

Article

Sustainability Management Model for Thai Ports: An ESG-Driven and Smart-Port-Enabled SEM Study

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Abstract

This research proposes and empirically examines a sustainability management model for Thai ports using environmental, social, and governance (ESG) indicators as the main analytical dimensions. Although ESG-based port sustainability has gained attention, limited evidence explains how ESG-based port management contributes to sustainable port management through smart port technology in the Thai port context. A quantitative survey was conducted with 115 practitioners of container terminal operators in Thailand. The questionnaire rated ESG practices, smart port technology, and sustainable port management on a seven-point scale. The measurement model was evaluated, and the structural relationships among constructs were tested using Partial Least Squares Structural Equation Modeling. The results indicate that the model has moderate to high explanatory power, with an average R^2 of 0.602, and six of the seven hypotheses were supported. The environmental port management dimension significantly influenced the social port management dimension, the governance port management dimension, and smart port technology, while the governance port management dimension significantly influenced smart port technology. The path from the social port management dimension to smart port technology was not supported. Smart port technology had a strong positive effect on sustainable port management. The indirect effect results indicate that smart port technology functions as an enabling mechanism linking environmental and governance port management dimensions to sustainable port management. These findings provide an evidence-based framework to support SDG achievement and long-term competitiveness of Thai ports.

Keywords: port management; sustainable port; smart port; ESG indicators; PLS-SEM

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1. Introduction

Global trade depends heavily on maritime transport because it connects production locations, markets, and logistics networks across regions. Sea transport is an important link between production systems, markets, logistics networks and consumers across regions with seaborne shipping representing the dominant share of world merchandise trade when measured by volume [1]. Due to the increase in maritime trade, ports have become strategic infrastructure to support cargo movement, national competitiveness, logistics efficiency and economic development [2].

In Thailand, ports are essential to maritime transport and import–export activities. A port can be defined as a facility where transfer of cargo from shore to ship and ship to shore takes place and also supports cargo storage, cargo handling, and cargo movement

[3,4]. According to the Thai Marine Department [5], maritime cargo transport through Thai coastal port areas in 2023 involved 76,988 vessel trips and approximately 441.956 million tons of cargo. The figures show that ports are the main transport facilities and also strategic infrastructure supporting Thailand's logistics activities and long-term economic development.

However, the growth of maritime transport is increasing pressure on ports to develop in a more systematic, responsible, and sustainable way. Ports must respond not only to rising cargo demand, but also to environmental, social, and governance expectations. This direction is consistent with the United Nations 2030 Agenda for Sustainable Development, which established 17 Sustainable Development Goals as a global framework for balancing economic growth, social inclusion, and environmental protection (United Nations, 2015) [6].

For Thailand, national policy is aligned with this global direction. The 13th Thailand National Economic and Social Development Plan, covering 2023–2027, emphasizes Thailand's role as a trade and investment gateway and as a sustainable logistics hub with lower carbon and GHG emissions [7]. In early 2024, the Port Authority of Thailand also announced a policy direction for developing ports based on Environmental, Social, and Governance principles in order to move toward sustainable ports [8]. These policy directions confirm that sustainable port development has become a strategic priority in Thailand.

The ESG framework provides a practical way to translate sustainability principles into port management [9,10]. ESG therefore allows ports to go beyond traditional metrics such as cargo throughput and financial return to include environmental responsibility, social value and governance quality as part of long-term performance. In this study, the ESG perspective is important because it provides a management-oriented framework for linking environmental responsibility, social accountability, and governance quality with port sustainability outcomes. It also helps port operators translate policy-level sustainability goals into measurable operational indicators and managerial priorities.

Nevertheless, Thai port operators and port managers still lack a standardized operational framework for guiding sustainable port development. Therefore, clear ESG-based port management indicators are essential for translating sustainability policies into measurable and practical actions. Without empirically validated indicators and models, ESG may remain at the policy level and not evolve into a practical or operational tool. Although previous studies have examined port sustainability indicators, green port practices, and smart port development, limited empirical evidence explains how ESG-based port management contributes to sustainable port management through smart port technology, particularly in the Thai port context. Therefore, the main research problem is not only the identification of ESG indicators but also the explanation of how these indicators operate together and how they are translated into sustainability outcomes through smart port technology. In particular, existing port sustainability studies have tended to examine ESG indicators, green port practices, or smart port technologies as separate research streams. Less attention has been given to explaining how ESG practices interact with smart port technology to generate measurable sustainability outcomes. This gap is important because ESG practices may not directly improve port performance unless they are supported by technological and organizational mechanisms that translate sustainability policies into operational actions.

This study advances prior work on Thai port sustainability by moving from indicator development to model testing. It builds on a previously published ESG indicator set for port management, which covers environmental, social, and governance indicators relevant to Thai ports [10]. While the previous study established an ESG indicator framework for Thai ports, the current study extends that work by empirically testing a structural

model that explains the relationships among ESG practices, smart port technology, and sustainable port management. To address the remaining research gap, this research specifies and empirically tests a sustainability management model in which smart port technology functions as an enabling mechanism linking ESG practices to sustainable port management.

Smart port technology can function as an enabling mechanism because digital monitoring, automation, data analytics, and integrated information systems allow ports to translate ESG-oriented practices into measurable operational and sustainability outcomes [11–13]. Structural equation modeling is employed because ESG management and smart port technology are multidimensional constructs. SEM allows for the investigation of relationships between latent variables, observed indicators, direct effects, indirect effects, and enabling mechanisms in an integrated model [14,15]. Thus, this study aims to develop and empirically examine an ESG-driven sustainability management model for Thai ports enabled by smart port technology. Rather than assuming a direct ESG-to-outcome pathway, this study focuses on how ESG practices are translated into sustainable port management through smart port technology as an enabling mechanism. Accordingly, this study addresses three research questions. First, how do ESG practices influence the implementation of smart port technology in Thai ports? Second, how does smart port technology contribute to sustainable port management? Third, does smart port technology function as an enabling mechanism that links ESG practices to sustainable port management? By answering these questions, this study contributes to the ESG-based port sustainability literature by transforming previously identified indicators into an empirically validated sustainability management model. In practical terms, the proposed model provides Thai port operators and policymakers with an evidence-based framework for prioritizing ESG practices and smart port technology implementation to support sustainable and competitive port systems.

The research was conducted through a quantitative survey of port practitioners working in container terminal operations in Thailand. The data were analyzed using Partial Least Squares Structural Equation Modeling to assess the measurement model, structural relationships, and indirect effects through smart port technology. The remainder of this paper is organized as follows. Section 2 presents the literature review and hypothesis development, including ESG-based sustainable port management, smart port technology, the TOE framework, sustainable port management, and the conceptual model. Section 3 explains the data and methods. Section 4 presents the empirical results and operational framework. Section 5 discusses the findings and implications. Section 6 concludes the study by summarizing the main findings, presenting the limitations, and suggesting directions for future research.

2. Literature Review and Hypothesis Development

2.1. Sustainable Port Management and ESG Practices

Sustainable port management is modern port development, which is not only evaluated by the operational performance, cargo throughput, service quality or economic contribution of ports but also balances competitiveness, environmental responsibility, social accountability and governance. This perspective reflects the core principle of sustainable development, which seeks to balance current development needs with the long-term capacity of future generations [16]. Sustainability is a matter of considerable interest in port activities because they affect energy consumption, greenhouse gas emissions, air and water pollution, waste production, occupational safety, community effects and stakeholder disputes. A participative managerial style of sustainable port management must address the environmental, social and institutional responsibilities borne throughout the planning, operation monitoring and performance assessment stages [17,18]. Ports are also

adopting sustainability indicators for enhancement and measurement of their environmental, social and governance (ESG) performance [9,19].

