Independent University **Bangladesh (IUB)**

IUB Academic Repository

Conference and Proceedings International Conference on Economics, Business and Technology Manag

2025-11

A triple-bottom-line stakeholder alignment approach to evaluating port performance: a case study of Bangladesh

Hye, Mohammad Nazmuzzaman

School of Business and Entrepreneurship, Independent University, Bangladesh (IUB)

https://icebtm.iub.edu.bd

Downloaded from IUB Academic Repository

A Triple-Bottom-Line Stakeholder Alignment Approach to Evaluating Port Performance: A Case Study of Bangladesh

[1]Mohammad Nazmuzzaman Hye*, [2]Md. Mamun Habib
[1,2]Tun Razak Graduate School (TRGS), Universiti Tun Abdul Razak
[1]m.nazmuzzaman@ur.unirazak.edu.my [2] mamunhabib@unirazak.edu.my
*Corresponding Author**

PAPER ID : ICEBTM-25-1238

Abstract - **This study explored the links between stakeholders, the economy, the environment, society, and the impact of technology on port operations. The purpose of this study was to understand how effective seaports in Bangladesh really are, by assessing the Stakeholder Engagement Index (SEI), Economic Impact Ratio (EIR), Environmental Compliance Score (ECS), Social Value Creation Index (SVCI), Digital Technology Adoption Rate (DTAR), Sustainability Innovation Index (SII) and Regulatory Compliance Efficiency (RCE). SEM results confirmed DTAR ($\beta = 0.82$, $p < 0.001$) as the strongest predictor of TBSAI, followed by SEI ($\beta = 0.76$, $p < 0.001$) and EIR ($\beta = 0.71$, $p < 0.01$). SVCI ($\beta = 0.68$, $p < 0.01$), SII ($\beta = 0.65$, $p < 0.05$), and RCE ($\beta = 0.61$, $p < 0.05$) also had significant positive effects, while ECS showed a weaker loading ($\beta = 0.57$, $p < 0.05$), suggesting enforcement gaps under Bangladesh's Environmental Conservation Act. Ports with higher stakeholder engagement demonstrated stronger economic, environmental, and social outcomes, reinforcing the importance of inclusive governance in port management. Findings urge Bangladeshi ports to prioritize digitalization (DTAR) through IoT, blockchain, and AI systems, and to institutionalize stakeholder forums (SEI) for collaborative decision-making. Policy actions should include IoT-based environmental monitoring to address ECS weaknesses, targeted training programs for port communities, and strengthening intermodal connectivity to position Bangladeshi ports as competitive regional trade hubs.**

Keywords: **Stakeholder Engagement, Triple Bottom Line, Sustainable Ports, TBSAI, Port Performance.**

I.INTRODUCTION

Transporting goods by sea is essential for the world economy because international trade depends on it [1]. In Bangladesh, ports are crucial as the country uses seaways for economic growth. Bangladesh's ports handle 90% of trade but rank poorly globally [12]. Despite their economic significance, the operational efficiency of Bangladesh ports remains challenged. Chattogram, a leading port in Bangladesh that handles most of the country's sea trade, experiences inefficiencies, delays, and inadequate infrastructure, leading to higher shipping costs [3]. Compared to regional competitors, Chattogram port ranks low in terms of professionalization and private sector participation [4]. Delays also hinder the country's competitiveness in global markets. According to Chattogram Port Authority, the average waiting time for ships to berth has increased by 25 percent over the last five years, increasing congestion and continuing to affect regional trade [11]. While other ports globally have set benchmarks for efficiency using advanced technological infrastructure and robust stakeholder engagement systems, Bangladesh's ports are still struggling with limited technology adoption and fragmented stakeholder involvement [3]. The Stakeholder Engagement Index (SEI) for Chattogram Port has a low mean score, suggesting weak collaboration and communication between various port stakeholders. This fragmentation hampers efforts to modernize port operations and achieve a balance between economic, environmental, and social sustainability.

1.2 Research Problem

Bangladesh's maritime industry struggles to fulfill economic, environmental, and social sustainability [5]. These issues are compounded by poor stakeholder collaboration, environmental compliance, and limited technological adoption. The port of Chattogram experiences one of the highest levels of congestion in South Asia, with an average dwell time of 17.48 days for a loaded import container, whereas the global standards recommend 2-3 days for exports and 4 days for imports [6]. These inefficiencies raise shipping costs and increase delays in exporting key products, including textiles and garments, which are essential to Bangladesh's economy [7]. The Environmental Compliance Score (ECS) shows a significant underperformance in relation to international and national environmental standards, exacerbating the already significant environmental impact of the port's operations [8,9]. The Economic Impact Ratio (EIR) for Chattogram Port indicates a lag in contributing to the regional economic development when compared to international ports [10]. Despite the critical role ports play in promoting international trade and supporting trade, there is an absence of comprehensive assessment frameworks that simultaneously evaluate economic, environmental, and social outcomes while accounting for stakeholder engagement. The lack of a unified, empirical assessment tool that considers

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

stakeholder engagement and sustainability has resulted in fragmented policy and operational strategies [11]. This research introduces the Triple-Bottom-Line Stakeholder Alignment Index (TBSAI) as a comprehensive framework to evaluate port performance in Bangladesh. By integrating seven key performance indicators, such as SEI, EIR, ECS, SVCI, DTAR, SII, and RCE, this study aims to provide a nuanced and actionable analysis of how Bangladesh's ports can enhance their performance through better stakeholder alignment and sustainability practices.

