improves coordination; improved

coordination facilitates adaptation; and enhanced resilience creates greater capacity to sustain long-term environmental investments.

3.8 Strategic Priorities for Green Port Management

The synthesis further indicates that port authorities should implement decarbonization strategies progressively rather than attempting to deploy all available technologies simultaneously. The first priority should be establishing baseline measurements of energy consumption, emissions, operational efficiency, and disruption exposure. Without reliable baseline data, it is difficult to determine which interventions provide the greatest environmental and resilience benefits.

The second priority is to implement measures with relatively strong co-benefits, particularly energy efficiency, digital monitoring, operational optimization, and renewable energy integration. These strategies can simultaneously reduce environmental impacts and strengthen operational capabilities. The third priority is

the development of supporting infrastructure for electrification and alternative fuels. This stage requires long-term investment planning because infrastructure decisions may lock ports into particular technological pathways.

The fourth priority is institutional and collaborative development. Port authorities should establish governance structures that enable stakeholders to coordinate investments, share data, establish environmental standards, and develop emergency response mechanisms. Finally, green port management should adopt continuous evaluation because technologies, energy markets, environmental regulations, and maritime risks are continually changing.

Table 6. Strategic Roadmap for Green and Resilient Ports

Stage	Strategic Focus	Key Actions	Performance Indicators
1. Baseline	Measurement and diagnosis	Emission inventory, energy audit, risk assessment	Carbon intensity, energy use, disruption exposure
2. Efficiency	Operational improvement	Equipment efficiency, scheduling, process optimization	Energy efficiency, waiting time, productivity
3. Digitalization	Smart management	IoT, AI, digital twins, real-time monitoring	Data visibility, response time, predictive accuracy
4. Clean energy	Energy transition	Renewable energy, storage, electrification	Renewable-energy share, fossil-fuel reduction
5. Clean fuels	Maritime fuel transition	Alternative-fuel infrastructure	Low-carbon fuel share
6. Governance	Collaborative transformation	Stakeholder partnerships and regulation	Participation, compliance, investment coordination
7. Resilience integration	Adaptive capacity	Scenario planning, contingency systems, redundancy	Recovery time, continuity, adaptive capacity
8. Continuous improvement	Long-term transformation	Monitoring, evaluation and strategy adjustment	Emission reduction and resilience performance

3.9 Discussion: Theoretical Implications

The findings provide several theoretical implications. First, the study extends the application of the Natural-Resource-Based View by demonstrating that environmental capabilities in port management can produce benefits beyond pollution reduction. Hart's NRBV emphasizes pollution prevention, product stewardship, and sustainable development as strategic capabilities associated with the natural environment. The present synthesis suggests that these environmental capabilities can also contribute to resilience by reducing resource dependence, improving operational efficiency, and increasing adaptive capacity.

Second, the findings strengthen the connection between sustainability and resilience research. Traditionally, sustainability and resilience have often been discussed as related but distinct research domains. Sustainability emphasizes long-term environmental, social, and economic performance, whereas resilience emphasizes the ability to cope with disruption and change. The literature reviewed in this study indicates

that these perspectives increasingly overlap in port management because environmental transition itself creates new operational requirements while climate and geopolitical disruptions simultaneously affect maritime logistics.

Third, the findings support a systems perspective on maritime decarbonization. Recent research shows that ports require combinations of decarbonization measures and context-specific strategies rather than isolated technological interventions. Therefore, the theoretical contribution of this study lies in conceptualizing green port management as an integrated capability composed of technological, operational, organizational, and governance dimensions.

3.10 Discussion: Managerial and Policy Implications

From a managerial perspective, port authorities should avoid treating decarbonization as a stand-alone environmental program. Instead, emission reduction should be incorporated into strategic planning, infrastructure investment, digital transformation, energy

management, risk management, and operational performance evaluation. Green investments should be prioritized according to their combined environmental and resilience benefits.

For policymakers, the findings indicate the importance of creating regulatory and financial conditions that enable ports to undertake long-term green investments. Standards for emissions measurement, incentives for renewable energy, support for electrification, alternative-fuel infrastructure, green shipping corridors, and requirements for environmental reporting can accelerate the transition. At the same time, policy instruments should recognize differences among ports because geographical location, cargo type, energy infrastructure, vessel traffic, financial capacity, and exposure to disruptions vary substantially.

