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Environmental process maturity: A sustainable theoretical framework for Polish ports

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Abstract

Ports are critical nodes in global trade and logistics, playing a vital role in the sustainability agenda due to their significant environmental and social impacts. Despite increasing attention to sustainability, there is limited research on frameworks that holistically assess the environmental process maturity of ports, especially in the context of Polish ports. This study aims to address the gap by proposing a conceptual model to assess the environmental process maturity of ports, integrating environmental performance, stakeholder engagement, and regulatory alignment. The model focuses on providing actionable insights for port authorities to enhance sustainability. The study employs a conceptual approach, synthesising information from sustainability frameworks, Corporate and Social Responsibility (CSR) models, and maturity assessments. Key constructs are operationalised through specific indicators to evaluate maturity levels across five progressive stages – Initial, Developing, Established, Integrated, and Optimised. The model is tailored to the unique challenges of Polish ports and contextualised within broader European Union sustainability goals. The proposed model bridges the gap between theoretical sustainability principles and practical applications. It provides a structured framework to evaluate and improve environmental processes, offering a roadmap for ports to transition from basic compliance to strategic environmental leadership. The model's adaptability enables benchmarking and alignment with global best practices. This study contributes to the discourse on sustainable port management by introducing an integrative framework for assessing environmental process maturity. It provides theoretical advancements and practical tools for enhancing port sustainability performance, particularly in Polish and European contexts.

Keywords

Environmental process maturity, sustainable port management, stakeholder engagement, regulatory compliance, Polish ports.

1. Introduction

Ports are critical nodes in global trade and logistics networks, serving as gateways for the movement of goods across continents. Their strategic role extends beyond economic contributions to include environmental and social impacts, making them pivotal actors in the sustainability agenda. With increasing global attention on environmental challenges such as climate change, air pollution, and resource depletion, the operations of ports are now scrutinised for their environmental sustainability (Dávid et al., 2024; Peris-Mora et al., 2005). This scrutiny is amplified by their significant contributions to greenhouse gas emissions, noise pollution, and habitat degradation, necessitating proactive and integrated environmental strategies (Klimek et al., 2019; Sogut and Erdogan, 2022).

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While sustainability in ports has gained scholarly attention (Housni et al., 2022; Mańkowski and Charłampowicz, 2021), research has largely focused on individual measures such as energy efficiency, emissions reduction, or green certifications. There is limited understanding of how ports can holistically develop and assess the maturity of their environmental processes. Existing frameworks, such as those for digital transformation and corporate social responsibility, often lack the specificity to address the environmental complexities of port operations. This gap is particularly evident in Polish ports, which face unique challenges related to infrastructural constraints, regulatory frameworks, and aligning local practices with broader European Union sustainability goals (Argyriou et al., 2019; Notteboom et al., 2020).

This paper aims to address this gap by proposing a conceptual model for assessing the environmental process maturity of Polish ports. This study seeks to provide a structured approach to evaluate and guide environmental maturity by drawing from existing sustainability frameworks, maturity models, and empirical insights from port operations. The model will offer theoretical insights into environmental process integration and practical guidance for port authorities, policymakers, and stakeholders seeking to enhance sustainability performance.

As ports increasingly operate at the intersection of economic efficiency and environmental responsibility, this research is timely and necessary. Focusing on Polish ports, this study provides a contextualised understanding of environmental process maturity while contributing to broader discourses on sustainable port management. The findings aim to advance theoretical knowledge and offer actionable recommendations for achieving higher levels of environmental sustainability in the port sector (Charłampowicz and Mańkowski, 2024; Klimek et al., 2019; Notteboom et al., 2020; Sogut and Erdogan, 2022).

This paper is organised as follows: the next section comprehensively reviews the relevant literature. Section 3 introduces the conceptual framework for assessing environmental process maturity in ports. Section 4 discusses the proposed model, followed by an exploration of its theoretical contributions in Section 5. Managerial implications are addressed in Section 6. Finally, the concluding section summarises the key findings, outlines research limitations, and suggests directions for future studies.