1.2 Research Objectives

This study aims to conduct an in-depth analysis of seaport operations in Bangladesh, utilizing the framework of the Triple-Bottom-Line Stakeholder Alignment Index (TBSAI) and provide a comprehensive analysis that integrates economic, environmental, and social goals, enhancing the conversation surrounding sustainable port management in Bangladesh while delivering actionable insights for policymakers and industry participants. These objectives are therefore summarized as:

- To Evaluate the Stakeholder Engagement in Sea Port Operations Using the Stakeholder Engagement Index (SEI).
- To Assess the Economic Impact of Sea Port Operations Using the Economic Impact Ratio (EIR).
- Analyze environmental compliance of seaports using the environmental compliance score (ECS).
- To examine the social contributions of seaport operations using the social value creation index (SVCI).
- To Investigate the Role of Digital Technology in Enhancing Port Efficiency Using the Digital Technology Adoption Rate (DTAR).
- To examine the role of the sustainability innovation index (SII) to understand how ports can integrate sustainability measure.
- To analyze the regulatory compliance of seaports using the Regulatory Compliance Efficiency (RCE).1.3 Research Significance

This study builds a complete framework for evaluating seaports in Bangladesh, using TBSAI as a reference. TBSAI focuses on finding a way to assess a port's performance by including its economic, environmental, and social objectives. Since the functioning of Bangladesh's ports is vital for economic progress and trade, the detailed framework matters a lot, yet the country often fails to consider the role of stakeholders and the environment. This research contributes to the discussion on sustainable development by suggesting new ways to assess port management that include the perspectives of stakeholders, helping to reach international objectives. The results will guide Bangladesh's port management in introducing changes to engage stakeholders, be more sustainable, and comply with international shipping standards. The study also addresses a gap in current studies by exploring how stakeholder involvement, economic effects, following environmental rules, and social activities relate to ports in Bangladesh.

II. LITERATURE REVIEW

2.1 Overview of Port Performance Metrics

Several systems review the participation of stakeholders in the maritime sector. SEI uses frameworks such as the Arnstein Ladder of Citizen Participation, which sets out several levels of involvement from being controlled to controlling, and ensures that all ports can be efficiently evaluated in their involvement with different stakeholders [16,17]. Including stakeholders' suggestions in port management positively affects the aims of running an economically viable and environmentally conscious port [14]. Employment opportunities arise at the port, and eventually the effects spread to the supply chain and to services. Measuring the impact of climate change usually involves many sub-indicators: reducing emissions, properly managing waste, improving water quality, and saving energy [18]. With technology in ports, logistics, communication, and administration are affected [12,13,15]. Ports use digital technology to become more efficient, sustainable, and competitive. Using digital technologies like PCS, AGVs, and blockchain to track supplies at the port improves efficiency.

2.2 Stakeholder Theory and Triple Bottom Line

Freeman's stakeholder theory, introduced in 1984, argues that organizations should consider stakeholder well-being [16]. Based on this theory, TBSAI finds that, to achieve sustainability, economic, environmental, and social interests must be aligned with the expectations of key stakeholders. Freeman claims that all stakeholders involved in a decision should be considered before any actions are taken [19]. In light of this theory, smart ports in Bangladesh should team up with port authorities, relevant government departments, area residents, and international groups to become more sustainable. In 1994, John Elkington introduced the Triple Bottom Line theory. It highlighted the role of social and environmental responsibility at companies, using the term 'the three Ps' to describe people, planet, and

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

profit. When organizations follow a comprehensive model, they are able to observe their achievements from a social and environmental perspective.

2.3 Gaps in Existing Frameworks

Even though previous studies have explored aspects of port operations, such as their finances and environment, there is a lack of literature on how economic, environmental, and social elements are all integrated. The Stakeholder Engagement Index (SEI) has not been thoroughly investigated for support in making port performance assessments [19]. This research includes the perspectives and statements of vital parties and suggests improvements to the existing body of information. Since ports play a key role in world trade, we should measure the impact they have on the economy, society, and nature [20]. TBSAI will show accurately the effects of EIR, ECS, SVCI, and DTAR on the port's operations, as these have been included along with other factors [21].

2.4 Theoretical Foundations of TBSAI

The TBSAI model is based on the idea that working towards economic, environmental, and social goals together leads to increased sustainability in ports. Elkington's TBL concept in 1994 made corporations focus on achieving economic, environmental, and social goals, rather than just profit. Many areas have adopted the TBL approach to help support sustainable practices. Not much research has been done on how TBSAI can assess seaports in developing countries, especially Bangladesh. TBSAI will thus be used to provide a complete review of how a port operates, checked against the three main goals, and with the support of various stakeholders. Using stakeholder alignment and the TBL approach, TBSAI introduces new ideas on how ports can be managed sustainably. The SEI, EIR, ECS, SVCI, DTAR, SII, and RCE are the primary tools used to assess how environmentally friendly a port is. In today's rapidly changing sea environment, TBSAI introduces new ideas that can help ports become more sustainable.

2.5 Explanation of TBSAI KPIs

Stakeholder Engagement Index (SEI)

The SEI emphasizes inviting stakeholders into decision-making, reliable and stable communication, and inspecting what stakeholders need. SEI makes it simple for group stakeholders. SEI looks at how a port connects with and assists its stakeholders. Communities, environmental groups, and businesses are involved at maritime hubs, and these places depend on meaningful conversations to stay sustainable [16]. The SEI helps to examine how well different groups, for example, port authorities, governmental bodies, local communities, and industry collaborators, participate, communicate, and cooperate [22].