The findings also reinforce the importance of international coordination. Maritime transportation operates across national borders, meaning that isolated national policies may not be sufficient to achieve system-wide decarbonization and resilience. The IMO's 2023 GHG Strategy establishes an ambition for international shipping to reach net-zero GHG emissions by or around 2050 and includes a 2030 target for reducing CO₂ emissions per transport work by at least 40% compared with 2008. These targets strengthen the strategic importance of ports as implementation nodes for maritime decarbonization.

3.11 Synthesis of the Main Findings

Overall, the literature analysis identifies five principal findings. First, green port management is increasingly understood as a multidimensional strategic capability rather than a narrow environmental management practice. Second, maritime decarbonization requires combinations of clean energy, electrification, alternative fuels, energy efficiency, digitalization, operational optimization, and governance. Third, digitalization functions as a critical enabling capability because it supports both emission reduction and real-time operational adaptation. Fourth, green port strategies can strengthen maritime logistics resilience by diversifying energy sources, improving operational flexibility, enhancing information visibility, and strengthening stakeholder coordination. Fifth, the effectiveness of green port management depends on integrating technological, organizational, environmental, and governance dimensions rather than implementing isolated interventions.

The central finding is therefore that green port management can serve as a strategic bridge between maritime decarbonization and logistics resilience. The environmental transition and resilience agenda should be designed together because many green strategies generate simultaneous environmental and operational benefits. However, potential trade-offs, including capital requirements, infrastructure dependence,

alternative-fuel availability, cybersecurity risks, and technological lock-in, must be incorporated into strategic decision-making. The most appropriate approach is consequently an integrated and context-specific green port strategy that evaluates each intervention according to its contribution to both emission reduction and the capacity of maritime logistics systems to anticipate, withstand, adapt to, and recover from disruptions.

5. Conclusion

This study concludes that green port management represents a strategic approach for addressing the interconnected challenges of maritime decarbonization and logistics resilience. The literature synthesis demonstrates that effective green port transformation requires an integrated combination of renewable energy adoption, port electrification, alternative low- and zero-carbon fuels, energy efficiency, green infrastructure, digitalization, environmental monitoring, and collaborative governance. These strategies do not merely reduce greenhouse gas emissions but can also strengthen the capacity of maritime logistics systems to anticipate, absorb, adapt to, and recover from disruptions. Digital technologies and data-driven operational management further enhance these outcomes by improving visibility, resource optimization, predictive capabilities, and decision-making. Therefore, green port management should be positioned beyond environmental compliance and understood as a strategic organizational capability that simultaneously supports environmental sustainability, operational efficiency, and maritime logistics resilience.

The study further argues that achieving resilient maritime decarbonization requires coordination among port authorities, shipping companies, terminal operators, logistics providers, energy suppliers, regulators, and other stakeholders. Green investments should consequently be evaluated not only according to their emission-reduction potential but also according to their contribution to energy security, operational continuity, adaptability, and recovery capacity. The integration of the Natural-Resource-Based View, resilience theory, and the Triple Bottom Line provides a broader conceptual foundation for understanding this relationship. Nevertheless, implementation remains dependent on financial resources, technological readiness, infrastructure availability, institutional coordination, human capabilities, and supportive policies. Future research should therefore validate the proposed framework through empirical studies across different port contexts and develop quantitative indicators for simultaneously measuring decarbonization performance and maritime logistics resilience.

