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Green Port Strategies for Indonesian Maritime Logistics: A Systematic Review of Mining Barging and General Cargo

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Abstract: Indonesia's maritime logistics, particularly its vital mining barging and general cargo sectors, face a critical tension between economic growth and environmental sustainability. While green port strategies are a national priority, a holistic synthesis connecting global principles to Indonesia's unique archipelagic context is absent. This study bridges that gap via a systematic literature review, adhering to PRISMA guidelines. A rigorous analysis of 37 high-quality articles (2015-2025), appraised via the CASP checklist, reveals a persistent "policy-practice gap" and an "implementation chasm." Findings confirm that while implementation is driven by regulatory compliance, it is severely constrained by prohibitive capital investment, fragmented governance, and challenging economic feasibility. In response, this review delivers the first integrated synthesis for these non-containerized sectors, proposing a novel conceptual framework that models the interplay of drivers and barriers. It also establishes a targeted research agenda focused on context-specific techno-economic models. This study provides a foundational, evidence-based roadmap for Indonesian stakeholders to foster a resilient and genuinely sustainable maritime logistics ecosystem.

Keywords: Green Port, Maritime Logistics, Mining Barging, General Cargo, Indonesia

INTRODUCTION

Facing mounting pressure to decarbonize, the global maritime industry—which handles over 80% of world trade and contributes nearly 3% of anthropogenic GHG emissions (Tadros et al., 2023)—is undergoing a paradigm shift. Driven by ambitious International Maritime

Organization (IMO) targets, concepts like "green ports" have evolved from peripheral concerns into core strategic pillars, focusing on energy efficiency, alternative fuels, and digitalization (Sardar et al., 2025).

The "green port" concept has emerged as a comprehensive framework to address these environmental challenges. It represents a paradigm shift where ports evolve from being passive landlords to proactive managers of their environmental footprint (Halpe et al., 2025). Core to this concept is the strategic implementation of measures aimed at decarbonization, operational efficiency, and the adoption of cleaner technologies (Alzahrani et al., 2021). The scope of a green port extends beyond merely controlling ship emissions; it encompasses a holistic system including energy management, waste management, efficient landside logistics, and the integration of renewable energy sources (Puig & Darbra, 2024; Sepehri et al., 2024). This proactive approach requires a combination of regulatory enforcement, incentive schemes, and technological innovation, with the ultimate goal of balancing economic growth with environmental stewardship (Alamouh et al., 2024).

This global transition holds profound implications for Indonesia, the world's largest archipelagic nation, whose economic growth, energy security, and national connectivity are inextricably linked to its maritime logistics capabilities (Humang et al., 2025). However, the global discourse on green ports is predominantly centered on containerized logistics. This focus overlooks the operational realities of nations like Indonesia, where the maritime backbone is dominated by high-volume, energy-intensive sectors such as mining barging and general cargo operations (Amin et al., 2021). These sectors present a critical tension: they are vital to the national economy yet pose significant environmental challenges, from GHG emissions to localized pollution (Sahri et al., 2020).

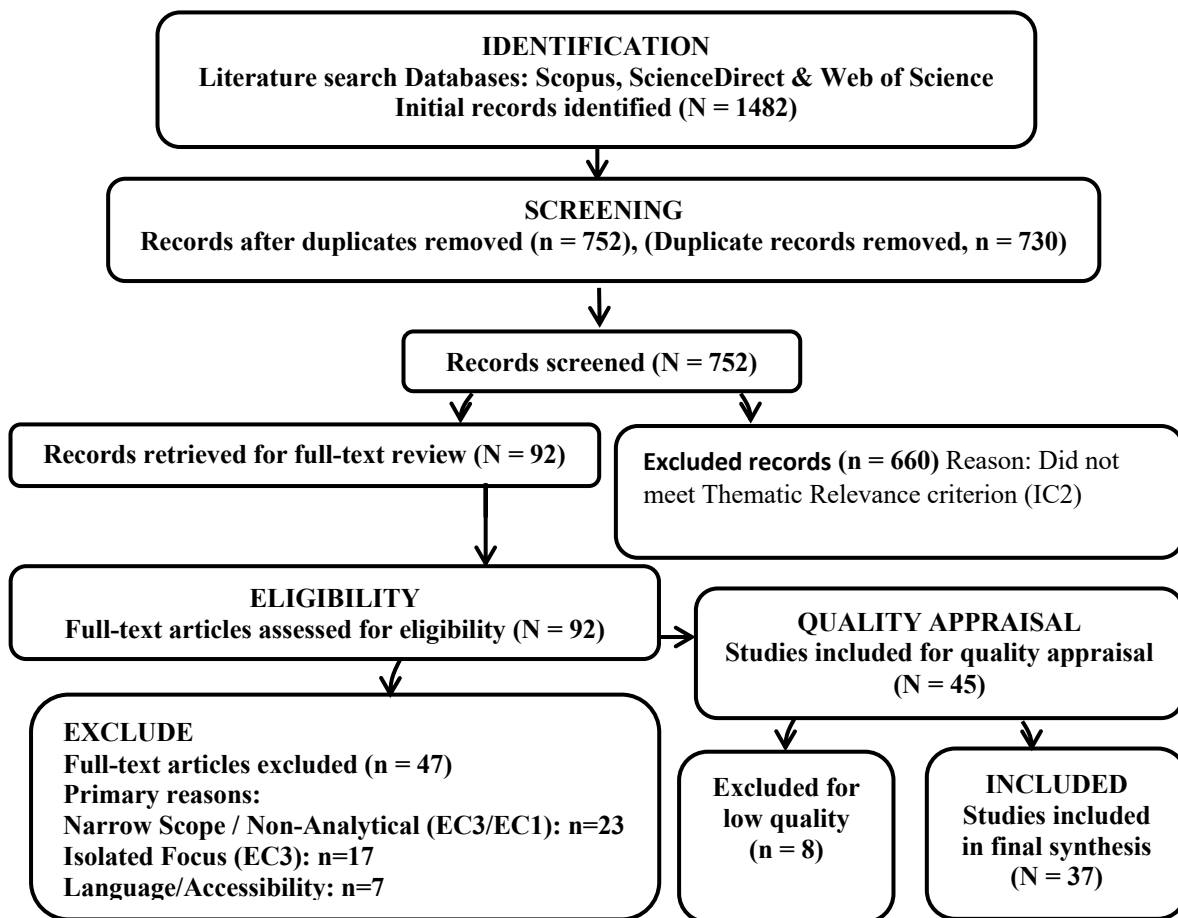
This disconnect between global, container-centric models and local, bulk-oriented realities creates a "policy-practice gap," where well-intentioned national strategies fail to translate into effective, on-the-ground implementation. Stakeholders in Indonesia's mining and cargo logistics sectors lack a clear, evidence-based roadmap for integrating sustainability in a way that is both environmentally effective and economically viable.