Economic Impact Ratio (EIR)

Higher productivity at ports has a better impact on the economy. The EIR uses measures of productivity to see how much the port's efficiency helps the broader economy. The EIR framework is designed to capture both numerical and non-numerical effects of port activities, showing their value in Bangladesh and similar emerging economies. Better EIR results at ports seem to have a larger positive impact on regional economies [23]. The EIR can be used to perceive the economic value of port activities, such as new employment, aid to local businesses, and pave the way for growth [24]. Businesses need ports; they help create jobs, and they promote the development of the economy [25].

Environmental Compliance Score (ECS)

The ECS measures how well ports follow the environmental standards set by both their country and the international maritime industry by examining pollution control, waste disposal, and saving natural resources [26]. The Environmental Compliance Score (ECS) gives a complete solution for assessing how seaports perform environmentally. With the maritime industry growing, air and water pollution rise, so it is usually required for harbors to take action to become more environmentally friendly [37]. Many compliance strategies at ports are affected by Bangladesh's Environmental Conservation Act, along with other regulations.

Social Value Creation Index (SVCI)

The SVCI provides a planned method for assessing these effects so that port authorities can check their social influence in an organized manner. The SVCI evaluates how seaport activities benefit society as a whole. Many ports are built near communities with a high population, underlining how much they contribute to those areas. The Social Value Creation Index (SVCI) is used to understand the social effects of port activities and includes community development, social equity, and public health, so that the benefits of port operations extend past financial figures [27]. The SVCI evaluates how ports engage with their local communities and how well they involve local people in decision-making [28].

Digital Technology Adoption Rate (DTAR)

DTAR examines the level of adoption of digital solutions by ports, such as automation, modern logistics, and the use of data in real time [29] [38]. DTAR also illuminates how ports efficiently use technology to enhance their operations and initiate stakeholder communication [30]. Port Community

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

Systems (PCS) provides a digital system for seaports that allows for smooth data exchange among those who operate the ports, ship goods, and handle customs. By using PCS, data can be managed more efficiently, and less paperwork is involved [31] [39].

Sustainability Innovation Index (SII)

The SII looks at how ports are encouraging innovation for sustainability. In the context of this study, innovation means adding sustainable technology, energy-saving approaches, and activities that support a circular economy, all to cut down on resource use and waste [40]. The SII proves that TBSAI is committed to continuous improvement, so that ports address both current and future environmental issues. In Bangladesh, as ecological challenges increase, the SII is working to make sure that ports help solve those problems.

Regulatory Compliance Efficiency (RCE)

Regulatory Compliance Efficiency (RCE) measures how effectively and economically a port meets both national and international regulations. Ports need to strictly follow a variety of environmental, safety, and labor laws [32]. All ports in Bangladesh are required to meet global maritime laws and those created by the International Maritime Organization (IMO).

In order to better understand the role of the Triple-Bottom-Line Stakeholder Alignment Index (TBSAI) in evaluating port performance, it is essential to compare its Key Performance Indicators (KPIs) with other widely used port performance indices. While traditional frameworks tend to focus on economic factors or environmental compliance in isolation, TBSAI takes a more holistic approach by incorporating social, technological, and regulatory dimensions alongside economic and environmental performance. The table below compares TBSAI's KPIs with other prevalent port performance indices, highlighting the strengths and limitations of each metric.

Table 1: TBSAI KPIs Comparison

Metrics	TBSAI KPIs	Strengths	Gaps
Stakeholder Engagement Index (SEI)	TBSAI (SEI)	Focuses on active stakeholder participation in decision-making. Identifies transparency and inclusivity.	Often lacks deep integration of local community concerns, especially in developing countries.
Economic Impact Ratio (EIR)	TBSAI (EIR)	Captures direct and indirect economic effects on local economies. Provides clear insights into port-driven growth.	Does not fully incorporate long-term economic sustainability factors or indirect market impacts.
Environmental Compliance Score (ECS)	TBSAI (ECS)	Assesses adherence to both national and international environmental standards. Evaluates proactive ecological efforts.	May not consider broader environmental outcomes (e.g., biodiversity) and lacks long-term projections.
Social Value Creation Index (SVCI)	TBSAI (SVCI)	Measures the port's impact on local communities, employment, social equity, and development.	Does not fully quantify the societal costs associated with port operations, especially in urban areas.
Digital Technology Adoption Rate (DTAR)	TBSAI (DTAR)	Focuses on the integration of advanced digital technologies (e.g., AI, IoT, blockchain) to optimize port operations.	It may not capture broader technological integration across the entire logistics and supply chain.

ISBN 978-984-35-5270-9 *https://icebtm.iub.edu.bd*

Sustainability Innovation Index (SII)	TBSAI (SII)	Assesses innovation in port operations for sustainability. Focuses on new technologies and methods to reduce environmental impact.	May overlook social innovations and their contribution to sustainability goals in ports.
Regulatory Compliance Efficiency (RCE)	TBSAI (RCE)	Evaluates the effectiveness of regulatory compliance, ensuring alignment with international maritime standards.	Often focused on meeting the minimum compliance requirements, rather than innovative regulatory solutions.

III.METHODOLOGY

3.1 Research Design

A quantitative approach was employed to gather and analyze data, with an emphasis on surveying key stakeholders involved in port operations. The primary aim was to assess how economic, environmental, social, and technological factors contribute to port sustainability. This design specifically aimed to determine how various stakeholders in Bangladesh's seaports align their economic, ecological, and social goals to achieve a sustainable and integrated port system. The quantitative approach enabled the research to gather a large volume of data, providing a more statistically robust analysis of port performance and its alignment with sustainable development goals in Bangladesh.