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References

- [1] A. Suhara and Z. Muttaqien, "Adaptation Strategies in Supply Chains Based on Local Wisdom in the Manufacturing Industry," *Int. J. Sci. Rev.*, vol. 2, no. 4, pp. 160–172, 2025.
- [2] A. Marino and E. Vermiglio, "Opportunity for Greener Maritime Transportation," in *Technology and Science for the Ships of the Future: Proceedings of the 21st International Conference on Ships and Maritime Research (NAV 2025), Messina, Italy, 18-20 June 2025*, SAGE Publications 1 Oliver's Yard, 55 City Road, London, EC1Y 1SP, 2025, pp. 231–239.
- [3] Ö. B. İnal and Ç. Dere, "An approach to green ports in terms of low-carbon energy and sustainability," *Int. J. Environ. Geoinformatics*, vol. 11, no. 1, pp. 43–49, 2024.
- [4] C. Boyke, S. D. Lazuardi, H. I. Nur, and E. W. Ardhi, "Sustainability in port development: Strategies for environmental, economic, and social resilience," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2025, p. 12021.
- [5] S. I. Mohammad, B. Al Qraini, S. A. Alenazi, A. Vasudevan, A. A. Shelash, and I. Ali, "Decarbonizing marine logistics: Multi-echelon green supply chain models for offshore vessel networks," *Sustain. Mar. Struct.*, pp. 227–247, 2025.
- [6] D. (UNCTAD), *Review of maritime transport 2023: Towards a green and just transition*. Stylus Publishing, LLC, 2023.
- [7] L. Sotnychenko, O. Haichenia, I. Kucher, and Y. Staneva, "Sustainable seaport development and strategic modernisation of maritime transport infrastructure," *Econ. Ecol. Socium*, vol. 10, no. 1, pp. 186–198, 2026.
- [8] O.-P. Brunila, "Decarbonising maritime transport Digitalisation and environmental management paving the transition for Baltic ports".
- [9] E. Jimenez and J. Karim, "Environmental Sustainability of Seaports Strategic Analysis, Modeling and Simulation," 2026.
- [10] E. Kostidi and D. Lyridis, "Decarbonizing ports for a sustainable future: Challenges and strategies," *Tech. Ann.*, vol. 1, no. 8, 2024.
- [11] C. P. Selvan, A. Nayar, M. R. Nagaraja, and M. Sahal, "INTEGRATING CLIMATE RESILIENCE AND CIRCULAR ECONOMY PRINCIPLES IN DEVELOPING GREEN-BLUE LOGISTIC CORRIDORS FOR A ZERO-EMISSION FUTURE," *Int. Marit. Transp. Logist.*, vol. 15, pp. 458–465, 2026.
- [12] F. Pisano, "Climate change resilience measures in ports: a multi-scale comparative analysis at European and international level," 2024.
- [13] F. Pisano and A. Gallo, "Review of the Climate Change Resilience Measures in Port Context," in *International Conference on Computational Science and Its Applications*, Springer, 2025, pp. 142–155.
- [14] M. Al Hasnat, "Technological innovation in renewable energy for green ports aimed at promoting sustainable development and effective environmental management," *Environ. Innov. Manag.*, vol. 1, p. 2530001, 2025.
- [15] A. G. Elkafas and I. S. Seddiek, "Application of renewable energy systems in seaports towards sustainability and decarbonization: Energy, environmental and economic assessment," *Renew. Energy*, vol. 228, p. 120690, 2024.
- [16] S. Zhou, T. Liang, X. Liu, M. Zhao, and J. Huang, "Smartization and resilience of ports and shipping," 2026, *Frontiers Media SA*.
- [17] D. Simon, "Logistics flow disruptions through the Suez Canal: enhancing supply chain risk management and resilience.," *Acta Logist.*, vol. 12, no. 3, p. 595, 2025.
- [18] T. Syriopoulos, P. Trakadas, M. Tsatsaronis, and Y. Xie, "applications of new technologies in maritime transport, ports and global supply chains," *Marit. Econ. Logist.*, pp. 1–9, 2026.
- [19] A. Kļavins, M. Feofilovs, F. Romagnoli, and V. Kirsanovs, "Life Cycle Assessment to Enhance Resilience of Maritime Infrastructure: A Conceptual Approach," *Mod. Technol. Enabling Innov. Methods Marit. Monit. Strength. Resil. Marit. Crit. Infrastructures*, pp. 20–42, 2024.
- [20] A. Mane, "Climate-Resilient and Sustainable Port Logistics: Evidence from Jawaharlal Nehru Port Authority, India," *ECOFIN SUMMIT'26 ECOFIN SUMMIT'26*, 2026.
- [21] A. Hamdy, A. Diab, and A. M. Eissa, "Digital Transformation and the Quality of Accounting Information Systems in the Public Sector: Evidence from Developing Countries," *Int. J. Financ. Stud.*, vol. 13, no. 1, p. 30, 2025, doi: 10.3390/ijfs13010030.

参考文献

- [1] A. Suhara 和 Z. Muttaqien, "基于制造业地方智慧的供应链适应策略", 《国际科学评论》 (*Int. J. Sci. Rev.*) , 第2卷, 第4期, 第160–172页, 2025年。

