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An Integrative Green Port Model: Formulating Sustainable Port Governance in Indonesia

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ABSTRACT

Ports play a vital role in national logistics but also generate significant environmental impacts. The Green Port concept offers a sustainable approach emphasizing economic efficiency, social responsibility, and environmental protection. This study aims to formulate an integrative Green Port model through the development of sustainable port governance in Indonesia. A descriptive-analytical method was applied, integrating Sustainability Theory, Resource-Based View, Technology Acceptance Model, and Governance Theory. The findings indicate that collaborative governance, technological innovation, and resource efficiency are key to achieving Green Port implementation. The proposed model serves as a practical framework for national Green Port policy and supports Indonesia's Net Zero Emission 2060 commitment

INTRODUCTION

Studies on Green Port development in Indonesia to date still face a significant gap. Most previous research has only focused on specific technical aspects such as emission reduction, electrification of loading and unloading equipment, or port document digitalization. In fact, the Green Port concept is inherently multidimensional, requiring the integration of sustainable infrastructure development, efficient operations, and transparent and collaborative governance.

The implementation of Green Ports in Indonesia remains partial, limited to pilot projects in several ports, and has not yet been integrated into a national standard. This condition creates conceptual, practical, regulatory, and methodological gaps. Conceptually, there is still no comprehensive theoretical framework that fully integrates the main dimensions of Green Port within the Indonesian context. Practically, field implementation remains fragmented and inconsistent among ports. From a regulatory standpoint, Indonesia has yet to establish a standardized set of indicators for measuring Green Port success. Methodologically, existing studies are largely descriptive in nature and have not yet produced a model that can be adopted or empirically tested. Therefore, there is an urgent need to formulate an Integrative Green Port model, both from academic and policy perspectives.

Ports play a strategic role within the global logistics system. More than eighty percent of world trade relies on maritime transport, making ports vital nodes in the international supply chain. For Indonesia—an archipelagic nation with over 17,000 islands—ports serve not only as gateways for global trade but also as inter-island connectors and domestic distribution hubs. Given such a strategic position, the quality of port infrastructure, operational efficiency, and sound governance are critical determinants of national competitiveness.

However, Indonesian ports still face numerous challenges. The national logistics cost remains high, ranging between 23 to 27 percent of Gross Domestic Product (GDP), far above the ASEAN average of around 15 percent. This high cost is driven by operational inefficiencies, bureaucratic complexity, and limited supporting infrastructure.

In addition to efficiency issues, ports also contribute significantly to environmental impacts. Port-related activities—ranging from cargo handling operations and vessel traffic to surrounding industrial activities—generate air pollution, liquid waste, solid waste, and coastal ecosystem degradation. Environmental pressures of this magnitude have increasingly drawn attention in line with the rising global awareness of climate change. Consequently, there is a growing need to transform port management, not only to emphasize economic objectives but also to balance them with environmental protection and social benefits.

Within this context, the Green Port concept emerges as a new paradigm offering a sustainable approach to modern port management. Green Port emphasizes the integration of economic efficiency, environmental sustainability, and social welfare. Developed countries have demonstrated successful implementation of this concept. For instance, the Port of Rotterdam in the Netherlands has successfully combined digitalization, clean energy use, and transparent governance. Meanwhile, the Port of Los Angeles in the United States stands out for its emission control policies and active community engagement, and Singapore has developed a smart port system that integrates operational efficiency with environmental management. These examples prove that Green Port is not merely an idealistic notion but a practical strategy capable of enhancing global competitiveness while ensuring environmental sustainability.

Indonesia has also begun efforts to adopt Green Port principles, albeit still in the early stages. Several ports have launched environmentally friendly initiatives, such as Teluk Lamong Port in Surabaya, recognized as a semi-automated port with eco-friendly systems. Other initiatives include port document digitalization, clean energy development, and decarbonization programs. However, these implementations remain partial and unintegrated within a comprehensive framework.

