



The Nexus of Digital Transformation and Green Industry for Sustainable Maritime Supply Chains: A Critical Systematic Literature Review

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Abstract: As an archipelagic nation, Indonesia is at a critical strategic juncture, concurrently advancing industrial modernization through its 'Making Indonesia 4.0' roadmap while committing to green economy principles. However, the practical application of this 'twin transition' within the nation's vital maritime supply chains encompassing port operations and shipping logistics remains underexplored. This study addresses this critical gap by conducting a rigorous Systematic Literature Review, adhering to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, to synthesize global evidence on the digital-green nexus specifically for the maritime context. A thematic analysis of twenty-seven selected articles identifies three pivotal clusters: (1) digital technologies as critical enablers for circular economy practices; (2) synergies fostering sustainable business models such as 'green shipping' and 'smart ports'; and (3) contextual barriers hindering implementation. The principal contribution of this review is a novel, contextualized framework that translates global findings into a strategic action plan. This plan proposes applicable systems like Port Community Systems and Digital Twins to help Indonesia achieve its national performance and Sustainable Development Goal targets. The significance of these findings lies in providing a clear roadmap for policymakers, port authorities, and maritime industry leaders to navigate the complexities of this twin transition.

Keywords: sustainable maritime supply chain; twin transition; digitalization; green shipping; smart port; maritime logistics.

1. Introduction

The global industrial landscape is undergoing a profound structural shift, defined by the concurrent imperatives of digital transformation and environmental sustainability a paradigm increasingly termed the 'twin transition' [1], [2]. For the maritime sector, which facilitates over 80% of global trade, this dual challenge is not merely an option but a strategic necessity for future competitiveness and resilience. As a major contributor to global greenhouse gas emissions, the industry faces immense pressure to decarbonize its operations, leading to the rise of

concepts like 'green shipping' and 'green ports' [3], [4].

Positioned as the world's largest archipelagic state, Indonesia's economic vitality and national connectivity are inextricably linked to the efficiency and sustainability of its maritime logistics [5]. Recognizing this, the Indonesian government has launched two cornerstone policies: the 'Making Indonesia 4.0' roadmap, which prioritizes the adoption of Industry 4.0 technologies [6], and a national commitment to a low-carbon economy [7]. As depicted in Figure 1, these two policy streams are not parallel but deeply intertwined, creating a central 'Twin Transition Nexus' where

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digitalization and green principles must converge within the specific industrial and supply chain context.

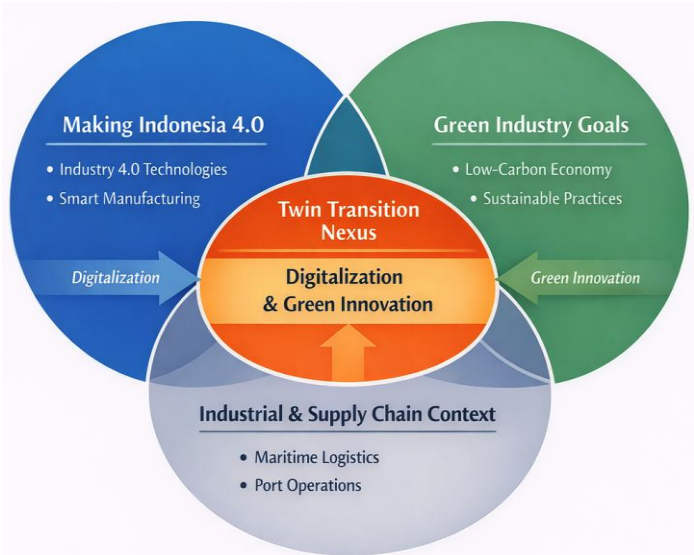


Figure 1. The Indonesian Policy Context: Intersecting 'Making Indonesia 4.0' and Green Industry Goals. [1][6][7]

To contextualize the urgency of navigating this nexus, a comparative analysis of key industrial and sustainability indicators against regional peers is presented in Table 1. The data highlights a critical challenge: while Indonesia's industrial sector is a major Gross Domestic Product contributor, its logistics performance lags regional competitors, and its carbon emissions are notably high. This disparity underscores the pressing need for an integrated strategy.