This study aims to bridge this critical gap by conducting the first systematic literature review focused specifically on green port strategies for mining barging and general cargo in Indonesia. By synthesizing and appraising the existing body of knowledge, this review addresses the following objectives: (1) to identify the primary drivers and barriers to sustainability adoption in these sectors; (2) to map the key technological and operational innovations applicable to the Indonesian context; (3) to assess the role of the existing policy and governance framework; and (4) to propose an integrated conceptual framework and a targeted research agenda. Ultimately, this review provides a foundational, evidence-based roadmap to guide Indonesian policymakers, port operators, and shipping companies toward a resilient and genuinely sustainable maritime logistics ecosystem.

METHOD

This study was designed and executed as a Systematic Literature Review (SLR), a research methodology structured to systematically identify, appraise, and synthesize a body of knowledge to answer specific research questions (Priatno et al., 2025). This approach was chosen for its capacity to provide a comprehensive, transparent, and reproducible overview of a fragmented research field, thereby minimizing bias and subjective interpretation (Sardar et al., 2025). To ensure methodological rigor and transparent reporting, this review strictly adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021).

The research process followed four sequential stages, as detailed in the PRISMA flow diagram presented in **Figure 1**.



Source: Adapted from Page et al. (2021)

Figure 1. PRISMA Flow Diagram for the Study Selection and Quality Appraisal Process.

Identification: A comprehensive search was conducted across three leading academic databases: Scopus, ScienceDirect, and Web of Science. The search covered literature published within the timeframe of January 2015 to December 2025. A predefined search string was designed to capture articles at the intersection of green ports, bulk/general cargo operations, and the Indonesian context. The primary query used for Scopus, with minor adaptations for other databases, was:

TITLE-ABS-KEY(("green port" OR "sustainable port" OR sustainability) AND (port OR terminal OR maritime OR shipping) AND ("mining barging" OR "bulk cargo" OR "general cargo") AND (indonesia OR "southeast asia"))

Screening: The initial search results were compiled, and duplicate records were removed. The titles and abstracts of the remaining articles were independently screened by two researchers against the predefined eligibility criteria. Any discrepancies were resolved through discussion to reach a consensus. These criteria, which govern the thematic and contextual boundaries of the review, are detailed in Table 1.

Table 1. Inclusion and Exclusion Criteria for Study Selection

Criteria	Code	Description
INCLUSION CRITERIA		
<i>(Studies had to meet all inclusion criteria)</i>		
Publication Type	IC1	Peer-reviewed journal article, conference proceeding, or comprehensive review.
Thematic Relevance	IC2	Explicitly discusses the intersection of: (a) Sustainability, green port/shipping, or decarbonization concepts; AND (b) Maritime logistics, port operations, or shipping AND (c) Has a direct link or high applicability to mining, bulk cargo (e.g., coal), or general cargo operations.
Geographical Context	IC3	Must have one of the following scopes:
		• Directly focused on Indonesia.
		• Regional focus (e.g., Southeast Asia) with clear implications for Indonesia.
Language	IC4	Published in English.
Timeframe	IC5	Published between January 2015 and December 2025.
EXCLUSION CRITERIA		
<i>(Studies were excluded if they met any exclusion criterion)</i>		
Document Type	EC1	Editorials, book reviews, commentaries, dissertations, and other non-peer-reviewed literature.
Irrelevant Focus	EC2	Overly specific or tangential topics, including but not limited to:
		• Studies focused exclusively on container logistics without transferable principles.
		• Studies on passenger transport (ferries) unless discussing broader operational sustainability.
Isolated Scope	EC3	• Purely technical engineering studies without a clear link to logistics or environmental management (e.g., material science, fluid dynamics).
		• Studies on non-maritime transport modes (e.g., aviation, pure road freight) unless used for direct comparison.
Isolated Scope	EC3	Focuses solely on one domain (e.g., only mining technology, only financial models) without a clear cross-sectoral link to sustainable maritime logistics.

Source: Authors' analysis (2025)

Eligibility and Quality Appraisal: The full texts of the articles that passed the initial screening were retrieved and assessed for final eligibility against the criteria in Table 1. Each eligible study was then subjected to a formal quality appraisal to ensure the robustness of the evidence base. This appraisal was conducted using the 10-item checklist from the Critical Appraisal Skills Programme (CASP, 2018), detailed in Appendix B.

