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Mapping the Maritime Economy: A Thematic Analysis of Research Trends and Emerging Directions

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ABSTRACT

The maritime economy, a cornerstone of global trade and economic development, is undergoing rapid transformation driven by technological advancements, sustainability challenges, and evolving regulatory frameworks. This study systematically organises and analyses 827 scientific articles from the Web of Science, employing a hybrid methodology integrating Social Network Analysis (SNA), the Binary Space Partitioning (BSP) clustering algorithm, and large language models (LLMs) to identify key research themes and emerging trends. Through an iterative "human-in-the-loop" process, we refine the clustering process, resulting in six main clusters and 26 subclusters spanning topics such as governance and strategic management, forecasting and modelling, port operations, digital innovations, sustainability, and risk management. The results reveal a marked shift toward sustainability-oriented and technology-driven research, emphasising the convergence of environmental responsibility, digital transformation, and operational resilience. The findings also highlight the growing role of autonomous technologies, big data analytics, and blockchain in reshaping maritime systems, while underscoring the need for adaptive governance frameworks and cross-sectoral collaboration.

1 Introduction

The maritime economy stands as one of the cornerstones of global trade, underpinning the seamless movement of goods and services across vast international waters, facilitating more than 80% of the world's merchandise exchange and serving as a critical enabler of globalisation [1]. Beyond its traditional role in shipping and logistics, the maritime domain today embodies a complex system shaped by technological innovation, environmental imperatives, and evolving governance frameworks. As advancements in digitalisation and green technologies transform traditional maritime practices, the sector is not only expanding its economic footprint but also fostering international collaboration and interdisciplinary research. In this rapidly evolving landscape, understanding the multifaceted dimensions of the maritime economy is essential for policymakers, industry leaders, and scholars alike.

In recent years, profound structural changes have redefined the maritime sector. The emergence of digital technologies such as big data analytics, blockchain, and autonomous systems has accelerated operational efficiency and transparency, while the global push for sustainability and decarbonization—anchored in the EU Green Deal, UN Sustainable Development Goals (SDGs 9, 13, and 14), and the EU Sustainable Blue Economy Strategy (2021)—has driven new paradigms of eco-efficient and resilient growth. These transformations highlight the urgent need for an integrated understanding of how maritime research is evolving across technological, environmental, and governance dimensions.

While the maritime economy has been the subject of numerous specialised studies, there remains a lack of comprehensive, data-driven mappings that synthesise its diverse research landscape and reveal how scientific attention has shifted over time. Traditional reviews often focus narrowly on single aspects such as port efficiency, sustainability, or logistics, without capturing the broader systemic interdependencies that characterise the field. Moreover, the rapid growth of digitalisation and automation in maritime contexts calls for new analytical frameworks capable of tracing interdisciplinary connections and identifying emerging knowledge frontiers.

To address this gap, our study systematically analyses 827 scientific articles on the maritime economy retrieved from the Web of Science. It employs an innovative hybrid methodology that combines Social Network Analysis (SNA), the Binary Space Partitioning (BSP) clustering algorithm, and Large Language Models (LLMs) within a human-in-the-loop framework. This approach enables the identification of thematic structures, key research communities, and evolving trends across the global maritime research landscape.

The overarching aim of our study is to organise, visualise, and interpret the intellectual structure of maritime economy research while providing an empirically grounded foundation for future academic and policy agendas. Specifically, we seek to answer the following research questions:

Central Research Question (CRQ):

CRQ: What are the dominant thematic structures and emerging trends in maritime-economy scholarship, and how are they interconnected?

Supporting Research Questions are:

RQ1 (Structure): Which clusters and subclusters best represent the intellectual organisation of maritime-economy research?

RQ2 (Evolution): How have these themes evolved over time in relation to digital, environmental, and governance transformations?

RQ3 (Method): How does a hybrid computational, human-in-the-loop approach improve the accuracy, interpretability, and replicability of large-scale bibliometric mapping?

Our contribution with this paper is:

(i) a validated thematic map of the field with interpretable visuals,

(ii) an empirical account of how themes evolve, and

(iii) a transparent methodological template that other researchers can reuse.

These outputs support scholars, policymakers, and industry stakeholders seeking evidence-based pathways for innovation, resilience, and sustainable growth in the maritime sector.

The remainder of this paper is organised as follows. Section 2 (Methodology) describes the research design, data collection and screening procedures, and the analytical approach used to identify and interpret thematic clusters. Section 3 (Results) presents the main findings, including the dominant themes and their evolution over time. Section 4 (Discussion) interprets these results, highlights key implications, acknowledges limitations, and suggests avenues for future research.

2 Methodology

This study adopts a hybrid bibliometric and computational text-analysis framework to systematically map the research landscape of the maritime economy. The methodological workflow (Figure 1) integrates traditional bibliometric procedures with advanced machine-learning techniques—specifically Social Network Analysis (SNA), the Binary Space Partitioning (BSP) clustering algorithm, and Large Language Models (LLMs)—within an iterative human-in-the-loop refinement process. This approach allows both quantitative network discovery and qualitative semantic validation, ensuring interpretive accuracy and thematic coherence.

For this analysis, we conducted a large-scale mapping of maritime-economy scholarship using a hybrid workflow that links bibliometric structure to thematic interpretation. The corpus comprises 827 peer-reviewed articles retrieved from Web of Science with a focused query on “maritime economy” and “maritime economics”. We removed duplicates, screened records for topical relevance, and retained the final set for analysis. For each article, we collected bibliographic metadata (titles, authors, journal, year, DOIs), reference lists, and abstracts.

We then constructed a directed citation network in which nodes represent articles and edges denote citation links within the corpus. After extracting the giant component to ensure connectivity and reduce noise from isolated items, the network contained 827 nodes and 2,641 directed edges. Edge weights reflect citation frequency and, where applicable, cosine similarity between article abstracts; when deriving text-based simi-

Figure 1 Study methodological framework

larities, we retained ties above a 0.70 threshold. All preprocessing steps were implemented in CiteSpace 6.4.1 and Gephi 0.10.1, and we document software versions and parameter settings for replication.