In the port context, ESG practices provide a management-oriented structure for converting broad sustainability goals into operational actions. Environmental practices address emissions, pollution control, energy use, waste, climate risk, and marine ecosystem protection. Social practices relate to workforce safety, labour welfare, human resource development, community relations, and stakeholder engagement. Governance practices focus on transparency, accountability, compliance, risk management, anti-corruption, reporting, and strategic decision-making [10].

According to previous research conducted by the authors [10], a set of indicators and a framework for ESG-based enhancing for sustainable port have been established, which combines environmental, social, and governance dimensions, as presented in Table 1. These indicators provide the necessary basis for implementing ESG practices in port operations. However, the previous framework was mainly focused on the development of indicators and conceptual classification, while the relationships between ESG practices are not well-tested. Therefore, the present study extends the established set of ESG indicators by using it in a structural equation model to investigate the direct and indirect effects of ESG practices with sustainable port management through smart port technology.

Table 1. ESG indicators in port management.

Indicator ID	Indicator
ENV—Environmental port management dimension	
ENV1	Reduction in port-related GHG emissions
ENV2	Air quality management within port areas
ENV3	Oil spill from port operations
ENV4	Noise impact control from port activities
ENV5	Energy-saving capability in port operations
ENV6	Operational waste management
ENV7	Resource-use efficiency in port operations
ENV8	Climate Risk Mitigation for Port Operations
ENV9	Environmental Management in Port Operation
SOC—Social port management dimension	
SOC1	Occupational safety and health of port employees
SOC2	Gender Diversity in Port Workforce
SOC3	Human Rights Compliance in Port Labor Practices
SOC4	Port Employee Turnover
SOC5	Non-Discrimination Practices in Port Employment
SOC6	Port Security Compliance
SOC7	Port Social Contribution Impact
SOC8	Port Training and Education Effectiveness
SOC9	Mechanisms for port-community engagement
GOV—Governance port management dimension	
GOV1	Port Financial Management Performance
GOV2	Port Operational Management Performance
GOV3	Diversity and Independence of Port Board Members
GOV4	Ethics and Anti-Corruption in Port Management
GOV5	Data Privacy Management in Port Operations
GOV6	External Assurance in Port Management
GOV7	Socioeconomic Compliance in Port operation
GOV8	Emergency Preparedness in Port Operations
GOV9	Port Innovation and Technology Advancement
GOV10	Business risk management in port operations

Adapted from Makkawan et al., 2025 [10].

2.2. Smart Port Technology for Sustainable Port Management

Smart port technology has become a vital tool for the modernization of traditional ports into more efficient, resilient and sustainable logistics systems. In this study, smart port technology refers to the application of digital and intelligent systems, including IoT, analytics, automation, AI-based tools, cloud platforms, cybersecurity, and integrated information systems, to support port operations, monitoring, coordination, and managerial decision-making. These technologies enable real-time monitoring of port operations, resource efficiency improvement, vessel waiting time reduction, cargo flow visibility improvement and port stakeholders' coordination improvement [11,12]. The smart port is not only technological modernization, but also a strategic application of technology to improve operational efficiency, environmental management and sustainable development.

The smart port and sustainable development have attracted the interest of recent port studies, including Sankla and Muangpan [20], which proposed a conceptual model for smart and sustainable port management in Thailand and identified that the development of smart ports should integrate the environmental, social and economic dimensions. In a similar vein, emerging systematic reviews suggest that smart ports are linked to digital transformation, sustainable performance, environmental monitoring, and the integration of intelligent infrastructure and stakeholders [21–23].

Smart port technology can be considered as an enabling mechanism that connects ESG-oriented port management with sustainable port management. Environmental practices can be supported by emissions monitoring, energy optimisation and waste tracking and climate-risk management. Social practices can be supported by digital safety systems, workforce training platforms, emergency response systems and community communication tools. And governance can be enhanced by data reporting, cyber security, regulatory compliance systems and evidence-based decision making. According to Niu et al. [24] found that smart port strategies can reduce congestion and enhance ESG performance, but the effect of smart port investment may depend on the interaction between smart port investment and port integration.

Furthermore, Recent studies also demonstrate that digital transformation can improve the competitiveness and sustainable performance of the ports. For example, Nguyen [25] developed a digital transformation index for container ports in Southeast Asia based on smart infrastructure, integration, governance and cybersecurity. Liu et al. [26] also determined that smart ports can facilitate sustainable shipping through the digital transformation of real port operations. Thus, smart port technology is appropriate to the present study because it offers the operational mechanism through which ESG practices can support sustainable port management. Therefore, this study hypothesizes that smart port technology is a mediating variable for the relationship between the ESG practices and sustainable port management in the proposed sustainability management model for Thai ports.

2.3. The Technology–Organization–Environment Framework as a Basis for Smart Port Technology Measurement

The Technology–Organization–Environment (TOE) framework provides a useful theoretical lens for measuring smart port technology by recognizing that port technology adoption is influenced by technological, organizational, and environmental conditions. Originally introduced by Tornatzky and Fleischer [27], the TOE framework explains technology adoption through three contextual conditions: technological readiness, organiza-

tional capability, and environmental pressure. Recently, the TOE framework has been applied in several studies like port digital transformation, smart port competitiveness, port community systems and the adoption of maritime technology [28–30]. The studies found that technology interoperability, Information and Communication Technology (ICT) integration, cyber security, port resources, managerial level support from ports and logistics service providers, operational structure of ports and policy supports with stakeholder pressures influence port digitalization. On the other hand, Nguyen [31] used TOE to illustrate that digital transformation in the maritime industry relies on technological innovations, but that is not sufficient without organizational readiness and external factors.

Based on the review and synthesis of previous studies using the Technology–Organization–Environment framework, smart port technology in this study is measured through three interrelated key dimensions: smart port technology utilization efficiency, smart port organizational management efficiency, and smart port external network connectivity. These TOE-based dimensions reflect the technological, organizational, and environmental contexts of smart port development. The TOE-based smart port technology indicators used as a mediator are presented in Table 2. These dimensions explain how smart port technology supports the transformation of ESG practices into improved sustainable port management.

Table 2. TOE-based smart port technology indicators as mediators.

Indicator ID	TOE-Indicator	Example Measurement Variables	References
ESG-T	Smart Port Technology Utilization Efficiency	1. Efficiency in using smart port equipment and systems. For example, quay cranes, Rubber-Tyred Gantry Crane (RTG), terminal operating systems, etc. 2. Application of automated systems for pollution detection, environmental monitoring, and surveillance in port operations.	Molavi et al. [11]; Yang et al. [12]; Iris & Lam [32]; Milošević et al. [33]; Yang, Y. C., & Hsieh, Y. H. [34]; Tsagkaris, P., and Moschovou, T. P. [35].
ESG-O	Smart Port Organizational Management Efficiency	1. Application of digital technology. For example, artificial intelligence, data analytics, processing, analyzing port operational data, etc. 2. Application of electronic office systems. For example, e-document systems to support administrative and internal workflow processes, etc.	Molavi et al. [11]; Jović et al. [28]; Wei and Hengsadeekul [29]; Nguyen [31].
ESG-E	Smart Port External Network Connectivity	1. Availability of digital platforms for exchanging and sharing information among port stakeholders. 2. Use of customs single window systems to support customs-related procedures. 3. Application of electronic transaction systems. For example, e-DO, e-payment, and e-booking, to facilitate external coordination and service delivery, etc.	Molavi et al. [11]; Yang et al. [12]; Wei and Hengsadeeku [29]; Thitanon [30]; Lucenti, I. C. [36].

