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LITERATURE REVIEW OF INTEGRATING SUSTAINABILITY AND DIGITAL INNOVATION IN WATERWAY TRANSPORT AND MARITIME LOGISTICS

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Modern waterway transport and maritime logistics industries are being transformed through sustainable practices combined with digital innovation which leads to better operational efficiency along with decreased environmental effects. Green technology adoption requires support from regulatory frameworks and financial incentives to meet emission reduction standards and promote investments in alternative fuels and energy-efficient solutions. IoT-enabled cargo tracking alongside blockchain supply chain transparency and AI predictive maintenance systems improve operational dependability through better resource management. Sustainable practices, including energy-efficient vessel design, route optimization, and shore power integration, contribute to lower fuel consumption and emissions. Smart ports and automated terminals streamline cargo handling, reducing energy use and improving supply chain efficiency. This study examines the relationship between regulatory policies, digital enablers, and sustainability strategies, demonstrating their collective impact on creating a more efficient and environmentally responsible maritime sector. This systematic review examines the intersection of sustainability and digital innovation in waterway transport and maritime logistics. Studies were sourced from Scopus, Web of Science, IEEE Xplore, ScienceDirect, and JSTOR, covering literature on supply chain efficiency, green technology, maritime logistics, inland waterway transport and digital transformation. A total of 52 studies met the inclusion criteria, focusing on regulatory policies, blockchain-enabled transparency, AI-driven predictive maintenance, and sustainable maritime and inland waterway operations. Findings highlight that digitalization enhances environmental sustainability while improving logistical efficiency. Future research should explore policy frameworks that encourage eco-digital maritime ecosystems. This study adheres to PRISMA 2020 guidelines to ensure transparency and rigor.

Keywords: sustainability, digital innovation, maritime logistics, waterway transport, supply chain efficiency

HIGHLIGHTS

- Integrates sustainability and digital tools in maritime logistics for enhanced efficiency and emissions reduction;
- Proposes a theoretical model linking policy, technology, and eco-practices in waterway transport;
- Uses PRISMA-guided systematic review across 52 studies to identify key trends and knowledge gaps;
- Demonstrates how blockchain, AI, and IoT jointly optimize compliance, tracking, and predictive maintenance.

1 Introduction

The growing role of waterway transport and maritime logistics within worldwide supply chains has led to thorough research about how sustainable methods integrate with digital transformation processes[1]. Waterway transport continues to serve as a vital link in international trade while undergoing changes through the adoption of environmentally friendly operational practices[2]. Modern research concentrates on creating renewable energy systems while also developing vessels that use energy more efficiently and operational methods which mitigate environmental effects.

The digital transformation currently underway in maritime logistics is fundamentally changing global supply chain operations[3]. Advancements in automation technology and data analytics together with Internet of Things and blockchain systems enable logistics companies to track cargo more precisely while optimizing shipping routes and facilitating better communication between shipping partners[4].Current research demonstrates that digital platforms play a crucial role in simplifying complex logistics operations fundamental to maritime trade.

The maritime industry experiences transformation through the combination of sustainable operational practices with digital innovation [5]. Real-time monitoring systems and sensor networks deployed in ships and ports deliver substantial improvements to both fuel management and emissions control [6]. The utilization of digital platforms allows companies to simulate diverse operational situations to forecast how various logistical plans affect environmental outcomes [7]. Integrated systems offer a comprehensive perspective of maritime logistics that positions technological progress alongside environmental protection as mutually beneficial goals[8]. The collaboration between these fields stimulates studies focusing on optimizing digital tools to meet sustainability goals and improve waterway transport operations.

New trends indicate that upcoming advancements will strengthen the eco-digital maritime ecosystem which will create opportunities for new strategies and policy frameworks[9]. Current pilot projects and research efforts actively investigate ways to connect emerging digital tools with environmental goals[10]. The advancement of maritime logistics toward greater agility and responsiveness depends on investments in new technologies and the use of thorough data analysis[11]. Current projects establish operational frameworks that combine digital optimization with environmental stewardship to create sustainable maritime practices as fundamental operational components[12]

Waterway transport and maritime logistics are undergoing a fundamental transformation due to the increasing pressure to adopt sustainable and digital solutions. While prior research has explored sustainability initiatives and digitalization separately, a comprehensive synthesis of their intersection in maritime logistics is lacking. Existing studies tend to focus on isolated aspects such as fuel efficiency, blockchain applications, or regulatory impacts, but no systematic review has integrated these dimensions to provide a holistic understanding. Given the urgent need for sustainable and efficient maritime operations amid climate change and regulatory challenges, this study conducts a systematic review to consolidate current research, identify knowledge gaps, and propose a strategic framework for an eco-digital maritime logistics ecosystem.

This systematic review aims to explore the intersection of sustainability and digital innovation in waterway transport and maritime logistics. Specifically, the review seeks to:

- Analyze the impact of sustainable practices on environmental performance in maritime operations.
- Examine the role of digital innovations in improving efficiency and transparency within maritime logistics.
- Identify synergies between sustainability and digital transformation that contribute to an eco-digital maritime ecosystem.
- Propose strategic recommendations for policymakers and industry stakeholders to foster sustainability-driven digitalization in maritime logistics

The paper is organized as follows: after this introduction, the methodology chapter explains the search criteria and processes employed for selecting and coding the relevant literature, while the review results chapter undertakes a thematic analysis of the findings, putting forward key strategies, impacts and knowledge gaps. The discussion summarizes those findings while drawing implications for theory, practice and policy. The conclusion contextualises the main themes and reflects on the research implications for the debate on sustainable development and digital innovation in waterway transport and maritime logistics.

2 Materials and methods

2.1 Phases of review

The systematic literature review was conducted in three main phases. The review process consists of three primary steps. Planning the review followed by conducting the review and then reporting the review findings. The methodological heterogeneity across studies (qualitative, quantitative, case studies) made statistical pooling unfeasible. A narrative approach was more appropriate to capture cross-sectoral insights on maritime sustainability and digital transformation. This approach aligns with previous systematic reviews on complex, multidisciplinary topics where data integration is challenging. Every phase includes stages that help maintain a reliable methodology in the review process. Each phase stage followed best practice standards for systematic literature reviews.

