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Sustainability Risk Model for Shipping Business Management in Thailand

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ABSTRACT

The shipping industry is an essential business factor of global trade, supporting the cargo movement in maritime shipping that is driving the world's economy. Therefore, sustainability and risk management need to improve the critical business approach toward sustainable business. This research aims to develop a sustainability risk model for shipping business management in Thailand. Structural equation modelling (SEM) is applied to create this model using the PLS method. The relationship and model findings are the sustainability risk for shipping management, three factors including Environmental, Societal, and Technological factors, a total of 10 indicators of sustainability risk that need to improve in 10 years, and the relationship of factors and indicators to confirm the shipping business sustainability. This model presents guideline concepts for the operation and implication planning for developing the sustainable shipping business and international standards. To operationalize the proposed framework, the indicators were defined as observable risk items and evaluated through a questionnaire-based assessment of shipping practitioners and managers in Thailand. PLS-SEM was used to examine measurement quality (reliability and validity) and to test the hypothesised effects among Environmental, Societal, and Technological factors. The validated model helps identify high-priority sustainability risks and supports decision-making for mitigation, capability development, and monitoring over the next decade.

Keywords: Sustainability Development; Sustainability Risk Factors; Sustainability Risk Indicators; Shipping Business

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1. Introduction

In recent years, the global risk landscape has become increasingly complex. Economic downturns, geopolitical tensions, public-health emergencies, cyber threats, and climate-related disasters have combined to create pervasive uncertainty for businesses and societies worldwide. These intertwined risks generate shocks that can disrupt production, trade, employment, and critical infrastructure, while also amplifying environmental and social vulnerabilities. As a result, sustainability is no longer viewed only as a long-term development goal; it has also become a strategic perspective for understanding and managing risks that cut across economic, environmental, and social dimensions over the long run.

Maritime transport is at the core of this discussion because over 80% of world trade by volume is carried by sea, and seaborne trade is projected to continue growing in the period 2024–2028 [1–3].The COVID-19 pandemic, supply-chain disruptions, and recent security incidents in key shipping lanes have demonstrated how quickly shocks can propagate through maritime networks, increasing transport costs, delaying cargo flows, and exposing vulnerabilities in global logistics systems [4]. At the same time, greenhouse-gas emissions from international shipping have risen, contributing to global climate change and leading to stricter regulatory and stakeholder pressure on the sector [4]. Recent empirical research shows that maritime security threats—such as piracy and oil theft—can raise logistics costs, erode investor confidence, and weaken the role of seaports as reliable trade gateways, thereby constraining blue-economy development and highlighting the close link between sustainability-related risks in shipping and broader economic outcomes [5]. Taken together, these developments highlight the need to understand sustainability risks in the shipping business in a more systematic way.

Against this global backdrop, Thailand's shipping industry faces similar sustainability challenges while playing a strategic role in the national economy. The Thai-owned fleet comprises 376 vessels with a total deadweight tonnage of 4,283,955 for vessels of 500 gross tonnage and above, and the total number of shipowners is approximately 95 companies [6], which indicates that the shipping business is essential to Thailand's trade competitiveness. However, Thai shipowners and ships are directly exposed to global and sustainability-related risks, and Thailand still lacks academic studies that systematically investigate these risks from the perspective of the shipping business. Existing research in the Thai maritime sector has concentrated mainly on port sustainability and smart-port development, while comparatively little attention has been given to sustainability risk in shipping companies themselves. Consequently, there is no practical tool to support planning and decision-making for sustainability risk management in the Thai shipping business. To address this gap, the present study develops a sustainability risk management model for the Thai shipping business that is aligned with international standards and global risk agendas, with the aim of supporting more resilient and sustainable shipping operations in Thailand.

1.1. Literature Review

1.1.1. Sustainability Risk Management

In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [7]. In this study, sustainability refers to balancing environmental, economic, and social objectives across generations so that development in one dimension does not occur at the expense of the others [8].

Risk is commonly defined as the "effect of uncertainty on objectives", emphasising how incomplete knowledge about events or circumstances can affect organisational decision-making and performance [9]. Building on this, the World Economic Forum (WEF) defines a "global risk" as the possibility that an event or condition will occur and negatively affect a significant proportion of global GDP, population, or natural resources [10]. These definitions highlight that sustainability and risk are closely related: sustainability provides a long-term strategic lens for identifying, assessing, and mitigating risks that span environmental, economic, and social dimensions [11].

In the shipping business, sustainability risk management therefore involves integrating sustainable development principles into risk management processes so that shipping companies can anticipate and manage environmental, technological, and societal risks that may threaten their long-term viability and performance.

1.1.2. Sustainability Risk Factors and Indicators

Global risk assessments provide an important basis for identifying sustainability-related risk factors. Each year, the WEF Global Risks Report surveys experts from business, government, civil society, and academia to identify the most critical global risks in terms of both impact and likelihood [12]. Over the past decade, these rankings have shifted away from primarily economic risks towards risks that are environmental, technological, and societal in nature—such as extreme weather events, biodiversity loss, natural resource shortages, cyber insecurity, and social polarisation [12–14].

Table 1 summarises the top 10 global risks ranked by expected impact over a ten-year period for 2022–2025. These risks can be grouped into three broad categories: Environmental, Technological, and Societal. This categorisation is directly relevant to the present study because it provides the conceptual basis for the three sustainability risk factors used in our shipping framework: the environmental risk factor (ENV), the technological risk factor (TEC), and the societal risk factor (SOC). In other words, the global risks identified by the WEF are translated into sustainability risk indicators that capture how environmental, technological, and societal pressures manifest in the shipping business.