In this study, the TOE framework is mainly used as a measurement base to structure smart port technology in terms of technological utilization, organizational management and external network connectivity. It is not used as an independent adoption model but as a theoretical lens to understand the technological, organizational and environmental factors of smart port technology in the proposed sustainability management model. Therefore, the proposed model remains primarily based on the ESG perspective, while the TOE framework is used to operationalize the smart port technology construct as an enabling mechanism within the ESG-driven sustainability management model.

2.4. Sustainable Port Management

Sustainable port management in this study refers to the outcome of ESG-driven and smart port-enabled management. This study moves beyond conventional port performance measures, including cargo throughput, operational efficiency, service quality, and financial returns, by focusing on sustainability-oriented performance indicators. It also shows the ability of ports to balance economic competitiveness, environmental responsibility, social contribution and governance quality. Therefore, sustainable port management is evaluated through two observable indicators: the realization of Sustainable Development Goals (SDGs) and the enhancement of sustainable port competitiveness.

The achievement of SDGs represents the contribution of port operations to achieving the SDGs [6]. According to Caliskan [37] identified the potential of linkages between the seaport sustainability initiatives and all the SDGs, with strong linkages to SDG 8, SDG 9, SDG 11, SDG 12, SDG 13 and SDG 17. Moreover, sustainable port development can support the implementation of SDGs through environmental protection, resource efficiency, climate action, stakeholder engagement, and sustainable maritime supply-chain management [38,39].

Sustainable port competitiveness enhancement refers to the ability of ports to strengthen their market and strategic positions through sustainable development. It is reflected in customer trust, growing port users, attractiveness to investors, business growth, revenue generation, profitability, stakeholder confidence, and national or international recognition. Sustainable port development can enhance the value of customer services, increasing the competitiveness, improving the economic contribution to the hinterland, and strengthening the competitiveness of the port in the long term [40–42].

2.5. Hypotheses Development and Conceptual Model

Based on the literature review, this study proposes that ESG practices function as managerial capabilities that enable sustainable port transformation and smart port technology is an operation-driven mechanism translating ESG oriented practices into sustainable performance in a port and terminal. The model is based on the assumption that the environmental, social, and governance port management dimensions are interrelated rather than independent areas of practice. Several previous studies have highlighted that environmental responsibility, social accountability, stakeholder participation, and governance quality should be considered as interconnected components of sustainable port management rather than separate dimensions [9,10,17,18]. Also, smart port technology can support sustainable port management through monitoring, coordination, decision-making, and sustainability-oriented operational outcomes [11–13].

The environmental port management dimension is expected to be associated with the social port management dimension because environmental responsibility often requires changes in operational routines, safety practices, employee awareness, stakeholder communication, and community-related practices. Ports that are proactive in managing emissions, waste, energy use, pollution, and climate risks are likely to pay greater attention to workplace safety, community impacts, and responsible operational practices. Based on prior studies on port sustainability, there are strong interconnections between the environmental port management dimension and social responsibility, stakeholder concerns, and community impacts in port areas [9,17,18].

H1. *The environmental port management dimension is positively associated with the social port management dimension (ENV → SOC).*

The social port management dimension is expected to be associated with the governance port management dimension because employee safety, human rights compliance, workforce development, non-discrimination, port security, and community engagement

require formal rules, accountability systems, stakeholder communication, and institutionalized decision-making. In ESG-based management, social responsibility is strongly linked to governance mechanisms such as stakeholder engagement, labor responsibility, and community accountability require formal policies, reporting systems, and ethical decision-making [9,10,19]. In this sense, social responsibility can contribute to improving the quality of governance by encouraging ports to formalize policies, improve their reporting and respond to stakeholder expectations.

H2. *The social port management dimension is positively associated with the governance port management dimension (SOC → GOV).*

The environmental port management dimension is also expected to be associated with the governance port management dimension because environmental management, pollution control, energy conservation, waste management, and climate-risk reduction require regulatory compliance, monitoring systems, risk management, reporting mechanisms, and managerial accountability. Hence, environmental responsibility in ports is not only a matter of port operational actions but also of institutional arrangements that ensure compliance, transparency, and continuous improvement [9,17,18]. Thus, ports with stronger environmental practices are likely to develop stronger governance systems to support environmental responsibility and long-term sustainability.

H3. *The environmental port management dimension is positively associated with the governance port management dimension (ENV → GOV).*

The environmental port management dimension is expected to be associated with smart port technology because environmental management requires digital monitoring, energy management systems, pollution detection systems, waste tracking, and data-driven environmental control.

H4. *The environmental port management dimension is positively associated with smart port technology (ENV → SMP).*

The social port management dimension is expected to be associated with smart port technology because workforce training, occupational safety, emergency response, port security, and community communication can be supported by digital platforms and smart systems.

H5. *The social port management dimension is positively associated with smart port technology (SOC → SMP).*

The governance port management dimension is expected to be associated with smart port technology because transparency, cybersecurity, data privacy, risk management, regulatory compliance, and strategic technology investment are important conditions for implementing smart port technology [11,12,29,31].

H6. *The governance port management dimension is positively associated with smart port technology (GOV → SMP).*

Smart port technology is expected to be associated with sustainable port management because digital systems, automation, data analytics, integrated platforms, and intelligent infrastructure can support operational efficiency, environmental monitoring, stakeholder coordination, transparency, and decision-making in ports. These capabilities ena-

ble ports to translate ESG practices into tangible sustainability outcomes, such as SDG contributions and sustainable port competitiveness. Previous studies have shown that smart port technologies and digital transformation can improve port efficiency, environmental management, stakeholder integration, and sustainable port management [11–13,43]. Sustainable port development is also closely related to SDG achievement and long-term port competitiveness [37–39,42].

H7. *Smart port technology is positively associated with sustainable port management (SMP → SUP).*

3. Data and Methods

3.1. Research Design

A quantitative survey design was used to obtain empirical data for testing the proposed sustainable port management model in the Thai port context. A cross-sectional survey approach was adopted to collect empirical perceptions from port practitioners at a single point in time [44] and to analyze the structural relationships among ESG practices, smart port technology, and sustainable port management. This design is suitable for examining a conceptual model with latent constructs and hypothesized structural relationships [14,15].

The research procedure consisted of three main stages: questionnaire development, data collection and analysis, and the development of the sustainable port management model. In the first stage, the questionnaire was developed based on ESG indicators, smart port technology indicators, and sustainable port management indicators derived from the literature. In the second stage, data were collected from port practitioners and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). In the final stage, the empirical results were used to develop an operational framework for sustainable port management in Thailand.

3.2. Population, Sample, and Data Collection

The population of this study consisted of 142 persons from top management, middle management, and operational management personnel working in container terminal operating companies. These respondents worked in departments directly involved in port operations, safety, and environmental management, as these departments are responsible for implementing environmental, social, and governance (ESG) practices in port operations. The population covered 19 container terminals operated by seven companies located in Laem Chabang Port and Bangkok Port, which are the two largest ports in Thailand. Because the research population was relatively small and clearly identifiable, this study employed an attempted census approach by distributing questionnaires to all 142 eligible practitioners. A total of 115 valid responses were obtained, representing a response rate of approximately 81.0%. This high response rate provided sufficient empirical coverage of the target population. The minimum sample size was calculated as 105 using Taro Yamane's [45] formula, assuming a 95% confidence level and a 5% margin of error. Therefore, the final dataset, consisting of 115 valid responses, exceeded the minimum sample size requirement and provided an adequate basis for statistical analysis. The respondent profile is presented in Section 3.3 to describe the empirical characteristics of the sample before model assessment.