The challenges are also considerable. From an infrastructure perspective, most Indonesian ports still lack fundamental facilities to support environmental sustainability principles—such as waste treatment plants, onshore power supply systems, and energy management systems. From an operational standpoint, ship and cargo services still face obstacles such as slow processing times, high costs, and limited digitalization implementation. From a governance standpoint, regulations on Green Port remain minimal, inter-agency coordination is suboptimal, and community participation around port areas remains low.

The success of a Green Port is largely determined by the integration of three key dimensions: infrastructure, operations, and governance. Sustainable infrastructure serves as the foundation for creating environmentally friendly ports. Efficient operations ensure smooth logistics flows at minimal cost, while collaborative governance guarantees transparency, accountability, and stakeholder participation. These three dimensions cannot function independently; rather, they are mutually reinforcing and can only generate optimal impact when formulated within an integrative model. Without such integration, modern infrastructure will not necessarily reduce logistics costs, advanced operations may fail to achieve transparency, and good governance will not be effective without adequate infrastructure and operational systems.

Therefore, the urgency of this research lies in formulating an Integrative Green Port Model capable of unifying these three dimensions within an applicable and coherent framework. The proposed model is expected to address Indonesia's unique challenges as an archipelagic nation with hundreds of ports possessing diverse characteristics. Moreover, it must align with global agendas, particularly the Sustainable Development Goals (SDGs) and Indonesia's commitment to achieving Net Zero Emissions by 2060. Through such an integrative model, the implementation of Green Port initiatives will no longer be sporadic but can evolve into a consistent and measurable national standard.

From an academic perspective, this research will contribute to filling the existing literature gap on Green Port development in Indonesia. Previous studies have primarily been descriptive in nature and have not yet advanced to the stage of formulating empirically testable conceptual models. This study seeks to produce a conceptual framework that is not only theoretically relevant but also practically applicable.

From a practical standpoint, the findings of this research will provide guidelines for policymakers, including the Ministry of Transportation, the Coordinating Ministry for Maritime Affairs and Investment (Kemenko Marves), state-owned port enterprises (BUMN), and local governments, in formulating policies for sustainable port development.

Furthermore, this research will support national development goals by enhancing logistics efficiency, strengthening port competitiveness at the regional level, and ensuring that Indonesia's maritime development proceeds in a sustainable manner. Hence, the Green Port can serve as a strategic pillar of Indonesia's maritime advancement—not merely as a response to global demands, but as a national strategy to achieve achieve a resilient, environmentally sound, and inclusive economy.

METHODS

Research Approach

This study employs a descriptive–analytical approach using a mixed-method design that combines qualitative and quantitative techniques.This approach was chosen because the development of an *Integrative Green Port Model* requires both an empirical understanding of current conditions (descriptive) and a theoretical construction (analytical) to produce a conceptual model that can be validated and applied in practice.

Based on the theoretical integration of Sustainability Theory, the Resource-Based View (RBV), the Technology Acceptance Model (TAM), and Governance Theory, this study seeks to explore the interrelationships among the key dimensions of the Green Port concept—namely sustainable infrastructure, operational efficiency through digitalization, and collaborative governance.

The purpose of these research questions is to guide a systematic examination of how these dimensions interact to form an integrative model of sustainable port management in Indonesia. Each question addresses a specific linkage among the variables, aiming to produce both theoretical contributions and practical policy implications for achieving the national vision of *Net Zero Emission 2060* and sustainable maritime development.

RQ1:

How does sustainable infrastructure influence operational efficiency and digital transformation in Indonesian ports implementing Green Port initiatives?

- **Focus:** The relationship between infrastructure and operations.
- **Theoretical linkage:** *Resource-Based View (RBV)* — sustainable infrastructure as a strategic resource that improves efficiency.

RQ2:

To what extent does operational efficiency, supported by digital adoption, affect the quality of governance and accountability in port management?

- **Focus:** The impact of operational and digital performance on governance.
- **Theoretical linkage:** *Technology Acceptance Model (TAM)* and *Governance Theory* — technology use and transparency enhancing governance.