2.2 Planning stage

2.2.1 Planning- stage 1: Research questions

The systematic literature was based on the identified need for a review in the domain of sustainability, digital innovation, waterway transport and maritime logistics. The rationale for conducting the systematic literature review is centered on exploring the relationships between sustainability, digital innovation, waterway transport and maritime logistics, particularly how these concepts interconnect and impact each other. This is important for understanding the strategies that governments and enterprises can implement to improve competitiveness and societal well-being, ensuring strategic alignment across technological adoption, ethical governance, and human capital development. In addition, the results of the systematic literature review can provide an appropriate framework that can help guide new research. The systematic literature review aims to answer the following research questions:

- RQ1: How do sustainable practices reduce negative environmental impacts in waterway transport?
- RQ2: How do digital innovations enhance efficiency in maritime logistics?
- RQ3: What synergies emerge from integrating sustainability with digital transformation in maritime operations?
- RQ4: Which strategies best support the development of an eco-digital maritime ecosystem?

2.2.2 Planning- stage 2: Developing review protocol

Due to the multidisciplinary nature of the research topics, databases such as Scopus, Web of Science, IEEE Xplore, DOAJ, JSTOR, ScienceDirect, ERIC, and the KoBSON platform were chosen. This diversified selection

aimed to mitigate indexing biases and ensure a wide-ranging capture of studies across fields like technology, marketing, industrial management, and social sciences. Google Scholar was also included as a supplementary engine to capture grey literature and extend the review's reach beyond traditional academic databases, providing a broader scope of insights and perspectives. There is a 10-year limitation date on the publication. We started the research in August and completed research in January 2025. Table 1 displays the search queries and keywords utilized during the database search process. Search queries were derived via a four-stage procedure that mapped each research question to controlled vocabulary sets, harvested additional synonyms from influential seed articles, and refined the Boolean strings through expert consultation and pilot testing. The final 36 queries (Table 1) ensured high recall and acceptable precision across all selected databases

Table 1. Keywords and search queries for literature review

Keywords	
Sustainability; Digital Innovation; Waterway; Maritime; Logistics; Transport; Supply Chain; Environmental; Optimization	
Search queries	
1. sustainable waterway transport practices 2. digital maritime logistics transformation 3. eco digital maritime ecosystem 4. green maritime logistics innovations 5. waterway transport renewable energy 6. maritime digital innovation strategies 7. maritime logistics supply chain 8. sustainable maritime operational practices 9. digital supply chain optimization 10. digital sensor maritime monitoring 11. maritime blockchain logistics integration 12. smart maritime logistics technologies 13. digital maritime supply chains 14. maritime logistics environmental performance 15. waterway transport efficiency improvements 16. ecofriendly maritime innovations 17. sustainable maritime supply chain 18. digital maritime operational efficiency	19. maritime logistics digital transformation 20. green maritime operational practices 21. digital maritime sensor networks 22. smart waterway transport systems 23. renewable energy maritime operations 24. digital maritime data analytics 25. environmental impact maritime logistics 26. maritime sustainability digital integration 27. digital eco maritime innovation 28. maritime logistics sustainability framework 29. waterway transport digital transformation 30. maritime operations green technologies 31. digital maritime predictive analytics 32. maritime logistics operational resilience 33. green waterway transport innovations 34. maritime digital monitoring systems 35. eco maritime supply chain 36. smart maritime energy management 37. green digital maritime transition

2.3 Conducting stage

2.3.1 Conducting- stage 1: Identification of research studies

During the initial phase of the systematic review process following preliminary database selection researchers focused on identifying relevant research studies within those databases. This involved executing a detailed and structured search strategy that has been developed to capture literature relevant to the research questions surrounding sustainability, digital innovation, waterway transport and maritime logistics. The search strategy was operationalized through a combination of keywords and search queries, which aligned with the thematic and conceptual framework of the review.

2.3.2 Conducting- stage 2: Selection of primary studies

Utilizing the previously selected databases, this stage involved a screening process where the search strategy, incorporating specific keywords and queries related to sustainability, digital innovation, waterway transport and maritime logistics were taken into consideration regarding the titles and abstracts. This was done in the first screening where records were excluded by title and by abstract. The selection process played a key role in distilling a vast amount of literature into a targeted set of primary studies which directly address the research questions and offer significant insights. To facilitate screening and selection, Zotero was used for reference management, and Rayyan AI was used for blind screening. Duplicates were removed automatically before the screening process. The review team worked together with support from diverse databases to obtain a balanced and comprehensive selection of primary studies.

2.3.3 Conducting- stage 3: Study quality assessment

After primary studies were chosen reviewers needed to evaluate their methodological quality and credibility to confirm that the review's findings would be based on dependable and accurate research. The initial screening of

studies started with their titles and abstracts. Two independent reviewers assessed each study, applying the inclusion and exclusion criteria. Selected studies were retrieved for a full-text review. The same two reviewers independently assessed the studies for eligibility. In cases where disagreements occurred, a third senior reviewer was consulted to resolve discrepancies. Assessment of report eligibility was conducted using defined inclusion and exclusion criteria. The exclusion criteria were:

- Lack of credibility
- Lack of peer-review
- Lack of relevancy
- Lack of methodological quality

The inclusion criteria functioned as the reverse of the previously stated exclusion criteria:

- Credibility
- Peer-reviewed
- Relevancy
- Methodological quality

Each study was assessed using a binary scoring system for the four inclusion/exclusion criteria: credibility, peer-review, relevancy, and methodological quality. A score of “1” was assigned if a criterion was met and “0” if not. Studies scoring at least 3 out of 4 were considered eligible for full-text review. Methodological quality was further evaluated using adapted CASP (Critical Appraisal Skills Programme) checklists depending on study type (qualitative, quantitative, mixed). Final inclusion required consensus by two reviewers; disagreements were resolved by a third reviewer.

After the selection of primary studies, the included studies were categorized for synthesis based on thematic relevance and methodological approach. Studies were grouped according to the following predefined themes:

- Sustainable operational practices in waterway transport and maritime logistics
- Digital transformation in maritime logistics and waterway transport
- Policy and regulatory frameworks
- Synergy between sustainability and digital innovation

The research team applied inclusion and exclusion criteria to search results which led to the exclusion of studies falling short of quality and relevance standards and 52 studies passing these criteria to be included in the review. The degree of explicitness in interpretation was evaluated by creating a theoretical model which includes elements from each study. The developed model includes the weight coefficients in its presentation.