Table 1. Top 10th Global risks ranked by impact over 10-year for the year 2022–2025.

Global Risks Ranked	Global Risks			
	2022	2023	2024	2025
1st	Climate action failure	Failure to mitigate climate change	Extreme weather events	Extreme weather events
2nd	Extreme weather	Failure of climate-change adaptation	Critical change to Earth systems	Biodiversity loss and ecosystem collapse
3rd	Biodiversity loss	Natural disasters and extreme weather events	Biodiversity loss and ecosystem collapse	Critical change to Earth systems
4th	Social cohesion erosion	Biodiversity loss and ecosystem collapse	Natural resource shortages	Natural resource shortages
5th	Livelihood crises	Large-scale involuntary migration	Misinformation and disinformation	Misinformation and disinformation
6th	Infectious diseases	Natural resource crises	Adverse outcomes of AI technologies	Adverse outcomes of AI technologies
7th	Human environmental damage	Erosion of social cohesion and societal polarization	Involuntary migration	Inequality
8th	Natural resource crises	Widespread cybercrime and cyber insecurity	Cyber insecurity	Societal polarization
9th	Debt crises	Geoeconomic confrontation	Societal polarization	Cyber espionage and warfare
10th	Geoeconomic confrontation	Large-scale environmental damage incidents	Pollution	Pollution

Source: World Economic Forum [10,12–14].

The United Nations Sustainable Development Goals (SDGs) further emphasise the need to address these risks in an integrated way. Several SDGs are closely connected to maritime transport and the shipping sector, particularly those related to decent work and economic growth (SDG 8), industry, innovation, and infrastructure (SDG 9), climate action (SDG 13), and life below water (SDG 14) [15]. Aligning sustainability risk factors with these goals helps ensure that risk management in the shipping business supports broader global efforts to reduce environmental, technological, and societal vulnerabilities.

1.1.3. Sustainability Risk in Shipping Business

The International Maritime Organization (IMO), as the United Nations specialised agency responsible for global standards on the safety, security and environmental performance of international shipping, also plays an important role in supporting the implementation of the Sustainable Development Goals (SDGs). Through its regulatory work on ship safety, pollution prevention, seafarer training and labour standards, and energy efficiency, IMO links the shipping sector most directly to SDGs Goal 8: IMO addresses issues related to seafarers' health and welfare, recognizing seafaring as an important source of employment, particularly in developing countries. Goal 9: IMO facilitates technological advances in shipping, such as autonomous ships and developments in the port sector, which contribute to global stability and sustainable development Goal 13: IMO develops measures to control greenhouse gas emissions from the shipping sector, aligning with the goals of the Paris Agreement. Goal 14: IMO implements global measures to prevent pollution from ships, playing a crucial role in achieving SDG 14 targets, which focus on decent work and economic growth, industry and infrastructure, climate action, and life below water [15]. These regulatory expectations frame many of the sustainability-related risks faced by shipping companies, including environmental risks (e.g., emissions and marine pollution), technological risks (e.g., compliance with new technologies and digital standards) and societal risks (e.g., seafarer welfare and human-rights protection).

Because shipping companies operate globally and are exposed to multiple external pressures, they face sustainability risks that cut across environmental, technological, and societal dimensions. A growing body of research has examined how such risks arise in maritime transport and how they can be managed through sustainable practices, regulations, and organisational capabilities [16]. Some studies highlight the benefits of green and sustainable solutions in maritime transport for improving both environmental outcomes and logistics performance [16]. Marine spatial planning has also been linked to the achievement of SDG 14 targets and indicators [17], and sustainability reporting has been used to align shipping companies with broader SDG responsibilities and collaborations along the maritime value chain [18].

Environmental risks. Environmental sustainability risks in shipping are associated with air emissions, marine pollution, and impacts on marine ecosystems. Koilo [19] highlights that shipping companies face sustainability risks from air and water pollution, climate-related regulatory changes, and the high costs of technical modifications required to meet environmental standards. Hasanspahić et al. [20] emphasise that modern shipping must address issues such as greenhouse-gas emissions, sulphur and particulate pollution, and waste management to remain environmentally sustainable. Beyond air emissions, ballast-water management and the discharge of hazardous substances are critical environmental risk issues. Onyena and Nwaogbe [21] provide a concrete example by assessing water quality and heavy-metal contamination in ballast water discharged by ships, showing that elevated levels of metals such as mercury and lead pose serious threats to marine ecosystems and human health when ballast water is not properly managed. These findings reinforce the need for shipping companies to comply strictly with international environmental regulations (e.g., MARPOL and the Ballast Water Management Convention) and to implement proactive measures to prevent and respond to pollution incidents.

Technological risks. Technological change and digitalisation create new forms of sustainability risk for shipping. Modern ships and ports rely on integrated information and communication systems for navigation, cargo handling, and logistics coordination. While such systems can improve efficiency, they also introduce vulnerabilities related to cyber security, data integrity, and system reliability. Empirical work on maritime cyber security shows that cyber incidents can disrupt ship operations, compromise safety, and lead to significant financial losses, for example, through ransomware attacks, manipulation of navigation data, or unauthorised access to cargo documentation [22]. Harish et al. [23] provide a decade-long review of maritime cyber security research and show how the sector has moved from awareness-raising and conceptual discussions towards detailed analyses of attack vectors, risk-assessment methods, and regulatory responses. Their review illustrates that cyber security is now recognised as a core strategic risk for sustainable shipping, given its implications for safety, operational continuity, and stakeholder trust. In the present study, these insights inform the technological sustainability risk indicators, which include cyber-related risks, system failures, and challenges associated with digital technologies and autonomous ship operations.