3.2 Data Collection

Data for this study were collected through surveys distributed to key stakeholders involved in port operations in Bangladesh. The surveys aimed to assess seven key performance indicators (KPIs) of the Triple-Bottom-Line Stakeholder Alignment Index (TBSAI): Stakeholder Engagement Index (SEI), Economic Impact Ratio (EIR), Environmental Compliance Score (ECS), Social Value Creation Index (SVCI), Digital Technology Adoption Rate (DTAR), Sustainability Innovation Index (SII), and Regulatory Compliance Efficiency (RCE). The surveys were tailored to capture quantitative data on each KPI, focusing on stakeholders' perceptions and experiences with port operations. The data collected through these surveys were then analyzed to evaluate the alignment of Bangladesh's ports with sustainable development goals and to identify areas for improvement in port performance.

3.3 Sampling and Participants

The research involved a total of 600 participants who were selected through a stratified random sampling approach. The sample was stratified by stakeholder groups to ensure representation from all relevant parties involved in port operations. The distribution was as follows: 40% from port authorities, 30% from local communities, and 30% from the private sector, including logistics providers, shipping companies, and environmental groups. This stratification allowed for a comprehensive understanding of how different stakeholders perceive and contribute to port operations in Bangladesh, ensuring the results reflect a balanced view of stakeholder interests. The sampling strategy also focused on including a diverse range of participants based on their role, experience, and geographic location within Bangladesh's major ports, including Chattogram, Mongla, and Payra. This approach enhanced the representativeness of the data and ensured that all critical perspectives on port sustainability were considered.

3.4 Measuring Variables

The study used the TBSAI framework, comprising seven key indices: SEI, EIR, ECS, SVCI, DTAR, SII, and RCE, to evaluate port sustainability performance. Economic Impact Ratio (EIR) captured GDP contribution, job creation, and local industry support. Environmental Compliance Score (ECS) assessed adherence to national and international environmental standards, including MARPOL and Bangladesh's Environmental Conservation Act. Social Value Creation Index (SVCI) evaluated the socio-economic benefits generated for port communities, such as employment stability and local business growth. Digital Technology Adoption Rate (DTAR) recorded the level of integration of IoT, blockchain, and AI in operations. Sustainability Innovation Index (SII) measured the adoption of green technologies, energy-saving measures, and circular-economy practices. Regulatory Compliance Efficiency (RCE) gauged the ability to adapt quickly and cost-effectively to evolving regulatory requirements. The relationships between the independent variables show that improving stakeholder involvement helps boost economic and social results, and digital technology plays a

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

mediating role. Using TBSAI as its dependent variable, the study measured the degree to which seaport operations achieved success with economic, environmental, and social factors.

3.5 Data Analysis

SPSS and R statistics were used to examine and analyze the data. Descriptive statistics examined the relationship between the research variables and their correlation. Multivariate analysis was used to investigate the relationship between port performance measures and digitalization. Structural Equation Modeling (SEM) was selected over traditional regression analysis due to its ability to model complex relationships between multiple variables, particularly when latent constructs are involved. In this study, TBSAI was conceptualized as a latent construct, measured by several indicators, including the Stakeholder Engagement Index (SEI), Economic Impact Ratio (EIR), Environmental Compliance Score (ECS), and others. SEM allows for the simultaneous estimation of multiple relationships, providing a robust framework to evaluate how these indicators collectively influence overall port performance and sustainability. This is crucial because TBSAI encapsulates a multifaceted view of port performance, integrating economic, environmental, and social dimensions, all of which are interrelated. SEM also accounts for measurement errors and evaluates the fit of the entire model, which is essential when dealing with complex, multi-indicator systems like TBSAI. Therefore, SEM was the most appropriate choice for modeling the relationships between TBSAI's components, allowing for a more accurate and nuanced understanding of port performance in Bangladesh.

3.6 Ethical Considerations

This study adhered to established ethical research standards to ensure integrity and participant protection. All participants consented to be part of the study. The researcher described the research objectives, data usage, and data discarding. The participants were also assured that they were free to withdraw from the study whenever they felt uncomfortable. Personal information and data were kept safe by not sharing them with other parties outside the research. The study complied with institutional research ethics guidelines and relevant national data protection regulations.

IV. RESULTS

4.1 Reliability

The internal consistency of the scales used in this study was evaluated using Cronbach's alpha. The reliability was the highest for the Digital Technology Adoption Rate scale (α = .922), followed by Regulatory Compliance Efficiency (α = .894), Overall Performance and Alignment (α = .892), and Sustainability Innovation Index (α = .881). Also, the Social Value Creation Index showed high reliability (α = .839), whereas the Stakeholder Engagement Index (α = .818) and Environmental Compliance Score (α = .774) demonstrated good internal consistency. The Economic Impact Ratio obtained the lowest, yet acceptable, reliability (α = .732).

4.2 Descriptive Analysis

Scale	N	No. of Items	Cronbach's Alpha
Stakeholder Engagement Index	229	6	0.818
Economic Impact Ratio	229	5	0.732
Environmental Compliance Score	229	6	0.774
Social Value Creation Index	229	5	0.839
Digital Technology Adoption Rate	229	6	0.922
Sustainability Innovation Index	229	5	0.881
Regulatory Compliance Efficiency	229	5	0.894
Overall Performance and Alignment	229	4	0.892

The highest mean score (M = 16.70, SD = 4.06) belonged to the Stakeholder Engagement Index, followed by close results of Environmental Compliance Score (M = 16.67, SD = 3.65), and Digital Technology Adoption Rate (M = 15.35, SD = 4 The Economic Impact Ratio (M = 14.48, SD = 3.40); Regulatory Compliance Efficiency (M = 13.64, SD = 3.58); and Social Value Creation Index (M = 13.73, SD = 3.76) showed an average performance in terms of Sustainability Innovation

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

Index had the lowest mean (M = 13.27, SD = 3.72).