3.3. Respondent Profile

This section presents the respondent profile of the research sample. There were 115 respondents from 19 container terminal operators (7 companies) in Thailand. Table 3 provides a summary of their information.

Table 3. Frequency and percentage of respondent information.

Respondent Information	Number	Percentage
Department of work		
Operation	98	85.2
Safety and Environment	11	9.6
Other (Top Management)	6	5.2
Position		
Top Management level	6	5.2
Middle Management level	34	29.6
Operational Management level	75	65.2
Education		
Below bachelor's Degree	11	9.6
Bachelor's Degree	64	55.7
Master's Degree	40	34.7
Doctorate's Degree	0	0
Working Experience		
0–5 Years	4	3.5
5–10 Years	22	19.1
Over 10 Years	89	77.4
Total	115	100.0

The respondent profile indicates that most respondents were directly involved in port operations. Most respondents worked in the operations department (85.2%) and held operational management positions (65.2%). In terms of experience, 77.4% had more than 10 years of working experience. These characteristics indicate that the respondents had sufficient practical knowledge to evaluate ESG practices, smart port technology, and sustainable port management in container terminal operations.

3.4. Questionnaire Development and Measurement

The questionnaire was developed based on the ESG indicator framework established in the authors' previous study on sustainable port management [10], together with relevant literature on smart port technology, the TOE framework, SDGs, and sustainable port competitiveness. The survey instrument was organized into two main parts. The first section was designed to gather respondents' background information, while the second section collected respondents' perceptions of the importance of indicators related to sustainable port management in Thailand. These indicators covered five main dimensions: environmental port management dimension, social port management dimension, governance port management dimension, smart port technology, and sustainable port management. The smart port technology construct was measured through three dimensions based on the TOE framework: smart port technology utilization efficiency, smart port organizational management efficiency, and smart port external network connectivity. Sustainable port management was measured through two outcome dimensions: the achievement of SDGs and the enhancement of sustainable port competitiveness.

A 7-point scale was used to gather respondents' opinions on the importance of each factor and indicator for sustainable port management in Thailand. This scale was selected because it allows respondents to express different degrees of perceived importance and

provides adequate sensitivity for measuring perceptions using multi-item latent constructs [46,47]. The questionnaire items used in the study are provided in Appendix A.

3.5. Data Analysis

PLS-SEM was applied as the main analytical technique to assess both the measurement properties and the structural paths of the proposed model. This method was selected because the proposed model included several latent variables, observed indicators, direct effects, indirect effects, and an enabling mechanism [15,48]. In addition to satisfying the sample size requirement based on Yamane's [45] formula, the sample size was considered acceptable for PLS-SEM because the largest number of structural paths directed at one endogenous construct was three, which satisfies the ten-times rule commonly used in PLS-SEM sample size assessment [15].

The data analysis was conducted in three steps. First, the measurement model was assessed using factor loadings, composite reliability, Cronbach's alpha, average variance extracted, and discriminant validity based on the Fornell–Larcker criterion. Second, the structural model was assessed using path coefficients, *t*-statistics, *p*-values, and coefficients of determination (R^2). Third, the indirect effects were examined to evaluate the enabling role of smart port technology in linking ESG-based port management with sustainable port management.

Because the study relied on self-reported survey data, several procedural controls were used during questionnaire administration to reduce the risk of common method bias. Respondents were informed that there were no correct or incorrect answers, and their opinions were collected anonymously and voluntarily. These procedures were intended to reduce evaluation apprehension and encourage respondents to provide accurate responses [49].

4. Results

4.1. Measurement Model Assessment

The measurement model was first evaluated to verify the adequacy of the indicators in measuring their associated latent constructs before the structural model was tested. The assessment included factor loadings, the composite reliability (CR), average variance extracted (AVE), Cronbach's alpha, discriminant validity based on the Fornell–Larcker criterion, and The Goodness of Fit (GoF).

Table 4 shows the factor loadings of the indicators obtained from the PLS-SEM analysis. The factor loadings were examined before assessing construct reliability and validity. Most indicators exceeded the recommended threshold of 0.708 [50], while SOC4 showed a lower but acceptable loading of 0.504. This indicator was retained because its loading remained above the minimum acceptable threshold of 0.50 and was theoretically relevant to the social sustainability dimension [50]. Therefore, all indicators were retained for further reliability and validity assessment.

Table 4. Factor loadings of measurement indicators.

ID	Indicator	Factor Loading				
		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
ENV1	Reduction in port-related GHG emissions	0.872				
ENV2	Air quality management within port areas	0.866				
ENV3	Oil spill from port operations	0.781				
ENV4	Noise impact control from port activities	0.738				
ENV5	Energy-saving capability in port operations	0.886				
ENV6	Operational waste management	0.818				

ENV7	Resource-use efficiency in port operations	0.858	
ENV8	Climate Risk Mitigation for Port Operations	0.862	
ENV9	Environmental Management in Port Operation	0.819	
SOC1	Occupational safety and health of port employees	0.828	
SOC2	Gender Diversity in Port Workforce	0.757	
SOC3	Human Rights Compliance in Port Labor Practices	0.790	
SOC4	Port Employee Turnover	0.504	
SOC5	Non-Discrimination Practices in Port Employment	0.776	
SOC6	Port Security Compliance	0.818	
SOC7	Port Social Contribution Impact	0.779	
SOC8	Port Training and Education Effectiveness	0.779	
SOC9	Port Community Engagement Mechanism	0.763	
GOV1	Port Financial Management Performance	0.863	
GOV2	Port Operational Management Performance	0.880	
GOV3	Diversity and Independence of Port Board Members	0.789	
GOV4	Ethics and Anti-Corruption in Port Management	0.855	
GOV5	Data Privacy Management in Port Operations	0.846	
GOV6	External Assurance in Port Management	0.815	
GOV7	Socioeconomic Compliance in Port operation	0.905	
GOV8	Emergency Preparedness in Port Operations	0.894	
GOV9	Port Innovation and Technology Advancement	0.752	
GOV10	Business risk management in port operations	0.861	
GOV11	Transparency in stakeholder communication	0.875	
ESG-T	Smart Port Technology Utilization Efficiency		0.946
ESG-O	Smart Port Organizational Management Efficiency		0.970
ESG-E	Smart Port External Network Connectivity		0.954
Y_SDG	The achievement of SDGs		0.951
Y_COM	Increase in sustainable port competitiveness		0.956

The reliability and convergent validity results of the measurement model are presented in Table 5. The composite reliability (CR) values ranged from 0.924 to 0.970, exceeding the recommended threshold of 0.70. Cronbach's alpha values ranged from 0.900 to 0.961, also exceeding the recommended threshold of 0.70 and indicating satisfactory internal consistency reliability. The average variance extracted (AVE) values ranged from 0.578 to 0.915, exceeding the recommended threshold of 0.50. These results indicate that the measurement model achieved adequate internal consistency reliability and convergent validity [50–52]. The Goodness of Fit (GoF) value was also calculated as an additional descriptive index of the overall model. The GoF value was 0.714, which exceeded the recommended threshold of 0.36 for a large effect size [53]. This result suggests that the proposed model had a high level of overall explanatory adequacy. However, the interpretation of the model primarily relied on the assessment of reliability, convergent validity, discriminant validity, and structural path significance rather than GoF alone.

Table 5. Reliability and convergent validity of the measurement model.