Societal risks. Societal sustainability risks in shipping relate to seafarers' working and living conditions, human rights, social cohesion on board, and relationships with coastal communities. Research has documented that long working hours, limited shore leave, inadequate welfare provisions, and poor safety culture can lead to fatigue, accidents, and mental-health problems among seafarers, with knock-on effects on safety and operational reliability [20]. Inequality and discrimination on board—based on nationality, rank, or other characteristics—can further undermine crew cohesion and well-being. Kakon et al. [24] examine factors influencing seafarers' human-rights preservation on board and identify critical dimensions such as physical and working conditions, employment terms and social welfare, health and safety, crew well-being and social support, and the enforcement of regulations. Their findings show that inadequate protection of seafarers' rights can create sustainability risks by increasing the likelihood of labour disputes, staff turnover, and reputational damage for shipping companies. These societal issues are reflected in the SOC sustainability risk indicators used in this study, which cover seafarer welfare, human rights, social inequality, and broader social pressures such as involuntary migration and human trafficking.

Taken together, the literature indicates that sustainability risk in the shipping business is multi-dimensional and deeply embedded in global risk trends. Environmental risks include emissions, climate-related regulations, and pollution from operations such as ballast-water discharge [19–21]; technological risks involve cyber insecurity, digital-system failures, and challenges associated with emerging technologies [22,23]; and societal risks encompass human-rights concerns, inequality on board, and broader social pressures affecting seafarers and communities [20,24]. The present study builds on these insights by integrating the various risk types into three sustainability risk factors—Environmental (ENV), Technological (TEC), and Societal (SOC)—and by developing a set of sustainability risk indicators for each factor.

2. Methodology

2.1. Data Population, Collection, and Questionnaire Design

This framework is developed as a mixed-method research study divided into two phases. In the first phase, a directed content analysis of the literature on sustainability risks in the shipping business was conducted for the period 2015–2024. The aim of this phase was to identify sustainability risk factors, indicators, and potential relationships among factors that could be used to design the conceptual framework and questionnaire.

The literature search was carried out in major academic databases (Scopus/Web of Science/ScienceDirect) and Google Scholar using combinations of keywords related to sustainability, risk, and shipping. Search strings combined terms such as "sustainable risk" AND "shipping", "risk in shipping", "environmental risk" AND "shipping", "social risk" AND "shipping", and "technological risk" AND "shipping". In total, the initial database searches returned 368 articles. Then the titles and abstracts were screened using predefined inclusion and exclusion criteria. Studies were included if they (i) focused on sea-going shipping companies or maritime transport, and (ii) explicitly addressed environmental, technological, or societal risks that could influence the sustainability of shipping operations or business performance. Following this screening, 42 full-text articles were retained for in-depth review and content analysis.

The population for this study comprises 113 individuals employed in the operations, safety/environment, and risk management departments of Thailand's top five shipping companies. In this study, "top five shipping companies" refers to the five Thai-controlled deep-sea shipping companies listed on the Stock Exchange of Thailand, whose combined fleet accounts for more than 80% of the total deadweight tonnage of the Thai-owned merchant fleet (vessels of 500 gross tonnage and above). These firms therefore represent the core segment of the Thai shipping business in terms of fleet capacity and market influence. Consequently, the empirical model developed in this study is most directly applicable to large, deep-sea shipping companies, and any generalisation to smaller or non-listed operators should be made with caution. A purposive sampling method, as a non-probability sampling technique, was applied to focus specifically on these five companies. According to Taro Yamane's [25] formula, at a 95% confidence level and a 5% margin of error, the required sample size was 89; in practice, 96 completed questionnaires were obtained from respondents. In addition, since the present study employs PLS-SEM, the achieved sample size was cross-checked against common PLS-SEM guidelines. In our model, the most complex endogenous construct (SRS) has three incoming paths (ENV, TEC, and SOC), and none of the latent constructs has more than five indicators. According to the 10-times rule proposed in the PLS-SEM literature [26,27], the minimum required sample size is 10 times the larger of these two numbers (i.e., 30–50 observations). The 96 valid responses, therefore, satisfy both the finite-population requirement and the PLS-SEM sample-size recommendation.

The data were collected using an online questionnaire. The survey link was distributed to the eligible respondents in the five shipping companies through their departmental coordinators in the operations, safety/environment, and risk management units. The questionnaire was prepared in Thai to match the working language of the respondents and to minimise misinterpretation. Before the full survey, the draft questionnaire was reviewed (IOC and pilot-tested). In the final version, each section of the questionnaire was accompanied by brief written instructions, the 5-point importance scale was explicitly defined on the cover page, and examples were provided for items that could be interpreted in multiple ways. Respondents were also provided with the researcher's telephone number and e-mail address and were informed that they could contact the researcher if they had any questions while completing the questionnaire. **Figure 1** shows this research methodology.