Each of the 9 relevant checklist questions was scored on a 4-point scale (4 = Yes, Fully Met; 1 = No). Question 5, specific to meta-analyses, was deemed not applicable and thus excluded from the final scoring. An Average Quality Score (from 1 to 4) was then calculated for each study by averaging the scores of the relevant items. This process yielded a final corpus of 37 high-quality articles, as no study was rated 'Low Quality' (Average Score < 2.1). The detailed quality appraisal results for each article are presented in Appendix C.

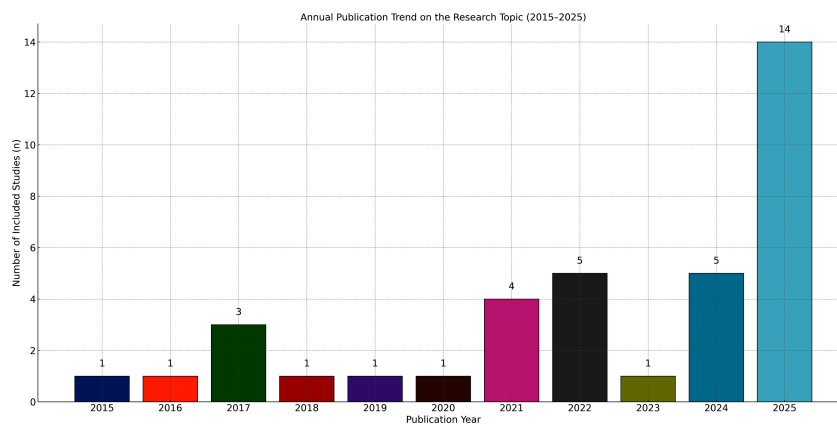
Data Extraction and Synthesis: Key information from the final 37 articles was systematically extracted into a thematic matrix (presented in Table 4). This included study context, methodology, key findings, novelty, and relevance to the research questions. A thematic analysis approach was then employed to synthesize the extracted data, allowing for the identification of recurrent patterns, dominant themes, and critical knowledge gaps that directly address the study's objectives (Farisyi et al., 2022).

RESULTS AND DISCUSSION

This chapter presents the integrated findings and interpretation derived from the systematic literature review. It begins with a descriptive analysis of the selected literature to establish the research landscape, followed by a detailed thematic synthesis that directly answers the study's research questions. The chapter concludes by presenting the study's primary theoretical and practical contributions: a novel conceptual framework and a targeted research agenda for Indonesia.

Landscape of the Reviewed Literature: A Descriptive Analysis

The systematic selection process culminated in a final corpus of 37 high-quality articles published between January 2015 and December 2025. The annual publication trend, illustrated in Figure 2, reveals a significant increase in research activity since 2020. This surge underscores a growing academic and policy interest in maritime decarbonization that aligns with global climate imperatives and highlights the timeliness of the present study.



Source: Authors' analysis (2025)

Figure 2. Annual Publication Trend on the Research Topic (2015-2025)

A descriptive overview of the final 37 articles is provided in **Table 2**. The analysis shows that while the literature is dominated by systematic reviews (48.6%) and studies with a global scope (64.9%), there is a crucial, albeit smaller, cluster of empirical and modeling studies focused specifically on Indonesia (21.6%). This distribution provides empirical evidence of a critical gap in context-specific research, which this review aims to address by synthesizing global knowledge for local application.

Table 2. Descriptive Statistics of the Analyzed Articles (N=37)

Category	Sub-Category	Frequency (n)	Percentage (%)	Key References
Research Method	Systematic/Literature Review	18	48.6%	(Jalali & Tei, 2025; Priatno et al., 2025; Sardar et al., 2025)
	Empirical/Case Study	9	24.3%	(Amin et al., 2021; Golden & Weisbrod, 2016; Utama et al., 2024)
	Modeling Optimization	6	16.2%	(Budiyanto et al., 2022; Gosens et al., 2022; Humang et al., 2025)
	Conceptual Framework	4	10.8%	(Alamouh et al., 2024; Othman et al., 2019)
Geographical Focus	Indonesia	8	21.6%	(Fathoni et al., 2017; Humang et al., 2025; Sahri et al., 2020)

Global / International	24	64.9%	(Halpe et al., 2025; Kondratenko et al., 2025; Tadros et al., 2023)
Other Specific Regions	5	13.5%	(Gosens et al., 2022; Munim et al., 2022; Oskarsson et al., 2021)
Total	37	100.0%	

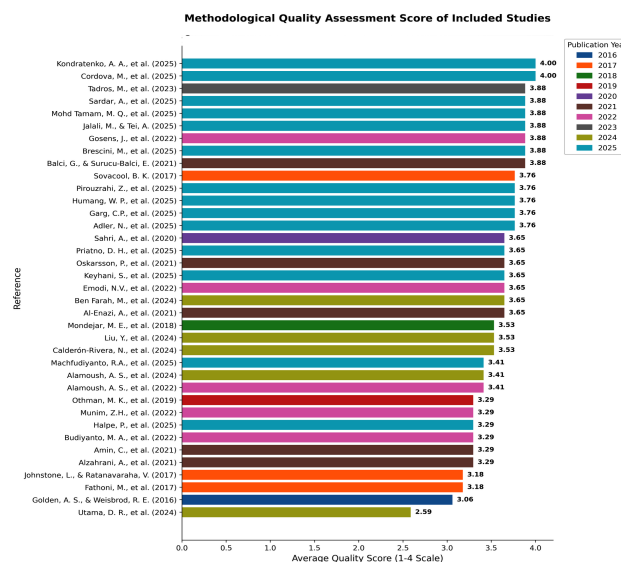
Source: Authors' analysis (2025)

The methodological quality of the included studies, assessed using the CASP checklist, was found to be robust. As summarized in Table 3 and visualized in detail in Figure 3, a majority of the articles (59.5%) were rated as 'High Quality,' with the remainder rated as 'Medium Quality.' Critically, no studies were assessed as 'Low Quality'. This lends strong confidence to the evidence base synthesized in this review.

