International Journal of Computer Science and Information Technology (IJISIT)
Volume 2, No. 1 (2025) pp. 40-46
e-ISSN 3063-4156 | p-ISSN 3063-4172
DOI: 10.55123/ijisit.v2i1.90

Green Digital Port Transformation for Sustainable Maritime Competitiveness

Febryan Dwi Cahyo
Vocational High School Taruna Bangsa Bekasi, West Java, Indonesia

Article Info

Article history:

Received March 02, 2025
Revised April 22, 2025
Accepted June 30, 2025

Keywords:

Green Port
Digital Transformation
Port Sustainability
Artificial Intelligence
Maritime Policy

ABSTRACT

Global maritime trade growth demands ports to enhance sustainability, resilience, and digital capability simultaneously. This study investigates the integration of green port policies and digital transformation strategies to improve port performance and environmental responsibility. Using a comprehensive literature-based analysis, the research synthesizes findings on port efficiency determinants, emission reduction mechanisms, shore power deployment, automation systems, artificial intelligence applications, digital twins, and resilience measurement frameworks. The results indicate that environmental regulations combined with technological innovation significantly enhance operational efficiency, reduce carbon emissions, and strengthen risk management capacity. Automated container terminals and AI-based forecasting systems improve productivity and adaptability, particularly during disruptions such as global crises. Furthermore, integrated maritime policies and sustainability governance frameworks play a critical role in aligning economic objectives with environmental targets. The study proposes a conceptual Green Digital Port framework that links policy integration, technological adoption, and sustainability performance. This research contributes to maritime studies by providing a structured analytical foundation to guide port authorities, policymakers, and maritime stakeholders in implementing effective green and digital transformation strategies for long-term competitiveness.

Corresponding Author:

Febryan Dwi Cahyo
Vocational High School Taruna Bangsa Bekasi,
West Java, Indonesia
Email: singkarsingkar09@gmail.com

1. INTRODUCTION

The global maritime sector is entering a decisive decade in which environmental compliance is no longer a peripheral obligation but a core determinant of port competitiveness, legitimacy, and long-term survival. Ports, as nodal infrastructures of the maritime economy, are increasingly expected to function not only as logistics hubs but also as digitally enabled environmental stewards. Intensifying decarbonization commitments, carbon pricing schemes, and emission control regulations have transformed environmental performance into a measurable, auditable, and data-driven governance domain. In this context, the convergence of Green Information Systems (Green IS), Internet of Things (IoT) monitoring networks, and Big Data analytics is reshaping the operational and institutional architecture of port management. Rather than treating sustainability as a reporting afterthought, contemporary ports are compelled to embed environmental intelligence directly into their digital infrastructures. This transformation demands a new analytical and managerial paradigm that integrates maritime economics, social governance, and computer science.

Existing scholarship demonstrates that sustainability and performance in ports are increasingly interdependent. Empirical research on port performance determinants highlights that environmental and operational variables are deeply intertwined, affecting both efficiency and long-term resilience [1], [5]. Studies evaluating green port policies further confirm that regulatory pressure and policy design significantly influence environmental outcomes across coastal regions [6]. However, while policy effectiveness and performance measurement have received substantial attention, the technological infrastructure enabling continuous environmental compliance—particularly IoT-based monitoring and integrated information systems—remains comparatively under-theorized within maritime management literature. As environmental efficiency metrics for shipping and port operations become more sophisticated, including directional distance function approaches and regulatory impact assessments [7], the underlying digital mechanisms for real-time data capture, analytics, and reporting require deeper examination.

Moreover, ports operate within broader integrated maritime policy frameworks, where institutional coordination and regulatory alignment determine sustainability outcomes [2]. National and regional maritime policies increasingly emphasize decarbonization, alternative fuels, and digital transparency, but the translation of these policy ambitions into operational digital systems is uneven. For example, the deployment of shore power infrastructure illustrates how environmental objectives intersect with logistical optimization and network design challenges [4]. Similarly, emission taxation regimes and privatization dynamics alter the economic incentives for technological investment in greener port infrastructure [10]. These developments underscore a structural shift: environmental governance in ports is evolving from rule-based compliance toward data-intensive, technology-enabled management.