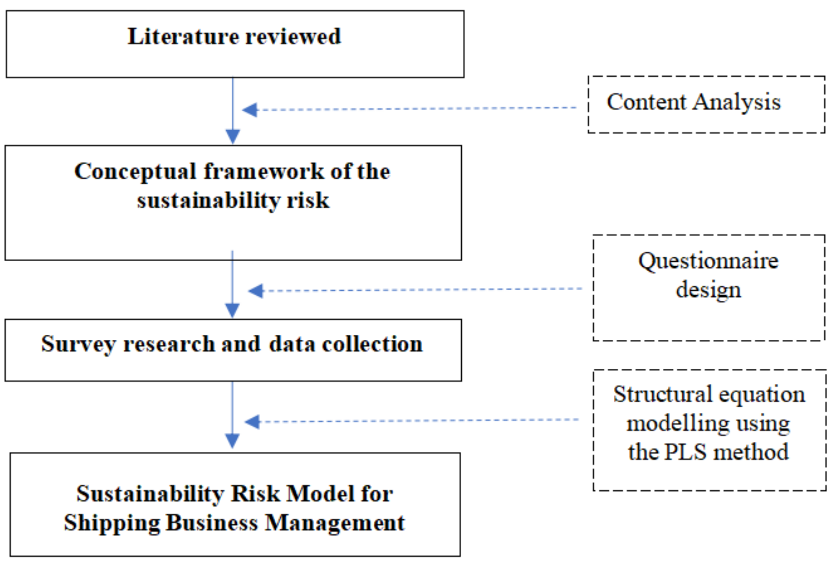

Figure 1. The framework of the research approach.

2.2. Data Analysis, Statistics Analysis, and Hypotheses

The two phases improved the factors, indicators, and relationships among factors to develop the sustainability risk model. Structural equation modelling was applied using the PLS method, which resulted in both a path model and a measurement model. These models were used to test the cause-and-effect relationships among factors and estimate the relationships between them and their indicators. The factors were utilised in path analysis for hypothesis testing, and the indicators were validated through confirmatory factor analysis within the model. The reason for choosing the PLS method in this research was to test the significance of the path analysis and determine the R^2 value, which indicates the variability of one factor explained by other factors. In this study, there are six hypotheses which drive the indicators to set a relationship among the factors as follows:

H1. *The societal factor (SOC) is positively influenced by the environmental risk factor (ENV).*

H2. *The societal factor (SOC) is positively influenced by the technological risk factor (TEC).*

H3. *The environmental factor (ENV) is positively influenced by the technological risk factor (TEC).*

H4. *The sustainability risk for shipping business management (SRS) is positively influenced by the societal risk factor (SOC).*

H5. *The sustainability risk for shipping business management (SRS) is positively influenced by the environmental risk factor (ENV).*

H6. *The sustainability risk for shipping business management (SRS) is positively influenced by the technological risk factor (TEC).*

2.3. Descriptive statistics of the research sample

This section presents the personal information of the research sample. There were 96 respondents from the top five shipping companies in Thailand. **Table 2** provides a summary of their personal information.

Table 2. Frequency and percentage of personal information.

Personal Information	Number	Percentage
Department of work		
Operation	54	56.3
Safety and Environment	27	28.1
Risk management	15	15.6
Position		
Management level	60	62.5
Operation level	36	37.5
Education		
Below bachelor's Degree	0	0
Bachelor's Degree	75	78.1
Master's Degree	21	21.9
Doctorate's Degree	0	0
Working Experience		
0–5 Years	24	25.0
5–10 Years	39	40.6
Over 10 Years	33	34.4
Total	96	100.0

3. Results

The results of this study are divided into three parts. The first part is about Sustainability risk factors and indicators. The second part is about the structural model results. The last part is about implementing sustainability in the shipping business.

3.1. Sustainability Risk Factors and Indicators

This study used the content analysis from the literature reviewed from 2015–2024 to find the factors, indicators, and relationships among factors. Summarised results are in **Tables 3–6**. Firstly, the sustainability risks in the environmental factor are presented in five indicators in **Table 3**. Secondly, **Table 4** presents three indicators of sustainability risks in the technological factor. Thirdly, the societal factor presents two indicators of sustainability risks in **Table 5**. Moreover, the list of sustainability risk factors and the specific sustainability risks within each factor. **Table 6** also includes a sample of measurement variables for each sustainability risk factor. The measurement variables are a guide to measure the sustainability management for each risk.

Table 3. Sustainability risks in the Environmental factor.

Sustainability Risk Factor	Sustainability Risk Indicators	References											
		World Economic Forum [12]	Deja, A., et al. [28]	World Ocean Initiative Economist Impact [29]	Maribus gGmbH [30]	Panahi et al. [31]	Rawson et al. [32]	MARUM [33]	Jägerbrand et al. [34]	Tiller et al. [35]	Liu et al. [36]	Balci et al. [37]	Toscano [38]
Environmental Risk (ENV)	Extreme weather conditions for ship navigation (ENV1)	●	●	●	●	●	●	●		●			
	Impact of climate change on shipping routes and sources of cargo. (ENV2)	●		●	●	●			●	●		●	
	Loss of marine biodiversity and ecosystem collapse by shipping activities (ENV3)	●	●	●	●			●	●	●	●		●
	The risk of resource shortages in shipping industry (ENV4)	●		●	●			●			●	●	
	Pollution from ship (ENV5)	●	●	●	●		●		●		●	●	●

Table 4. Sustainability risks in the Technological factor.

Sustainability Risk Factor	Sustainability Risk Indicators	References													
		World Economic Forum [10]	Triepels, R., et al. [39]	Yang et al. [40]	Jensen et al. [41]	Wang et al. [42]	Mileski, et al. [43]	Mednikarov et al. [44]	Al Ali et al. [45]	Akpan et al. [46]	Progoulakis et al. [47]	Vinnem and Utne [48]	Chang et al. [49]	Falari et al. [50]	Guo et al. [51]
Technological Risk (TEC)	Instances of misinformation and disinformation in shipping cargo documentation, port formalities, and ship navigation. (TEC1)	●	●	●	●	●		●							
	Risk of using autonomous ships (TEC2)	●							●	●		●	●	●	●
	Cyber insecurity in shipping (TEC3)	●				●	●	●	●	●	●	●	●	●	●

Table 5. Sustainability risks in the societal factors.