Table 3. Methodological Quality Appraisal of Included Studies (N=37)

Quality Rating	Score Range (out of 40)	Frequency (N)	Percentage (%)	Key Methodological Characteristics / Flaws
High	>30	22	59.5%	Studies in this category typically featured a comprehensive search strategy, clearly articulated research questions, and a robust synthesis method.
Medium	21 – 30	15	40.5%	Studies in this category generally employed a sound methodology but often lacked a key element, such as a formal quality appraisal of their own literature or a non-systematic search.
Low	<21	0	0.0%	No studies included in the final sample were rated as low quality.
Total		37	100.0%	

Source: Authors' analysis based on the CASP Systematic Review Checklist (CASP, 2018).



Source: Authors' analysis (2025)

Figure 3. Methodological Quality Assessment Score of Included Studies (N=33)

Thematic Synthesis and Interpretation of Key Findings

The thematic analysis of the 37 articles, detailed in the comprehensive evidence matrix in Table 4, reveals a complex and often contradictory sociotechnical landscape. The following sections interpret these findings by systematically addressing each research question.

Table 4. Thematic Matrix: Synthesis of Key Findings from Selected Literature (N=37)

Reference	Study Context & Methodology	Key Findings & Novelty	Relevance to Research Questions (RQs)
Theme 1: Foundational Concepts, Policy, and Indonesian Context (2015-2020)			
Golden & Weisbrod (2016)	Title: Trends, Causal Analysis, and Recommendations from 14 Years of Ferry Accidents. Methodology: Causal Analysis Scope: Global, with focus on Indonesia	Key Findings: Highlights systemic operational and safety issues in archipelagic nations like Indonesia, linked to vessel quality, overcrowding, and inadequate training. Novelty: Provides a comprehensive dataset and analysis of accident causation.	Relevance (Context): Crucial for understanding operational risks and social sustainability challenges (a key barrier) in the Indonesian maritime context (RQ1).
Johnstone & Ratanavaraha (2017)	Title: Green Freight Movement: The Dilemma of the Shifting of Road Freight to Alternatives. Methodology: Mathematical Modeling Scope: Egypt	Key Findings: Analyzes the policy and infrastructure needs to make shifting cargo to water/rail viable. Novelty: A model to evaluate the impact of modal shifts away from road transport.	Relevance (Justification): Provides foundational arguments for the necessity of green maritime logistics as a sustainable alternative to road freight.
Fathoni et al. (2017)	Title: Analysis to assess potential rivers for cargo transport in Indonesia. Methodology: AHP Analysis Scope: Indonesia	Key Findings: Proposes a method to assess and prioritize river segments for cargo transport development. Novelty: A new supporting decision tool for developing inland water transport in Indonesia.	RQ3 (Policy): Provides a direct policy-making tool for developing inland/river transport for cargo in Indonesia.
Mondejar et al. (2018)	Title: A review of the use of organic Rankine cycle power systems for maritime applications. Methodology: Literature Review Scope: Global	Key Findings: ORC for waste heat recovery can yield significant fuel savings on ships, but economic feasibility remains a barrier. Novelty: Comprehensive overview of a key energy efficiency technology.	RQ2 (Technology): Details a specific, mature technology for enhancing energy efficiency on vessels.
Othman et al. (2019)	Title: The Sustainable Port Classification Framework for Enhancing the Port Coordination System. Methodology: Descriptive Analysis Scope: Malaysia (framework is generalizable)	Key Findings: Proposes a framework to classify ports based on sustainability criteria. Novelty: Connects port classification directly with sustainability metrics, a key concept for defining "Green Port."	Relevance (Framework): Directly addresses the "Sustainable Port" concept and provides a framework relevant for RQ4.
Sahri et al. (2020)	Title: A critical review of marine mammal governance and protection in Indonesia. Methodology: Critical Review & Policy Analysis Scope: Indonesia	Key Findings: Reveals policy gaps regarding environmental impacts from shipping (e.g., underwater noise pollution). Novelty: Comprehensive institutional analysis of Indonesian marine governance.	RQ3 (Policy): Offers an in-depth analysis of the national regulatory landscape, forming the backdrop for green port policy.
Theme 2: Implementation, Drivers, and Barriers (RQ1)			