Each study was independently reviewed by two reviewers the same two reviewers conducted all stages of the review process—including study selection, quality assessment, and data extraction—to ensure consistency. Any disagreements were resolved through discussion, with a third reviewer acting as an arbitrator if necessary. The risk of bias using a predefined scoring matrix based on methodological quality, data transparency, and potential conflicts of interest. Each study was rated on a scale from 0 (high risk) to 3 (low risk) per criterion, scores were recorded, and studies with high risk of bias were excluded or weighted accordingly in the analysis. Automation tools such as Rayyan AI and Zotero were used for bias assessment and citation tracking.

2.3.4 Conducting- stage 4: Data extraction and synthesis

After rigorous data extraction and synthesis, the selected studies had their main findings integrated across various disciplines which led to the creation of a theoretical framework for sustainability, digital innovation, waterway transport and maritime logistics. The research relied on specialized tools such as Canva for building model. If critical study details were missing, missing details primarily included incomplete methodological descriptions, unclear sample sizes, or lack of outcome quantification necessary for comparative analysis, the authors were **c**ontacted via email to request clarification. If no response was received, comparable data from similar studies were used to estimate trends where possible. Studies with significant missing data that could not be reasonably estimated were excluded from the synthesis.

All extracted data were organized into Excel spreadsheets to facilitate thematic mapping. A narrative synthesis was conducted, summarizing major findings in text form with supporting tables and charts. Data were visualized using Canva, presenting sustainability and digitalization trends in maritime logistics.

2.4 Reporting

2.4.1 Reporting- stage 1: Specifying dissemination

Choosing effective dissemination strategies required identifying the best channels and formats to broadcast the systematic review's findings to a wide audience. Stakeholders from academia, industry sectors and policymaking bodies can utilize the synthesized insights from extensive studies which cover diverse areas. The dissemination plan selected academic journals, conferences, industry publications, and digital platforms to achieve extensive visibility and impact.

2.4.2 Reporting- stage 2: Formatting and evaluating

This final stage of the systematic review process includes report formatting and evaluation to satisfy publication requirements while maintaining clarity and comprehensive content that remains relevant. The paper gained credibility through the thorough choice of databases which led to high-quality included studies. The comprehensive findings from multiple sources have been systematically organized to deliver a coherent synthesis that powerfully demonstrates evidence about sustainability, digital innovation, waterway transport and maritime logistics. Through peer evaluation and co-author review the paper meets top academic standards and maintains relevance which prepares it for dissemination to enhance discourse and research in the field. Discrepancies between reviewers were resolved by a third senior reviewer. If relevant data were missing or unclear, study authors were contacted via email for clarification.

To avoid **publication bias** (where only studies with significant findings are published), searches included grey literature **sources** such as conference proceedings, government and industry reports and reprints available on arXiv, SSRN, and ResearchGate.

Citations and formatting tasks were performed through the Zotero software.

2.5 PRISMA protocol

To ensure transparency and methodological rigor, the review followed the PRISMA 2020 guidelines. The following figure outlines the review flow. This structured process improves the reliability of study selection and ensured that all included literature met predefined quality and relevance criteria.

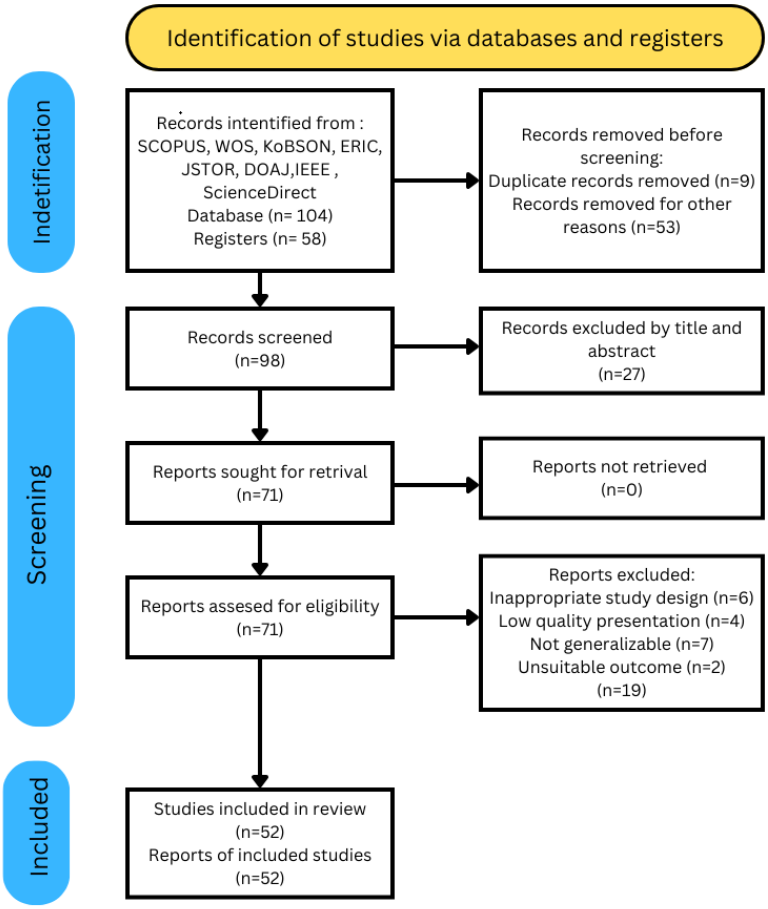

Fig. 1. PRISMA protocol

3 Results and discussion

3.1 Literature review and categorization of results

Our review identifies results about sustainability and digital innovation in waterway transport and maritime logistics which the results and discussion section explores. The section breaks down information into major thematic categories:

- Sustainable operational practices in waterway transport
- Digital transformation in maritime logistics
- Eco-friendly fuel and energy efficiency

- Real-time monitoring and predictive analytics
- Supply chain transparency and blockchain integration
- Maritime logistics optimization through digitalization
- Synergy between sustainability and digital innovation
- Policy and regulatory influences on maritime sustainability
- Challenges in implementing digital and sustainable strategies
- Future pathways for an eco-digital maritime ecosystem

Our examination of these elements demonstrates how digital innovation connects with waterway transport and maritime logistics to influence long-term sustainability goals.