Sustainability Risk Factor	Sustainability Risk Indicators	References							
		World Economic Forum [12]	Iussich and Maglić [52]	Becker-Weinber [53]	Deiana et al. [54]	Senu [55]	Kołodziej and Kołodziej-Durnaś [56]	Huget, Hailey [57]	Zhang et al. [58]
Societal Risk (SOC)	The risk of involuntary migration and trafficking on ships (SOC1)	●	●	●	●	●			
	Strike and societal polarisation on ship (SOC2)	●					●	●	●

Table 6. Sustainability risks and measurement variable.

Sustainability Risk Factor	Sustainability Risk Indicators	Measurement Variable
Environmental Risk (ENV)	Extreme weather conditions for ship navigation (ENV1)	·Provide a weather tracking and alert system for the company's fleet in the event of encountering extreme weather conditions such as typhoons, super-typhoons, and hurricanes. ·The shipping company has procedures for vessels in the fleet in case of extreme weather conditions. ·The crew is well-trained to handle situations when the vessel encounters extreme weather conditions.
	Impact of Climate Change on shipping routes and sources of cargo. (ENV2)	·Having policies, plans, or long-term strategies in place to reduce greenhouse gas emissions from ships. ·Having plans in place to prepare for any changes in future shipping routes resulting from polar ice melt, sea level rise, changes in coastlines, and sea surface temperatures, etc ·Having plans to prepare for potential changes in cargo sources due to global climate change. This could include discovering new oil reserves after melting polar ice caps, agricultural products being affected by reduced production from traditional sources because of natural disasters, etc. ·Invest in vessels designed to run on alternative fuels such as LNG and methanol or be ready for hydrogen or ammonia. ·Invest in carbon/blue-carbon credits.
	Loss of marine biodiversity and ecosystem collapse by shipping activities. (ENV3)	·Measures must be put in place to ensure that the company's fleet strictly adheres to the rules and regulations when navigating in marine conservation and protection areas. ·Implementing measures to prevent pollution and waste from entering the sea is essential for safeguarding coral reefs and the sea ecosystem. ·Having insurance or financial coverage to protect against risks that may occur in coastal areas or coral reefs. ·Measures are in place for the company's fleet to strictly comply with the Ballast Water Management Convention to avoid the spread of invasive species in ballast water. ·Measures must be taken to ensure that the company's fleet strictly complies with the Anti-Fouling Systems Convention.
	The risk of resource shortages in shipping industry. (ENV4)	·The availability of support or funding for organisations or projects aimed at preventing crises related to shortages of marine natural resources. ·Promote strict compliance with the United Nations Convention on the Law of the Sea within the company's fleet, emphasising the conservation and sustainable utilisation of ocean resources.
Sustainability Risk Factor	**Sustainability Risk Indicators**	**Measurement Variable**
Environmental Risk (ENV)	Pollution from ship (ENV5)	·Measures must be taken to ensure that the company's fleet strictly complies with the International Convention on the Prevention of Marine Pollution from Ships. ·Having insurance or financial coverage to protect against risks from pollution from a ship. ·Employ an emergency cleanup company in case of pollution from a ship. ·Measures should be implemented to manage ships that pose pollution risks, such as old ships or those not compliant with MARPOL. ·The crew are well-trained to be aware of and prevent pollution from ships.

Table 6. *Cont.*

Sustainability Risk Factor	Sustainability Risk Indicators	Measurement Variable
Technological Risk (TEC)	Instances of misinformation and disinformation in shipping cargo documentation, port formalities, and ship navigation. (TEC1)	·Regularly evaluate the effectiveness of risk management strategies for misinformation and disinformation and make adjustments as needed. ·Foster a culture of transparency and accountability within the organisation, where individuals are encouraged to report instances of misinformation and disinformation without fear of reprisal. ·Develop comprehensive crisis communication plans that outline procedures for addressing misinformation and disinformation during emergencies or crises. ·Implement monitoring and surveillance systems to track the spread of misinformation and disinformation within the organisation. ·Develop fact-checking mechanisms to verify the accuracy of information before sharing it internally or externally.
	Risk of using autonomous ships (TEC2)	·Conduct a risk assessment and identify the hazards and vulnerabilities that are introduced by autonomous ships; develop risk mitigation plans based on the risk assessment. ·Measures must be taken to ensure that the company's autonomous ships comply with IMO and relevant regulations and standards. ·Having a system to monitor and evaluate autonomous ships and AI technologies to identify potential issues and anomalies and take necessary corrective action. ·Provide training for ship and shore employees programs to enhance the understanding of ship and shore employees of autonomous ships and AI technologies, their relationship to their functions, and risk management strategies. ·Collaborate with shipping partners, regulatory authorities, classification organisations, insurance providers, cybersecurity experts, etc., to share best practices; disseminate lessons learned; identify emerging threats and vulnerabilities related to autonomous ships and AI technologies in the shipping industry; and develop shared management and regulatory strategies to address the same.
Sustainability Risk Factor	**Sustainability Risk Indicators**	**Measurement Variable**
Technological Risk (TEC)	Cyber insecurity in shipping (TEC3)	·Provide cybersecurity awareness training for the ship's crew to ensure they understand the risks, recognise threats, and know how to respond to threats. ·Having a system for continuously monitoring cybersecurity threats, and detecting the weaknesses in the cyber system on the ship. ·Having a cybersecurity incident response plan. ·Measures should be taken to reduce the likelihood and impact of cyber insecurity incidents. Measures must be in place to ensure the company's fleet vessels comply with IMO regulations, standards, and guidelines, as well as the International Ship and Port Facility Security Code (ISPS Code).
Societal Risk (SOC)	The risk of involuntary migration and trafficking on ships. (SOC1)	·Having measures in place to ensure the company's fleet's compliance with international laws, conventions, and regulations related to human rights, maritime safety, and immigration, including the protocols of the IMO and the ILO. ·Implement procedures to verify the legitimacy of cargo and passengers, including screening for potential indicators of trafficking or smuggling activities. ·Provide training and awareness programs for crew members on recognising and responding to signs of involuntary migration, human trafficking, and smuggling. ·Implement security measures onboard vessels to prevent unauthorised access, including emergency response procedures to deter and respond to security threats related to involuntary migration.
	Strikes and societal polarisation on ship (SOC2)	·Develop risk management plans that include mitigation measures, contingency plans, and monitoring mechanisms to address and mitigate risks in strikes and societal polarisation on a ship. ·Establish mechanisms, processes, and procedures to resolve disputes fairly and transparently, reducing the risk of strikes and polarisation on a ship. ·Invest in projects that support social welfare programs on ships and in areas affected by shipping operations.