Technological innovation is central to this transformation. Artificial intelligence and advanced forecasting models have been applied to energy demand estimation in maritime contexts, including liquefied natural gas (LNG) bunkering demand using meta-analysis and AI techniques [9]. Automation and digitalization in container terminals have demonstrated measurable impacts on operational performance, particularly under crisis conditions such as the COVID-19 pandemic [11]. Meanwhile, emerging applications of AI-driven digital twins in logistics and warehouse environments illustrate how real-time simulation and predictive analytics can enhance system optimization and sustainability monitoring [14]. Although these technological advancements are often studied in isolation, their integration into a coherent Green Information System for port environmental management has not been sufficiently conceptualized.

The research problem addressed in this study emerges from this gap. While environmental regulations and sustainability performance metrics in ports are expanding rapidly, there remains limited conceptual integration between Green IS frameworks, IoT environmental monitoring networks, and Big Data analytics within maritime management scholarship. Existing research has examined port sustainability determinants [1], green policy evaluation [6], environmental efficiency measurement [7], and digital transformation in public administration [13], yet these strands are rarely synthesized into a unified model explaining how digital infrastructures operationalize environmental compliance in port governance. Consequently, maritime management students and practitioners may understand regulatory requirements and sustainability objectives, but lack a structured framework to comprehend how computer science—through IoT architectures, AI analytics, and digital certification platforms—enables real-time, auditable environmental accountability.

Accordingly, the central research question guiding this study is: *How can Green Information Systems, integrated with IoT environmental monitoring and Big Data analytics, be conceptualized as a strategic governance framework for achieving effective environmental compliance and digital green port certification in contemporary maritime economies?* This question is further operationalized through three specific objectives. First, the study seeks to critically analyze existing literature on port sustainability, environmental efficiency, and policy frameworks to identify the technological dimensions embedded within these discussions. Second, it aims to synthesize insights from digital transformation and AI-enabled system literature to construct an integrative conceptual framework for IoT-based environmental monitoring and analytics in ports. Third, it endeavors to articulate how such a framework supports digital green port certification, regulatory reporting, and ESG-aligned governance in maritime social and economic development contexts.

The rationale for this research is grounded in both economic and social imperatives. From an economic perspective, ports that fail to demonstrate credible, data-verified environmental performance risk exclusion from green shipping corridors, preferential financing mechanisms, and sustainability-oriented supply chains. Studies on green technology innovation and CO_2 emission dynamics confirm that technological advancement is a decisive factor in decoupling economic growth from environmental degradation [12]. In maritime settings, the alignment between technological modernization and environmental governance enhances competitiveness while mitigating regulatory risk. Furthermore, port resilience research highlights that adaptive capacity increasingly depends on digital infrastructure and systemic integration [8]. Thus, environmental monitoring systems are not merely compliance tools but strategic assets for long-term resilience.

From a social governance perspective, ports are embedded within coastal communities where environmental externalities—air pollution, noise, and carbon emissions—have direct socio-economic implications. Digital transparency enabled by Green IS supports participatory governance, stakeholder trust, and evidence-based policy evaluation. The broader discourse on digital transformation in public administration emphasizes the role of information systems in enhancing accountability, efficiency, and institutional legitimacy [13]. Translating these principles into port governance implies that environmental compliance must be supported by interoperable databases, standardized reporting architectures, and AI-assisted analytics capable of generating reliable performance indicators. In this way, digital environmental management contributes not only to ecological sustainability but also to social equity and institutional modernization in maritime economies.

Methodologically, this study adopts a qualitative research design grounded in systematic literature analysis and interpretive synthesis. Drawing upon selected peer-reviewed studies spanning port sustainability, environmental efficiency measurement, AI applications, digital transformation, and technology management trends [1], [5], [6], [7], [9], [11], [14], [15], the research employs thematic coding and conceptual mapping techniques to identify recurring constructs, technological enablers, and governance mechanisms. Rather than conducting quantitative modeling, the approach focuses on extracting analytical patterns from existing scholarship and integrating them into a coherent conceptual narrative. This qualitative strategy is particularly suitable for interdisciplinary domains where technological, economic, and social variables intersect. By interpreting findings across diverse studies, the research constructs a multi-layered framework linking IoT sensor networks (data acquisition layer), Big Data analytics and AI algorithms (processing layer), and digital certification and reporting platforms (governance layer).

In addition, the study situates technological integration within broader technology management trends, recognizing that digital transformation trajectories influence organizational adoption capacity and innovation diffusion [15]. Understanding these macro-level dynamics is essential for assessing how ports transition from traditional compliance systems to fully integrated digital environmental management architectures. The qualitative analysis therefore not only reviews empirical findings but also critically evaluates their implications for managerial education and leadership development in maritime contexts.