- Waterway transport sustainability efforts have resulted in multiple eco-friendly operational strategies that work towards reducing environmental impact. The use of alternative fuels like liquefied natural gas (LNG), biofuels, methanol, ammonia and hydrogen represents a primary strategy for cutting down on greenhouse gas emissions [13]. The maritime industry currently directs investment toward developing energy-efficient ship designs by implementing hull adjustments and hydrodynamic enhancements which improve fuel consumption rates and decrease emissions [14]. These initiatives establish waterway transport compliance with global environmental standards while supporting sustainable supply chain operations. SUSTAINABLE OPERATIONAL PRACTICES IN WATERWAY TRANSPORT
- In addition to exploring fuel alternatives shipping companies [15] have used operational strategies including route optimization and slow steaming to boost sustainability [16]. By choosing optimal travel routes and maintaining steady cruising speeds ships can reduce their fuel consumption through these techniques [17]. Real-time navigational systems together with satellite-based tracking systems improve operational efficiency through instant alerts about traffic situations, weather changes, and port congestion [18]. Modern developments in maritime technology help achieve sustainability targets while cutting operating expenses for shipping industries. SUSTAINABLE OPERATIONAL PRACTICES IN WATERWAY TRANSPORT
- Digital advancements in maritime logistics are reshaping existing supply chain frameworks. Through the implementation of autonomous shipping systems [19] alongside port automation and AI-driven predictive analytics ports enhance the throughput of goods across water transport networks [20]. Digital twin technology integration enables real-time maritime operation simulations and assists stakeholders in pinpointing operational inefficiencies to support data-based decision-making [21]. The new logistics innovations advance supply chain flexibility and cut operation delays which leads to improved reliability and cost savings in maritime shipping. DIGITAL TRANSFORMATION IN MARITIME LOGISTICS
- IoT technology implementation has greatly enhanced monitoring capabilities for cargo shipments alongside increasing logistics transparency [22]. Real-time data from container-embedded sensors monitors cargo conditions by tracking temperature changes, humidity levels, and handling events. The collected data helps maintain proper transport conditions which prevents spoilage and reduces waste for perishable and sensitive materials [23]. Through the use of AI-powered analytics shipping companies can predict demand shifts which enables them to optimize fleet usage and reduce idle time [24]. DIGITAL TRANSFORMATION IN MARITIME LOGISTICS
- The transition to cleaner power sources represents a major advancement in making waterway transport more sustainable [25]. Hybrid propulsion systems together with solar-assisted vessels and wind-powered shipping are becoming increasingly popular as companies work to reduce their carbon emissions. Hybrid vessels operate through a dual system of traditional fuels combined with renewable energy sources which enhances energy efficiency while decreasing reliance on fossil fuels [26]. Current developments reveal a strong dedication to maintaining sustainable practices within maritime operations. ECO-FRIENDLY FUEL AND ENERGY EFFICIENCY
- In maritime sustainability efforts energy management systems function as key components. Smart energy grids onboard ships enable efficient power distribution while storing surplus renewable energy for future use [27]. Ships use shore power solutions to connect to electrical grids when docked which reduces emissions because vessels don't need to run their engines during port stays [28]. The progress in technology supports the larger objective of reducing carbon emissions from the maritime sector[29].ECO-FRIENDLY FUEL AND ENERGY EFFICIENCY
- The integration of AI and IoT technologies has greatly increased the importance of real-time monitoring in maritime logistics operations[30]. Predictive analytics tools process vessel performance data to predict potential mechanical problems which allows for preventive maintenance that avoids expensive equipment failures [31]. Shipping companies that detect operational inefficiencies at an early stage can execute corrective actions which improve fuel efficiency and extend the life of essential components. The move toward predictive maintenance represents a revolutionary change in maritime logistics because it minimizes downtime and enhances dependability. REAL-TIME MONITORING AND PREDICTIVE ANALYTICS