Finally, sustainability risk for shipping business management for long-term sustainability in shipping, three core areas must be effectively managed: shipping finance, regulatory compliance, and operational practices.

- Sustainability risk in shipping finance: Sustainable finance supports investments in green technology, alternative fuels, and emission-reducing infrastructure, crucial for aligning financial practices with environmental standards. This approach is reinforced by green financing options, which encourage reduced environmental impacts [59].

- Sustainability risk in shipping regulations: Compliance with international regulations like those from the IMO minimises risks related to pollution (MARPOL) and crew welfare, directly enhancing operational reliability and safety [11,60].
- Sustainability risk in shipping operations: Operational sustainability includes optimising routes, adopting energy-efficient technologies, and ensuring safe working conditions. These practices improve efficiency, cut costs, and support environmental goals, fostering resilience in the industry [16,61].

3.2. The Structural Model Results and Model Fitted

The conceptual framework was developed using a triangulation approach involving three data sources: an extensive review of academic journals, observations of participants from the top five shipping companies in Thailand, and semi-structured interviews with sustainability risk management experts from the top ten shipping companies in Thailand.

This comprehensive conceptual framework serves as the foundation for the structural model in **Figure 2**, which illustrates the sustainability risk factors, the associated sustainability risks, and the interrelationships among these risks. The structural model encompasses three critical factors of sustainability risk management: environmental, technological, and societal.

The results of the structural equation model are presented in **Figure 2**. The average R2 value is 0.301, indicating that the model is moderately strong [62]. The average of cross-loading is above 0.6 (60%). The structural equations are as follows:

ENV = 0.257TEC; R2 = 0.066

SOC = 0.634TEC + 0.126ENV; R2 = 0.376

SRS = 0.501TEC + 0.34ENV + 0.009SOC; R2 = 0.461

Table 7 summarises the results of the hypothesis testing, including path coefficients, t-values, and p-values. Using PLS to estimate the structural paths, five hypotheses (H2–H6) are supported, whereas H1 is not. Although H4 (SOC → SRS) is statistically significant, its path coefficient is extremely small (Path coefficient = 0.009, $p < 0.05$). Given this negligible magnitude, we do not interpret SOC as a strong direct driver of sustainability risk management; instead, societal issues appear to play only a minor direct role in the present model. By contrast, H1, which hypothesises a direct relationship between ENV and SOC, is not supported (*p*-value = 0.193), indicating that environmental risks do not significantly explain the societal risk factor. In practice, the five ENV indicators do not meaningfully affect the SOC indicators—namely, the risks of involuntary migration and trafficking on ships and strikes and societal polarisation on board. This implies that environmental risks and their indicators primarily affect the ecosystem directly, whereas societal risks are more strongly shaped by technological factors and their associated indicators [45,55].

Table 8 presents the results of Average R^2, Average Composite Reliability (CR), Average Variance Extracted (AVE), and Cronbach's alpha, which explain the quality of the model measurement. The R^2 represents the variability of a factor explained by other factors [63]. The R^2 values range from 0.066 to 0.461, with an average of 0.301, indicating a moderate explanatory power of the model. The Goodness of Fit (GoF) is 0.410, indicating that the data fits the model at a moderate level [64,65]. CR is used to assess the reliability of latent variables, and an average CR value of 0.776 (above 0.70) is generally acceptable and indicates good internal consistency among the indicators of the latent variable (Hair, 2016). The average Cronbach's alpha is about 0.6 (0.576), which means that the model is acceptable for exploratory research [66].

Table 9 presents the cross-construction correlations. The values on the diagonal (in bold) represent the square root of the Average Variance Extracted (AVE) for each factor. The discriminant validity value for each factor is greater than the correlations between that factor and other factors. This indicates that the factor being studied can be clearly distinguished from different factors and fitted [67].