Dimension	CR	AVE	Cronbach's Alpha
ENV	0.954	0.696	0.945
SOC	0.924	0.578	0.906
GOV	0.966	0.722	0.961
SMP	0.970	0.915	0.954
SUP	0.952	0.909	0.900
Average	0.953	0.764	0.933

GoF is 0.714.

The cross-construct correlations based on the Fornell–Larcker criterion are presented in Table 6. The values on the diagonal (in bold) represent the square root of the Average Variance Extracted (AVE) for each factor and these values should be greater than its correlations with other latent variables in the model. Therefore, the results in Table 6 indicate that the measurement model has an acceptable level of discriminant validity [50,51].

Table 6. The cross-construct correlation (Fornell–Larcker criteria).

Dimension	ENV	SOC	GOV	SMP	SUP
ENV	0.835				
SOC	0.671	0.760			
GOV	0.693	0.743	0.850		
SMP	0.748	0.673	0.738	0.957	
SUP	0.674	0.692	0.736	0.825	0.954

4.2. Structural Model Assessment and Hypothesis Testing

The structural model was evaluated to test the hypothesized relationships among the constructs after the measurement model met the required reliability and validity criteria. The assessment focused on path coefficients, *t*-statistics, *p*-values, and coefficients of determination (R^2). The significance of the structural paths was evaluated using the bootstrapping procedure in PLS-SEM. A two-tailed test at the 0.05 significance level was applied, with *p*-values below 0.05 and *t*-statistics greater than or equal to 1.96 indicating statistically significant relationships [50].

The coefficient of determination (R^2) values were 0.450 for SOC, 0.620 for GOV, 0.659 for SMP, and 0.680 for SUP, with an average R^2 of 0.602. These findings indicate that the model explained 45.0% of the variance in the social port management dimension, 62.0% of the variance in the governance port management dimension, 65.9% of the variance in smart port technology, and 68.0% of the variance in sustainable port management. According to Chin's [54] criteria, R^2 values of 0.19, 0.33, and 0.67 can be interpreted as low, moderate, and high explanatory power for the variance. Therefore, the R^2 value obtained in this study suggests that the proposed model provides moderate to high explanatory power for sustainable port management in Thailand.

The structural equations of the proposed model can be expressed as follows:

$$\text{SOC} = 0.671\text{ENV}; R^2 = 0.450$$

$$\text{GOV} = 0.505\text{SOC} + 0.354\text{ENV}; R^2 = 0.620$$

$$\text{SMP} = 0.415\text{ENV} + 0.135\text{SOC} + 0.350\text{GOV}; R^2 = 0.659$$

$$\text{SUP} = 0.825\text{SMP}; R^2 = 0.680$$

Figure 1 presents the structural model results obtained from the PLS-SEM analysis. The model shows the relationships among the environmental port management dimension, the social port management dimension, the governance port management dimension, smart port technology, and sustainable port management.

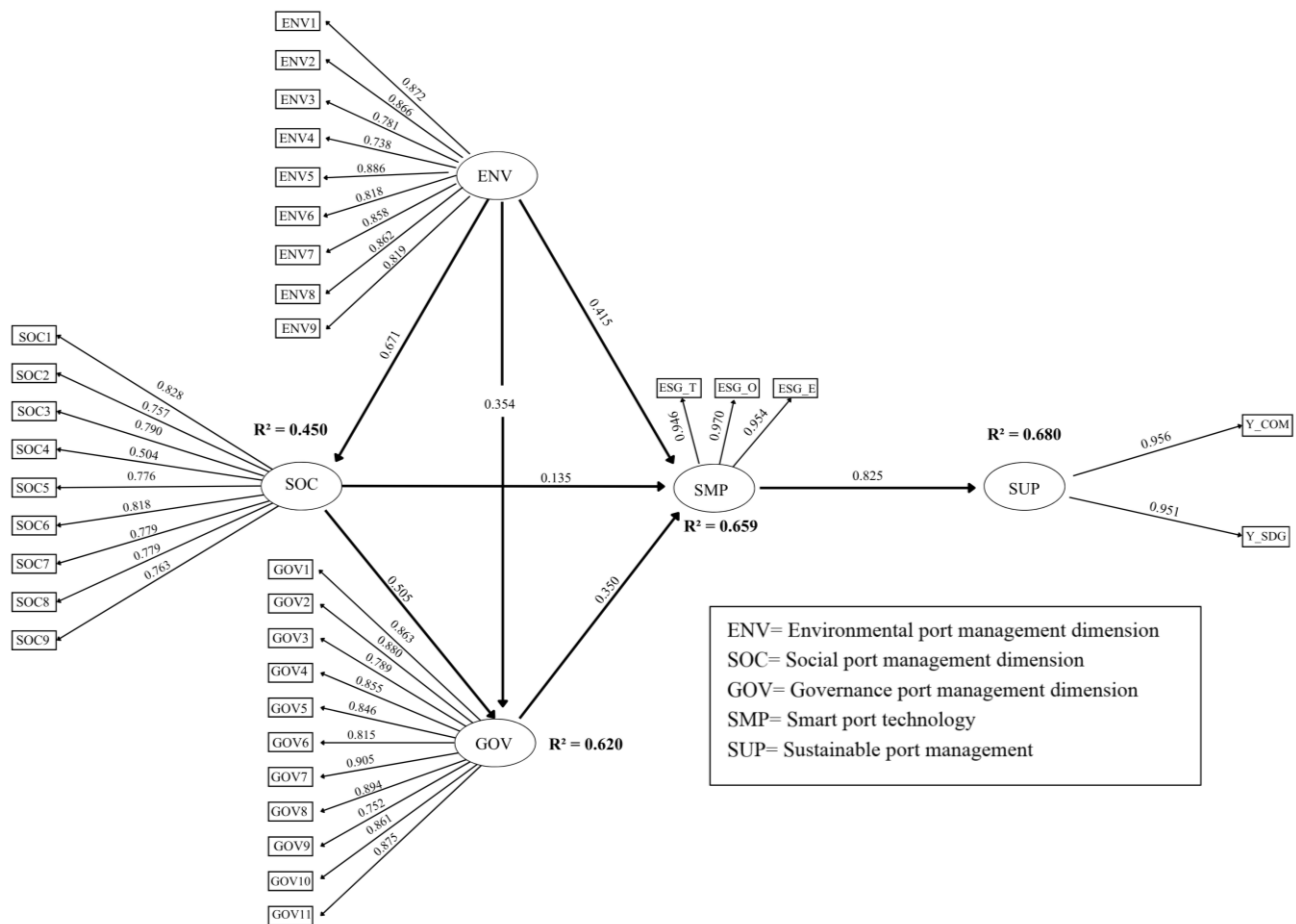


Figure 1. Sustainable port structural model results.

The results of hypothesis testing, including the path coefficients, *t*-statistics, and *p*-values obtained from the PLS-SEM analysis, are presented in Table 7. Overall, the analysis supported six of the seven proposed hypotheses, with only H5 failing to reach statistical significance. The indirect-effect results suggest that smart port technology serves as a practical mechanism through which environmental and governance-related port practices are converted into sustainability outcomes. However, the path from the social port management dimension to smart port technology was not statistically significant.

Table 7. Results of hypothesis testing.

Path	Path Coefficient	t-Test	<i>p</i> -Value	Results
H1: ENV → SOC	0.671	10.276	0.000	Supported
H2: SOC → GOV	0.505	5.309	0.000	Supported
H3: ENV → GOV	0.354	3.973	0.000	Supported
H4: ENV → SMP	0.415	4.984	0.000	Supported
H5: SOC → SMP	0.135	1.304	0.192	Not supported
H6: GOV → SMP	0.350	2.988	0.003	Supported
H7: SMP → SUP	0.825	22.624	0.000	Supported

4.3. Indirect Effects and Enabling Role of Smart Port Technology

The indirect effects were examined to evaluate the enabling role of smart port technology in linking ESG-based port management with sustainable port management. A two-tailed test at the 0.05 significance level was applied, with *t*-statistics greater than or equal to 1.96 and *p*-values below 0.05 indicating statistically significant indirect effects [50].