- Beyond maintenance, real-time monitoring of fuel consumption rates, exhaust gas emissions (e.g., CO_2, NO_x, SO_x), engine performance, and other operational parameters that affect compliance with international maritime environmental regulations enhances environmental compliance. Maritime operators must follow emission standards set by governments and regulatory bodies while digital monitoring solutions deliver precise information about fuel consumption and pollutant levels [32]. These systems permit operators to adjust engine performance instantly to maintain regulatory compliance and improve energy efficiency. Continuous emissions monitoring combined with adjustment capabilities makes real-time data analytics fundamental for contemporary maritime logistics operations. REAL-TIME MONITORING AND PREDICTIVE ANALYTICS
- The maritime logistics sector is undergoing a transformation through blockchain technology which offers secure and transparent systems for tracking records. Blockchain technology records each step of the shipping process in an unchangeable ledger which lowers fraud risks and improves traceability[33]. The enhanced visibility enables stakeholders to authenticate shipments which maintains transparency and efficiency in supply chain operations. Blockchain technology reduces supply chain risks by increasing accountability [34]. SUPPLY CHAIN TRANSPARENCY AND BLOCKCHAIN INTEGRATION
- The ability to track transactions through blockchain technology supports compliance with regulatory standards. Real-time shipment data access by authorities enables compliance verification with import/export regulations while minimizing delays from manual document processing[35]. Smart contracts which function as self-executing blockchain-based agreements automate payments and contract fulfillment to simplify logistics operations. Administrative tasks decrease while operational efficiency improves across maritime supply chains [36]. SUPPLY CHAIN TRANSPARENCY AND BLOCKCHAIN INTEGRATION
- Digital transformation is reshaping maritime logistics management by introducing advanced technologies that enhance operational efficiency, transparency, and decision-making. Supply chain optimization platforms driven by artificial intelligence utilize extensive datasets to perform immediate updates on fleet scheduling and adjust warehouse operations and inventory levels in real time [37]. Through automation logistics providers minimize manual operations while gaining the ability to respond rapidly to demand fluctuations. The implementation of these advanced technologies helps to improve supply chain efficiency while minimizing resource waste [38]. MARITIME LOGISTICS OPTIMIZATION THROUGH DIGITALIZATION
- A major advancement in maritime logistics is digital twin technology because it produces virtual representations of shipping operations [39]. Operators can analyze various scenarios including route modifications and fuel optimization through simulations which do not interfere with actual operations[40]. By analyzing predicted outcomes before actual deployment decision-makers can make more informed choices which improves the flexibility and adaptability of maritime logistics operations to shifting market trends. MARITIME LOGISTICS OPTIMIZATION THROUGH DIGITALIZATION
- Digital solutions merged with sustainability objectives have created enhanced efficiency levels within maritime logistics operations [41]. Companies can monitor their environmental performance continuously through AI-driven sustainability dashboards which measure important metrics including fuel usage and emission outputs [42]. Shipping companies use these sustainability insights to create specific initiatives which meet both regulatory requirements and corporate responsibility objectives. SYNERGY BETWEEN SUSTAINABILITY AND DIGITAL INNOVATION
- Digital innovation alongside sustainability measures together produces positive outcomes for port operations. AI-driven scheduling systems deployed in automated port terminals help minimize congestion while improving cargo handling efficiency [43]. Electric cranes and autonomous guided vehicles support[44] environmental sustainability through reduced emissions and minimized energy use. These digital advancements promote the overarching objective of achieving sustainable and efficient maritime logistics operations. SYNERGY BETWEEN SUSTAINABILITY AND DIGITAL INNOVATION
- The creation and implementation of sustainable maritime logistics policies heavily depend on governments and regulatory bodies. The transition to cleaner fuels and greener port operations happens because new environmental mandates and stricter emissions rules demand it [45]. Shipping companies need to invest in digital monitoring tools [46] and establish sustainable business practices to meet policy requirements. Regulatory measures protect the environment while driving industry innovation to improve efficiency. POLICY AND REGULATORY INFLUENCES ON MARITIME SUSTAINABILITY
- New financial rewards are established to promote sustainable methods within maritime logistics operations. Green financing options and carbon credit programs offer funding to businesses implementing renewable energy solutions and eco-friendly vessel technologies [47]. Governments develop supportive ecosystems for extended investment in sustainable shipping networks through the integration of financial regulations with environmental objectives [48]. POLICY AND REGULATORY INFLUENCES ON MARITIME SUSTAINABILITY
- Advancements in sustainable and digital maritime logistics have made progress but many challenges still exist. Numerous companies, especially small and medium-sized enterprises face significant obstacles due

to the expensive nature of implementing digital solutions and sustainable technologies. The absence of uniform global regulations creates compliance complexity because organizations must adhere to diverse sustainability rules across different regions. Multiple barriers prevent eco-digital solutions from achieving extensive adoption [49]. CHALLENGES IN IMPLEMENTING DIGITAL AND SUSTAINABLE STRATEGIES

- Industry reluctance toward change continues to present significant barriers. Traditional methods are familiar to many maritime operators who show hesitation before investing in technologies that have not yet been proven effective. To address this challenge, we need educational training programs that demonstrate the long-term advantages of digital and sustainable investments. A collaborative effort across the industry and acceptance of new technologies will drive the move toward an eco-digital maritime ecosystem [50]. CHALLENGES IN IMPLEMENTING DIGITAL AND SUSTAINABLE STRATEGIES
- The future creation of an eco-digital maritime ecosystem requires persistent advancements in technology along with substantial financial backing [51]. The maritime industry sees significant opportunities through the development of AI-driven autonomous ships and hydrogen-powered vessels[52]. Research and development initiatives need to concentrate on improving these technological solutions until they become scalable and easily accessible for widespread implementation. FUTURE PATHWAYS FOR AN ECO-DIGITAL MARITIME ECOSYSTEM
- Future maritime logistics will depend on joint actions between governments and industry partners together with technology providers. Shipping industry resilience and environmental responsibility will advance faster through standardized sustainability frameworks combined with digital infrastructure investment and cross-sector partnerships [53]. The upcoming advancements will help maritime logistics stay competitive and meet increasing demand for sustainable global trade. FUTURE PATHWAYS FOR AN ECO-DIGITAL MARITIME ECOSYSTEM

3.2 Literature overview

The research on sustainability and digital innovation in waterway transport and maritime logistics finds its visual representation through a mind map which highlights key thematic areas. The document presents a structured overview demonstrating how sustainability initiatives and technological progress influence maritime logistics operations. Specific references connect to every key thematic area to demonstrate literature support for various study aspects.

The primary focus of the mind map centers on environmental preservation combined with technological progress in waterway transport and maritime logistics. Ten key thematic areas extend from this central theme to map the major research dimensions. Every thematic area includes specific references that identify studies which provide insights into their respective topics.

Key thematic areas and their relevance:

- Sustainable operational practices in waterway transport - This section examines sustainable operational strategies including alternative fuel use (LNG, biofuels, hydrogen), route optimization methods, and slow steaming techniques. The outlined methods function to lower greenhouse gas emissions while enhancing energy efficiency within maritime logistics operations.
- Digital transformation in maritime logistics - The impact of automation, AI-driven predictive analytics, digital twins, and IoT in optimizing maritime operations is examined. These technologies enhance efficiency, improve cargo tracking, and enable data-driven decision-making.
- Eco-friendly fuel and energy efficiency - Alternative fuel adoption along with hybrid-electric propulsion systems and energy management solutions work together to decrease environmental footprints in maritime logistics.
- Real-time monitoring and predictive analytics - The combination of AI and IoT technologies to monitor vessel performance and emissions in real-time undergoes analysis. Predictive analytics enables proactive maintenance as well as optimization of fuel efficiency while ensuring environmental compliance.
- Supply chain transparency and blockchain integration - Maritime logistics stands to benefit from blockchain technology through enhanced supply chain transparency and traceability while reducing fraud. Decentralized databases and smart contracts improve both compliance and transaction verification processes.
- Maritime logistics optimization through digitalization - This section examines how IoT technology alongside blockchain solutions and smart logistics practices enhance supply chain optimization. The analysis focuses on digital twin applications and how artificial intelligence affects operational efficiency.
- Synergy between sustainability and digital innovation - Digital advancements and sustainability initiatives demonstrate their interconnected relationship in this analysis. The integration of AI solutions for sustainability with electric cranes and autonomous vehicles in port operations has been documented through multiple case studies.