Table 1. Comparative Analysis of Industrial and Sustainability Indicators in Southeast Asia (2014–2024) [8]

Indicator	Indonesia	Thailand	Vietnam
Gross Domestic Product Growth (annual %)	5.0%	3.5%	6.5%
Industry, value added (% Gross Domestic Product)	39.8%	42.1%	38.0%
Exports (% Gross Domestic Product)	21.5%	65.3%	93.3%
Logistics Performance Index Score (1 to 5)	3.0	3.5	3.3
Carbon Dioxide emissions (kilotons)	563,3	258,5	342,7

Despite this clear policy alignment, a significant gap persists in practical implementation. While global literature on the digital-green nexus is expanding (Irajifar, Chen, Lak, Sharifi, & Cheshmehzangi, 2023), and port maintenance remains absent (cf. Sepehri et al., 2024). This research aims to address this critical void. The primary research question is: How can the global academic literature on the digital-green nexus be synthesized and contextualized to create an actionable framework for advancing sustainable maritime supply chains in Indonesia? To answer this, this study conducts a Critical Systematic Literature Review to map existing evidence, identify thematic clusters, and develop a novel conceptual framework and strategic action plan. This paper is structured as follows: Section 2 outlines the methodology, Section 3 presents the results, Section 4 discusses the findings and proposes the action plan, and Section 5 concludes the study.

2. Materials and Methods

This section delineates the conceptual and methodological approach adopted in this study. It first details the multi-level theoretical framework that serves as the analytical lens, followed by the rigorous Systematic Literature Review protocol employed for evidence synthesis.

2.1. Theoretical Foundations

To comprehensively analyze the intricate dynamics between industrialization, technology, governance, and sustainability, this study employs a hierarchical multi-level theoretical framework.

At the macro level, the analysis is informed by the Grand Theory of Socio-Technical Systems, which posits that social and technical elements are deeply intertwined and co-evolve (Eby, Sinoway, & Parisi, 2000). This perspective is crucial for understanding the twin transition not merely as a technological upgrade, but as a complex systemic shift involving actors, institutions, and technologies a view particularly relevant to the large-scale industrial transformation envisioned in Indonesia's maritime sector [1].

To explicate firm-level behavior and policy influence within this systemic context, this study draws upon two Middle-Range Theories. First, the Dynamic Capabilities View is utilized to analyze how firms "sense, seize, and reconfigure" resources to adapt to the twin transition, highlighting the necessity of developing both digital and green competencies [2]. Second, Institutional Theory provides a lens to examine how external pressures from studies confirm the positive impact of digital adoption at Indonesian port terminals [9], a comprehensive framework linking enabling technologies with practices like smart, circular.

regulatory bodies, industry norms, and societal expectations shape corporate adoption of digital-green practices [11].

Finally, at the operational level, the analysis is grounded in the principles of an Applied Theory, the Circular Economy. The Circular Economy serves as the primary operational framework for "green industry," offering concrete strategies enabled and optimized by digitalization [12], [13]. By integrating these theoretical tiers, this study transcends descriptive review to offer a conceptually rich, multi-dimensional analysis of the digital-green nexus.

2.2. Systematic Literature Review Protocol

This study employs a Systematic Literature Review methodology to ensure a comprehensive, unbiased, and replicable synthesis of academic literature [14]. The review adheres to a pre-defined protocol structured into three distinct stages: identification, screening, and inclusion, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [15]. The initial identification stage targeted the global evidence base via two premier scholarly databases: Scopus and Web of Science (Core Collection). The search, executed in October 2025, covered the period from January 1, 2014, to October 31, 2025. This systematic search yielded a total of 1,920 records. Following the identification phase, 420 duplicate records were removed, leaving 1,500 unique records for the screening process. The entire process is illustrated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram in Figure 2.