Social network analysis (SNA) was used to characterise the structure of this citation graph and to provide a principled representation of scholarly communication. Standard metrics such as degree, weighted degree, and path-based centrality were used to identify influential articles and cohesive areas of research. Community structure in the citation network was taken as an empirical proxy for research fields and subfields and served as the backbone for the thematic analysis.

To obtain communities at multiple levels of granularity, we applied a Binary Space Partitioning (BSP) clustering algorithm to the citation network. BSP generates a hierarchical partition tree suited to large, sparse graphs such as citation data, allowing us to read the structure from broad macro-clusters to fine-grained subclusters while avoiding both over-merging and over-fragmentation. We set the maximum tree depth to 12 and explored cosine similarity thresholds of 0.60, 0.70, and 0.80; the main results reported here are based on the 0.70 threshold. Sensitivity checks across these parameter ranges showed that macro-level communities were stable. The procedure initially yielded 246 leaves, but only 11 clusters contained more than four papers, and very small clusters (e.g. fisheries and offshore energy) were excluded from substantive interpretation because they fell below our minimum size threshold.

To improve interpretability without influencing cluster membership, we used a large language model (LLaMA-3.2-3B, temperature 0.2) to generate concise candidate labels and descriptor terms from the titles and abstracts of the papers in each cluster and subcluster. These proposals were treated as suggestions only and were subjected to systematic human review.

We implemented a human-in-the-loop adjudication protocol to ensure internal coherence and boundary clarity. Two authors independently inspected the articles in each (sub)cluster and rated topic coherence, presence of canonical anchor papers, and boundary clarity on a 1–5 rubric. A third author resolved disagreements, and all merges or splits were logged with a short justification to maintain an audit trail. A stratified 10% re-audit produced an inter-rater agreement above 0.85, exceeding our target of 0.80 and supporting the semantic validity of the final taxonomy.

For transparency and reuse, we will make available, upon request, the cleaned bibliographic records, node and edge lists, and per-paper cluster and subcluster assignments, together with the exact Web of Science query string, software versions, random seeds, similarity thresholds, and BSP depth. We also release the LLM label proposals, the adjudication rubric, inter-rater agreement statistics, and the final list of cluster and subcluster labels, enabling other researchers to replicate or extend the analysis.

Finally, to capture the temporal evolution of the field, we derived annual time series of article counts, citations, and author keywords. Keywords were assigned to the dominant cluster of the articles in which they appear, producing per-cluster trajectories that are later summarised in Figure 2 (articles and citations over