RQ3 :

How can the integration of sustainable infrastructure, operational efficiency, and collaborative governance be formulated into an effective Green Port model for Indonesia's maritime sector?

- **Focus:** Integration of the three dimensions into a holistic model.
- **Theoretical linkage:** *Sustainability Theory* and *Collaborative Governance* — balancing environmental, social, and economic objectives through multi-stakeholder governance.

The qualitative method was utilized to explore the contextual, regulatory, and managerial aspects of Green Port implementation, while the quantitative method was applied to empirically test the interrelationships among the main variables within the integrative framework through statistical modeling.

Type and Design of the Study

This research falls under the category of model development research, conducted through three interrelated stages:

1. Exploratory Stage This stage identifies key variables and indicators of Green Port dimensions through literature review, policy document analysis, and in-depth interviews with key stakeholders.
2. Verification Stage This stage tests the relationships among variables using empirical surveys conducted at the selected port locations.
3. Formulation StageThis stage integrates the findings from the previous stages to construct the *Integrative Green Port Model for Indonesia*, which is subsequently validated through *expert judgment* and focus group discussions (FGD).

Research Locations and Subjects

The study focuses on two representative ports that exhibit different operational and governance characteristics:

1. Benoa Port (PT Pelindo Regional 3, Bali)Represents a multipurpose commercial and tourism-oriented port. The research focuses on the application of *Green Cruise Port* principles and the adoption of energy-efficient operations.
2. Tanjung Batu Shore Base (Pertamina Transkontinental, Balikpapan) Represents an industrial–energy port and national offshore base. The research focuses on environmental management, logistics integration, and the implementation of *Health, Safety, Security, and Environment (HSSE)* systems.

The research subjects include:

- Port authority officials and management from PT Pelindo and Pertamina Transkontinental
- Officials from the Directorate General of Sea Transportation and the Coordinating Ministry for Maritime Affairs and Investment (Kemenko Marves)
- Port users, logistics operators, and local government representatives
- Maritime experts and academics

Types and Sources of Data

1. Primary Data
    - In-depth interviews with port managers, regulators, and users
    - Survey questionnaires on perceptions of infrastructure, operational, and governance aspects
    - Direct observation of port facilities, energy systems, and digitalization processes
2. Secondary Data
    - Official documents from the Ministry of Transportation, Kemenko Marves, Pelindo, and Pertamina Transkontinental
    - Reports such as the *Green Port Assessment (2022)*, sustainability reports, and port performance data
    - Academic journals and international publications on Green Port development (e.g., Rotterdam, Singapore, Los Angeles)

Population and Sampling

The population of this study includes all relevant stakeholders involved in Green Port implementation at the two selected locations.Sampling was conducted using a purposive sampling technique, involving approximately 60 respondents:

- 20 respondents from Benoa Port
- 40 respondents from Tanjung Batu Shore Base

The selection criteria include:

- Minimum five years of professional experience in port, logistics, or environmental management
- Direct involvement in the implementation of green, digital, or governance-related port initiatives

Data Collection Techniques

1. Semi-structured interviews with port management, government officials, and industry experts.
2. Structured questionnaires using a 5-point Likert scale to assess stakeholder perceptions of each Green Port dimension.
3. Field observation of port infrastructure, digital systems, and environmental management practices.

Document analysis of relevant regulations, policy frameworks, and operational reports.

Overview

This chapter presents the empirical findings obtained from both qualitative and quantitative analyses conducted at Benoa Port (PT Pelindo Regional 3, Bali) and Tanjung Batu Shore Base (Pertamina Transkontinental, Balikpapan). The findings are structured according to the three key dimensions of the proposed Integrative Green Port Model:

1. Sustainable Infrastructure,
2. Operational Efficiency and Digitalization, and
3. Collaborative Governance.

The analysis integrates field observations, interview results, survey data, and documentary reviews to provide a comprehensive understanding of Green Port implementation in Indonesia.