2. Literature review

The theoretical foundation of this study is grounded in integrating sustainability frameworks and maturity models within the context of port operations. Sustainability in ports involves balancing economic growth, environmental protection, and social responsibility (Klimek et al., 2019). This study adopts a systemic perspective, viewing ports as complex systems where environmental process maturity reflects the extent to which environmental practices are integrated into operations, strategy, and stakeholder engagement.

Environmental sustainability in ports has traditionally been examined through the lenses of Corporate and Social Responsibility (CSR) and operational efficiency. Klimek et al. (2019) emphasise the role of CSR in fostering stakeholder engagement and environmental stewardship, particularly in Polish ports. However, current practices often remain fragmented, focusing on isolated initiatives such as emissions reduction or energy efficiency without a cohesive framework for process integration (Sogut and Erdogan, 2022).

Sustainability reporting frameworks provide valuable insights into performance measurement but fall short in evaluating process maturity (Boullauazan et al., 2023; Notteboom et al., 2020). These frameworks highlight critical metrics like emissions monitoring and waste management but lack the granularity needed to assess the development and integration of environmental processes across maturity stages. Furthermore, while tools such as the EcoPorts initiative promote environmental monitoring, they do not adequately address process standardisation or continuous improvement (Argyriou et al., 2019).

Despite advancements in sustainability initiatives, the concept of environmental process maturity in ports remains underexplored (Charłampowicz and Mańkowski, 2024; Haezendonck and Van Den Berghe, 2020). While models like the Digital Readiness Index for Smart Ports provide maturity assessments for technological innovation (Philipp, 2020), comparable frameworks for environmental processes are lacking. Additionally, there is a limited understanding of how stakeholder engagement and regulatory compliance contribute to advancing environmental maturity (Sogut and Erdogan, 2022). The need for an integrative model that aligns environmental, social, and economic dimensions is particularly pressing for Polish ports, which face unique challenges related to their infrastructural and regulatory environments.

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The major constructs of this study include environmental process maturity, stakeholder engagement, and regulatory compliance. Environmental process maturity is defined as the extent to which a port integrates environmental considerations into its operational and strategic frameworks, encompassing dimensions such as emissions reduction, energy efficiency, and waste management (Argyriou et al., 2019; Charłampowicz and Mańkowski, 2024; Klimek et al., 2019). Stakeholder engagement refers to the active involvement of port users, local communities, and policymakers in environmental initiatives (Olofsson et al., 2023). Regulatory compliance encompasses adherence to international and local environmental standards, such as those highlighted in the European Sea Ports Organization's EcoPorts initiative (Notteboom et al., 2020).

Operationalising these constructs requires a structured approach. For instance, environmental process maturity can be assessed through indicators such as adopting renewable energy, implementing emissions monitoring systems, and achieving green certifications (Notteboom et al., 2020; Sogut and Erdogan, 2022). Stakeholder engagement can be measured through surveys, public consultations, and partnerships (Klimek et al., 2019). Regulatory compliance can be evaluated by analysing adherence to emissions standards and waste management protocols (Argyriou et al., 2019; Chlomoudis et al., 2024).

The relationships between these constructs are critical to developing an environmental process maturity model. Stakeholder engagement acts as a catalyst for advancing environmental maturity by fostering collaboration and accountability (Klimek et al., 2019). Regulatory compliance provides a baseline for environmental practices, ensuring that ports meet minimum standards while striving for continuous improvement (Argyriou et al., 2019). Together, these constructs form an interconnected framework that drives the evolution of environmental processes from basic compliance to strategic integration and innovation.

By synthesising insights from existing literature, this study addresses the gap in assessing environmental process maturity in ports. The proposed model advances theoretical understanding and provides practical tools for enhancing sustainability in Polish ports, contributing to the broader discourse on sustainable port management.

3. Conceptual framework for assessing environmental process maturity in ports

The proposed model for assessing environmental process maturity in ports builds upon the identified gaps in the literature, providing a comprehensive framework that integrates environmental performance, stakeholder engagement, and regulatory alignment into a structured maturity assessment tool. This model is particularly tailored to address Polish ports' specific challenges and opportunities, considering their strategic role in the Baltic region and the European Union's sustainability mandates (European Commission, 2019).