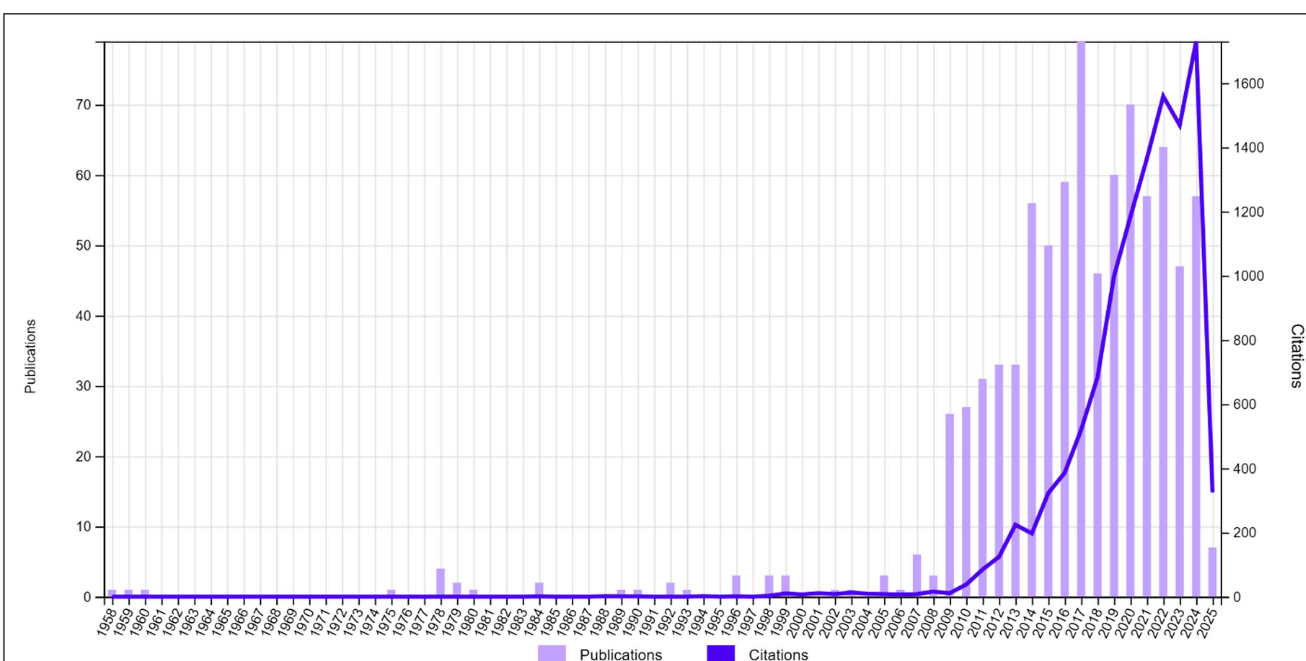

Figure 2 Articles and citations by year

Table 1 Summary of Thematic Clusters in our Maritime Economy Research

Cluster No.	Cluster Title	Main Focus Areas	Representative Keywords	Share of Total Articles (%)
1	**Governance, Strategy, and Risk Management**	Maritime policy, regulatory frameworks, strategic alliances, risk mitigation, and port reforms	governance, regulation, market dynamics, alliances, resilience	24
2	**Forecasting, Modelling, and Technological Innovations**	Predictive modelling, shipbuilding economics, data analytics, simulation and system dynamics	forecasting, modelling, big data, shipbuilding, investment	17
3	**Port Operations, Efficiency, and Infrastructure**	Port performance, connectivity, terminal design, and network efficiency	port choice, connectivity, infrastructure, DEA, logistics	19
4	**Digital Innovations and Autonomous Technologies**	Blockchain, automation, digitalisation, MASS, smart operations	blockchain, big data, autonomy, AI, digital transformation	13
5	**Sustainability and Environmental Solutions**	Eco-efficiency, clean energy, decarbonization, climate adaptation	sustainability, decarbonization, alternative fuels, green ports	15
6	**Operational Risks, Social, and Environmental Challenges**	Systemic risks, social acceptance, stakeholder engagement, and environmental stressors	risk, reliability, social license, resilience, adaptation	12

time) and Figure 3 (cluster activity over time). The resulting taxonomy comprises six main clusters with coherent subclusters, which provide the structure for the results reported in Section 3 and are summarised in Table 1.

The six identified clusters collectively align with the strategic objectives of the European Green Deal and the EU Sustainable Blue Economy Strategy (2021), which call for the twin transition toward a climate-neutral, digitally empowered, and socially inclusive maritime sector.

Clusters focusing on Sustainability and Environmental Solutions (Cluster 5) and Operational Risks, Social, and Environmental Challenges (Cluster 6) directly support the Green Deal's commitment to decarbonization, circular resource use, and climate adaptation within maritime systems. Meanwhile, Digital Innovations and Autonomous Technologies (Cluster 4) reflect the EU's emphasis on digital transformation and smart infrastructure as enablers of competitiveness and efficiency in the blue economy.

The Governance, Strategy, and Risk Management (Cluster 1) and Forecasting, Modelling, and Technological Innovations (Cluster 2) clusters mirror the Strategy's call for improved ocean governance, data transparency, and innovation-driven policy instruments, while Port Operations, Efficiency, and Infrastructure (Cluster 3) contribute to sustainable mobility and the integration of maritime logistics into the EU's trans-European transport network (TEN-T).

These clusters demonstrate that the academic evolution of the maritime economy is strongly converging with Europe's long-term vision of a regenerative, knowledge-based, and digital economy.

3 Results

In this section, we present the results of our analysis, organised into six main clusters and 26 subclusters, each representing a distinct thematic area within the maritime economy research. These clusters were carefully curated through a combination of social network analysis, large language models, and human expertise, ensuring a balanced and accurate representation of the research landscape. For each cluster, we have identified and highlighted three to five key documents that serve as foundational or highly influential works within that thematic area. These documents were selected based on their citation impact, relevance to the cluster's theme, and contribution to the broader field of maritime economy research.

By presenting these clusters and subclusters, along with their key documents, we aim to provide a comprehensive overview of the current state of maritime economy research. This structured approach highlights the diversity of topics within the field and provides a navigable map of the research landscape for researchers, policymakers, and industry stakeholders. The inclusion of key documents within each cluster serves as a starting point for further exploration, enabling readers to delve deeper into specific areas of interest.

Table 2 organises the maritime economy literature into six main thematic clusters, each broken down into specific subclusters that capture distinct topics and methods. Together, these 26 subclusters map how research spans governance and strategy, forecasting and modelling, port operations and infrastructure, digital innovations, sustainability, and operational/social-environmental risks.

Table 2 Clusters and subclusters

Cluster	Subcluster ID	Subcluster title
Governance, Strategy, and Risk Management	1.1	Maritime Policy, Governance, and Strategic Impacts
	1.2	Industry Dynamics, Marketing, and Competitive Strategy
	1.3	Governance, Regulation, and Reforms
	1.4	Strategic Management, Infrastructure, and Market Dynamics
	1.5	Governance, Risk, and Resilience in Maritime Systems
	1.6	Strategic Alliances and Operational Economics in Container Shipping
	1.7	Strategic Marketing and Social Stakeholder Dynamics
	1.8	Strategic Investment and Port Choice Dynamics
Forecasting, Modelling, and Technological Innovations	2.1	Forecasting, Modelling, and Operations
	2.2	Terminal Operations, Stowage Planning, and Operational Optimisation
	2.3	Forecasting and Predictive Modelling
	2.4	Shipbuilding Economics and Investment
	2.5	Service Design and Intermodal Transport Solutions
Port Operations, Efficiency, and Infrastructure	3.1	Port Choice, Performance, and Efficiency
	3.2	Maritime Connectivity and Network Analysis
	3.3	Connectivity, Network Analysis, and Strategic Infrastructure
	3.4	Port Efficiency and Operational Performance
	3.5	Terminal Design and Infrastructure
Digital Innovations and Autonomous Technologies	4.1	Digital Innovations, Blockchain, and Big Data Analytics
	4.2	Autonomous Shipping and Automation
	4.3	Efficiency Measurement and Profit Management
Sustainability and Environmental Solutions	5.1	Sustainability, Eco-Efficiency, and Shipping Ecosystems
	5.2	Environmental Sustainability and Clean Shipping
	5.3	Environmental Sustainability and Climate Adaptation
Operational Risks, Social, and Environmental Challenges	6.1	Risk, Reliability, and Sustainability in Shipping
	6.2	Environmental, Social, and Operational Challenges

The following section details each of the six clusters and their constituent subclusters, highlighting representative articles that illustrate core themes, methods, and contributions. Note that only a small set of representative articles is highlighted for each subcluster, and some may diverge slightly from the subcluster label. Labels were derived from the fifteen most influential articles in each subcluster. Presenting all of them would substantially increase the length of the manuscript.