Oskarsson et al. (2021)	<p>Title: India's new coal geography. Methodology: Case Study Analysis Scope: India</p>	<p>Key Findings: Analyzes the powerful economic and policy drivers behind coastal power plants fueled by imported coal. Novelty: Frames coastal coal infrastructure as a "new coal geography."</p>	<p>RQ1 (Drivers): Highly relevant for understanding the strong drivers behind coal logistics, which green policies must compete with.</p>
Balci & Surucu-Balci (2021)	<p>Title: Blockchain adoption in the maritime supply chain: Examining barriers Methodology: Empirical Modeling Scope: Global</p>	<p>Key Findings: Identifies "lack of stakeholder support" and "lack of government regulations" as critical barriers to technology adoption. Novelty: Uncovers hierarchical relationships between these barriers.</p>	<p>RQ1 (Barriers): Directly identifies barriers for a specific technology, offering a micro-level analysis of implementation challenges.</p>
Amin et al. (2021)	<p>Title: Impact of maritime logistics on archipelagic economic development in eastern Indonesia. Methodology: Stochastic Frontier Analysis Scope: Eastern Indonesia</p>	<p>Key Findings: Shows that high logistics costs and low port efficiency harm economic development on small islands. Novelty: Quantifies the impact of maritime logistics costs on a regional economy in Indonesia.</p>	<p>RQ1 (Barriers): Empirically demonstrates how high logistics costs and port inefficiency act as major barriers in the Indonesian archipelagic context.</p>
Munim et al. (2022)	<p>Title: Transshipment port's competitiveness forecasting Methodology: ANP Modeling Scope: Bangladesh</p>	<p>Key Findings: Quantitatively includes "green port management" as a key component of port competitiveness. Novelty: Demonstrates that green management is a measurable driver of competitiveness.</p>	<p>RQ1 (Drivers): Directly positions "green port management" as a driver for competitiveness.</p>
Gosens et al. (2022)	<p>Title: China's decarbonization and energy security plans will reduce seaborne coal imports Methodology: Installation-level Modeling Scope: China</p>	<p>Key Findings: Finds that China's national decarbonization policies will drastically reduce demand for seaborne coal imports. Novelty: A granular model showing how national policy directly impacts maritime trade flows of a key commodity.</p>	<p>RQ1 (Drivers): A powerful example of how national policy acts as a major driver affecting coal logistics.</p>
Emodi et al. (2022)	<p>Title: Transport sector decarbonisation in the Global South: A systematic literature review. Methodology: SLR Scope: Global South</p>	<p>Key Findings: Identifies key decarbonization challenges in developing countries (funding, fuel competition) Novelty: Focuses specifically on the unique challenges of the Global South.</p>	<p>Relevance (Context for RQ1): Provides a broader contextual understanding of the barriers that are particularly acute in developing nations like Indonesia.</p>
Alamouh et al. (2024)	<p>Title: Investigating determinants of port decarbonisation implementation Methodology: Conceptual Framework Scope: Global</p>	<p>Key Findings: Identifies key constructs for successful port decarbonization (governance, relationships). Novelty: Applies Implementation Theory to the port decarbonization context.</p>	<p>RQ1 (Drivers/Barriers) & RQ3 (Policy): Directly addresses implementation determinants and provides a framework for understanding governance.</p>
Calderón-Rivera et al. (2024)	<p>Title: Barriers and solutions for sustainable development of inland waterway transport: A literature review. Methodology: Literature Review Scope: Global</p>	<p>Key Findings: Presents a framework of barriers (governance, operational, infrastructural) and solutions for sustainable inland waterway transport (IWT). Novelty: Systematically classifies</p>	<p>RQ1 (Barriers): Directly addresses the barriers relevant to the mining barging sector and other inland transport.</p>

		barriers and solutions for the IWT sector.	
Utama et al. (2024)	<p>Title: The effect of digital adoption and service quality on business sustainability</p> <p>Methodology: Empirical Study (SEM)</p> <p>Scope: Indonesia</p>	<p>Key Findings: Digital adoption and strategic alliances are key indirect drivers for achieving business sustainability in Indonesian ports.</p> <p>Novelty: Empirically proves the role of alliances in the Indonesian context.</p>	<p>RQ1 (Drivers): Identifies key drivers specific to the Indonesian port context.</p>
Halpe et al. (2025)	<p>Title: Challenges and opportunities for ports in achieving net-zero emissions</p> <p>Methodology: Perspective Review</p> <p>Scope: Global</p>	<p>Key Findings: Outlines significant economic, technological, and policy challenges (barriers) for ports in achieving net-zero.</p> <p>Novelty: Frames the port's role as a central node for facilitating vessel emissions reduction.</p>	<p>RQ1 (Drivers/Barriers): Directly maps out the primary challenges and opportunities for green ports.</p>
Priatno et al. (2025)	<p>Title: A Systematic Review of Current Risk Management Models in Inland Water Transportation.</p> <p>Methodology: SLR</p> <p>Scope: Global, with focus on Indonesia</p>	<p>Key Findings: Highlights that the Indonesian context for inland water transport risk is critically under-researched.</p> <p>Novelty: Integrates global findings with Indonesia's specific challenges related to barging.</p>	<p>RQ1 (Barriers): Crucial for understanding risks in mining barging in Indonesia.</p>
Garg et al. (2025)	<p>Title: Evaluation of value creating factors in green shipping corridors.</p> <p>Methodology: Fuzzy SWARA</p> <p>Scope: Global Expert Panel</p>	<p>Key Findings: Identifies "Energy Efficiency" and "Attracting Green Investments" as critical value drivers. Novelty: Quantifies and ranks the factors that create value in green shipping initiatives.</p>	<p>RQ1 (Drivers): Directly identifies and ranks the key economic and environmental drivers for green shipping.</p>
Machfudiyanto et al. (2025)	<p>Title: Enhancing Small-Scale LNG supply Chains</p> <p>Methodology: Delphi Method</p> <p>Scope: Indonesia</p>	<p>Key Findings: Develops a risk-based SS-LNG supply chain scheme with mitigation strategies for archipelagic regions.</p> <p>Novelty: A contextualized risk-based approach with innovations like terminal clustering for Indonesia.</p>	<p>RQ1 (Barriers) & RQ2 (Technology): Directly addresses risk (a barrier) and supply chain schemes (operational innovation) for LNG in Indonesia.</p>
Theme 3: Technological and Operational Innovations (RQ2)			
Al-Enazi et al. (2021)	<p>Title: A review of cleaner alternative fuels for maritime transportation.</p> <p>Methodology: Review</p> <p>Scope: Global</p>	<p>Key Findings: Evaluates the feasibility of LNG, hydrogen, and ammonia as alternative fuels.</p> <p>Novelty: Provides a comparative analysis of the entire supply chain for each fuel.</p>	<p>RQ2 (Technology): Provides a detailed technical comparison of leading alternative fuel options.</p>
Alzahrani et al. (2021)	<p>Title: Decarbonisation of seaports: A review...</p> <p>Methodology: Literature Review</p> <p>Scope: Global</p>	<p>Key Findings: Categorizes seaport decarbonization efforts into technology clusters (renewables, smart control). Novelty: Emphasizes the necessity of a total life cycle approach for port technologies.</p>	<p>RQ2 (Technology): Provides a comprehensive overview of relevant technologies for green ports.</p>
Budiyanto et al. (2022)	<p>Title: Estimation of CO2 emissions for ship activities at container port</p>	<p>Key Findings: Develops a bottom-up model to estimate CO2 emissions from ship activities in port. Novelty: Provides a</p>	<p>RQ2 (Technology/Operations): Offers a methodology for measuring performance, a</p>