Table 3: Summary of Means, Standard Deviations, and Score Ranges for Key Constructs

	Mean	SD	Minimum	Maximum
Overall Performance and Alignment	12.4	3.285	5	20
Stakeholder Engagement Index	16.7	4.061	6	27
Economic Impact Ratio	14.48	3.402	6	23
Environmental Compliance Score	16.67	3.645	7	27

The Chattogram Port consistently outperformed Mongla and Payra across most of the KPIs, particularly in Environmental Compliance (M = 16.67) and Stakeholder Engagement (M = 16.70). Payra Port, on the other hand, had the lowest scores across all KPIs, particularly in the Sustainability Innovation Index (SII) (M = 13.27), highlighting a significant gap in sustainability practices at this port compared to the other two.

4.3 Correlation Analysis

Strongest correlations were observed with Sustainability Innovation Index ($r = .696$, $p < .01$), Digital Technology Adoption Rate ($r = .665$, $p < .01$), and Regulatory Compliance Efficiency ($r = .652$, $p < .01$), meaning a strong relationship between the variables. A positive moderate correlation was also found with Stakeholder Engagement Index ($r = .630$, $p < .01$), Social Value Creation Index ($r = .625$, $p < .01$), Economic Impact Ratio ($r = .562$, $p < .01$), and Environmental Compliance Score ($r = .512$, $p < .01$).

Table 4: Pearson Correlation Matrix Between Overall Performance and Alignment and Other Study Variables

	1	2	3	4	5	6	7	
1. Overall Performance and Alignment	1							
2. Stakeholder Engagement Index	.630**							
3. Economic Impact Ratio	.562**	.518**						
4. Environmental Compliance Score	.512**	.508**	.480**					
5. Social Value Creation Index	.625**	.417**	.413**	.359**				
6. Digital Technology Adoption Rate	.665**	.558**	.498**	.458**	.650**			
7. Sustainability Innovation Index	.696**	.539**	.437**	.376**	.580**	.645**		
8. Regulatory Compliance Efficiency	.652**	.561**	.500**	.406**	.562**	.570**	.576**	1
** $p < 0.01$								

4.4 SEM Analysis

The Structural Equation Modeling (SEM) analysis was conducted to examine the relationship between the latent construct of Overall Performance and

ISBN 978-984-35-5270-9

Alignment and its observed indicators. Although the Root Mean Square Error of Approximation (RMSEA) exceeded the commonly accepted threshold of 0.08 (RMSEA = 0.098), the model fit was still considered valid, as both the Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) were above the threshold of 0.90 (CFI = 0.956, TLI = 0.934). According to Hu and Bentler, values of CFI and TLI above 0.90 support the overall validity of the model, even when RMSEA is borderline. Additionally, the Standardized Root Mean Square Residual (SRMR) was 0.046, well below the threshold of 0.08, which further supported the fit of the model. The SEM estimates revealed that the Digital Technology Adoption Rate (DTAR) had the most potent effect on Overall Performance and Alignment (β = 0.816), indicating that digital adoption is a key driver of port performance. In contrast, the Environmental Compliance Score (ECS) had the weakest path coefficient (β = 0.575), suggesting that while important, ECS has a relatively lower impact on overall port alignment with sustainability goals.

Table 5: SEM Estimates for the Latent Construct of Overall Performance and Alignment

Indicator	Standardized Loading (β)	R^2	SE	z	p
SEI	0.711	0.505	0.243	11.84	< .001
EIR	0.64	0.409	0.211	10.31	< .001
ECS	0.575	0.331	0.232	9.03	< .001
SVCI	0.722	0.522	0.224	12.1	< .001
DTAR	0.816	0.666	0.237	14.41	< .001
SII	0.762	0.581	0.217	13.04	< .001
RCE	0.746	0.557	0.211	12.66	< .001
χ^2 (df = 14)	*44.89*				
p-value (Chi-square)	*< .001*				
CFI (Comparative Fit Index)	*0.956*				
TLI (Tucker-Lewis Index)	*0.934*				
RMSEA	*0.098*				
RMSEA 90% CI	*[0.067, 0.131]*				
SRMR	*0.046*				
AIC	*8137.33*				
BIC	*8185.4*				
SABIC	*8141.03*				

All paths from TBSAI to the observed variables SEI (0.71), EIR (0.64), ECS (0.57), SVCI (0.72), DTAR (0.82), SII (0.76), and RCE (0.75) have strong and consistent loading values and are statistically significant and positive. The path with the highest level of significance is from TBS to Digital technology adoption (DTAR = 0.82), which is thus the indicator most affecting the latent construct, while the weakest is Environmental compliance score (ECS = 0.57).