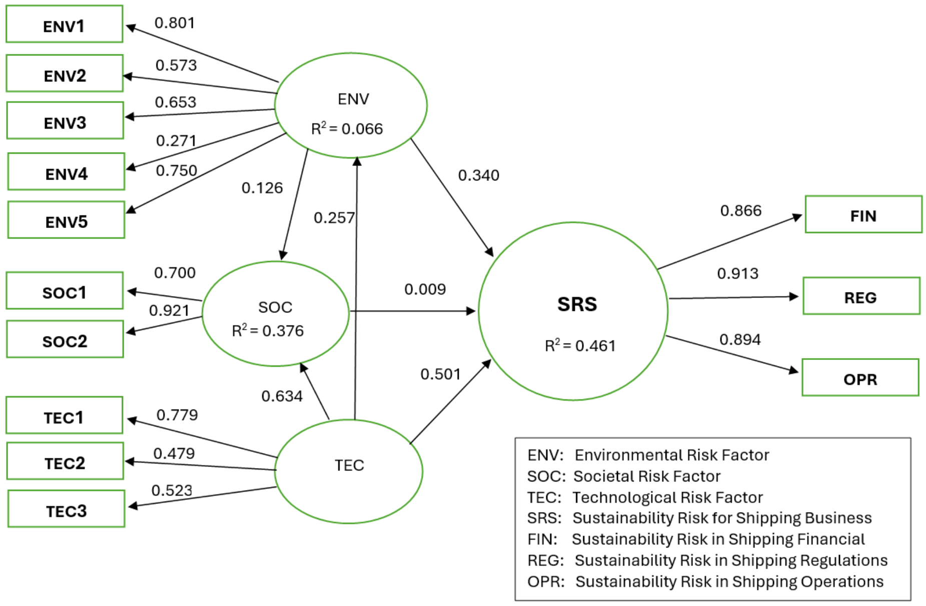

Figure 2. Sustainability risk model results.

Table 7. The results of hypothesis testing.

Path	Path Coefficient	*t*-Test	*p*-Value	Results
H1. *ENV* à *SOC*	0.126	1.515	0.193	Non- support
H2. *TEC* à *SOC*	0.634	11.323	0.000	Support
H3. *TEC* à *ENV*	0.257	2.632	0.006	Support
H4. *SOC* à *SRS*	0.009	4.504	0.000	Support
H5. *ENV* à *SRS*	0.340	2.570	0.014	Support
H6. *TEC* à *SRS*	0.501	9.278	0.000	Support

Table 8. Reliability and validity of the structure model.

Factors	R^2	CR	AVE	Cronbach's Alpha
ENV	0.066	0.758	0.406	0.673
TEC		0.799	0.370	0.223
SOC	0.376	0.626	0.669	0.536
SRS	0.461	0.921	0.795	0.871
Average	0.301	0.776	0.560	0.576

Note: GoF is 0.410.

Table 9. The cross-construction correlation.

Factors	ENV	TEC	SOC	SRS
ENV	**0.637**			
TEC	0.257	**0.608**		
SOC	0.126	0.634	**0.817**	
SRS	0.340	0.501	0.009	**0.891**

In line with common PLS-SEM guidelines, the model evaluation followed a two-step procedure. First, the measurement (outer) model was assessed using indicator loadings, composite reliability, AVE, Cronbach's alpha, and Fornell–Larcker discriminant validity (**Tables 8** and **9**), all of which fall within acceptable ranges.

Second, the structural (inner) model was evaluated by checking multicollinearity among the predictor constructs and examining the path coefficients, t-values, and R^2 values. For the outer model, variance inflation factor (VIF) values for all indicators ranged from approximately 1.05 to 2.78, well below the commonly recommended cut-off at 3.0, indicating no serious multicollinearity problems. Collinearity diagnostics for the predictor constructs in the inner model were likewise within acceptable limits, supporting the robustness of the structural relationships [26].

As shown in **Tables 8** and **9**, most constructs achieve AVE values close to or above the recommended threshold of 0.50. One exception is the technological risk construct (TEC), whose AVE is 0.370. Nevertheless, the composite reliability of TEC is above 0.60 and all of its indicators have statistically significant loadings above 0.40. Following the view that convergent validity can still be considered adequate when AVE is below 0.50 but composite reliability exceeds 0.60 [68,69], TEC is retained in the model to preserve the theoretical and content coverage of technology-related sustainability risks.

3.3. The Implementation of Sustainability Shipping Business

As of factors/indicators confirming 3.2 above and the results of the model fitting conclusion in the sustainability management of shipping operations towards sustainable business, with **Figure 3**, sustainability shipping management with sustainability risk shipping of three factors and ten indicators approach.

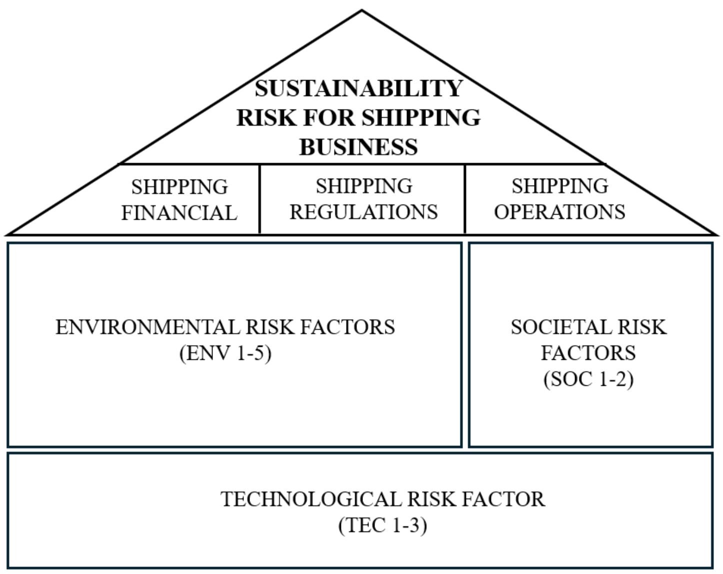

Figure 3. Sustainability shipping management.

The environmental risk factor (ENV) refers to the risks that are impacted by environmental problems, causing global warming and consequences to critical changes to Earth's systems. These ecological problems have persisted for a long time and are expected to increase in intensity, continuing to impact in the long term. One of the primary causes of these issues is greenhouse gas emissions [10]. Five main sustainable risks develop this factor: ENV1–5.