- Policy and regulatory influences on maritime sustainability - The effect of global policies and carbon taxes together with financial rewards and green shipping programs on maritime industry operations is evaluated. The section explains how governments enforce sustainability regulations.
- Challenges in implementing digital and sustainable strategies - The barriers to adopting digital and sustainable maritime practices are explored, including high implementation costs, lack of standardization, and resistance to technological change.
- Future pathways for an eco-digital maritime ecosystem - The section discusses upcoming technological solutions including AI autonomous ships and hydrogen-powered vessels that aim to create smart maritime infrastructure for sustainable efficiency.

Figure 2 presents a visual overview of the literature, mapping key thematic areas at the intersection of sustainability and digital innovation in maritime logistics

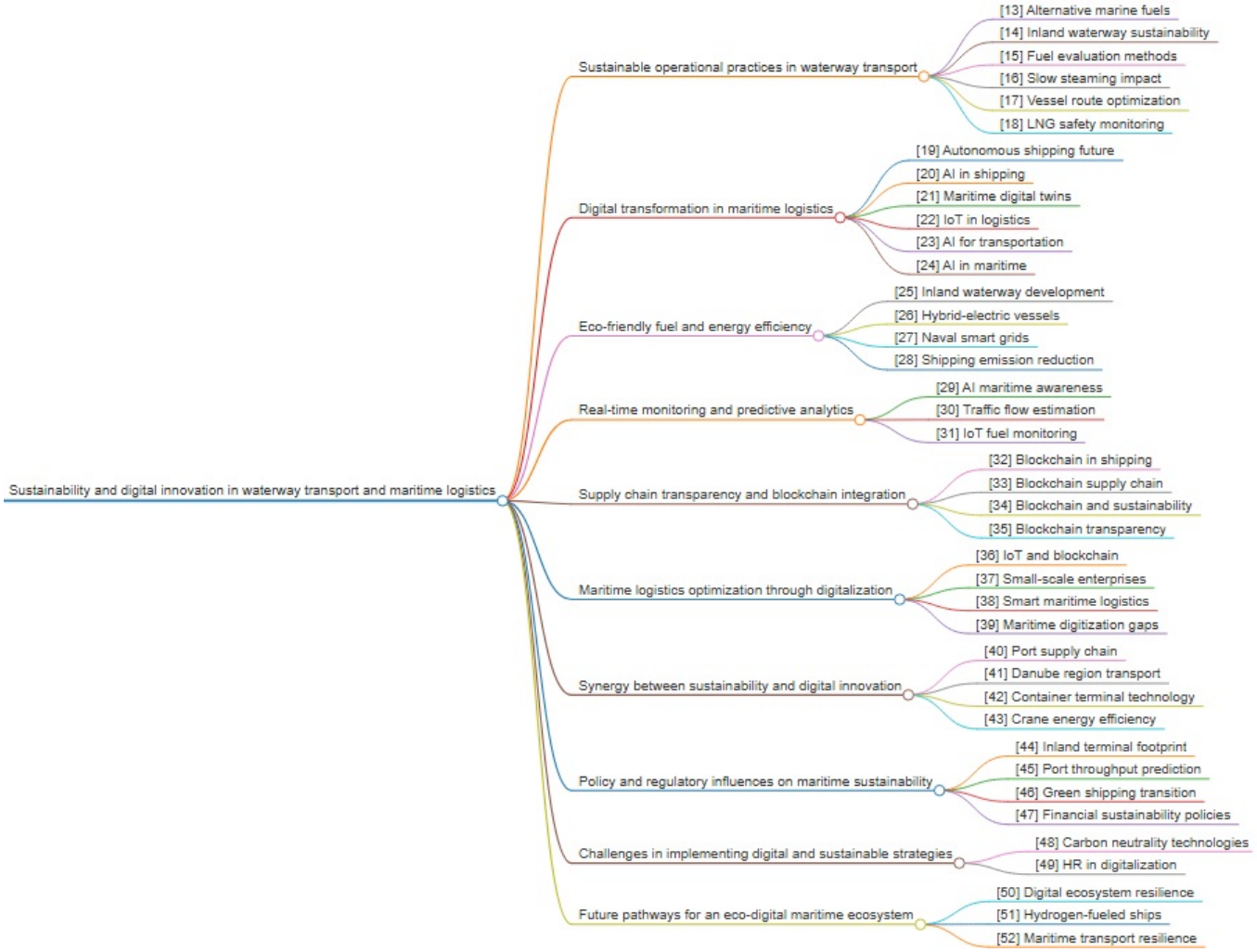

Fig. 2. Literature overview

The mind map provides a visual representation of how sustainability and digital innovation intersect within the maritime industry. It helps in organizing the literature review by showing which references contribute to each thematic area. This structured approach supports the systematic analysis of existing research, allowing for a clearer understanding of challenges, opportunities, and future directions in maritime logistics.

The following key outcomes were extracted from each study:

- Sustainability outcomes**:** Reduction in emissions, energy efficiency improvements, adoption of alternative fuels, compliance with environmental regulations.
- Digital innovation outcomes**:** Implementation of blockchain, IoT, AI, predictive maintenance systems, and automation in maritime logistics.
- Supply chain efficiency metrics**:** Reduction in transit time, cost optimization, cargo tracking efficiency, and supply chain transparency.
- Policy and regulatory impact**:** Compliance with international sustainability frameworks, government incentives, and regulatory barriers.

All available results that aligned with these outcome domains were extracted. In cases where multiple outcomes were reported, the most relevant data for maritime sustainability and digital innovation were prioritized based on study relevance and methodological quality.

In table below we can see summy of key real lif impact metrics based on literature. Data used in Table 2. Is publicly available.