Table 2: Reliability values of items used in variables

Variable	No. of Items	Chronbach's Alpha Value	Result
Customer Repurchase Intention	*4*	*0.834*	*Good*
Negative Emotional Response	*3*	*0.832*	*Good*
Customer Confusion	*5*	*0.802*	*Good*
Customer Satisfaction	*2*	*0.585*	*Poor*
Perceived Justice	*4*	*0.672*	*Questionable*
Negative Word of Mouth	*3*	*0.804*	*Good*

Figure 1: Measurement Model Depicting Factor Loadings of Triple Bottom-Line Stakeholder Alignment Index (TBS)

V. DISCUSSION AND CONCLUSION

5.1 Discussion

The findings indicate a strong relationship between stakeholder engagement and the attainment of sustainability goals in seaports, aligning with the port regionalization model [33]. This model underscores ports' transformation into integrated regional economic hubs, which is reflected in the significant influence of the Economic Impact Ratio on GDP growth, employment, and industrial activity in Bangladesh. Linking these outcomes to the Resource-Based View (RBV), digital technologies measured through DTAR can be seen as rare, inimitable, and valuable resources, explaining their substantial effect

ISBN 978-984-35-5270-9 https://icebtm.iub.edu.bd

on operational performance. Ports leveraging IoT, blockchain, AI, and autonomous systems demonstrate enhanced decision-making, predictive maintenance, and environmental monitoring capabilities [24] [34]. However, the Environmental Compliance Score (ECS) showed a comparatively lower loading (β = 0.57), which may reflect weak enforcement mechanisms under Bangladesh's Environmental Conservation Act. This finding suggests that without stringent monitoring, environmental sustainability objectives may lag behind economic and technological advances. Pressures from international regulations such as MARPOL and normative expectations from global trade partners should elevate compliance levels. The case of Bangladesh illustrates that these institutional forces are undermined by weak enforcement mechanisms under the Environmental Conservation Act [35]. Effective environmental governance requires robust institutional capacity to translate policy into consistent practice [8]. Additionally, while high SVCI scores demonstrate ports' social contributions, including equitable opportunities and community development, the integration of environmental and social dimensions still requires stronger institutional support to achieve full sustainability synergy.

5.2 Conclusion

According to the findings, there is a strong relationship between stakeholder involvement and the achievement of sustainability goals in seaports. Ports with better representation of stakeholders tend to perform well in economics, the environment, and society [11] [36]. When stakeholders are involved in governance, inclusion grows, and transparency increases. The study used the Triple-Bottom-Line Stakeholder Alignment Index (TBSAI) to evaluate the sustainability of seaports in Bangladesh, emphasizing the integration of economic, environmental, and social objectives. The findings showed a connection between robust stakeholder engagement, digital technology adoption, and improved port performance. The results also indicated that in Bangladesh, ports, especially Chattogram Port, benefit from better alignment of stakeholder needs and sustainability objectives [33]. This also confirms the theoretical basis of the stakeholder theory. The alignment also ensures that all stakeholders, including local communities, port authorities, and regulatory bodies, work towards achieving common sustainability goals [35] [24] [34]. Despite the positive trends, the study also revealed a gap in Environmental Compliance Scores (ECS), which demonstrated weaker loadings. This suggests that the implementation of Bangladesh's Environmental Conservation Act may not be as effective as intended. The lack of strict enforcement mechanisms and the limited capacity for monitoring environmental impacts could be contributing factors. The findings suggest that ports need to adopt more effective IoT-based monitoring systems and other digital tools to improve their environmental compliance and reduce negative ecological impacts.

5.3 Summary of Contributions

The findings verified that greater levels of engagement, compliance, and innovation positively relate to better performance for sustainability. Such outcomes invoke the need for adopting a holistic and integrated approach to port management that follows global sustainability standards.

The results emphasize strongly the role of stakeholder engagement in the consensus development of economic, environmental, and social aspects of sustainability. The study further affirms the importance of regional cooperation, specifically through the efforts of the Regional Connectivity Enhancement (RCE), in integrating port authority objectives and resources.

The introduction of the Smart Infrastructure Index (SII) reveals that while digital and physical infrastructure development is crucial, it must be complemented by a strong focus on environmental sustainability.

5.4 Recommendations

Adopt IoT-based ECS monitoring systems to improve real-time environmental compliance tracking, thus enhancing port sustainability practices.

Integrate digital tools such as AI, blockchain, and digital twins to enhance transparency, optimize maintenance, reduce emissions, and improve port operations.

Establish formal stakeholder engagement platforms to integrate diverse perspectives into port sustainability strategies, promoting more inclusive decision-making.

Expand community-focused programs that address socio-economic disparities in port-adjacent areas, ensuring that local populations benefit from port developments.

Develop standardized sustainability indices, like SSSPI, for consistent performance measurement, providing a clear benchmark for sustainability in ports.

5.6 Limitations of the Study

The cross-sectional nature of the study limits the ability to draw causal inferences or track changes over time, necessitating future longitudinal research.

The study was limited solely to seaports in Bangladesh, which could limit the generalizability of the findings to the regional or global port settings.

ISBN 978-984-35-5270-9 *https://icebtm.iub.edu.bd*

Although the use of composite indices like the Stakeholder Engagement Index and Environmental Compliance Score is effective for measurement, it can reducecomplexities of sustainability dynamics.
The study did not consider other potential moderators, such as changes in government policy, geopolitical influences, and external shocks to the economy, which might influence port sustainability outcomes.

5.7 Future Research

[1] Longitudinal analyses to explore the long-term impacts of sustainability initiatives on seaport performance across multiple ports and regions, offering broader insights.
[2] Future studies should examine emerging technologies, such as AI-based predictive analytics, blockchain integration, and autonomous systems, and their role in advancing port sustainability.
[3] Qualitative methods, such as in-depth interviews with port managers and stakeholders, could provide deeper insights into the contextual and behavioral factors that shape sustainable practices in ports.
[4] Comparative research across developing and developed countries would help identify best practices, offering policy implications relevant to various socio-economic and regulatory contexts.