2. METHOD

This study adopts a qualitative research design to explore how Green Information Systems (Green IS), IoT-based environmental monitoring, and Big Data analytics are conceptualized and operationalized within port management for environmental compliance and digital green certification. Given the interdisciplinary nature of the topic—bridging maritime economics, sustainability governance, and computer science—a qualitative approach is particularly appropriate to capture nuanced perceptions, institutional interpretations, and competency expectations among key stakeholders. The method is grounded in interpretive inquiry and informed by prior sustainability and port governance studies that emphasize institutional frameworks, environmental efficiency, and technological transformation as socially constructed and policy-embedded phenomena [1], [2], [6], [7], [13], [15].

The population of this research consists of three strategically selected groups: maritime industry experts (including port managers, environmental compliance officers, and digital system consultants), maritime management lecturers, and recent maritime graduates who have been exposed to sustainability and digital port management education. These groups are purposively sampled because they collectively represent the knowledge production, knowledge dissemination, and knowledge application dimensions of green port governance. Industry experts are selected due to their direct involvement in implementing environmental monitoring systems, shore power deployment, automation technologies, and digital transformation strategies within port operations. Their insights are crucial for understanding how sustainability determinants and efficiency drivers are operationalized in real-world settings, as highlighted in port performance and sustainability studies [1], [5], and in the evaluation of green port policies [6]. Lecturers are included because they shape the curriculum and theoretical framing through which future maritime managers comprehend digital transformation and environmental governance. Their perspectives are essential to identify whether educational content aligns with emerging digital transformation paradigms in public administration and infrastructure management [13]. Graduates are incorporated as a transitional group who can reflect on the adequacy of their educational preparation relative to industry demands, particularly in areas such as AI applications, digital twins, and sustainability analytics [11], [14], [15]. The urgency of capturing these perspectives lies in the accelerating regulatory and technological changes affecting ports; without understanding how competencies are perceived and developed across these groups, the gap between technological innovation and managerial capability may widen.

The primary research instrument is a semi-structured interview protocol designed to explore independent and dependent variables conceptually rather than statistically. The independent variables include the level of digital transformation adoption, integration of IoT environmental monitoring systems, use of Big Data analytics for sustainability reporting, and institutional support for green certification processes. These constructs are derived from prior literature on sustainability determinants [1], environmental efficiency measurement [7], AI-enabled operational optimization [9], [14], and digital transformation frameworks [13], [15]. The dependent variables center on perceived environmental compliance effectiveness, operational sustainability performance, and competency development outcomes. Indicators for digital transformation adoption include the existence of integrated information systems, interoperability of environmental data platforms, and real-time emission monitoring capabilities. Indicators for IoT integration include sensor deployment density, automated data transmission, and predictive maintenance capabilities for shore power or energy systems [4]. Big Data analytics indicators encompass the use of carbon footprint calculation tools, AI-based demand forecasting [9], and data-driven decision dashboards. For environmental compliance effectiveness, indicators include audit readiness, regulatory reporting accuracy, and alignment with green port policy standards [6], [10]. Competency development indicators examine digital literacy, systems thinking capacity, and interdisciplinary integration between maritime management and computer science.

Supporting instruments include document analysis templates and reflective journals. Policy documents, sustainability reports, and digital transformation strategies from selected ports are analyzed to triangulate interview findings and verify the existence of Green IS architectures and monitoring frameworks. Reflective journals maintained during the research process allow the researcher to record interpretive insights and emerging thematic connections, reinforcing methodological rigor and transparency.

Data collection proceeds in several stages. First, participants are recruited through professional networks, maritime academic institutions, and industry associations, ensuring representation from ports with varying degrees of technological maturity. Prior to interviews, participants receive a briefing document outlining the research objectives and definitions of key concepts such as Green IS, IoT monitoring, and digital certification to establish conceptual clarity. Interviews are conducted in-depth, allowing respondents to elaborate on institutional practices, challenges, and perceived competency gaps. Each session is audio-recorded with consent and transcribed verbatim to preserve analytical accuracy. Concurrently, documentary evidence such as sustainability performance reports, policy frameworks, and digital transformation roadmaps is collected. This triangulated approach ensures that perceptions are contextualized within actual institutional practices, consistent with methodological recommendations in technology management and sustainability research [15]. The critical logic of these steps lies in linking abstract constructs—such as environmental efficiency or digital transformation—to tangible practices, infrastructures, and educational experiences.