Table 8 presents the specific indirect effects of ESG practices on sustainable port management through smart port technology. The results show that the indirect effect of the environmental port management dimension on sustainable port management through smart port technology was positive and statistically significant ($\beta = 0.342$, $t = 5.008$, $p < 0.001$). The indirect effect of the governance port management dimension on sustainable port management through smart port technology was also positive and statistically significant ($\beta = 0.289$, $t = 2.910$, $p = 0.004$). However, the social port management dimension did not have a statistically significant indirect effect on sustainable port management through smart port technology ($\beta = 0.111$, $t = 1.304$, $p = 0.192$).

Table 8. Indirect effects through smart port technology.

Indirect Path	Indirect Effect	t-Test	p-Value	Result
ENV → SMP → SUP	0.342	5.008	0.000	Supported
SOC → SMP → SUP	0.111	1.304	0.192	Not supported
GOV → SMP → SUP	0.289	2.910	0.004	Supported

These findings suggest that smart port technology may function as an enabling mechanism linking the environmental and governance port management dimensions with sustainable port management. However, the social port management dimension was not indirectly associated with sustainable port management through smart port technology. This suggests that the social port management dimension may require stronger governance support or organizational readiness to be more closely linked to smart-port-enabled sustainability outcomes.

4.4. Operational Framework for Sustainable Port Management in Thailand

Based on the structural model results in Figure 1, the operational framework for sustainable port management in Thailand was developed as shown in Figure 2. The models suggest that the environmental, social, and governance port management dimensions should not be treated as separate activities. Instead, they should be managed as integral parts that support smart port technology and drive sustainable port management. The models indicate that the environmental port management dimension is the first operational foundation. The social and governance port management dimensions strengthen institutional readiness and smart port technology functions as an enabling mechanism for linking ESG practices with measurable sustainability outcomes.

Figure 2 provides an operational framework for sustainable port management, which could serve as a pathway for Thai ports. Ports should focus on improving the environment first, then improving social and governance port management systems, using smart port technology as an enabling mechanism, and monitoring sustainable port management in terms of SDG contributions and enhancing competitiveness.

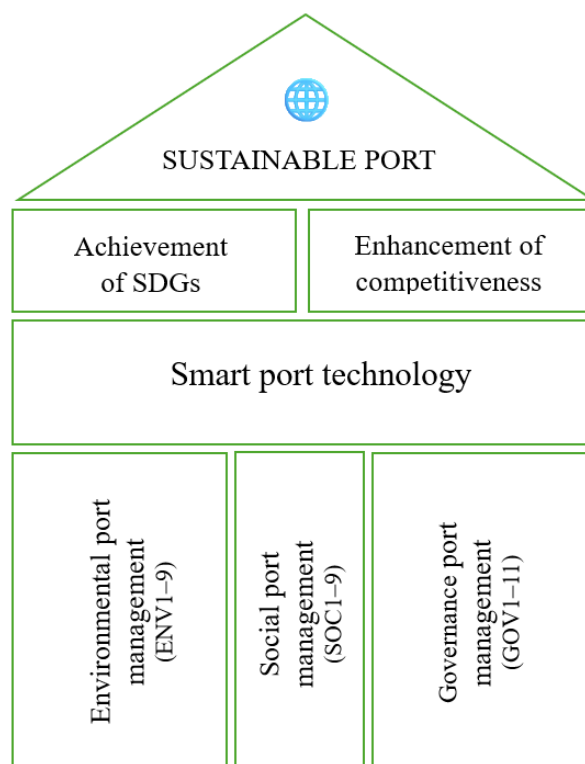


Figure 2. Operational framework for sustainable port management in Thailand.

The environmental port management dimension plays a central role in the implementation process and has a positive effect on the social port management dimension, the governance port management dimension, and smart port technology. In terms of operational management, this means that Thai ports may begin sustainable port development by improving practical environmental actions, such as greenhouse gas reduction, air quality control, energy conservation, waste management, resource efficiency, environmental management, and climate risk mitigation. In addition to reducing environmental impacts, it is also important to build safer working conditions, improve regulatory compliance, and develop more systematic port management.

The social port management dimension is a supporting practice for sustainable port management. Figure 1 indicates that the social port management dimension has a significant effect on the governance port management dimension, but its direct influence on smart port technology is not supported. This finding suggests that social issues within the social port management dimension, such as employee safety and health, training and education, human-rights compliance, non-discrimination, port security, and community engagement, are important to the human and stakeholder foundation of port sustainability. However, these practices may not directly lead to smart-port-technology-enabled sustainable port management outcomes unless they are supported by good governance systems.

The governance port management dimension provides the institutional framework that helps translate ESG practices into operational management. Figure 1 indicates that the governance port management dimension has a significant effect on smart port technology. This implies that transparency, ethical management, anti-corruption, data privacy, emergency preparedness, risk management, innovation, and stakeholder communication are necessary conditions for implementing smart port technology. In practice, governance determines how data are collected, how decisions are made, how risks are controlled, and how technology investment is prioritized.

In the proposed model, smart port technology is positioned as a mediating variable that enables ESG practices to be implemented more effectively. The strong association be-

tween smart port technology and sustainable port management suggests that ESG practices may have greater practical value when supported by smart port technology, such as automation, digital platforms, and intelligent systems.

Finally, a sustainable port management performance assessment should be carried out from the perspective of sustainability and competitiveness. The models in Figures 1 and 2 define sustainable port management through the achievement of SDGs and the enhancement of sustainable port competitiveness. This implies that port performance should not be evaluated only by cargo throughput, service speed, or financial return. It should also consider whether port activities contribute to SDGs, increase customer confidence, attract port customers and investors, drive business growth, improve profitability, enhance stakeholder confidence, and improve national or international standing in the long term. Thus, the value of the model's implementation is its ability to connect policy-level sustainability with operational practices and performance.

5. Discussion

The findings support the proposed sustainability management framework for Thai ports, which is based on ESG as the foundation and smart port technology as a mediating mechanism. The model had moderately high explanatory power with an average R^2 of 0.602, and six of the seven hypotheses were supported. This suggests that the environmental, social, and governance port management dimensions are important to the development of sustainable port management. However, their contribution to sustainable port management may depend substantially on the enabling role of smart port technology.

One important finding is the strong association between smart port technology and sustainable port management, with a path coefficient of 0.825. The indirect effect results also show that smart port technology significantly links the environmental port management dimension and the governance port management dimension with sustainable port management. The indirect effect of the environmental port management dimension on sustainable port management through smart port technology was significant ($\beta = 0.342$, $t = 5.008$, $p < 0.001$), and the indirect effect of the governance port management dimension on sustainable port management through smart port technology was also significant ($\beta = 0.289$, $t = 2.910$, $p = 0.004$). The results suggest that advanced technologies and digital systems may support ESG implementation through real-time environmental monitoring, AI-based energy management, automation, data analytics, digital documentation, stakeholder information-sharing platforms, and electronic transaction systems [11,12,32,33]. This is consistent with Othman, El-Gazzar, and Knez [13], who found that smart port practices and technology applications play a role in improving sustainable port performance along three dimensions: economic, social, and environmental dimensions. It also aligns with Behdani [43], who proposed that Port 4.0 and advanced digital technologies can improve operational efficiency and support port sustainability.