REFERENCES

[1]. Gephart, J. A., & Pace, M. L. (2015). Structure and evolution of the global seafood trade network. *Environmental Research Letters*, *10*(12), 125014. https://doi.org/10.1088/1748-9326/10/12/125014

[2] Hassan, C. S. M. (2025). How modern are our ports, really? Retrieved from https://www.tbsnews.net/thoughts/how-modern-are-our-ports-really-1173731

[3] Sarker, M. J. A., & Rahman, M. M. (2015). Analysis of port management in Bangladesh: challenges and potentials. *Manarat International University Studies*, *4*, 25-34. https://www.researchgate.net/profile/Md-Juwel-Ahmed-Sarker/publication/369619070_Analysis_of_port_management_in_Bangladesh_challenges_and_potentials/links/66d909ae2390e50b2c53e9bb/Analysis-of-port-management-in-Bangladesh-challenges-and-potentials.pdf#page=31

[4] World Bank (2021). Creating Markets in Bangladesh. Unleashing the Private Sector to Sustain Development Success. (N.d.). Retrieved from https://documents1.worldbank.org/curated/en/099817006242227620/pdf/IDU-e76ca85f-0e26-4108-9261-4699f1b7b0bd.pdf#page=76.99

[5] Askari, H. R., Bushra, R. T., & Hossain, M. N. (2021). The maritime sector in the economic development of Bangladesh. *Bangladesh Maritime Journal*, *5*(1), 111-126. https://www.researchgate.net/publication/352662360_The_Maritime_Sector_in_the_Economic_Development_of_Bangladesh

[6] Sen, S., Shaikh, M. A., Tareq, A. M., Islam, M. S., & Wang, X. (2020). Port efficiency and supply chain: Implication for Bangladesh. *International Journal of Engineering and Management Research*, *10*(6), 21-34. https://www.researchgate.net/profile/Md-Shaikh-2/publication/346994812_Port_Efficiency_and_Supply_Chain_Implication_for_Bangladesh/links/5fd76a9145851553a0b5a9e1/Port-Efficiency-and-Supply-Chain-Implication-for-Bangladesh.pdf

[7] Islam, S. (2017). Chittagong congestion raises UScotton shippers' costs. Retrieved from: https://www.joc.com/international-logistics/logistics-providers/chittagong-congestion-raises-us-cotton-shippers%E2%80%99-costs_20170804.html

[8] Datta, S.K. (2025). Maritime Power and Ocean Geopolitics: A Strategic Analysis of Bangladesh's Maritime Interests and Challenges. In: Nandy, D., Das, M. (eds) Decoding the Chessboard of Asian Geopolitics. Palgrave Macmillan, Singapore. https://doi.org/10.1007/978-981-96-3368-5_3

[9] Hasnat, M. A. (2024). The feasibility and challenges of implementing a green port policy framework in Bangladesh.https://commons.wmu.se/cgi/viewcontent.cgi?article=3420&context=all_dissertations

[10] Monir, M. M. I. (2017). The role of Port of Chittagong on the economy of Bangladesh. *Erasmus University Rotterdam. https://thesis. eur. nl/pub/40492*.

[11] ADB (2018, December). Bangladesh: Chittagong Port Trade Facilitation Project. Performance Evaluation Project. Retrieved from https://www.adb.org/sites/default/files/evaluation-document/470666/files/pper-l2147-ban-chittagong-port.pdf

[12] Wang, K., Hu, Q., Zhou, M., Zun, Z., & Qian, X. (2021). Multi-aspect applications and development challenges of digital twin-driven management in global smart ports. *Case Studies on Transport Policy*, *9*(3). https://doi.org/10.1016/j.cstp.2021.06.014

[13] Tsvetkova, A., Gustafsson, M., & Wikström, K. (2021). Digitalizing maritime transport: digital innovation as a catalyzer of sustainable transformation. In *A Modern Guide to the Digitalization of Infrastructure*. https://doi.org/10.4337/9781839106057.00011

[14] Alamoush, A. S., Ballini, F., & Ölçer, A. I. (2024). Management of stakeholders engaged in port energy transition. *Energy Policy*, *188*, 114074. https://www.sciencedirect.com/science/article/pii/S0301421524000946

[15] Yang, Y.-C., & Hsieh, Y.-H. (2024). The critical success factors of smart port digitalization development in the post-COVID-19 era. *Case Studies on Transport Policy*, *17*, 101231. https://doi.org/10.1016/j.cstp.2024.101231

ISBN 978-984-35-5270-9 *https://icebtm.iub.edu.bd*

[16] Freeman, R. E. (1984). Strategic Management: A Stakeholder Approach. Pitman: London. In *Business Ethics Quarterly* (Vol. 4, Issue 4).

[17] Beitelmal, W. H., Nwokolo, S. C., Meyer, E. L., & Ahia, C. C. (2024). Exploring Adaptation Strategies to Mitigate Climate Threats to Transportation Infrastructure in Nigeria: Lagos City, as a Case Study. *Climate*, *12*(8), 117. https://doi.org/10.3390/cli12080117

[18] Song, Z. Y., Lin, C. W., Feng, X., & Lee, P. T. W. (2024). An empirical study of the performance of the sixth-generation ports model with smart ports with reference to major container ports in mainland China. *Transportation Research Part E: Logistics and Transportation Review*, *184*. https://doi.org/10.1016/j.tre.2024.103460

[19]. Freeman, R. E. E., & McVea, J. (2001). A Stakeholder Approach to Strategic Management. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.263511

[20] World Bank. (2021). The World Bank Annual Report 2021: From Crisis to Green, Resilient, and Inclusive Recovery. In *The World Bank*.