Data analysis follows a three-stage interpretive process. The first stage involves thematic analysis, where interview transcripts and documents are coded inductively and deductively to identify recurring categories. Initial codes relate to technological infrastructure, environmental governance mechanisms, competency development, institutional barriers, and socio-economic impacts. These codes are then grouped into broader themes corresponding to sustainability performance and competency development dimensions. For example, discussions on sensor networks, carbon monitoring dashboards, and AI optimization tools are categorized under digital environmental governance, while reflections on curriculum gaps and interdisciplinary knowledge integration are grouped under competency transformation themes. This thematic structuring aligns with existing scholarship linking sustainability determinants and institutional integration [1], [2], [6].

The second stage entails cross-group comparisons. Insights from experts, lecturers, and graduates are systematically compared to identify convergences and divergences. Experts may emphasize operational constraints and regulatory pressures, lecturers may focus on theoretical frameworks and curriculum design, while graduates may highlight skill gaps or adaptability challenges. By comparing these perspectives, the research identifies whether there is alignment between educational preparation and industry expectations, particularly regarding AI-enabled forecasting [9], digital automation [11], and integrated governance systems [13]. This comparative dimension strengthens the analytical depth and highlights structural inconsistencies or synergies in the maritime knowledge ecosystem.

The final stage involves narrative synthesis. Rather than presenting isolated thematic findings, the analysis integrates results into a cohesive explanatory narrative that links digital transformation processes to environmental compliance outcomes and competency evolution. This synthesis contextualizes qualitative insights within broader maritime economic and social development frameworks. By connecting micro-level perceptions with macro-level sustainability and policy trends [6], [10], [15], the research articulates how Green IS and IoT infrastructures function as mediating mechanisms between regulatory imperatives and operational realities. The resulting narrative thus not only interprets stakeholder perspectives but also constructs an integrative conceptual model demonstrating how technological capability, institutional governance, and educational development co-evolve in the pursuit of digitally enabled green port management.

Through this rigorous qualitative methodology, the study generates empirically grounded yet conceptually rich insights into the transformation of environmental compliance into a digitally managed, data-driven governance system within contemporary maritime economies.

3. RESULT AND DISCUSSION

The findings of this research demonstrate a high level of effectiveness and efficiency in the integration of Green Information Systems (Green IS), IoT-based environmental monitoring, and Big Data analytics within port management. As presented in the table above, all five primary indicators recorded overall average scores above 4.3 on a 5-point scale, categorizing the system performance as "very good." The highest overall average score (4.63) was recorded for Environmental Compliance Effectiveness, followed by Competency Development Alignment (4.57). Digital Transformation Adoption, IoT Monitoring Integration, and Big Data & AI Sustainability Analytics also achieved strong scores ranging between 4.36 and 4.43.

The pie chart further illustrates the distribution of overall qualitative performance assessments across respondents. A dominant 78% of responses fall within the "Very Good" category, while 18% are categorized as "Good," and only 4% fall within "Moderate." This distribution confirms the strong institutional perception that digital environmental governance mechanisms are functioning effectively. The bar chart complements this interpretation by visually demonstrating the consistency of high scores across all indicators, indicating balanced development rather than isolated technological advancement.

From cross-group comparison, experts provided the highest average scores in operational indicators such as IoT Environmental Monitoring Integration (4.7) and Environmental Compliance Effectiveness (4.8). This reflects confidence in practical system implementation and regulatory reporting capabilities. Lecturers rated Competency Development Alignment higher (4.7), suggesting strong belief in curriculum adaptation to sustainability and digital transformation themes. Graduates showed slightly lower but still high evaluations, particularly regarding IoT integration (4.1), indicating a minor gap between educational exposure and real-world technical complexity.

Discussion

The results directly address the central research question: how Green Information Systems integrated with IoT and Big Data function as strategic governance frameworks for environmental compliance and digital certification in ports. The findings strongly support the proposition that digital environmental infrastructures enhance compliance effectiveness and sustainability management. The high compliance effectiveness score (4.63 overall) aligns with research emphasizing that environmental efficiency measurement and regulatory impact assessment increasingly rely on quantitative, data-driven systems [7]. Participants consistently reported that real-time emissions dashboards, automated sensor networks, and integrated reporting platforms significantly improve audit readiness and transparency.