3.1 Cluster 1: Governance, Strategy, and Risk Management

This cluster consolidates research on maritime policy, governance reforms, and strategic market dynamics. It includes studies examining regulatory frameworks, competitive strategies, and risk management practices that are crucial for resilient maritime operations. The cluster also addresses how strategic alliances and operational economics shape industry responses to market uncertainties and disruptions. This cluster presents a comprehensive view of how governance and strategy drive sustainable and adaptive practices in the maritime economy.

Subcluster 1.1: Maritime Policy, Governance, and Strategic Impacts

This subcluster focuses on examining maritime policy coherence, governance frameworks, and strategic factors shaping maritime transport and trade. The studies explore how policies, regulatory frameworks, and strategic market dynamics interact to influence maritime sustainability and economic performance.

In Asslam et al. [2] analysis the coherence of Pakistan's National Maritime Policy with provincial, national, and international obligations, revealing significant gaps in addressing emerging sustainability challenges is presented, while Yu & Di [3] investigates the coordination between maritime economies and marine carrying capacity in China's Bohai Rim, highlighting the critical role of robust governance in regional maritime development. Strategic Impacts on Trade and Market Dynamics are presented in Zhang et al. [4] with evaluations of the impact of Northern Sea Route fuel costs on bilateral trade between China and the EU, demonstrating that alternative shipping routes can reduce costs and boost exports, and Sun et al. [5] examines the dynamic relationship among global economic policy uncertainty, food prices, and ocean transportation, emphasizing strategic implications for food security and market stability. Intermodal Freight Diversion is presented in Hasan et al. [6] with an analysis of barriers to intermodal freight diversion from road to inland water transport in Bangladesh, and suggests operational and regulatory improvements to enhance cost-efficiency in freight movement.

Subcluster 1.2: *Industry Dynamics, Marketing, and Competitive Strategy*

This subcluster explores competitive dynamics, strategic marketing, and network resilience within the maritime and shipbuilding industries, with research addressing how companies leverage innovative marketing strategies and adapt their brand architectures in a rapidly evolving market. The studies also examine the resilience of maritime networks and the strategic implications of inter-port connectivity on competitive positioning. Notteboom et al. [7] examine how container shipping companies enhance their competitive edge through influencer marketing by emphasising internal influencers and a management-centric approach in a B2B context, while in [8] they investigate branding strategies following mergers and acquisitions, revealing how carriers' visual identity choices reflect complex strategic decision-making. Complementing these insights, Grant [9] analyses PortMiami's regional maritime network, demonstrating that inter-port connectivity and the vulnerability of partner ports play a crucial role in shaping long-term strategy.

Subcluster 1.3: *Governance, Regulation, and Reforms*

This subcluster assesses port governance, regulatory mechanisms, and reform processes that shape the operating environment of ports, particularly across different regional contexts. Zheng and Negenborn [10] study dual regulation mechanisms at the Port of Shanghai, using a principal-agent approach to determine optimal tariffs, capacities, and efficiency levels while demonstrating that sequential actions by central and local governments can lead to significant distortions and affect operator profits. Suárez-Alemán, Serebrisky, and de León [11] review decades of port reforms in Latin America and the Caribbean, highlighting how decentralisation and market liberalisation efforts have led to mixed outcomes and identifying critical areas for improvement in port governance.

Subcluster 1.4: *Strategic Management, Infrastructure, and Market Dynamics*

This subcluster focuses on strategic maritime management, infrastructure investments in emerging economies, and market and relational dynamics within port logistics and cruise terminal operations, offering insights into how strategic decisions and partnerships shape industry development. The research in this area spans from the emergence of strategic maritime management as a discipline to empirical analyses of private entry in cruise terminals and the nuanced effects of relationship marketing in different cultural contexts.

Wang and Mileski [12] promote strategic maritime management as an emerging field, adapting an academic discipline maturity model to map its evolutionary path and identify gaps and opportunities for further research. Parola and Lam [13] investigate logistics infrastructure projects in emerging economies through the lens of public-private partnerships, revealing how financial and technical complexities drive dependence-reducing strategies. Pallis, Parola, Satta, and Notteboom [14] explore private entry strategies and internationalisation patterns in Mediterranean cruise terminal operations, highlighting the shift towards privatisation and the emergence of international operators. Chen, Chang, Hsu, and De Leon [15] examine the impacts of guanxi and relationship marketing in port logistics, demonstrating how interpersonal and interorganizational dynamics vary between Asian and Latin American contexts to influence firm performance and supply-chain effectiveness.

Subcluster 1.5: *Governance, Risk, and Resilience in Maritime Systems*

Governance, Risk, and Resilience in Maritime Systems examines how market structures, risk management strategies, and adaptive capacities shape the operational sustainability of ports and maritime networks under various disruptions. The theme focuses on understanding the interplay between regulatory investments, crisis-induced shocks, and systemic vulnerabilities ranging from natural hazards to global economic crises such as COVID-19. It also highlights the importance of designing comprehensive frameworks that enhance the resilience of interconnected transport networks.

Wang, Chin, and Su [16] develop a two-stage game model to analyse the preventive and adaptive investments made by seaport and dry port authorities in mitigating diversified risks, showing that strategic cooperation and careful consideration of vulnerability asymmetries are essential to avoiding free-riding issues in preventive measures. Fedi, Faury, Rigot-Muller, and Montier [17] assess the impact of COVID-19 on container port hierarchies in the Western Mediterranean and Northern Europe, revealing that while the crisis has exposed significant resilience disparities among ports, it has not fundamentally restructured the hierarchy, though it has underscored the shortcomings of maritime alliances. Notteboom, Pallis, and Rodrigue [18] compare the disruptions caused by the COVID-19 pandemic with those of the 2008–2009 financial crisis, analysing the differential effects on supply chains, operational strategies, and port connectivity to illustrate how varied adaptive mechanisms lead to distinct market outcomes. Verschuur, Pant, Koks, and Hall [19] propose a systemic risk framework that addresses the indirect and cascading disruptions resulting from natural hazards, emphasising the need for enhanced resilience across interconnected networks to mitigate potential supply chain losses in the face of climate change.