Table 2. Real life impact metrics

Category	Real-Life Example	Impact
Environmental Impact Metrics	Maersk's carbon reduction	41% CO_2 reduction per container since 2008
	Slow steaming	30-50% fuel savings and emissions reduction
	Rotterdam's shore power	40-50% CO_2 cut while in port
Digitalization Performance	TradeLens blockchain	40% faster documentation, 20% cost savings
	MSC smart containers	25% fewer cargo losses, 15% transit time reduction
	AI in Port of LA	30% faster unloading, 12% increased throughput
Regulatory Compliance	IMO 2020 sulfur cap	95% compliance by shipping firms
	EU ETS for shipping	60% of companies complying by 2025
	Green Ship Certifications	10-20% port fee discounts for certified eco-ships

3.3 Theoretical model for integration of sustainability and digital innovation in waterway transportation and maritime logistics

Digital innovation and sustainability in waterway transport and maritime logistics depend on the foundational conditions set by policy, regulatory, and financial frameworks. Policies for environmental protection and emissions control demand lower greenhouse gas emissions while promoting cleaner fuel alternatives and energy-saving technologies. The implementation of carbon taxation alongside financial incentives creates economic forces that influence business decisions and drive companies to adopt sustainable practices. Standard compliance requirements across the industry create consistency in maritime logistics operations and prevent regulatory fragmentation while promoting widespread adoption of sustainable practices. Companies receive necessary financial support for their investments in emerging technologies and alternative energy solutions through green financing and investment policies. Working together with international regulatory bodies enables worldwide uniformity in sustainability standards which supports easier cross-border maritime trade and shared environmental accountability.

Technological advancements function as catalysts to improve efficiency and transparency in maritime and waterway logistics operations. IoT-based cargo tracking systems enable real-time shipment visibility which helps reduce inefficiencies and losses from mismanagement or shipment delays. Supply chain transparency driven by blockchain technology secures maritime trade integrity through tamper-proof transaction records that help maintain regulatory standard compliance. The AI-powered predictive maintenance system allows proactive vessel condition management which lowers unexpected failures while enhancing fuel efficiency metrics. Companies utilize digital twin simulation tools for advanced scenario modeling which helps them optimize operational strategies ahead of implementation to minimize risks and boost efficiency. These technologies serve as the fundamental infrastructure for both sustainability initiatives and regulatory compliance operations. The following section presents a theoretical model (Figure 3) that illustrates how sustainability and digital innovation interact within waterway and maritime logistics systems.

In maritime and waterway logistics eco-friendly solutions put policy objectives and technological innovations into concrete operational uses. The shipping industry achieves lower carbon emissions through alternative marine fuels like LNG, hydrogen, and biofuels which support emission control regulations. The integration of aerodynamic modifications with advanced propulsion technologies in energy-efficient vessel design improves fuel consumption rates to meet environmental standards. Route optimization and slow steaming strategies enhance voyage performance by reducing fuel usage while ensuring reliable delivery. Pollutant management becomes effective through waste and emission reduction strategies which frequently employ both advanced waste treatment systems and exhaust gas cleaning technologies. The practical implementation of technological innovations and regulatory mandates is achieved through these sustainability-focused measures.

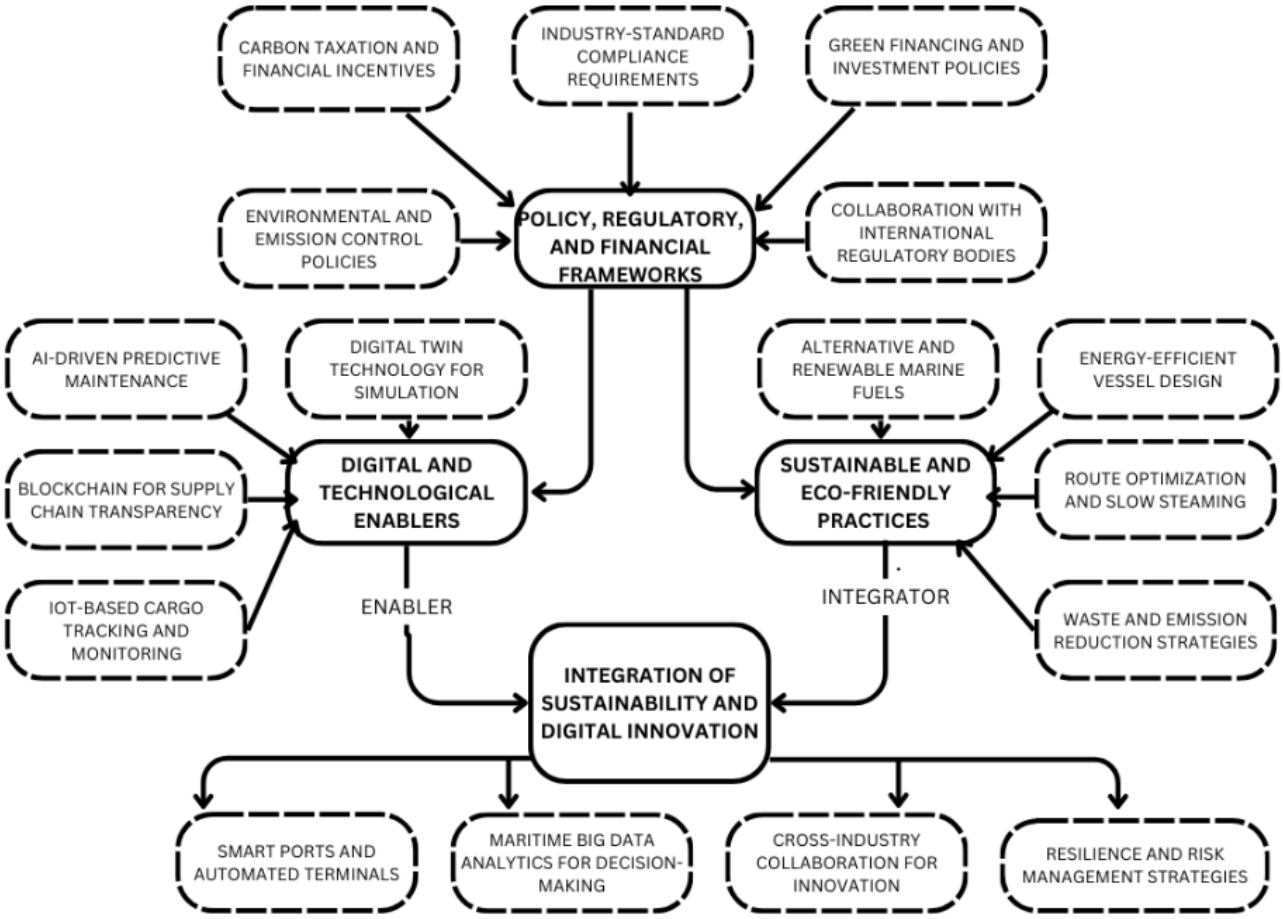

Fig. 3 Theoretical model for integrating sustainability and digital innovation in waterway transportation and maritime logistics