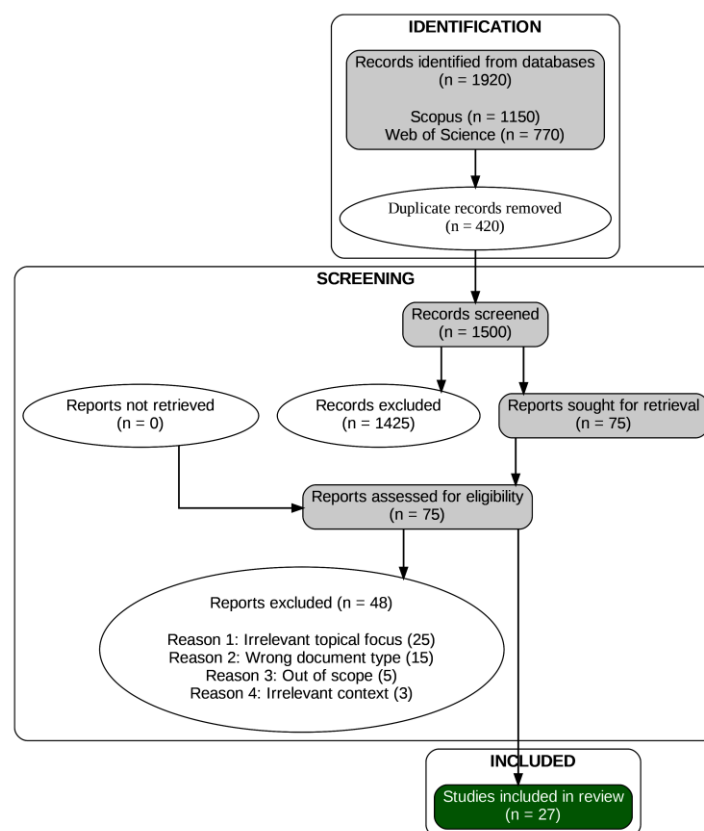


Figure 2. PRISMA 2020 Flow Diagram for the Systematic Study Selection Process.

The screening process was conducted in two phases using the Rayyan web application. In the first phase, the titles and abstracts of the 1,500 records were screened, resulting in the exclusion of 1,425 records. In the second phase, 75 reports were sought for retrieval. These 75 full-text articles were then assessed for eligibility. Forty-eight reports were excluded for specific reasons: irrelevant topical focus ($n = 25$), wrong document type ($n = 15$), out of scope ($n = 5$), and irrelevant context ($n = 3$). Consequently, a final corpus of 27 studies was included in the systematic review.

For the final synthesis stage, a structured data extraction form was used (see Appendix A). A thematic synthesis was employed to generate the analytical "clusters" presented in the results. For the bibliometric analysis, VOSviewer software was used to generate keyword co-occurrence maps.

3. Results

This section provides a concise description of the review's findings, beginning with a

descriptive profile of the literature, followed by bibliometric mapping and a synthesis of the core thematic clusters identified.

3.1. Descriptive Profile and Publication Trends

The analysis of the final corpus of twenty-seven articles elucidates a nascent yet rapidly consolidating research domain. As illustrated in Figure 3, publication output has accelerated markedly. A striking 93% of the articles were published since 2021, with this exponential growth trajectory, peaking in 2024, directly paralleling the intensifying global policy focus on the twin transition and underscoring the timeliness of this review.

Further analysis of the corpus's characteristics, summarized in Table 2, reveals the methodological state of the field. There is a clear predominance of literature reviews (Systematic, Scoping, or Narrative; 74%) and conceptual papers (15%), contrasted by a significant paucity of empirical studies (11%). This distribution strongly suggests that the research domain is currently in a phase of theoretical development and consolidation,

rather than widespread empirical validation, thereby highlighting the need for structured conceptual frameworks such as the one proposed in this study. Geographically, the reviewed literature is concentrated in Europe and Asia, with the manufacturing and general logistics sectors serving as the primary industrial context for analysis