	<p>Methodology: Emission Modeling Scope: (Implicitly Indonesia)</p>	<p>quantitative basis for a "green port index."</p>	<p>key part of operational innovation.</p>
Farah et al. (2024)	<p>Title: A survey on blockchain technology in the maritime industry Methodology: Survey/Review Scope: Global</p>	<p>Key Findings: Investigates blockchain's impact on supply chain transparency and offers a roadmap for integration. Novelty: Presents a practical framework for adopting blockchain in maritime operations.</p>	<p>RQ2 (Technology): Details a key digital technology for enhancing transparency and efficiency.</p>
Liu et al. (2024)	<p>Title: Unveiling the potential of digital twins in logistics Methodology: SLR Scope: Global</p>	<p>Key Findings: Identifies key services and capabilities of Digital Twins (DTs) for monitoring and optimization. Novelty: Proposes a framework to categorize DT applications.</p>	<p>RQ2 (Technology): Details a key digital innovation for enhancing operational efficiency.</p>
Brescini et al. (2025)	<p>Title: Techno-economic and environmental assessment of carbon capture solution Methodology: Review Scope: Global</p>	<p>Key Findings: Chemical absorption is the most mature carbon capture method for ships but has high energy demands. Novelty: Comprehensive techno-economic comparison of Onboard Carbon Capture (OCCS) technologies.</p>	<p>RQ2 (Technology): In-depth information on a key emerging technology for ship decarbonization.</p>
Kondratenko et al. (2025)	<p>Title: Existing technologies and scientific advancements to decarbonize shipping by retrofitting. Methodology: Review Scope: Global</p>	<p>Key Findings: Identifies promising pathways for retrofitting: green energy, carbon capture, and biofuels. Novelty: Systematically categorizes available retrofitting technologies.</p>	<p>RQ2 (Technology): Primary source for identifying specific technologies applicable to barges and cargo ships.</p>
Mohd Tamam et al. (2025)	<p>Title: The roadmap to carbon neutrality for the maritime industry Methodology: Review Scope: Global</p>	<p>Key Findings: Provides a roadmap for decarbonizing ship engines via alternative fuels, considering port infrastructure. Novelty: Integrates engine technology with fuel pathways and port readiness.</p>	<p>RQ2 (Technology): Directly addresses the technological pathways to decarbonize vessels.</p>
Keyhani et al. (2025)	<p>Title: Review on marine plastic pyrolysis oil: Turning pollution into a maritime fuel. Methodology: Review Scope: Global</p>	<p>Key Findings: Proposes pyrolysis of marine plastic waste to generate a compatible alternative fuel. Novelty: First comprehensive assessment of marine litter as a pyrolysis feedstock for maritime fuel.</p>	<p>RQ2 (Technology): Introduces a novel, circular-economy technology solution relevant to green port waste management.</p>
Jalali & Tei (2025)	<p>Title: Maritime technology attention trends: Buzzwords, stability, and emerging patterns. Methodology: SLR Scope: Global</p>	<p>Key Findings: Differentiates between transient buzzwords (e.g., blockchain) and sustained trends (e.g., alternative fuels, green ports). Novelty: Uses temporal data to analyze attention patterns and distinguish hype from transformative trends.</p>	<p>RQ2 (Technology): Provides a high-level strategic overview of the entire technological landscape, identifying which innovations are most enduring.</p>
Theme 4: Policy, Regulation, and Governance (RQ3)			
Sovacool (2017)	<p>Title: Reviewing, Reforming, and Rethinking Global Energy Subsidies</p>	<p>Key Findings: Highlights how massive subsidies for fossil fuels act as a major barrier to a sustainable energy transition.</p>	<p>RQ3 (Policy) & RQ1 (Barriers): Offers a fundamental explanation for the systemic barriers</p>