The findings also show that the environmental port management dimension plays an important role in the model. This dimension significantly influences the social port management dimension, the governance port management dimension, and smart port technology. This suggests that the environmental port management dimension may serve as an initial operational foundation for sustainable port development [18]. The governance port management dimension was significantly associated with smart port technology, suggesting that technological transformation in ports may require strong governance and institutional readiness to support smart port technology implementation [28,31]. Such governance readiness may also support sustainability, accountability, and long-term competitiveness.

Although the social port management dimension showed a stronger direct association with the governance port management dimension than the environmental port man-

agement dimension, the overall structural model suggests that the environmental port management dimension plays a broader foundational role because it is significantly associated with the social port management dimension, the governance port management dimension, and smart port technology. This finding implies that environmental concerns may act as an initial operational driver of ESG-based port management, while social issues may contribute to sustainable port management more indirectly through governance-related mechanisms.

However, the path from the social port management dimension to smart port technology was not statistically supported. This does not mean that the social dimension is unimportant; rather, it suggests that, in the Thai port context, technology adoption may be driven more by environmental pressure and governance requirements than by the social port management dimension alone. The indirect effect from the social port management dimension to sustainable port management through smart port technology was also not statistically significant ($\beta = 0.111$, $t = 1.304$, $p = 0.192$). This result suggests that the social port management dimension may require stronger governance support, organizational readiness, and digital capability before it becomes more closely linked to smart-port-enabled sustainability outcomes, as prior studies indicate that port digitalization and smart port development depend on organizational readiness, managerial support, policy support, digital skills, and employee technology readiness [29,31,55].

The measurement results showed that SOC4 (port employee turnover) in the social port management dimension had the lowest factor loading among the social indicators at 0.504. This suggests that employee turnover may not yet be perceived as a strong indicator of social sustainability compared with more visible indicators such as employee safety and health, training and education, and community engagement. However, employee turnover remains relevant to workforce stability and organizational sustainability, and future studies may reconsider this indicator in relation to employment structure. In addition, this indicator was retained in the model because its factor loading remained above the minimum acceptable threshold of 0.50, which can be considered acceptable in exploratory or theory-building research when the indicator is theoretically relevant [50].

The originality of this study lies in extending ESG-based port sustainability research from indicator identification to empirical model testing in the Thai port context. Previous studies have often examined ESG indicators, green port practices, or smart port technologies as separate research streams, whereas this study integrates ESG port management dimensions and smart port technology into a single structural model. The findings provide empirical evidence that smart port technology can function as an enabling mechanism linking ESG-based port management with sustainable port management outcomes. For Thai ports, the model provides practical guidance for prioritizing environmental management, governance readiness, and smart port technology investment to support SDG achievement and long-term competitiveness.

Overall, the results extend previous ESG indicator development by empirically testing the contribution of ESG practices to sustainable port management through smart port technology. The findings show that sustainable port management should not be treated as separate environmental, social, and governance activities. ESG practices should be integrated with smart port technology to achieve SDGs [38,39] and improve the long-term competitiveness [40–42] of Thai ports. This study makes a significant contribution by empirically demonstrating that smart port technology can function as a mechanism to translate ESG practices into sustainable port management outcomes. This finding extends the identification of indicators to the empirical validation of how ESG practices operate within a smart-port-enabled sustainability model, building on previous ESG indicator-based studies. The findings can be used as a practical guide for Thai port operators and policy-

makers in prioritizing environmental and governance practices and investment in smart port technology to enhance port sustainability and competitiveness.

6. Conclusions

This study developed and empirically tested an ESG-driven and smart-port-enabled sustainability management model for Thai ports. The survey results from 115 practitioners from container terminals indicate significant relationships among ESG port management dimensions, smart port technology, and sustainable port management. The environmental port management dimension is an important foundation of the social port management dimension, the governance port management dimension, and smart port technology, while smart port technology has a positive effect on sustainable port management.

In relation to the research questions, the findings show that ESG practices are associated with smart port technology mainly through the environmental and governance port management dimensions. Smart port technology is also strongly associated with sustainable port management and functions as an enabling mechanism linking the environmental and governance port management dimensions with sustainable port management. However, the relationship between the social port management dimension and smart port technology was not statistically supported, suggesting that social issues may require stronger governance support and organizational readiness before they become closely linked to smart-port-enabled sustainability outcomes.

The study contributes to the port sustainability literature by extending ESG-based indicator development toward empirical model testing in the Thai port context. From a practical and policy perspective, the proposed model provides several implications for Thai port operators and policymakers. First, port authorities and terminal operators should treat the environmental port management dimension as an initial policy priority because it is associated with the social port management dimension, the governance port management dimension, and smart port technology. Policy actions may include setting measurable targets for greenhouse gas reduction, air quality management, energy conservation, waste management, resource-use efficiency, and climate-risk mitigation in port operations. These targets should be integrated into port development plans and monitored through digital systems to ensure that environmental policies can be translated into operational practices.

Second, the findings suggest that governance readiness should be strengthened before or alongside smart port investment. Policymakers and port managers should develop clear governance mechanisms for data privacy, cybersecurity, risk management, transparency, emergency preparedness, and stakeholder communication. These mechanisms are important because smart port technology requires reliable data, accountable decision-making, and institutional support. In practice, smart port investment should not focus only on purchasing equipment or digital platforms, but should also include governance rules, staff training, data-sharing protocols, and coordination mechanisms among port authorities, terminal operators, government agencies, shipping lines, and other stakeholders. Third, although the direct relationship between the social port management dimension and smart port technology was not statistically supported, social issues should not be excluded from policy planning. Instead, social policies related to occupational safety, workforce training, port security, non-discrimination, and community engagement should be linked more closely with governance systems and digital platforms. This would help ensure that smart port development supports not only operational efficiency and competitiveness, but also broader sustainability outcomes, including SDG achievement, stakeholder confidence, and long-term sustainable port competitiveness.

This study has several limitations. First, the data were based on self-reported perceptions from port practitioners; therefore, some respondents, particularly lower-level em-

ployees, may have provided cautious or socially desirable answers to sensitive questions related to governance, social responsibility, or organizational practices. Second, the study focused on container terminal operators in Thailand; therefore, the findings may not fully represent other types of ports or terminals. Future research should extend the scope of the study to other types of terminals, including multipurpose terminals and bulk cargo terminals, as well as major ports in other regions of Thailand, such as Songkhla Port and Ranong Port. Such an extension would increase the comprehensiveness of the model and improve its ability to explain sustainable port management at the national level.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Human Research Ethics Committee of Burapha University (protocol code Approval No. IRB4-415/2568 and date of approval 9 December 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical considerations.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ESG	Environmental, Social and Governance
SDGs	Sustainable Development Goals
ENV	Environmental port management dimension
SOC	Social port management dimension
GOV	Governance port management dimension
SMP	Smart port technology
SUP	Sustainable port management
ICT	Information and Communication Technology
TOE	Technology–Organization–Environment

Appendix A

Research Questionnaire

Sustainability Management Model for Thai Ports: An ESG-Driven and Smart-Port-Enabled SEM Study

1. Objectives

1 To identify the indicators and examine the relationships among the environmental, social, and governance port management dimensions and sustainable port management in Thailand.

2 To develop a sustainable port management model for Thailand.

2. Structure of the Questionnaire: This questionnaire consists of three sections, as follows:

Section 1: General Information of the Respondents

Instructions: Please read each question carefully and provide the required information in the blank spaces. Please also tick (✓) the box that corresponds to your information.