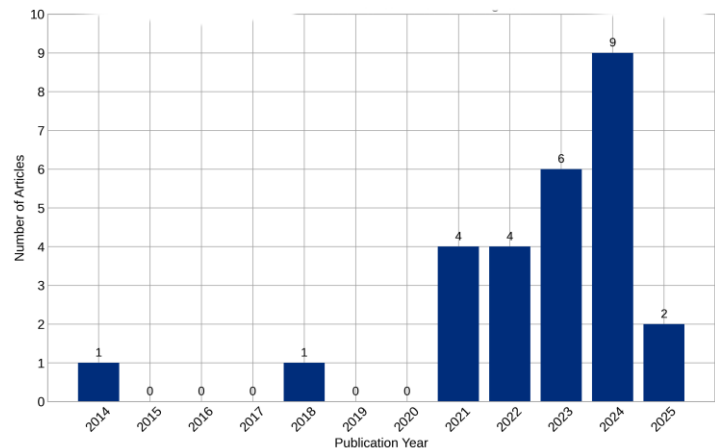


Figure 3. Annual Publication Trends of Global Literature on the Digital-Green Nexus (2014-2025).

Table 2. Descriptive Profile of the Reviewed Literature Corpus (N=27)

Category	Sub-Category	N	%
Methodology	Systematic / Bibliometric Review	17	63.0%
	Narrative Review	3	11.1%
	Conceptual/Framework	4	14.8%
	Empirical (Case/Survey)	3	11.1%
Industry Focus	Manufacturing (General)	10	37.0%
	General / Not Sector-Specific	8	29.6%
	Other Sectors (Construction, Agri-food, etc.)	9	33.4%

3.2. Bibliometric Mapping and Thematic Synthesis

The keyword co-occurrence analysis (Figure 4) confirms "circular economy" as the

central conceptual node. The thematic analysis subsequently revealed three robust research clusters, which are synthesized in Table 3.

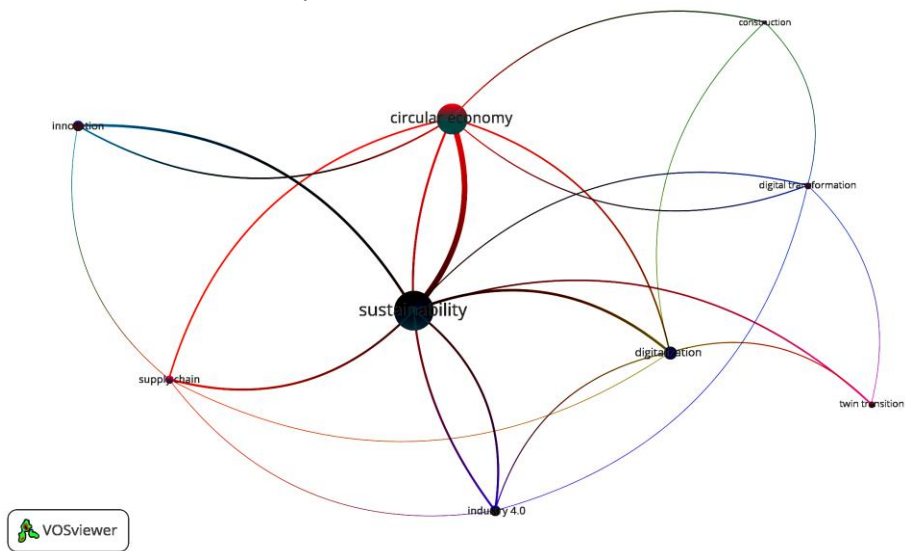


Figure 4. Bibliometric Map of Keyword Co-occurrence Network.

Table 3. Thematic Synthesis of Key Research Clusters and their Relevance to Indonesia

Cluster	Global Findings	Key Enabling Technologies	Contextual Relevance for Indonesia's Maritime Sector
1. Digital Enablers	Digitalization acts as an instrumental lever for resource efficiency and operational transparency.	Internet of Things, Artificial Intelligence, Blockchain [16], [17].	Directly supports 'Making Indonesia 4.0' goals [6]. Blockchain is critical for export traceability [18], while the Internet of Things provides verifiable data for green port indices [19] and enhances customs efficiency [20].
2. Circular Economy Synergies	Digital platforms enable "Smart Circular Economy" concepts and novel business models.	Digital Platforms, Product-Service Systems, Reverse Logistics Networks (Govindan, 2023).	Creates significant opportunities for waste valorization (e.g., ship-generated waste) within a green port strategy [21]. However, implementation is currently constrained by the high logistics costs inherent to the Indonesian archipelago [5].
3. Contextual Barriers	The success of the twin transition is heavily mediated by contextual factors; high capital investment and workforce skill gaps are major universal hurdles [2], [22].	Not applicable.	Global barriers are significantly amplified by local factors such as fragmented governance [11] and archipelagic geography [5]. This is particularly acute for Small and Medium-sized Enterprises, which face challenges in digital adoption (cf. Utama et al. 2024) and navigating workforce skill mismatches [23].