	Methodology: Literature Review Scope: Global	Novelty: Provides a political economy framework for understanding subsidy reform.	facing green technologies: the existing energy system is heavily subsidized.
Alamoush et al. (2022)	Title: Ports' role in shipping decarbonisation: A common port incentive scheme Methodology: Content Analysis Review Scope: Global	Key Findings: Existing port incentive schemes are often ineffective. Novelty: Proposes a seven-action framework for a common, effective port incentive scheme.	RQ3 (Policy): Directly addresses the role of port-level policies (incentives) in driving sustainability.
Tadros et al. (2023)	Title: Review of current regulations, available technologies, and future trends in the green shipping industry. Methodology: Comprehensive Review Scope: Global	Key Findings: Maps current IMO regulations and integrates them with technological facets. Novelty: Provides a holistic overview linking policy, technology, and operations.	RQ3 (Policy): A foundational paper detailing the current regulatory landscape that drives green port initiatives.
(Humang et al., 2025)	Title: Hub-and-spoke network design to optimize government subsidy costs Methodology: Empirical Modeling Scope: Indonesia	Key Findings: A hub-and-spoke model can significantly reduce operational costs and government subsidies for maritime transport in Indonesia. Novelty: A data-driven framework for optimizing Indonesia's Sea Tollway program.	RQ3 (Policy): Directly analyzes the impact of a key Indonesian maritime policy (subsidies).
Adler et al. (2025)	Title: The impact of governance on the technical efficiency of container ports. Methodology: Stochastic Frontier Analysis Scope: Asia	Key Findings: Shows that independent regulators and privatization foster higher technical efficiency. Novelty: Quantifies the impact of governance models on port performance.	RQ3 (Policy): Provides empirical evidence on how governance structures impact port performance (transferable to general cargo).
Theme 5: Methodological Examples and Foundational Reviews			
Sardar et al. (2025)	Title: Advancements and obstacles in improving the energy efficiency of maritime vessels: A systematic review. Methodology: SLR Scope: Global	Key Findings: Examines challenges in assessing ship energy efficiency and advancements in ship design. Novelty: Aims to provide a comprehensive understanding to drive future research.	RQ1 (Barriers) & RQ2 (Technology): A methodologically strong SLR that directly maps to the core RQs of this study.
Pirouzrahi et al. (2025)	Title: Applying system dynamics modelling to modal shift: A systematic review. Methodology: SLR Scope: Global	Key Findings: Identifies core causal loops for modeling modal shift policies in freight transport. Novelty: Provides an initial framework for future quantitative research on modal shift.	Relevance (Methodology): A strong methodological example for policies aimed at shifting freight to more sustainable modes like maritime.
Vishwakarma et al. (2025)	Title: Applications of AI to low carbon decision support system for global supply chains. Methodology: SLR Scope: Global	Key Findings: Synthesizes trends in AI-driven approaches for carbon reduction. Novelty: Develops a conceptual framework for low-carbon decision support systems using AI.	Relevance (Methodology): Excellent model for structuring a conceptual framework from an SLR.

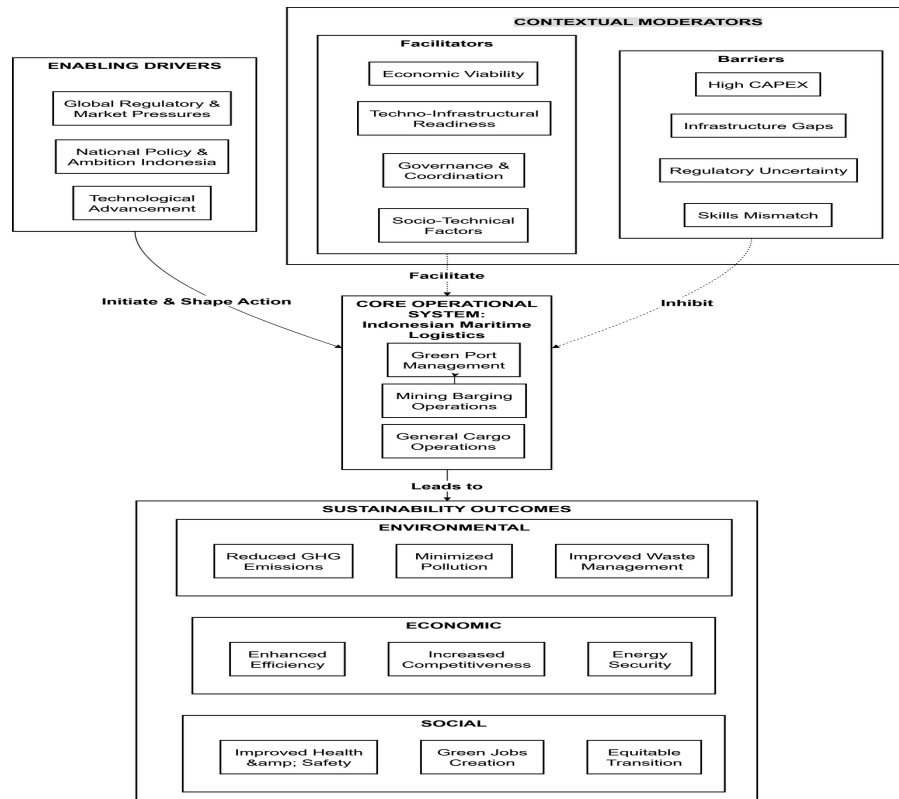
Source: Authors' analysis (2025)

(RQ1) What are the primary drivers and barriers to sustainability adoption? The synthesis confirms that the push for sustainability in Indonesia's maritime sector is predominantly "compliance-driven," with international regulations from the IMO as the most powerful driver (Tadros et al., 2023). However, these are consistently juxtaposed against formidable barriers, chiefly high capital investment (Halpe et al., 2025) and the challenging political economy of energy, where fossil fuel subsidies create an uneven playing field (Sovacool, 2017). This tension is particularly acute in Indonesia, where high logistics costs and port inefficiencies in its archipelagic setting act as significant operational barriers (Amin et al., 2021). Furthermore, strong economic drivers for traditional fossil fuel logistics, particularly for coal, create significant inertia that green policies must overcome (Gosens et al., 2022; Oskarsson et al., 2021).

(RQ2) What are the key technological and operational innovations? The analysis highlights a clear "implementation chasm." While the global literature provides a rich portfolio of technological solutions—including alternative fuels (Al-Enazi et al., 2021) and digital tools like Digital Twins (Liu et al., 2024)—a conspicuous absence of research documents their practical application for Indonesia's domestic barging and general cargo fleets. Analysis of maritime technology trends suggests that while concepts like "green ports" are gaining sustained attention, others like blockchain may be part of a hype cycle, urging a focus on proven technologies (Jalali & Tei, 2025). This confirms that obstacles are less a lack of options and more rooted in challenging economic feasibility and a persistent policy-practice gap.