Subcluster 1.6: *Strategic Alliances and Operational Economics in Container Shipping*

Strategic Alliances and Operational Economics in Container Shipping explores how strategic partnerships, merger waves, and economies of scale are reshaping the container shipping industry. This theme delves into the evolution of collaborative agreements, the impact of market consolidation, and the economic rationale behind scaling vessel sizes under varying market conditions. It offers a comprehensive perspective on how alliances and operational strategies drive competitiveness and market efficiency.

Ghorbani et al. [20] present a comprehensive review of over 25 years of research on strategic alliances, demonstrating how these collaborations have come to dominate global container shipping capacity and outlining future research directions. Complementing this, Crotti, Ferrari, and Tei [21] analyse merger waves and alliance stability, showing that vertical integration among carriers and terminal operators can mitigate market share losses and improve alliance resilience, provided that cooperative measures extend to all partners. Meanwhile, Ge et al. [22] conduct a comparative economic analysis of ultra-large containerships, revealing that while further scale increases up to 25,000 TEU can yield economies of scale, such expansion is economically viable only under conditions of favourable freight rates and high load factors.

Subcluster 1.7: *Strategic Marketing and Social Stakeholder Dynamics*

Strategic Marketing and Social Stakeholder Dynamics in Maritime Operations investigates how market dynamics and social factors influence port performance and competitiveness, emphasising both the role of innovative marketing strategies and the importance of securing community acceptance. This theme examines the dual challenge faced by maritime actors in managing internal marketing initiatives while simultaneously addressing external perceptions and stakeholder concerns. It underscores that success in maritime operations requires a delicate balance between leveraging strategic influencer marketing and fostering a strong social license to operate through proactive stakeholder engagement.

Moeremans and Dooms [23] develop a model of social license to operate that demonstrates how positive local community experiences and effective stakeholder engagement can lead to greater acceptance of port operations, particularly in Flemish seaports. In parallel, Notteboom et al. [7] analyse the strategic use of influencer marketing in container shipping, revealing that companies like Maersk and MSC prioritise internal influencers and management-centric protocols to optimise their B2B marketing strategies.

Subcluster 1.8: *Strategic Investment and Port Choice Dynamics*

Strategic Investment and Port Choice Dynamics examines how operational efficiency, stowage planning, vessel design, and port productivity feed into long-term investment decisions and the relative attractiveness of ports. This theme focuses on how the challenges of increasing ship size and associated diseconomies of scale shape where capacity expansions are warranted, which ports can effectively handle mega-ships, and how multiport service design reallocates traffic. It underscores that integrated operational planning is not only about improving capacity utilisation, reducing fuel consumption, and minimising environmental impacts, but also about influencing capital allocation and port selection in competitive shipping networks. Jeong and Kim [24] investigate the relationship between containership size and quay crane productivity at Busan New Port, revealing that while larger ships offer economies of scale, they also lead to lower crane productivity due to increased congestion and operational challenges, thereby affecting the returns to investments in larger vessels and terminal equipment.. In a complementary study, Chou and Shiau [25] propose a comprehensive stowage planning approach that considers the entire voyage, demonstrating that a central planner can significantly enhance vessel capacity utilisation, reduce ballast water and fuel consumption, and ultimately improve profitability, with implications for how carriers design service networks and prioritise ports within a route.

3.2 Cluster 2: Forecasting, Modelling, and Technological Innovations

Cluster 2 unites a diverse array of research that leverages advanced quantitative methods and cutting-edge technologies to revolutionise forecasting, shipbuilding, and operational planning within the maritime industry. This cluster explores how sophisticated modelling techniques, such as deep learning and system dynamics, alongside innovations in data analytics and operational optimisation, can address the complexities of economic uncertainty, regulatory pressures, and logistical efficiency.

Subcluster 2.1: *Forecasting, Modelling, Operations*

Forecasting, Modelling, and Operations examines how modern forecasting techniques and modelling approaches, often enabled by new data and analytics, improve maritime planning and performance. The work in this area applies deep learning, large-scale data analysis, and econometric models to track complex market behaviour and forecast key industry indicators. Taken together, these studies offer practical toolkits for managing uncertainty, refining vessel and fleet decisions, and responding to shifting operational and market conditions.

Qi et al. [26] investigate the dynamic interplay between global economic policy uncertainty and crude oil transportation by analyzing the Baltic Dirty Tanker Index, revealing a resonance effect under different supply, demand, and capacity scenarios, while Su et al. [26] deploy a deep ensemble model combining CNN, BiLSTM, and attention mechanisms to forecast the Baltic Dry Index with exceptional accuracy, highlighting the value of integrated forecasting approaches in the shipping industry. In a related vein, Gorman et al. [27] offer a comprehensive overview of big data analytics in freight transportation, discussing how emerging data sources and analytical capabilities are reshaping operational strategies across various transport modes. Complementing these studies, Ge et al. [22] perform a comparative economic analysis on the feasibility of ultra-large containerships by incorporating market-based and operational conditions, demonstrating that further scale increases can yield economies of scale provided that freight rates and load factors remain favourable.

Subcluster 2.2: *Terminal Operations, Stowage Planning, and Operational Optimisation*

Terminal Operations, Stowage Planning, and Operational Optimisation focus on enhancing the efficiency of container terminal operations by refining stowage planning, optimising yard and berth allocation, and improving overall operational performance. This theme explores how innovative planning methods and advanced simulation techniques can increase capacity utilisation, reduce fuel consumption, and mitigate environmental impacts while addressing complex operational constraints. By integrating analytical frameworks and empirical studies, these contributions offer practical solutions for both shipping lines and terminal operators to boost profitability and operational resilience.