4. Discussion

The thematic clusters synthesized in Table 3 provide a structured lens through which to interpret the digital-green nexus in the Indonesian maritime context. This section critically discusses these clusters, integrating them with real-world technological applications, contextualizing their relevance for Indonesia's unique archipelagic landscape, and linking them to broader global sustainability agendas.

4.1. The Role of Digital Technologies in Enabling Maritime Circularity (Cluster 1)

The findings from Cluster 1 confirm that Industry 4.0 technologies are not merely tools for incremental efficiency gains but are fundamental enablers of the maritime circular economy [12]. For instance, the Internet of Things moves beyond simple cargo tracking to enable the real-time monitoring of engine performance and fuel consumption, providing verifiable and granular data essential for establishing credible green port indices (cf. Budiyanto et al. 2022). Furthermore, Blockchain technology directly addresses the pervasive trust deficits and information asymmetries in complex, multi-stakeholder maritime supply chains, offering a robust mechanism to verify

sustainability claims for Indonesian export commodities [17], [18].

4.2. Synergies for Green Shipping and Smart Ports (Cluster 2)

Cluster 2 highlights the powerful synergy between digital and green initiatives, which materializes in the tangible concepts of 'Green Shipping' and 'Smart Ports'. This ranges from Artificial Intelligence-driven route optimization algorithms that minimize fuel burn, to automated port equipment that reduces energy consumption [4]. The development of 'Green Shipping Corridors' represents the zenith of this synergy, creating dedicated maritime routes where digital infrastructure and supportive green policies converge to enable zero-emission voyages [3]. For Indonesia, adopting such models is critical for transforming its key ports into smart, sustainable, and circular logistics hubs [10], [21], [24].

4.3. Contextual Barriers Amplified in the Indonesian Archipelago (Cluster 3)

The review of Cluster 3 confirms that universal hurdles such as high capital investment and workforce skill gaps are major barriers [2], [22]. These challenges are significantly amplified in Indonesia due to its

archipelagic geography, creating a "digital divide" [5], and fragmented governance among Pentahelix stakeholders [11]. Overcoming these barriers requires a profound focus on developing human capital with "twin skills" competency in both digital systems and green proto [23], [24].

4.4. Digital Twin Applications in the Maritime Sector: Global Precedents for Indonesia

To bridge the gap between conceptual potential to practical application, it is crucial to examine established international use cases for key technologies like the Digital Twin. A Digital Twin is a dynamic virtual replica of a physical asset, process, or system that is updated with real-time data, allowing for advanced simulation, monitoring, and predictive analysis. The literature highlights several impactful applications that are directly relevant to Indonesia's maritime challenges.

One of the most powerful applications is the creation of a Port Digital Twin. As explored by [25], a port digital twin integrates data streams from various sources into a single virtual model. A leading real-world example is the Port of Rotterdam, which uses a comprehensive digital twin to monitor all vessel movements and infrastructure in real-time, enabling just-in-time arrivals and departures. For Indonesia, implementing a port digital twin at a major hub like Tanjung Priok could drastically reduce vessel waiting times and optimize yard management, thereby improving the Logistics Performance Index and reducing emissions.

Furthermore, the concept extends to the vessels themselves. Mouzakitis et al. (2023) introduce the VesselAI architecture, which leverages a Digital Twin of a ship combined with

extreme-scale analytics. This system can predict equipment failures, recommend the most fuel-efficient speed and route, and monitor emissions compliance. For Indonesia's "Tol Laut" (Sea Toll) program, equipping vessels with such capabilities could lead to substantial fuel savings and a significant reduction in the national carbon footprint.