(RQ3) What is the role of the regulatory and policy framework? The findings confirm the "policy-practice gap" in Indonesian maritime governance. High-level national policies often fail to translate into the granular incentives and robust enforcement needed at the operational level (Alamouh et al., 2022). Studies on port governance suggest that independent regulators are crucial for improving efficiency (Adler et al., 2025), yet the Indonesian context is characterized by regulatory uncertainty and fragmented coordination (Sahri et al., 2020). The need for specific policy tools to support the development of inland water transport for cargo has also been identified as a critical area for government intervention in Indonesia (Fathoni et al., 2017).

(RQ4) How can these elements be integrated into a cohesive framework for Indonesia? In response to the fragmented nature of the existing literature, this study's primary contribution is to synthesize these disparate elements into a cohesive, actionable model. This is achieved through the formulation of a novel conceptual framework, presented in Figure 4, which illustrates the dynamic interplay between exogenous drivers, contextual moderators, the core operational system, and sustainability outcomes.



Source: Authors' analysis (2025)

Figure 4. A Proposed Conceptual Framework for Sustainable Port, Mining Barging, and General Cargo Operations in Indonesia

Furthermore, to translate this synthesis into practice, a targeted research agenda is developed and presented in Table 5. This agenda directly addresses the critical knowledge gaps identified during the review, steering future inquiry toward integrated, solution-oriented research specific to Indonesia’s bulk and general cargo sectors.

Table 5. Identification of Research Gaps and Future Research Agenda

Identified Research Gap	Proposed Research Questions / Direction	Rationale and Potential Impact for Indonesia	Key References for Context
1. Lack of Contextualized Techno-Economic Models for the Indonesian Bulk Sector	1. Develop a multi-objective optimization model for Indonesia's coal and mineral barging supply chain, balancing cost, delivery time, and carbon emissions. 2. What is the levelized cost of abatement (LCA) for key decarbonization technologies (e.g., engine retrofiting, alternative fuels) when applied specifically to the Indonesian domestic barging fleet ?	The synthesis of the 37 articles confirms that while some optimization models exist, there is a distinct lack of quantitative techno-economic models tailored to Indonesia's unique archipelagic geography and price-sensitive market. Such models are crucial to build viable business cases, attract investment, and enable scalable green technology adoption in the nation's core bulk logistics sector.	(Amin et al., 2021; Humang et al., 2025; Priatno et al., 2025)
2. Under-representation of Socio-Economic and "Just	1. What are the potential impacts of the green maritime transition on employment, skills, and livelihoods for maritime workers and coastal communities in	The curated literature is heavily focused on technological and policy aspects, with a significant gap confirmed regarding the human dimension of	(Emodi et al., 2022; Golden & Weisbrod,

Transition" Dimensions	<p>Indonesian mining regions (e.g., Kalimantan, Sumatra)?</p> <hr/> <p>2. How can "just transition" principles be incorporated into Indonesia's green port policies to ensure equitable outcomes, mitigate social resistance, and enhance operational safety?</p>	<p>decarbonization, especially in the context of the Global South. Research into this area is critical for Indonesia to design an equitable transition, build public trust, and ensure the benefits of sustainability are shared, aligning with national development goals.</p>	2016; Sahri et al., 2020)
3. Implementation Barriers for Digital Technologies among SMEs	<p>1. What are the primary barriers (e.g., financial, technical, human capital) to the adoption of digital logistics technologies for small and medium-sized (SME) and informal operators in Indonesia's domestic maritime sector?</p> <hr/> <p>2. Develop and pilot a low-cost, scalable digital platform for monitoring vessel efficiency and emissions, tailored for the domestic fleet.</p>	<p>While the review identified studies on advanced digital innovations (e.g., Digital Twins), it also revealed a clear absence of research focusing on their practical implementation challenges and affordability for the SME and informal operators that form the backbone of Indonesia's domestic fleet. This gap needs to be filled to democratize efficiency gains and improve data collection.</p>	(Balci & Surucu-Balci, 2021; Utama et al., 2024)
4. Absence of Specific "Green Barging" and "Green Bulk Terminal" Frameworks	<p>1. What specific operational practices, technologies, and Key Performance Indicators (KPIs) constitute a "Green Barging" standard for Indonesian inland and archipelagic waters?</p> <hr/> <p>2. Formulate a certifiable "Green Bulk & General Cargo Terminal" framework for Indonesian ports, moving beyond existing container-focused models to address the unique challenges of coal, mineral, and general cargo handling.</p>	<p>This is the most critical gap directly highlighted by the review. The analysis confirmed that while "Green Port" is a common term, its application in the literature is overwhelmingly focused on container operations. The synthesis revealed no specific, standardized framework for the bulk and general cargo operations that are dominant in many Indonesian ports. Developing tailored standards is essential to guide investment, standardize operations, and create a clear regulatory pathway.</p>	(Priatno et al., 2025), (Calderón-Rivera et al., 2024); (Othman et al., 2019); (Budiyanto et al., 2022);

Source: Authors' analysis (2025)

CONCLUSION

This systematic literature review concludes that the integration of green port strategies within Indonesia's vital mining barging, and general cargo sectors is caught in a critical nexus of competing priorities. While primarily 'compliance-driven' by international regulations, sustainability adoption is severely constrained by a persistent 'policy-practice gap,' high capital investment barriers, and an 'implementation chasm' between available global technologies and their practical application in the unique Indonesian context. The global discourse remains overwhelmingly container-centric, failing to address the specific operational realities of the bulk and general cargo operations that are foundational to Indonesia's economy. In response, this study provides the first integrated synthesis for these under-researched sectors, proposing a novel conceptual framework (Figure 4) that holistically models these complex interactions and a targeted research agenda (Table 5) to guide future inquiry. Ultimately, this review confirms that a more context-specific approach is required and offers a foundational, evidence-based roadmap for Indonesian stakeholders to collaboratively foster a maritime logistics ecosystem that is not only competitive and resilient but also genuinely sustainable.

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