Ambrosino and Sciomachen [28] propose a stowage-planning procedure that effectively handles hazardous containers by adhering to the International Maritime Dangerous Goods Code, which assists shipping line coordinators in optimising available space and accommodating diverse stowage strategies across shipping alliances. In a complementary approach, Chou and Shiau [25] demonstrate how adopting an entire voyage perspective in stowage planning can significantly improve vessel capacity utilisation, reduce ballast water carried, and lower fuel consumption, thereby enhancing both operational efficiency and environmental performance. In parallel, Weerasinghe, Perera, and Bai [29] provide a comprehensive systematic review of operations research applications in container terminal optimisation, revealing that while genetic algorithms, integer linear programming, and heuristics dominate the field, there remains a promising avenue for integrating neural network and deep learning models to tackle dynamic operational challenges. Supporting these insights, Carboni et al. [30] introduce a microscopic traffic simulation approach that models internal vehicle flows at container terminals, offering terminal operators a decision-support tool to evaluate management strategies, optimize performance, and assess environmental impacts under various operational scenarios.

Subcluster 2.3: *Forecasting and Predictive Modelling*

Forecasting and Predictive modelling in maritime systems harnesses advanced forecasting techniques and machine learning approaches to predict key operational metrics, such as shipbuilding demand, cargo throughput, and freight rates. This theme addresses the complex interplay between economic dynamics and operational performance, providing decision-makers with vital insights into market uncertainties and strategic planning. By integrating diverse models and leveraging real-world data, these studies aim to improve predictive accuracy and enhance the overall efficiency of maritime operations.

Mudunkotuwa et al. [31] propose an econometric forecasting model tailored to a transhipment hub, using trade flow data from major production centres to assess the resilience and adaptability of the Port of Colombo amid global disruptions. Complementing this, Morales-Ramírez et al. [32] employ vector autoregressive models to predict national port cargo throughput in Mexico, revealing that macroeconomic variables from both Mexico and the United States have a significant, albeit temporary, causal effect on throughput movement. Meanwhile, Guo et al. [33] introduce a novel hybrid forecasting strategy that combines error evaluation and reinforcement learning to predict ocean freight rates, effectively outperforming traditional methods and offering a more accurate tool for navigating market volatility.

Subcluster 2.4: *Shipbuilding Economics and Investment*

The theme of shipbuilding economics and investment focus ties together critical aspects of maritime industry research, emphasising the economic factors, market dynamics, and regulatory influences that shape decision-making in ship construction and valuation. These studies collectively explore how pricing, demand forecasting, and investment strategies adapt to volatile market conditions and emerging environmental regulations. By analysing historical data, market trends, and predictive modelling, they offer insights into the financial and operational challenges faced by shipyards and vessel owners.

The paper by Han et al. [34] investigates shipbuilding demand through a system dynamics model, focusing on the LNG carrier market to forecast long-term demand amidst volatility and regulatory shifts. Its strength lies in integrating macro-level shipping market components and scenario analyses, revealing how transport demand and carbon regulations amplify demand cycles while shipyard capacity stabilises them. Similarly, Pruyn and Yan's study [35] examines newbuilding prices and lead times for bulk carriers using generalised additive models, highlighting the interplay between market sentiment and IMO greenhouse gas regulations. The research effectively models price influences but notes that lead time predictions need refinement, reflecting the complexity of shipbuilding timelines under economic and regulatory pressures. In contrast, Pruyn et al.'s earlier work [36] reviews second-hand vessel valuation over two decades, proposing a simple method based on micro-economic factors like vessel specifics rather than predictive demand models. This historical analysis underscores a shift from market efficiency debates to detailed asset valuation, offering a foundational perspective that complements the forward-looking approaches of the other two papers.

Subcluster 2.5: *Service Design and Intermodal Transport Solutions*

The theme of service design and intermodal transport solutions centres on optimising short-sea shipping and intermodal logistics to improve efficiency, cost-effectiveness, and integration across transport chains. These studies address the challenges of designing services that link maritime and inland transport modes, responding to diverse logistical needs and competitive pressures. Through innovative methodologies and empirical analysis, they highlight how strategic service design can enhance connectivity and sustainability in freight movement.

The paper by Santos et al. [37] develops a methodology for designing short-sea-shipping services within intermodal chains, using freight demand estimation and logistic regression to size a Ro-Ro ship for a Portugal-Madeira-Morocco route. It effectively demonstrates how tailored ship capacity and route planning can boost economic viability, particularly for linking EU and non-EU regions. Similarly, Hasan et al. [6] explore barriers to shifting freight from road to inland water transport in Bangladesh, employing a total logistics cost approach to compare transport modes along the Dhaka-Chittagong corridor. Their findings underscore inland water transport's cost advantages despite longer transit times, suggesting that infrastructure and service enhancements could further strengthen its competitiveness. Van den Berg and de Langen's study [38] assesses shipping lines' intermodal value propositions, surveying shippers and forwarders in the Netherlands to understand preferences for port-to-port, door-to-door, and inland terminal services. The research reveals distinct priorities between the two groups, affirming that inland terminal offerings add value by bridging maritime and inland logistics, tailored to customer roles in the supply chain.

3.3 Cluster 3: Port Operations, Efficiency, and Infrastructure

The cluster investigates the critical interplay between performance optimisation, innovative design, and robust connectivity in port systems within the maritime transport landscape. It focuses on enhancing operational efficiency, streamlining terminal layouts, and strengthening network integration to meet the demands of global supply chains. By examining the dynamics of resource management, infrastructure development, and strategic linkages, this cluster addresses the challenges of congestion, cost reduction, and competitiveness in an increasingly complex industry.

Subcluster 3.1: *Port Choice, Performance, and Efficiency*

The subcluster on Port Choice, Performance, and Efficiency delves into the critical factors influencing how ports are selected, evaluated, and optimised within the maritime transport ecosystem, focusing on shipper preferences, service provider dynamics, and operational efficiency. These studies employ innovative frameworks and data-driven approaches to assess port performance, offering insights into managing congestion, reducing costs, and enhancing competitiveness in global supply chains. By examining both user and provider perspectives alongside detailed efficiency metrics, they provide a comprehensive understanding of port operations and their economic implications.