- [2] A. Marino 和 E. Vermiglio, “迈向更加绿色的海运运输机遇”, 载于《面向未来船舶的技术与科学: 第21届国际船舶与海事研究会议 (NAV 2025) 论文集》, 意大利墨西拿, 2025年6月18–20日, SAGE Publications, 1 Oliver's Yard, 55 City Road, London, EC1Y 1SP, 2025年, 第231–239页。
- [3] Ö. B. İnal 和 Ç. Dere, “从低碳能源与可持续性角度探讨绿色港口”, 《国际环境地理信息学期刊》(Int. J. Environ. Geoinformatics), 第11卷, 第1期, 第43–49页, 2024年。
- [4] C. Boyke, S. D. Lazuardi, H. I. Nur 和 E. W. Ardhi, “港口发展中的可持续性: 环境、经济与社会韧性的战略”, 载于《IOP地球与环境科学会议系列》(IOP Conference Series: Earth and Environmental Science), IOP Publishing, 2025年, 第12021页。
- [5] S. I. Mohammad, B. Al Qraini, S. A. Alenazi, A. Vasudevan, A. A. Shelash 和 I. Ali, “海运物流脱碳: 面向海上船舶网络的多层级绿色供应链模型”, 《可持续海洋结构》(Sustain. Mar. Struct.), 第227–247页, 2025年。
- [6] D. (UNCTAD), “《2023年海运运输回顾: 迈向绿色与公正转型》”, Stylus Publishing, LLC, 2023年。
- [7] L. Sotnychenko, O. Haichenia, I. Kucher 和 Y. Staneva, “可持续港口发展与海运运输基础设施的战略现代化”, 《经济、生态与社会》(Econ. Ecol. Socium), 第10卷, 第1期, 第186–198页, 2026年。
- [8] O.-P. Brunila, “海运运输脱碳: 数字化与环境管理推动波罗的海港口转型”。
- [9] E. Jimenez 和 J. Karim, “海港环境可持续性: 战略分析、建模与模拟”, 2026年。
- [10] E. Kostidi 和 D. Lyridis, “港口脱碳迈向可持续未来: 挑战与策略”, 《技术年鉴》(Tech. Ann.), 第1卷, 第8期, 2024年。
- [11] C. P. Selvan, A. Nayar, M. R. Nagaraja 和 M. Sahal, “将气候韧性与循环经济原则融入绿色—蓝色物流走廊建设: 迈向零排放未来”, 《国际海事运输与物流》(Int. Marit. Transp. Logist.), 第15卷, 第458–465页, 2026年。
- [12] F. Pisano, “港口气候变化韧性措施: 欧洲与国际层面的多尺度比较分析”, 2024年。
- [13] F. Pisano 和 A. Gallo, “港口背景下气候变化韧性措施综述”, 载于《计算科学及其应用国际会议论文集》(International Conference on Computational Science and Its Applications), Springer, 2025年, 第142–155页。
- [14] M. Al Hasnat, “旨在促进可持续发展与有效环境管理的绿色港口可再生能源技术创新”, 《环境创新与管理》(Environ. Innov. Manag.), 第1卷, 第2530001页, 2025年。
- [15] A. G. Elkafas 和 I. S. Seddiek, “海港可再生能源系统的应用: 能源、环境与经济评估视角下的可持续性与脱碳”, 《可再生能源》(Renew. Energy), 第228卷, 第120690页, 2024年。
- [16] S. Zhou, T. Liang, X. Liu, M. Zhao 和 J. Huang, “港口与航运的智能化与韧性”, Frontiers Media SA, 2026年。
- [17] D. Simon, “苏伊士运河物流流动中断: 增强供应链风险管理韧性”, 《物流学报》(Acta Logist.), 第12卷, 第3期, 第595页, 2025年。
- [18] T. Syriopoulos, P. Trakadas, M. Tsatsaronis 和 Y. Xie, “新技术在海运运输、港口和全球供应链中的应用”, 《海事经济与物流》(Marit. Econ. Logist.), 第1–9页, 2026年。
- [19] A. Kļavins, M. Feofilovs, F. Romagnoli 和 V. Kirsanovs, “通过生命周期评估提升海事基础设施韧性: 概念性方法”, 载于《促进海事监测创新方法的现代技术与加强海事关键基础设施韧性》, 第20–42页, 2024年。
- [20] A. Mane, “气候韧性与可持续港口物流: 来自印度贾瓦哈拉尔·尼赫鲁港务局的证据”, 《ECOFIN峰会'26》(ECOFIN SUMMIT'26), 2026年。
- [21] A. Hamdy, A. Diab 和 A. M. Eissa, “公共部门数字化转型与会计信息系统质量: 来自发展中国家的证据”, 《国际金融研究》(Int. J. Financ. Stud.), 第13卷, 第1期, 第30页, 2025年。DOI: 10.3390/ijfs13010030。

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