At its core, the model conceptualises environmental process maturity as a multi-dimensional construct comprising three interrelated dimensions: environmental performance, stakeholder engagement, and regulatory alignment. Each dimension is operationalised through specific criteria and indicators, allowing for the systematic evaluation of a port's maturity level. The five maturity levels – Initial, Developing, Established, Integrated, and Optimised – represent a progression from basic compliance to strategic environmental leadership.

The environmental performance dimension evaluates implementing practices to reduce the port's environmental impact, including emissions reduction, energy efficiency, and waste management—indicators for this dimension based on established frameworks such as EcoPorts (Notteboom et al., 2020). Ports at the initial maturity level typically exhibit ad hoc or reactive environmental practices, while those at the optimum level demonstrate advanced integration of green technologies such as renewable energy systems and hydrogen-powered equipment.

The second dimension, stakeholder engagement, measures the extent to which ports collaborate with and respond to the needs of their stakeholders, including local communities, port users, and regulatory bodies. Stakeholder engagement is a critical component of CSR (Klimek et al., 2019), fostering trust and collaboration essential for advancing environmental maturity (Olofsson et al., 2023). This dimension includes indicators such as structured stakeholder consultations, public environmental performance reporting, and partnerships for sustainability initiatives.

The third dimension, regulatory alignment, assesses the port's adherence to local, national, and international environmental standards. This dimension emphasises compliance and proactive alignment with emerging standards such as the European Green Deal and International Maritime Organization (IMO) emissions reduction targets (Argyriou et al., 2019). For instance, ports at the initial maturity level may meet only basic regulatory requirements, whereas those at the optimum level actively contribute to developing new environmental policies and standards.

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The model's evaluation process involves three key stages: assessment, benchmarking, and improvement planning. During the assessment stage, ports are evaluated against defined indicators for each dimension using data collection methods, including performance audits, stakeholder surveys, and compliance reviews. Benchmarking involves comparing the port's performance with best practices from leading ports. Finally, improvement planning enables ports to develop targeted action plans for advancing to higher maturity levels, incorporating feedback mechanisms to ensure continuous progress.

To illustrate the model's practical application, Table 1 provides an example of the evaluation criteria and maturity levels of the environmental performance dimension. These adaptable criteria can be customised to address specific local and regional contexts.

Table 1. Environmental process maturity assessment for ports

Maturity Level	Criteria for Environmental Performance
Initial	Minimal compliance with environmental regulations; limited implementation of basic waste management practices.
Developing	Adoption of structured emissions monitoring systems; basic energy efficiency measures.
Established	Integration of renewable energy sources; systematic waste segregation and recycling programs.
Integrated	Implementation of advanced emissions reduction technologies; active participation in international environmental initiatives.
Optimised	Use of cutting-edge green technologies (e.g., hydrogen-powered equipment); development of port-specific sustainability standards.

The proposed model offers several advantages for Polish ports. By systematically evaluating their environmental process maturity, ports can identify specific areas for improvement, prioritise resource allocation, and develop strategies aligning with local challenges and global sustainability goals.

Additionally, the model provides a basis for comparative analysis, enabling ports to benchmark their progress against peers and industry leaders. This is particularly relevant for Polish ports seeking to align with the European Union's sustainability agenda while maintaining regional competitiveness.

4. Discussion

The proposed model for assessing port environmental process maturity aligns with and extends existing frameworks and studies on sustainability and CSR. Its emphasis on integrating environmental performance, stakeholder engagement, and regulatory alignment into a cohesive framework addresses the limitations of current models, such as the EcoPorts (Notteboom et al., 2020). While EcoPorts provides valuable tools for environmental monitoring, it lacks the depth required to evaluate the progression of environmental practices through maturity stages, a gap this model seeks to fill.

The model also builds on the theoretical underpinnings of CSR by operationalising stakeholder engagement as a critical dimension (Klimek et al., 2019). This approach enhances the traditional CSR perspective by embedding it within a maturity framework, providing a structured pathway for ports to evolve from basic compliance to advanced collaboration and innovation. Such integration is especially relevant given the emphasis that stakeholder-driven initiatives are pivotal for achieving long-term environmental goals (Olofsson et al., 2023).