The merging of sustainability with digital innovation creates the convergence point at which policies, technologies and sustainable practices unite to establish a resilient maritime and inland waterway logistics system. Automated terminals and smart ports improve operational efficiency through optimized cargo handling processes which also contribute to reduced idle times and improved port sustainability. Decision-making in maritime and inland waterway big data analytics uses large datasets to discover patterns while optimizing supply chain performance and improving resource allocation. Innovative cross-industry partnerships between regulatory bodies and maritime technology providers produce collective advancements in sustainable practices and digital transformations. Through resilience and risk management strategies maritime and inland waterway logistics systems maintain their adaptive capabilities against external pressures including climate change effects and geopolitical disruptions as well as supply chain disruptions.

Building on the theoretical model that integrates sustainability and digital innovation in waterway transport and maritime logistics, the following research questions explore the practical implications and effectiveness of these strategies in shaping a more efficient and environmentally responsible maritime sector.

RQ1: How do sustainable practices reduce environmental impacts in waterway transport? Waterway transport sustainability reduces environmental impacts by using alternative fuels along with energy-efficient ship designs and emission control systems. Stricter emission standards have sped up the adoption of liquefied natural gas (LNG), biofuels, and hybrid propulsion systems which together lead to substantial reductions in carbon footprints. Fuel consumption reduction is achieved by implementing optimized routing and slow steaming strategies without sacrificing operational efficiency. Shore power systems enable vessels to cut emissions during their time in port to maintain cleaner operational standards. Advanced filtration technologies combined with waste management systems address water pollution issues while supporting international sustainability objectives in maritime logistics.

RQ2: How do digital innovations enhance efficiency in maritime logistics? Automation combined with data-driven decision-making and real-time monitoring enables digital innovations to enhance maritime logistics efficiency. IoT devices that track cargo shipments deliver precise location and condition information which minimizes losses while streamlining logistics operations. Supply chain operations benefit from blockchain technology which ensures transaction security and enhances transparency while eliminating fraud and operational inefficiencies. AI-based predictive maintenance systems allow shipping businesses to foresee equipment malfunctions while reducing both

downtime and maintenance expenses. Through operational simulations digital twin technology permits stakeholders to enhance their strategies before execution which enhances adaptability while reducing costs.

RQ3: What synergies emerge from integrating sustainability with digital transformation in maritime operations? When maritime operations combine sustainability initiatives with digital transformation, they achieve better environmental responsibility and more efficient logistics. Automated port terminals that use AI and IoT technology achieve energy savings and cargo handling optimization which shows how digital innovations support sustainable practices. AI-powered analysis platforms monitor fuel efficiency alongside emission rates to enable shipping businesses to adhere to regulations and discover savings potential. Through blockchain applications companies maintain compliance tracking which ensures uniform sustainability practices throughout global supply chains. Together these advancements help create a maritime sector that operates with greater clarity while achieving higher efficiency and environmental sustainability.

RQ4: Which strategies best support the development of an eco-digital maritime ecosystem? An eco-digital maritime ecosystem emerges through combined efforts in policy development, technological innovation, and cooperative industry engagement. The establishment of regulatory frameworks and monetary incentives by governments serves as the key driver for the adoption of clean energy solutions alongside digital innovations. Smart port infrastructure investments that involve AI automation and electrification systems create long-term operational efficiency while supporting sustainable development. The partnership between maritime companies, technology creators, and government decision-makers drives the implementation of industry standards which connect digital transitions to sustainable objectives. Effective risk management strategies build resilience which allows the maritime sector to tackle new challenges without sacrificing operational and environmental efficiency.

4 Conclusions

Waterway transport and maritime logistics are experiencing a transformative shift due to the combined implementation of digital innovation and sustainable practices which boosts operational efficiency while minimizing environmental damage. Regulatory standards alongside financial benefits stimulate companies to adopt environmentally friendly methods through emission control policies and investments in green technology. IoT-based cargo tracking systems together with blockchain-driven supply chain transparency and AI-enabled predictive maintenance help optimize logistics operations while meeting environmental regulations. The maritime supply chains experience enhanced operational oversight and resource optimization alongside improved resilience through these technological innovations.

While this review provides a synthesis, it is limited by the heterogeneity of the included studies, many of which differ in scope, methodology, and regional focus. Quantitative comparisons were constrained by inconsistent reporting of impact metrics across sources. Additionally, reliance on published literature may introduce publication bias, despite efforts to include grey literature. The lack of expert reviewers within the team may also limit the depth of technical interpretation in specialized domains like alternative fuels or ship design.

The findings offer actionable insights for policymakers, port authorities, and logistics managers. The review identifies key technologies—such as AI-driven analytics, IoT-based monitoring, and alternative fuels—that can guide investment priorities. It also highlights the need for harmonized regulatory frameworks and financial incentives to accelerate adoption. By outlining the benefits of integrating sustainability and digital tools, the study supports decision-making for building resilient, low-emission, and data-driven maritime logistics systems.

Operational strategies that promote sustainability help to decrease environmental impact within the maritime industry while ensuring economic performance remains stable. Alternative fuels combined with energy-efficient vessel designs and emission-reduction technologies reduce carbon emissions and help organizations meet regulatory standards. Digital transformation and sustainability work together as automated terminals and smart ports improve cargo handling efficiency and reduce energy usage. To create an advanced maritime logistics system that balances adaptation, efficiency, and environmental responsibility the industry must sustain investment in these technologies while working together

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7 Conflict of interest statement

There are no conflicts affecting the research.

8 Author contributions

Stefan Ugrinov – Conceptualization, methodology, writing – original draft, literature search. Dragan Ćoćkalo - Formal Analysis, validation, supervision, writing – review & editing. Mihalj Bakator - Data curation, visualization, writing – review & editing. Sanja Stanisavljev - formal analysis, validation, supervision, writing – review & editing.

9 Availability statement

There is no dataset associated with the study or data is not shared.

10 Supplementary materials

There are no supplementary materials to include.

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