Talley and Ng's work [39] introduces a cargo port choice equilibrium model that simultaneously considers shippers and port service providers, revealing how their interdependent decisions shape network-wide port selection outcomes. Their subsequent study [40] builds on this by proposing a port congestion probability metric, derived from the equilibrium model, to evaluate performance and guide congestion management strategies with a clear, actionable formula. In a related focus on performance, Ashley et al. [41] use nonnegative matrix factorisation on vessel timestamp data to rank container ports based on quayside efficiency, offering a practical, ship-operator-centric index that highlights ports with minimal port times. Complementing this, Lei and Bachmann [42] econometrically analyse 11 direct port efficiency indicators from Canadian ports, linking metrics like berth utilisation and truck turnaround time to freight rate variations, thus quantifying their cost impacts with precise elasticities.

Subcluster 3.2: *Maritime Connectivity and Network Analysis*

The subcluster 3.2 explores the intricate web of global shipping networks, focusing on how connectivity metrics, trade dynamics, and network reconfigurations shape maritime trade routes and economic outcomes. These studies employ advanced analytical tools, from data envelopment analysis (DEA) to gravity models, to quantify port and country connectivity, assess competitive positioning, and predict the impacts of strategic initiatives like the Belt and Road Initiative.

Xu et al. [43] propose two indices derived from global liner shipping network data to measure countries' trade importance, demonstrating that ports with trans-shipment roles significantly enhance a nation's trade status by facilitating third-party trade mediation. Similarly, Martinez-Moya et al. [44] construct a composite port connectivity indicator for Mediterranean container ports using Benefit-of-the-Doubt and Common Set of Weights methods in DEA, highlighting how superior connectivity bolsters port competitiveness in a fiercely contested region. Mishra et al. [45] refine UNCTAD's Liner Shipping Connectivity Index with a stochastic multicriteria approach, offering a probabilistic ranking that identifies China and Singapore as top connectivity hubs due to robust network integration. In a complementary vein, Saeed et al. [46] use a gravity model to analyse the Belt and Road Initiative's impact on maritime network reconfiguration, finding that fewer trans-shipments enhance bilateral trade flows across key chokepoints like the Suez and Panama Canals. Tsantis et al. [47] conduct a systematic literature review to identify factors driving direct container shipping connections, developing a framework that links trade dynamics, infrastructure, and carrier strategies to improved bilateral trade potential.

Subcluster 3.3: *Connectivity, Network Analysis, and Strategic Infrastructure*

This subcluster explores the interplay between port connectivity, network configurations, and strategic infrastructure planning, offering tools to evaluate port attractiveness and resilience in global shipping systems. These studies develop sophisticated indices and models, integrating network theory and empirical data, to assess how infrastructural dynamics and connectivity influence port choice and supply chain efficiency. Yue and Mangan [48] present a systematic literature review to define reliability in container shipping networks, proposing a framework that spans infrastructure, network configuration, and connectivity, which clarifies diverse reliability dimensions and their practical implications. In a related focus on network analysis, Wang et al. [49] introduce the Composite Connectivity Index, blending connectivity and centrality measures via two-stage DEA and network theory, effectively ranking Chinese hub ports like Shanghai and Shenzhen for their global attractiveness. Mueller et al. [50] model European container port choice with a detailed logit approach, incorporating 11 factors like fuel prices and hinterland changes, revealing how shifting transport costs reshape port market shares and hinterland reach.

Subcluster 3.4: *Port Efficiency and Operational Performance*

The theme of port efficiency and operational performance centres on evaluating how effectively ports manage resources and handle cargo, using quantitative methods like DEA and econometric models to inform operational and investment decisions. These studies assess productivity, technical efficiency, and the impact of factors such as port size, traffic volume, and operational practices across diverse geographic and economic contexts. The paper by Seth and Feng [51] uses stepwise selection and window analysis within DEA to evaluate the efficiency of 15 US container ports since 2000, revealing insights into productivity trends and identifying investment priorities to enhance operational planning. Julien et al. [52] compare Caribbean SIDS ports to top global ports and other SIDS using DEA and econometric methods, finding that Caribbean ports lag in technical efficiency but show productivity gains, suggesting underutilization rather than inefficiency as a key issue. Luna et al. [53] apply DEA to assess cargo-handling efficiency at a Mexican container terminal over six months, showing that prolonged handling times and excess crane use significantly reduce efficiency, offering specific recommendations to boost productivity. Hynes et al. [54] examine Irish and North Atlantic Spanish ports from 2000-2015 using a double-bootstrap DEA, demonstrating that larger ports achieve higher technical efficiency, a trend amplified post-recession, highlighting the challenges smaller ports face in peripheral markets.

Subcluster 3.5: *Terminal Design and Infrastructure*

The theme of terminal design and infrastructure explores how container terminals are classified, designed, and integrated with supporting infrastructure like dry ports to optimise logistics and operational efficiency. These studies delve into layout evolution, resource allocation, and management characteristics, employing methods ranging from dynamic modelling to fuzzy logic to address modern shipping demands.

Alessandri et al. [55] propose a dynamic model and nonlinear programming approach to optimise logistics in intermodal terminals, showing that predictive control can efficiently allocate handling resources despite complex binary decision variables. Khaslavskaya and Roso [56] review a decade of dry port research, identifying five key thematic areas—conceptual debates, environmental and economic impacts, performance, and network roles—underscoring the diverse global applications and future research potential. Adenso-Díaz et al. [57] use a fuzzy AHP method to classify container terminals in the Spanish port system, demonstrating that incorporating expert judgment refines management insights beyond traditional metrics like TEUs. Gharehgozli et al. [58] trace the evolution of container terminal layouts from traditional to automated designs, noting that modern layouts prioritise efficiency and smaller footprints to meet rising container traffic demands.