Finally, the literature points towards the potential of a Network-Level Digital Twin. A compelling precursor to this is the Port of Rotterdam's "Container 42" project, which involved a sensor-equipped container traveling the globe to build a digital twin of its own supply chain journey. For Indonesia, this concept can be scaled up to create a "Tol Laut Digital Twin" a virtual replica of the entire inter-island logistics network. Such a system could simulate and optimize national cargo flows, helping policymakers to identify systemic bottlenecks and test the impact of new policies in a risk-free virtual environment [5].

4.5. An Integrated Strategic Framework, Action Plan, and Projected Impact

The significance of this transition extends beyond national targets, aligning directly with the United Nations' Sustainable Development Goals, as detailed in Table 4. Bridging the gap between global theory, applicable systems, and local reality, this study proposes an integrated conceptual framework, visualized in Figure 5. The successful operationalization of this framework is projected to yield measurable improvements in Indonesia's key indicators, as estimated in Table 5. To translate these findings into practice, Table 6 outlines a strategic action plan with applicable frameworks and solutions tailored for Indonesia.

Table 4. Mapping of Digital-Green Maritime Initiatives to Relevant Sustainable Development Goals

Digital-Green Initiative/Technology	Primary SDGs Targeted	Relevance and Impact Mechanism in the Maritime Context
Smart Port Operations (IoT, AI for efficiency, automation)	SDG 9: Industry, Innovation, and Infrastructure SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production	IoT sensors and AI-driven analytics optimize energy consumption in terminals and reduce truck idling times, leading to less air pollution in port cities (SDG 11) and more efficient, resilient infrastructure (SDG 9). Automation promotes resource efficiency, aligning with sustainable industrial patterns (SDG 12).
Green Shipping	SDG 7: Affordable and Clean	AI-powered route and speed optimization directly

Digital-Green Initiative/Technology	Primary SDGs Targeted	Relevance and Impact Mechanism in the Maritime Context
(Alternative fuels, AI-driven route optimization)	Energy SDG 13: Climate Action SDG 14: Life Below Water	cuts fuel consumption, tackling climate change by reducing GHG emissions (SDG 13). The shift to cleaner fuels (e.g., LNG, ammonia, hydrogen) supports clean energy goals (SDG 7) and minimizes marine pollutants like sulfur oxides, protecting life below water (SDG 14).
Circular Economy Practices (Digital platforms for waste valorization, predictive maintenance)	SDG 8: Decent Work and Economic Growth SDG 9: Industry, Innovation, and Infrastructure SDG 12: Responsible Consumption and Production	Digital platforms for ship-generated waste create new markets for valorization, fostering industrial innovation (SDG 9) and creating new "green jobs" (SDG 8). Predictive maintenance extends the lifespan of maritime assets, directly supporting sustainable production and consumption patterns (SDG 12).
Digital Supply Chain Transparency (Blockchain for traceability)	SDG 12: Responsible Consumption and Production SDG 16: Peace, Justice, and Strong Institutions	Blockchain provides an immutable and transparent ledger for tracking goods from origin to destination. This enhances institutional accountability by reducing fraud and corruption in logistics (SDG 16) and enables consumers and regulators to verify sustainability claims (e.g., sustainably sourced seafood), promoting responsible consumption (SDG 12).