Section 2: Importance Level and Port Management Practices Based on Environmental, Social, and Governance (ESG) Indicators. This section contains questions regarding the level of importance and the implementation of port management based on environmental, social, and governance (ESG) indicators. Please tick (✓) the box that best reflects your opinion regarding the importance of each indicator, using a 7-point rating scale from 7 to 1, as described below:

7 means that the environmental, social, and governance indicators in port management are extremely high importance.

6 means that the environmental, social, and governance indicators in port management are high importance.

5 means that the environmental, social, and governance indicators in port management are slightly high importance.

4 means that the environmental, social, and governance indicators in port management are of moderate importance.

3 means that the environmental, social, and governance indicators in port management are slightly low importance.

2 means that the environmental, social, and governance indicators in port management are low importance.

1 means that the environmental, social, and governance indicators in port management are the lowest importance.

Section 3: Related Suggestions

Instructions: If you have any related suggestions, please write your comments in the suggestion box provided.

The researcher would like to sincerely thank you for your kindness in taking the time to provide your opinions and valuable suggestions, which will be beneficial to this research.

Researcher Team

Section 1: General Information of the Respondents

1 Position Level

- ☐ First-line management
- ☐ Middle management
- ☐ Top management
- ☐ Others: _____

2 Educational Level

- ☐ Below bachelor's degree
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ Doctoral degree

3 Work Experience

- ☐ 0–5 years
☐ 5–10 years
☐ More than 10 years

4 Department/Division

- ☐ Marine Operations Department
☐ Safety Management Department
☐ Others: _____

5 Port/Terminal Where You Work _____

Section 2: Sustainable Port Management Indicators from the Perspective of Shipping Lines

Please tick (✓) the box that best represents your opinion regarding the importance of sustainable port management indicators based on the Environmental, Social, and Governance (ESG) framework.

ESG Indicator	Level of Importance						
	Lowest 1	Low 2	Slightly Low 3	Moderate 4	Slightly High 5	High 6	Extremely High 7
ENV – Environmental port management dimension							
Please tick (✓) the box that best reflects your opinion regarding the importance of environmental indicators in port management, using a 7-point rating scale from 7 to 1.							
ENV1 Reduction in port-related GHG emissions (e.g., CO ₂ emissions and other greenhouse gas emissions)							
ENV2 Air quality management within port areas (e.g., PM _{2.5} concentration and the number of days when air quality exceeds the standard)							
ENV3 Oil spill from port operations (e.g., the number of oil spill incidents and the volume of oil spilled)							
ENV4 Noise impact control from port activities (e.g., noise levels from port operations and community complaints regarding noise problems)							
ENV5 Energy-saving capability in port operations (e.g., energy consumption per cargo throughput and energy-saving rate)							
ENV6 Operational waste management (e.g., the number of incidents involving illegal waste discharge into the sea and the number of waste/garbage disposal points within the port)							
ENV7 Resource-use efficiency in port operations (e.g., water reuse and waste recycling rate)							
ENV8 Climate Risk Mitigation for Port Operations (e.g., investment in climate-resilient infrastructure and climate risk response plans)							
ENV9 Environmental Management in Port Operation (e.g., environmental policy implementation and ISO 14001 certification [56])							
SOC – Social port management dimension							
Please tick (✓) the box that best reflects your opinion regarding the importance of social indicators in port management, using a 7-point rating scale from 7 to 1.							
SOC1 Occupational safety and health of port employees (e.g., the number of accidents, the use of personal protective equipment (PPE), and employee health check-ups)							
SOC2 Gender Diversity in Port Workforce (e.g., the proportion of female employees, the proportion of female supervisors, and gender diversity policies)							
SOC3 Human Rights Compliance in Port Labor Practices (e.g., complaints related to human rights violations and human rights policies)							
SOC4 Port Employee Turnover							

(e.g., employee turnover rate and the proportion of newly recruited employees)

SOC5 Non-Discrimination Practices in Port Employment
(e.g., complaints related to discrimination and diversity in employment)

SOC6 Port Security Compliance
(e.g., compliance with ISPS Code requirements and cybersecurity threat incidents)

SOC7 Port Social Contribution Impact
(e.g., the number of CSR projects and the number of local employment opportunities created)

SOC8 Port Training and Education Effectiveness
(e.g., employee training hours and employee skill development programs)

SOC9 Mechanisms for port-community engagement
(e.g., local community engagement activities and community satisfaction scores)

GOV—Governance port management dimension

Please tick (✓) the box that best reflects your opinion regarding the importance of governance indicators in port management, using a 7-point rating scale from 7 to 1.

GOV1 Port Financial Management Performance
(e.g., debt-to-asset ratio and transparent disclosure of financial information)

GOV2 Port Operational Management Performance
(e.g., berth occupancy rate, average vessel turnaround time, and container throughput)

GOV3 Diversity and Independence of Port Board Members
(e.g., the percentage of independent board members and the percentage of female board members)

GOV4 Ethics and Anti-Corruption in Port Management
(e.g., the number of reported fraud and ethical misconduct cases and the existence of anti-corruption policies)

GOV5 Data Privacy Management in Port Operations
(e.g., the number of data breaches or privacy-related incidents under the Personal Data Protection Act (PDPA) and the existence of personal data protection policies)

GOV6 External Assurance in Port Management
(e.g., certification or verification by external organizations, such as ISO certification and licensed auditors)

GOV7 Socioeconomic Compliance in Port operation
(e.g., the number of violations of labor-related laws and the amount of fines related to legal non-compliance)

GOV8 Emergency Preparedness in Port Operations
(e.g., the existence of an up-to-date emergency response plan and the percentage of port personnel trained in emergency response)

GOV9 Port Innovation and Technology Advancement
(e.g., the number of innovation and technology projects and the budget allocated for innovation and technology development)

GOV10 Business risk management in port operations
(e.g., the existence of an enterprise risk management (ERM) system and the identification and assessment of business risks)

GOV11 Transparency in stakeholder communication
(e.g., the existence of policies promoting stakeholder engagement and public information disclosure)

Smart Port Technology Indicators

Please tick (✓) the box that best reflects your opinion regarding the importance of the following smart-port technology indicators in supporting sustainable port management, using a 7-point rating scale from 7 to 1.

ESG-T Smart Port Technology Utilization Efficiency
(e.g., the efficiency of technology utilization in quay cranes, rubber-tired gantry cranes (RTGs), and terminal operating systems (TOS), as well as the use of automated systems for pollution detection)

ESG-O Smart Port Organizational Management Efficiency (e.g., the use of technology for data storage, the application of artificial intelligence (AI) and data analytics for data analysis and processing, and the use of electronic office systems to support documentation and administrative work, such as e-document systems)

ESG-E Smart Port External Network Connectivity (e.g., the availability of digital platforms for data exchange and information sharing among stakeholders, the use of Customs Single Window systems for customs procedures, and the implementation of electronic transactions such as e-DO, e-payment, and e-booking)

Sustainable Port Management

Please tick (✓) the box that best reflects your opinion regarding the importance of the following indicators in reflecting sustainable port management, using a 7-point rating scale from 7 to 1.

Y1 Y1 Contribution to the realization of the Sustainable Development Goals (SDGs) (e.g., contribution to the achievement of the SDGs)

Y2 the enhancement of sustainable port competitiveness (e.g., increased profitability and an increase in the number of customers or terminal users)

Section 3: Additional Suggestions or Comments (if any)

Please provide any additional suggestions or comments related to sustainable port management indicators, if any.

The researcher would like to sincerely thank you for your time and kind cooperation in completing this questionnaire.

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