4.2 Descriptive Findings

4.2.1 General Profile of Research Locations

- Benoa Port represents a multipurpose terminal with a strong tourism orientation and a growing emphasis on cruise operations. The port has initiated several environmental programs such as waste management systems, shore power planning, and the use of energy-efficient lighting. However, full digital integration and onshore energy systems remain under development.
- Tanjung Batu Shore Base, operated by Pertamina Transkontinental, serves primarily as an offshore logistics base supporting oil and gas operations in East Kalimantan. The port exhibits a relatively advanced environmental management framework, including an established *Health, Safety, Security, and Environment (HSSE)* system and systematic waste treatment. However, operational digitalization is still limited to internal systems and does not fully connect with external stakeholders.

Respondents' Characteristics

A total of 60 respondents participated in the survey and interviews, consisting of 35 male and 25 female participants. The majority (72%) have more than five years of experience in port or maritime logistics management.Occupationally, respondents include port authority officials, operations managers, engineers, and environmental officers.Educational backgrounds are predominantly in engineering, environmental science, and management, reflecting the multi-disciplinary nature of Green Port implementation.

Infrastructure Dimension

Field observations reveal that both ports have adopted initial stages of green infrastructure development, yet with different levels of maturity.

- Benoa Port focuses on *energy-saving technologies* (LED lighting, solar panels in administrative areas) and *waste segregation facilities*. However, the port lacks onshore power supply (OPS) for vessels, which remains a crucial gap in emission reduction.
- Tanjung Batu Shore Base has established a *liquid waste treatment plant* and *oil spill contingency system*. Its infrastructure is built to meet environmental standards under Pertamina Group's HSSE framework. Despite these advancements, further electrification of port equipment and integration with renewable energy sources are still in the planning phase.

These findings support the Resource-Based View (RBV) framework: ports that invest in environmentally sustainable infrastructure gain strategic resources that enhance competitiveness and compliance with international standards.

Operational Dimension

Both ports demonstrate efforts toward digitalization and efficiency, though implementation varies.

- At Benoa Port, operational efficiency is being improved through the INAPORTNET system (electronic clearance and documentation). However, manual procedures still exist, particularly in cargo documentation and inter-agency coordination.
- Tanjung Batu Shore Base integrates digital systems for internal fleet monitoring and cargo scheduling. The use of real-time tracking for offshore logistics shows higher digital maturity compared to Benoa.

Interview data confirm that digital technology adoption correlates strongly with management commitment and staff competency — key aspects described in the Technology Acceptance Model (TAM). Stakeholders perceive digital tools as beneficial for reducing processing time and improving transparency.

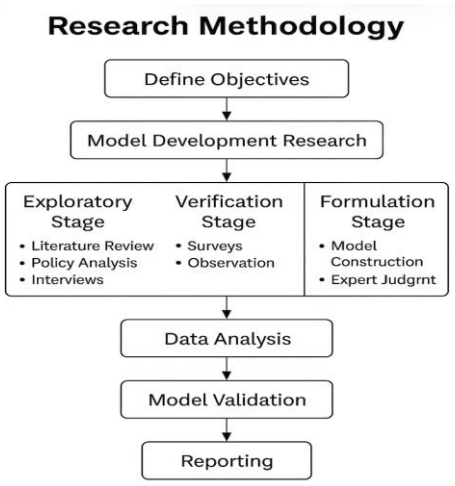

Figure 1. Methodology

Governance Dimension

The governance structures of both ports show progress toward collaborative and accountable management, yet institutional coordination remains fragmented.

- Benoa Port engages multiple stakeholders, including the Bali Provincial Government, Pelindo Regional 3, and cruise operators. However, regulatory overlaps between local environmental agencies and national port authorities create coordination challenges.
- Tanjung Batu Shore Base operates under a more centralized governance structure via Pertamina Transkontinental. Its decision-making process follows corporate sustainability protocols, though external stakeholder participation (community, local government) is still limited.

These findings align with Collaborative Governance Theory, suggesting that effective Green Port governance requires not only internal commitment but also horizontal collaboration among public, private, and community actors.