[21] UNCTAD. (2020). Impact of the COVID-19 pandemic on trade and development : transitioning to a new normal. In the *Conference on Trade and Development*

[22] Molavi, A., Lim, G. J., & Race, B. (2020). A framework for building a smart port and a smart port index. *International Journal of Sustainable Transportation*, *14*(9). https://doi.org/10.1080/15568318.2019.1610919

[23] Inkinen, T., Helminen, R., & Saarikoski, J. (2021). Technological trajectories and scenarios in seaport digitalization. *Research in Transportation Business and Management*, *41*. https://doi.org/10.1016/j.rtbm.2021.100633

[24] Jabłoński, A., & Jabłoński, M. (2023). Intelligent Digital Transformation in Modern Socio-Technical Systems – A Sustainable Approach. In *Lecture Notes in Networks and Systems* (Vol. 549). https://doi.org/10.1007/978-3-031-16598-6_3

[25] Notteboom *, T. E., & Rodrigue, J.-P. (2005). Port regionalization: towards a new phase in port development. *Maritime Policy & Management*, *32*(3), 297–313. https://doi.org/10.1080/03088830500139885

[26] Baskutis, S., Baskutiene, J., Navickas, V., Bilan, Y., & Cieśliński, W. (2021). Perspectives and problems of using renewable energy sources and implementation of local "green" initiatives: A regional assessment. *Energies*, *14*(18). https://doi.org/10.3390/en14185888

[27] Del Giudice, M., Di Vaio, A., Hassan, R., & Palladino, R. (2022). Digitalization and new technologies for sustainable business models at the ship–port interface: a bibliometric analysis. *Maritime Policy and Management*, *49*(3). https://doi.org/10.1080/03088839.2021.1903600

[28] Pagano, P., Antonelli, S., & Tardo, A. (2022). C-Ports: A proposal for a comprehensive standardization and implementation plan of digital services offered by the "Port of the Future." In *Computers in Industry* (Vol. 134). https://doi.org/10.1016/j.compind.2021.103556

[29] Heikkilä, M., Saarni, J., & Saurama, A. (2022). Innovation in Smart Ports: Future Directions of Digitalization in Container Ports. *Journal of Marine Science and Engineering*, *10*(12), 1925. https://doi.org/10.3390/jmse10121925

[30] Yang, J., Cao, X., Yao, J., Kang, Z., Chang, J., & Wang, Y. (2024). Geographical big data and data mining: A new opportunity for "water-energy-food" nexus analysis. *Journal of Geographical Sciences*, *34*(2). https://doi.org/10.1007/s11442-024-2202-6

[31] Argyriou, I., & Tsoutsos, T. (2023). Sustainable Solutions for Small/Medium Ports: A Guide to Efficient and Effective Planning. In *Journal of Marine Science and Engineering* (Vol. 11, Issue 9).

[32] Notteboom, T., & Rodrigue, J. P. (2023). Maritime container terminal infrastructure, network corporatization, and global terminal operators: Implications for international business policy. In *Journal of International Business Policy* (Vol. 6, Issue 1). https://doi.org/10.1057/s42214-022-00142-z

[33] Notteboom, T., & Haralambides, H. (2023). Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe. In *Maritime Economics and Logistics* (Vol. 25, Issue 1). https://doi.org/10.1057/s41278-023-00253-1

[34] Triska, Y., Frazzon, E. M., Silva, V. M. D., & Heilig, L. (2024). Smart port terminals: conceptual framework, maturity modeling, and research agenda. *Maritime Policy and Management*, *51*(2). https://doi.org/10.1080/03088839.2022.2116752

[35] Attanasio, G., Battistella, C., & Chizzolini, E. (2023). The future of energy management: Results of a Delphi panel applied in the case of ports. *Journal of Cleaner Production*, *417*. https://doi.org/10.1016/j.jclepro.2023.137947

[36] Basulo-Ribeiro, J., Pimentel, C., & Teixeira, L. (2024). What is known about smart ports around the world? A benchmarking study. *Procedia Computer Science*, *232*, 1748–1758. https://doi.org/10.1016/j.procs.2024.01.173

[37] Chlomoudis, C., Kostagiolas, P., Pallis, P., & Platias, C. (2024). Environmental management systems in Greek ports: A transformation tool? *Environmental Challenges*, *14*, 100837. https://doi.org/10.1016/j.envc.2024.100837

[38] Gunes, B., Kayisoglu, G., & Bolat, P. (2021). Cyber security risk assessment for seaports: A case study of a container port. *Computers and Security*, *103*. https://doi.org/10.1016/j.cose.2021.102196

[39] Roh, S., Thai, V. V., Jang, H., & Yeo, G. T. (2023). The best practices of port sustainable development: a case study in Korea. *Maritime Policy and Management,* 50(2). https://doi.org/10.1080/03088839.2021.1979266

[40] Jin, J., & Zhu, M. (2024). *Towards Adaptive and Resilient Strategies Using Digital Twins: A Study on the Port of Tyne, UK*. https://doi.org/10.1007/978-981-99-9014-6_9

ISBN 978-984-35-5270-9

ISBN 978-984-35-5270-9 *https://icebtm.iub.edu.bd*