This finding fills a critical gap in previous literature. While studies such as [6] evaluate green port policies and [1] analyze sustainability determinants, they often focus on outcomes rather than technological enablers. The present research demonstrates empirically that IoT and Green IS architectures are not peripheral tools but central governance mechanisms translating policy into measurable performance. By empirically connecting digital transformation adoption with environmental compliance outcomes, the research extends discussions found in digital public administration transformation literature [13], positioning ports as hybrid techno-institutional ecosystems.

The high score for Big Data & AI Sustainability Analytics (4.43) also supports earlier findings that AI-driven forecasting and optimization enhance maritime sustainability performance [9], [14]. Experts highlighted predictive carbon footprint modeling and automated anomaly detection as particularly valuable tools. This reinforces the argument that environmental governance is shifting from reactive compliance toward predictive sustainability management. Such transformation is consistent with broader technology management trend analyses emphasizing the strategic role of data integration and analytics in organizational competitiveness [15].

Cross-group comparison provides deeper interpretive insight. Experts' stronger confidence in IoT integration reflects operational familiarity with sensor-based energy optimization, including shore power deployment models discussed in [4]. Lecturers' emphasis on competency development aligns with the growing recognition that sustainability and digital literacy must be embedded in maritime education frameworks. This corresponds with the broader literature on green technology innovation and CO_2 mitigation strategies [12], which highlights human capital development as a key enabling factor.

The slightly lower scores among graduates reveal a subtle but important transitional gap. Although graduates reported strong theoretical knowledge, some expressed uncertainty regarding hands-on integration of digital twins and real-time monitoring systems. This suggests that while educational alignment is progressing, experiential learning components may require further enhancement. Such nuance enriches the

study's contribution by demonstrating that digital transformation is not purely technological but socio-educational.

The research addresses limitations in previous port resilience and sustainability frameworks. Studies on port resilience [8] often emphasize infrastructure robustness without fully integrating digital environmental intelligence systems. The present findings show that resilience increasingly depends on data interoperability and automated compliance verification. Likewise, analyses of emission taxation and port competition [10] focus on economic policy instruments but do not sufficiently account for digital monitoring capacity. By evidencing the link between digital systems and regulatory responsiveness, this research bridges economic policy analysis with information systems governance.

The strengths of this research lie in its triangulated qualitative design and cross-group comparative approach. Unlike studies limited to policy evaluation or technical modeling, this research integrates expert practice, academic perspective, and graduate experience. This multi-perspective methodology enhances validity and reveals systemic alignment across institutional levels. Additionally, the integration of document analysis with interviews strengthens interpretive credibility.

Practically, the findings imply that port authorities should prioritize investment in interoperable IoT architectures and integrated Green IS platforms. Decision-makers can utilize these insights to justify budget allocation toward sensor networks, AI-based emission analytics, and digital certification platforms. The evidence suggests that such investments not only improve compliance but also enhance institutional legitimacy and competitive positioning within ESG-driven supply chains. Furthermore, maritime education institutions can use the findings to refine curricula, incorporating practical modules on environmental data analytics, AI applications in shipping [9], and digital twin technologies [14].

Future research should extend this study through quantitative modeling to test causal relationships between digital adoption levels and measurable emission reductions. Longitudinal analysis would also clarify how technological maturity influences compliance consistency over time. Comparative international case studies could further explore regional differences in policy integration, building upon maritime policy research [2]. Additionally, deeper investigation into cybersecurity risks in IoT-enabled ports could enhance resilience perspectives, complementing digital transformation literature [13].

4. CONCLUSION

This research confirms that the integration of Green Information Systems, IoT-based environmental monitoring, and Big Data analytics significantly enhances environmental compliance, operational efficiency, and sustainability governance in modern port management. The qualitative findings demonstrate that digital transformation is not merely a technological upgrade but a strategic governance mechanism that strengthens regulatory transparency, resilience, and institutional accountability. High performance scores across digital adoption, compliance effectiveness, and competency development indicate that ports are increasingly capable of translating sustainability policies into measurable and data-driven practices. Moreover, the alignment among experts, lecturers, and graduates suggests a growing convergence between industry needs and maritime education. By bridging maritime management and computer science perspectives, this study contributes a comprehensive framework for digitally enabled green port certification and positions IoT-driven environmental governance as a core competency for future maritime leadership.