The technological risk factor (TEC) refers to the risks that adverse outcomes of AI and advanced technologies are anticipated to rise rapidly over the next decade. As AI becomes increasingly widespread and is expected to expand further, its utilisation alongside advanced technology aids in navigation and the operation of autonomous ships. This improves the efficiency and safety of vessels and introduces potential risks to the maritime and shipping business. These risks may arise from intentional threats like cyberattacks or unintentional ones such as software bugs. Furthermore, misinformation and disinformation pose significant challenges in the shipping business, particularly concerning cargo documents and ship/port operations. These issues may arise from the intentional release of incorrect information or the use of inaccurate information without verification, potentially endangering both lives and property while disrupting the smooth flow of maritime transport. Three main sustainable risks develop this factor: TEC1–TEC3.

The societal risk factor (SOC) refers to various cultural, racial, religious, and attitudinal issues among crew members. This includes conflicts and divisions of opinion that may arise from welfare management and various compensation disparities, potentially causing rifts among the crew members and leading to a strike on the ship. Additionally, the social factor encompasses involuntary migration via ship transportation and the trafficking of workers from undeveloped and developing countries. Two main indicators (SOC1–SOC2) operationalise this factor for sustainability risk management.

The sustainability risk for the shipping business (SRS) involves integrating sustainable development and risk management practices in the shipping industry. The SRS framework consists of environmental risk factors, technological risk factors, and societal risk factors. It focuses on three key sustainability risk indicators: shipping financial, shipping regulations, and shipping operations.

This study developed and tested a sustainability risk model for the Thai shipping business, focusing on three higher-order factors—environmental (ENV), technological (TEC), and societal (SOC)—and a sustainability risk management construct for shipping (SRS). The structural equation modelling results show that technological risk is the strongest driver of sustainability risk management in Thai shipping companies, followed by environmental risk, while the direct effect of societal risk on SRS is relatively small and the path from ENV to SOC is not supported. Overall, the model explains 46.1% of the variance in SRS, indicating a moderate explanatory power.

The significant role of ENV is consistent with earlier work that highlights environmental and regulatory pressures as key drivers of sustainable shipping practices. Studies such as Koilo [19], and Hasanspahić et al. [20] show that air and water pollution, climate-related regulations, and costly technical upgrades are central sustainability risks that shipping companies must manage. Our results confirm that Thai shipping companies also perceive environmental risks—ranging from climate change and extreme weather to emissions and pollution, including ballast-water and waste management—as important triggers for strengthening sustainability risk management.

At the same time, the Thai case underlines the prominence of technological risks. The strong TEC → SRS path, together with significant links from TEC to ENV and SOC, suggests that digitalisation, cyber security, and information integrity are central channels through which sustainability risks are transmitted and controlled. This finding is in line with recent literature on maritime cyber security, which documents the increasing impact of cyberattacks, system failures, and data-related vulnerabilities on shipping operations and safety [22,41,42,45]. Our study extends this work by embedding technological risk in a broader sustainability risk model and showing that, for Thai deep-sea shipping companies, technology-related vulnerabilities are perceived as a core strategic concern rather than a peripheral technical issue.

Compared with neighbouring Asian countries, the pattern is partly similar and partly distinct. In our Thai case, environmental risks are likewise important, but technological risks clearly dominate the sustainability risk management construct. This may reflect differences in fleet structure, listing status, and the stage of digitalisation between Thai and other Asian shipping companies. Although SOC shows only a small direct effect on SRS in our model, prior studies on seafarer welfare, working conditions, and human rights [52–56] suggest that social issues remain critical and may be embedded within environmental and technological risk-management practices rather than appearing as a separate, dominant driver in the statistical model.

4. Conclusions

The shipping industry faces significant global risks that could influence its long-term sustainability and operational stability. These risk management in shipping span three critical factors—environmental, technological, and societal—all of which have the potential to impact daily operations and overall growth. Consequently, shipping companies must prioritise identifying and managing these risks to ensure sustainable business practices.

This study developed a comprehensive sustainability risk model for managing Thailand's shipping industry. The model identifies and maps the relationships between critical factors and indicators crucial for achieving sustainability in the shipping sector. The model encompasses three main factors with a total of 10 indicators: Environmental (5 indicators), Technological (3 indicators), and Societal (2 indicators), each representing areas that require focused improvement over the next 10 years. Beyond identifying specific sustainability risk indicators, this study provides examples of measurable variables for each risk factor, enabling companies to apply a strategic framework for effective risk mitigation. This actionable model supports decision-making processes, offering guidelines for integrating sustainable practices into business operations.

Future research may further refine this model by assessing the unique sustainability risk management affecting Thai ports, especially by addressing environmental, technological, and societal challenges specific to port operations. Expanding the model's application to port sustainability would support a more integrated approach across Thailand's maritime sector.

Author Contributions

Conceptualization, K.M. and T.M.; methodology, K.M and T.M.; validation, T.M.; formal analysis, K.M.; investigation, T.M.; resources, K.M.; data curation, K.M.; writing—original draft preparation, K.M.; writing—review and editing, K.M. and T.M.; visualization, T.M.; supervision, K.M.; project administration, K.M. and T.M.; funding acquisition, K.M. and T.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was approved by the Human Research Ethics Committee of Burapha University (Approval No. IRB2-083/2567)

Informed Consent Statement

The study was conducted in accordance with the ethical principles for research involving human participants and was approved by the Human Research Ethics Committee of Burapha University. 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 conflict of interest.

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