Compared to technological maturity models (Philipp, 2020), the proposed model incorporates environmental and regulatory dimensions often absent from technology-focused assessments. By including regulatory alignment, the model addresses the dynamic nature of environmental standards and the need for ports to comply with and influence emerging policies. This dimension is particularly important in light of the European Green Deal and the International Maritime Organization's GHG reduction targets (Eide et al., 2011; Shi and Gullett, 2018).

The structured progression across five maturity levels – Initial, Developing, Established, Integrated, and Optimised – adds a developmental perspective to evaluating environmental practices. Unlike existing frameworks, which often present static assessments, this model allows for longitudinal progress tracking, enabling ports to benchmark their development against best practices and industry leaders such as Rotterdam and Hamburg. The model's adaptability to local contexts, including Polish ports, further enhances its applicability, addressing the unique infrastructural and regulatory challenges these ports face.

5. Theoretical Contribution

This study contributes to the existing body of knowledge by advancing the conceptual understanding of environmental process maturity in ports. Unlike prior research studies that often focus on individual sustainability measures, this model

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provides an integrated framework that links environmental performance, stakeholder engagement, and regulatory alignment. The study introduces a novel way of assessing and guiding sustainability practices by operationalising these dimensions within a structured maturity framework. The added value can also be seen from a methodological perspective, particularly in the method used to identify the maturity levels the ports have reached or aim to achieve concerning environmental aspects.

The model also reinterprets CSR in the context of ports by embedding it within the maturity progression, demonstrating how stakeholder engagement can evolve from basic consultations to strategic partnerships. Furthermore, it extends the scope of regulatory compliance by emphasising proactive contributions to policy development, offering a new lens through which the relationship between ports and regulatory frameworks can be viewed. These contributions highlight ports' potential to transition from passive adopters of environmental standards to active leaders in sustainability innovation.

6. Managerial implications

The proposed model offers actionable insights for port authorities and policymakers seeking to enhance sustainability practices. By identifying specific indicators for environmental performance, stakeholder engagement, and regulatory alignment, the model provides a roadmap for systematic improvement. Port managers can use the model to assess their maturity level, identify gaps, and prioritise interventions, such as investing in renewable energy technologies or strengthening stakeholder collaboration mechanisms.

Moreover, the model's adaptability allows ports to tailor the framework to their unique contexts, balancing global sustainability standards with local challenges. For instance, Polish ports can leverage the model to align with the European Green Deal while addressing regional infrastructural constraints. The structured progression of maturity levels also enables ports to set clear, achievable goals, fostering a culture of continuous improvement.

The model is a benchmarking tool, enabling ports to compare their performance with industry leaders and adopt best practices. This comparative analysis can inform strategic decisions, such as resource allocation and policy advocacy, ensuring that sustainability initiatives are effective and scalable. By integrating environmental process maturity into strategic planning, ports can enhance their competitiveness while contributing to broader sustainability goals.

7. Conclusions

This study introduces a comprehensive model for assessing environmental process maturity in ports, addressing a critical gap in the literature. The model's integration of environmental performance, stakeholder engagement, and regulatory alignment provides a holistic framework for evaluating and advancing sustainability practices. Key findings highlight the importance of structured maturity progression, stakeholder-driven initiatives, and proactive regulatory compliance.

The study offers significant practical implications, particularly for Polish ports, which can use the model to navigate the dual challenges of regional constraints and global sustainability mandates. However, the model's applicability is not without limitations. Its reliance on specific indicators may require customisation for diverse operational contexts, and its effectiveness depends on the availability of accurate data and stakeholder buy-in. Moreover, the presented model is a conceptual framework which has not been verified empirically.

Future research could explore the model's implementation in a broader range of port settings, examining its adaptability and impact across different regions. Additionally, longitudinal studies could assess the long-term effectiveness of the model in driving environmental improvements, contributing to the evolving discourse on sustainable port management.

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