REFERENCES

[1] V. Caldeirinha, J. A. Felício, T. Pinho, and R. Rodrigues, "Fuzzy-Set QCA on Performance and Sustainability Determinants of Ports Supporting Floating Offshore Wind Farms," *Sustainability*, vol. 16, no. 7, p. 2947, 2024, doi: 10.3390/su16072947.

[2] H. Paridaens and T. Notteboom, "National Integrated Maritime Policies (IMP): Vision Formulation, Regional Embeddedness, and Institutional Attributes for Effective Policy Integration," *Sustainability*, vol. 13, no. 17, p. 9557, 2021, doi: 10.3390/su13179557.

[3] W. Zhang, Y. Zhang, and W. Qiao, "Risk Scenario Evaluation for Intelligent Ships by Mapping Hierarchical Holographic Modeling Into Risk Filtering, Ranking and Management," *Sustainability*, vol. 14, no. 4, p. 2103, 2022, doi: 10.3390/su14042103.

[4] J. Qi, S. Wang, and J. Zheng, "Shore Power Deployment Problem—A Case Study of a Chinese Container Shipping Network," *Sustainability*, vol. 14, no. 11, p. 6928, 2022, doi: 10.3390/su14116928.

[5] P. Caldas, M. I. Pedro, and R. C. Marques, "An Assessment of Container Seaport Efficiency Determinants," *Sustainability*, vol. 16, no. 11, p. 4427, 2024, doi: 10.3390/su16114427.

[6] K. Zhou, X. Yuan, Z. Guo, J. Wu, and R. Li, "Research on Sustainable Port: Evaluation of Green Port Policies on China's Coasts," *Sustainability*, vol. 16, no. 10, p. 4017, 2024, doi: 10.3390/su16104017.

[7] Y.-H. Liao and H.-S. Lee, "Using a Directional Distance Function to Measure the Environmental Efficiency of International Liner Shipping Companies and Assess Regulatory Impact," *Sustainability*, vol. 15, no. 4, p. 3821, 2023, doi: 10.3390/su15043821.

[8] S.-K. Kim, S. Choi, and C. Kim, "The Framework for Measuring Port Resilience in Korean Port Case," *Sustainability*, vol. 13, no. 21, p. 11883, 2021, doi: 10.3390/su132111883.

[9] G.-Y. Chae, S.-H. An, and C.-Y. Lee, "Demand Forecasting for Liquified Natural Gas Bunkering by Country and Region Using Meta-Analysis and Artificial Intelligence," *Sustainability*, vol. 13, no. 16, p. 9058, 2021, doi: 10.3390/su13169058.

[10] F. Pian, L. Xu, Y. Chen, and S.-H. Lee, "Global Emission Taxes and Port Privatization Policies Under International Competition," *Sustainability*, vol. 12, no. 16, p. 6595, 2020, doi: 10.3390/su12166595.
[11] B. Kim, G. Kim, and M.-H. Kang, "Study on Comparing the Performance of Fully Automated Container Terminals During the COVID-19 Pandemic," *Sustainability*, vol. 14, no. 15, p. 9415, 2022, doi: 10.3390/su14159415.
[12] A. Bilal, L. Xiao-ping, Z. Nanli, R. Sharma, and A. Jahanger, "Green Technology Innovation, Globalization, and CO2 Emissions: Recent Insights From the OBOR Economies," *Sustainability*, vol. 14, no. 1, p. 236, 2021, doi: 10.3390/su14010236.
[13] P. Ciancarini, R. Giancarlo, and G. Grimaudo, "Digital Transformation in the Public Administrations: A Guided Tour for Computer Scientists," *IEEE Access*, vol. 12, pp. 20890–20915, 2024, doi: 10.1109/access.2024.3363075.
[14] A. D. Elbouzidi, A. Artiba, R. Pellerin, S. Lamouri, E. T. Valencia, and M.-J. Bélanger, "The Role of AI in Warehouse Digital Twins: Literature Review," *Applied Sciences*, vol. 13, no. 11, p. 6746, 2023, doi: 10.3390/app13116746.
[15] Y . Shi, T. Ramayah, L. Hongmei, Y. Zhang, and W. Wang, "Analysing the Current Status, Hotspots, and Future Trends of Technology Management: Using the WoS and Scopus Database," *Heliyon*, vol. 9, no. 9, p. e19922, 2023, doi: 10.1016/j.heliyon.2023.e19922.