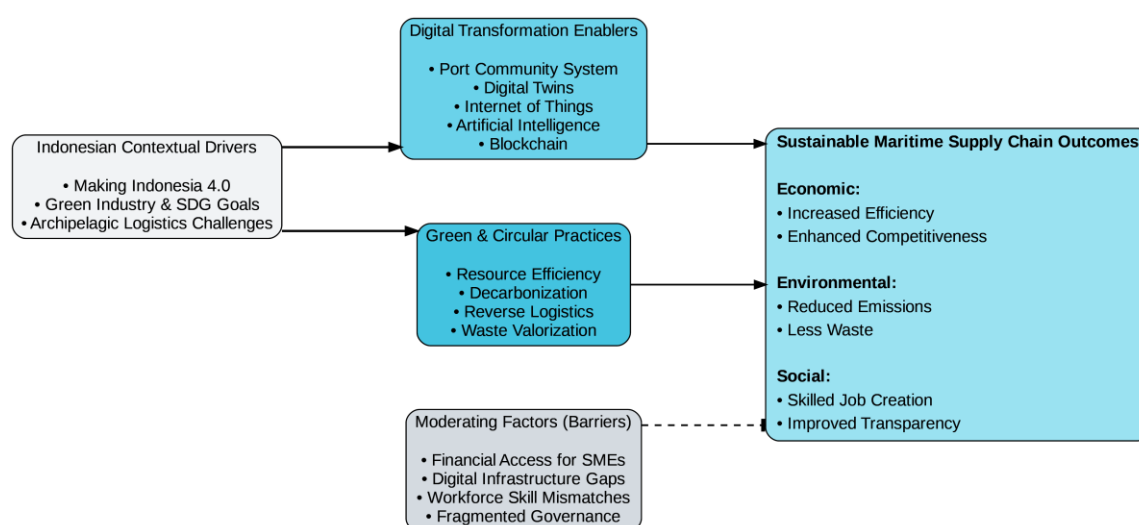


Figure 5. An Integrated Conceptual Framework for Indonesia's Maritime Twin Transition.

Table 5. Projected 5-Year Impact of Sustainable Development Goal-Aligned Digital-Green Transition on Indonesia (2025–2029)

Indicator	2025 (Baseline)	2026	2027	2028	2029
Gross Domestic Product Growth (annual %)	5.0%	5.9%	6.1%	6.2%	6.3%
Industry, value added (% of Gross Domestic Product)	39.8%	40.2%	40.6%	41.0%	41.5%
Logistics Performance Index Score (scale of 1 to 5)	3.0	3.2	3.4	3.6	3.8
Carbon Dioxide Emissions (kilotons)	563,3	575	585	590	592

Table 6. A Strategic Action Plan for Indonesia's Maritime Twin Transition

Strategic Pillar	Applicable Framework	Proposed Solution and Application for Indonesia
1. Performance Measurement & Investment Case	Maritime Twin Transition Scorecard: A quantitative framework to measure performance beyond traditional financial metrics.	Application: Pilot a scorecard at major and feeder ports. The scorecard should include Key Performance Indicators such as Carbon Intensity Indicator, Logistics Performance Index components, and Return on Investment on green technologies. This data will create an evidence-based business case to attract investment.
2. Inclusive Ecosystem Development	Tiered Digital-Green Adoption Model for Small and Medium-sized Enterprises: A structured pathway for smaller players to gradually adopt technologies with clear incentives.	Application: Develop a government-backed digital platform offering subsidized "starter packs" for maritime Small and Medium-sized Enterprises. These packs could include access to basic track-and-trace software, modules on green shipping regulations, and facilitated access to financing for green equipment upgrades.
3. Integrated Governance & Smart Regulation	"Green Shipping Corridors" Policy Framework: A regulatory and incentive-based framework to promote low/zero-emission shipping on specific, high-volume routes.	Application: Launch a pilot "Green Corridor" on the Jakarta-Surabaya route. Vessels participating in would be required to use the national Port Community System and meet specific emission standards. Incentives could include priority berthing, reduced port fees, and green financing access.
4. Archipelagic Circular Logistics Network	Hub-and-Spoke Reverse Logistics Model: A geographically viable model for waste collection and processing in an archipelago.	Application: Utilize a Digital Twin to model and simulate a reverse logistics network. Designate major ports as "Circular Hubs" for processing maritime waste collected from smaller "spoke" islands. This leverages digital technology to make a maritime circular economy practical for Indonesia.

5. Conclusions

This Critical Systematic Literature Review confirms that digital transformation is the indispensable linchpin for a competitive and green maritime ecosystem. The primary theoretical contribution is a novel, integrated conceptual framework that operationalizes global best practices for Indonesia. Practically, this research offers a strategic action plan, highlighting applicable systems and frameworks to address Indonesia's unique archipelagic context, improve its performance on key indicators, and align with global Sustainable Development Goals. While this review is limited by its reliance on secondary data, it lays a robust foundation for future empirical research to validate and refine the proposed solutions.

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