1. Descriptive Statistics

Table 1. Analysis Of Survey Data Shows The Following Average Perception Scores (On A 5-Point Likert Scale):

Dimension	Benoa Port Mean Score	Tanjung Batu Mean Score	Interpretation
Infrastructure	3.68	4.12	Both ports show moderate to high development, with Tanjung Batu performing better in waste management and energy use.
Operations	3.55	3.89	Efficiency and digitalization improving; INAPORTNET widely used but incomplete integration persists.
Governance	3.72	4.01	Governance structure relatively strong, but transparency and stakeholder engagement still evolving.

Overall, both ports scored between 3.5–4.0, indicating moderate implementation of Green Port principles.

SEM–PLS Analysis Results

The results of the Structural Equation Modeling (SEM–PLS) analysis confirm significant relationships among the three main dimensions:

- Sustainable Infrastructure → Operational Efficiency:
  Positive and significant (path coefficient = 0.62; $p < 0.01$).
  This suggests that environmentally friendly infrastructure directly enhances operational efficiency.
- Operational Efficiency → Governance Quality:Positive and significant (path coefficient = 0.55; $p < 0.05$).Efficient operations foster greater transparency andstakeholder trust.
- Infrastructure → Governance Quality (Indirect Effect):
  Mediated through operational efficiency, indicating the integrative nature of the model.

These results validate the Integrative Green Port Model framework, showing that infrastructure, operations, and governance are interconnected pillars that collectively drive sustainability.

Model Validation

The model was reviewed through expert judgment and Focus Group Discussions (FGD) involving representatives from:

- Ministry of Transportation (Sea Transportation Directorate),

- Kemenko Marves,
- PT Pelindo Regional 3,
- Pertamina Transkontinental, and
- Academic experts in maritime sustainability.

Experts confirmed that the model captures the complexity of port sustainability in Indonesia, emphasizing:

1. The importance of multi-level governance (national–regional–corporate).
2. The need for standardized Green Port indicators at the national level.

The inclusion of digital transformation as a central enabler of sustainability

RESULTS AND DISCUSSION

The findings indicate that Green Port implementation in Indonesia is transitional rather than fully institutionalized.While Benoa and Tanjung Batu demonstrate tangible progress, the transformation remains partial and uneven across dimensions.

From a theoretical perspective:

- The Sustainability Theory is validated, as both ports balance economic, environmental, and social priorities.
- The Resource-Based View (RBV) explains how strategic infrastructure investments create long-term advantages.
- The Technology Acceptance Model (TAM) justifies the role of user perceptions in digital adoption success.
- The Governance Theory underscores collaboration and accountability as drivers of effective policy execution.

Thus, the Integrative Green Port Model provides a holistic and empirically grounded framework that unites these perspectives, offering both academic and practical contributions to Indonesia's maritime governance and its Net Zero Emission 2060 roadmap.

Summary of Findings

1. Both ports exhibit moderate Green Port implementation with notable strengths in environmental infrastructure and HSSE systems.
2. Operational efficiency is improving through digitalization, but interconnectivity and standardization are still limited.
3. Governance frameworks exist but require stronger multi-stakeholder coordination and transparency.
4. Empirical tests confirm that infrastructure, operations, and governance are mutually reinforcing dimensions.
5. The validated model offers a practical reference for national Green Port policy and sustainable maritime management.

CONCLUSION

This study has developed and validated an Integrative Green Port Model that unites three essential dimensions — *sustainable infrastructure, operational efficiency and digitalization, and collaborative governance* — within the context of Indonesian port management. Based on field research conducted at Benoa Port (PT Pelindo Regional 3, Bali) and Tanjung Batu Shore Base (Pertamina Transkontinental, Balikpapan), several key conclusions can be drawn:

1. Green Port development in Indonesia is at a transitional stage. Both Benoa and Tanjung Batu have demonstrated tangible progress toward sustainability, yet implementation remains partial and uneven. The ports have initiated several environmentally friendly programs, but comprehensive integration of sustainability across all operations is still evolving.
2. Sustainable infrastructure serves as a foundational driver for efficiency. The empirical findings confirm that investment in environmentally friendly infrastructure — such as waste management systems, clean energy use, and electrification — significantly enhances operational performance and resource optimization. This aligns with the Resource-Based View (RBV), emphasizing infrastructure as a strategic asset contributing to long-term competitiveness.

3. Operational efficiency is strengthened through digital transformation. The adoption of port digitalization systems, including INAPORTNET and internal fleet monitoring tools, demonstrates the growing acceptance of technology. Consistent with the Technology Acceptance Model (TAM), user perceptions of usefulness and ease of use play a decisive role in the success of digital implementation.
4. Collaborative governance ensures transparency and accountability. Governance structures involving multiple stakeholders — government, port operators, private sectors, and local communities — are critical for sustaining the Green Port agenda. The study finds that clear regulatory coordination, stakeholder participation, and institutional accountability are necessary to prevent fragmentation and ensure policy coherence, as explained by Collaborative Governance Theory.
5. The Integrative Green Port Model is empirically validated and contextually relevant.
   Structural Equation Modeling (SEM–PLS) results indicate strong and positive interrelations among the three dimensions, confirming that infrastructure influences operations, and together they enhance governance performance. The model thus provides a holistic and adaptable framework for advancing sustainable port management in Indonesia.
6. Theoretical and practical contributions are significant. Theoretically, the study extends sustainability and governance discourse by integrating multiple frameworks — Sustainability Theory, RBV, TAM, and Governance Theory — into a unified model. Practically, it provides policymakers with a structured approach for designing national Green Port standards consistent with Indonesia's commitment to Net Zero Emission 2060 and the Sustainable Development Goals (SDGs).

Policy Implications

The validated model carries several strategic implications for national port policy and management:

1. Institutionalization of Green Port Standards The government should formalize a *National Green Port Framework* that clearly defines assessment criteria, performance indicators, and compliance mechanisms across all Indonesian ports.
2. Investment in Sustainable Infrastructure Incentives for clean energy utilization, onshore power supply (OPS), and renewable energy integration should be prioritized to reduce carbon emissions and operational costs.
3. Acceleration of Digital Port Transformation The integration of digital systems across agencies — customs, environment, and port authorities — is essential to enhance transparency and reduce bureaucracy.
4. Strengthening Collaborative Governance Multi-stakeholder coordination involving public agencies, private operators, and coastal communities should be institutionalized through formal collaboration platforms and environmental stewardship programs.
5. Capacity Building and Human Resource Development Continuous education, training, and awareness programs for port personnel and stakeholders are crucial for sustaining Green Port principles in the long term.

Limitations of the Study

This research acknowledges several limitations:

- The study focuses on two case locations (Benoa and Tanjung Batu), which, while representative, may not capture all variations of port typologies across Indonesia.
- Quantitative analysis is limited to 60 respondents; future studies may expand sample size for broader statistical generalization.
- Environmental and operational data rely partly on self-reported information, which may introduce response bias.

Recommendations for Future Research

1. Future studies should expand the model application to other major Indonesian ports, such as Tanjung Priok, Makassar, and Sorong, to validate its scalability.
2. Comparative international research could enhance understanding of how Indonesian ports perform relative to global Green Port leaders (e.g., Rotterdam, Singapore, Antwerp).
3. Further investigation is recommended into the economic impacts of Green Port adoption, including cost–benefit analyses and emission reduction outcomes.
4. Integrating climate resilience and adaptation indicators could strengthen the model's relevance to future maritime sustainability policies.

Final Remarks

The *Integrative Green Port Model* proposed in this dissertation contributes to Indonesia's strategic goal of building an environmentally responsible, digitally empowered, and efficiently governed maritime sector. By harmonizing sustainability, technology, and governance principles, the model provides a blueprint for transitioning Indonesian ports from compliance-based management toward innovative, resilient, and globally competitive Green Port systems — supporting the nation's long-term vision of Sustainable Maritime Prosperity and Net Zero Emission 2060.

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