3.4 Cluster 4: Digital Innovations and Autonomous Technologies

This cluster highlights the digital transformation in maritime operations, focusing on blockchain, big data, and automation technologies. It explores how these technologies enhance efficiency, transparency, and safety across shipping and port ecosystems, reshaping traditional practices in response to modern logistical demands. By addressing operational improvements, strategic frameworks, and profit optimisation, this cluster highlights the potential of cutting-edge tools to drive resilience and competitiveness in the maritime sector.

Subcluster 4.1: *Digital Innovations, Blockchain, and Big Data Analytics*

The subcluster examines how cutting-edge technologies transform maritime supply chains and terminal operations by improving efficiency, transparency, and decision-making. These studies highlight the potential of blockchain to streamline documentation and enhance trust, while big data analytics unlocks new operational insights across freight transport modes. Li et al. [59] review blockchain's application in the maritime industry, showing it can boost efficiency, security, and sustainability by addressing paperwork inefficiencies and data-sharing challenges. Gorman et al. [27] explore big data analytics in freight transportation, noting that new data sources and analytics capabilities are reshaping research and operational practices across air, ocean, rail, and road modes. Amico and Cigolini [60] use a simulation based on the port of Livorno to demonstrate that blockchain-based bills of lading reduce container lead times by 3-4% and dwell times by up to 30%, enhancing terminal efficiency and equipment utilisation.

Subcluster 4.2: *Autonomous Shipping and Automation*

This subcluster investigates how advanced technologies reshape maritime operations, from defining automation levels and critical success factors to assessing their impacts on efficiency, safety, and port interactions. These studies collectively explore the transition to Maritime Autonomous Surface Ships (MASS), emphasising operational enhancements, ecosystem changes, and the infrastructural adaptations required for successful integration. They connect through a shared focus on how autonomy disrupts traditional shipping and port dynamics, offering both technical and strategic insights.

Tsvetkova and Hellström [61] analyse value creation in autonomous shipping from an ecosystem perspective, showing that MASS can transform logistics chains by reducing crew costs and enhancing ship intelligence, benefiting shipowners, operators, and technology providers. Poornikoo and Overgard [62] propose a fuzzy logic approach to define levels of automation in MASS, addressing ambiguity in existing frameworks and providing a clearer operational language that complements studies like Tsvetkova's by grounding autonomy in practical terms. Kurt and Aymelek [63] assess the operational and economic advantages of autonomous ships, highlighting improved safety and efficiency while identifying navigational and port interaction challenges, linking to Tsvetkova's ecosystem focus by detailing MASS-port interoperability needs. Li and Yuen [64] identify critical success factors for autonomous ship adoption using a theory-driven model, ranking technological readiness and environmental fit as key drivers, offering a strategic roadmap that aligns with Kurt's findings on practical implementation hurdles.

Subcluster 4.3: *Efficiency Measurement and Profit Management*

The subcluster of efficiency measurement and profit management focuses on enhancing seaport operational efficiency and profitability through advanced analytical techniques, addressing challenges like simultaneity bias and stochastic disruptions. These studies develop innovative frameworks to refine efficiency estimates and optimise management strategies, offering practical tools for port authorities to boost competitiveness under uncertainty. They connect by tackling distinct yet complementary aspects of port performance, measurement accuracy and profit resilience, within a shared goal of operational improvement. Rodseth et al. [65] introduce a non-parametric method to mitigate simultaneity bias in seaport efficiency measurement, using data from Norway's eight largest container ports to demonstrate how joint estimation of production and control functions improves accuracy over traditional approaches. Cuong et al. [66] propose a hybrid decision support system combining recurrent neural networks and fractional-order sliding mode control to manage seaport profits under supply chain disruptions, showing through Busan and Incheon case studies that it reduces costs and enhances resilience.

3.5 Cluster 5: Sustainability and Environmental Solutions

This cluster tackles the urgent issues of environmental sustainability, clean shipping technologies, and eco-efficiency within maritime ecosystems. It explores how ports and shipping operations can support global decarbonization efforts by adopting innovative energy solutions, smart technologies, and adaptive approaches to lessen climate effects. By focusing on lifecycle emissions, operational resilience, and ecosystem interactions, it connects technological progress with policy strategies to improve the maritime industry's environmental and economic outcomes. Together, these initiatives highlight a forward-looking vision for sustainable shipping, harmonising ecological priorities with feasible execution across varied maritime settings.

Subcluster 5.1: *Sustainability, Eco-Efficiency, and Shipping Ecosystems*

The theme of sustainability, eco-efficiency, and shipping ecosystems examines how ports and maritime operations can align with environmental goals through eco-efficient practices, conceptual frameworks for sustainable shipping hubs, and the integration of smart technologies. These studies address the pressing need for decarbonization and resilience in maritime systems, linking operational efficiency with ecological health and broader ecosystem dynamics. They relate by exploring sustainability from distinct angles, empirical performance, theoretical ecosystems, and smart technology applications, toward a unified vision of green shipping.

Bulak [67] employs a non-parametric frontier approach to assess eco-efficiency in the world's 21 busiest seaports, identifying Qingdao and Cartagena as leaders and providing pathways for others to enhance sustainability under UN climate goals. Zhang et al. [68] conceptualise the shipping ecosystem using ecological analogies, defining its 3C elements (Core actors, Cooperating sectors, Circumstance factors) and offering a framework to understand its evolution, which complements Bulak's focus by situating eco-efficiency within a broader systemic context. Liu et al. [69] revisit the smart port concept through a population ecology lens, using Tianjin port to illustrate how smart technologies enhance sustainability, and propose a novel "health" evaluation framework that ties into Zhang's ecosystem perspective by assessing operational stability and growth potential.

Subcluster 5.2: *Environmental Sustainability and Clean Shipping*

The theme of environmental sustainability and clean shipping explores lifecycle energy solutions, alternative propulsion technologies, and the cost-effectiveness of policies to foster a cleaner maritime economy, aiming to reduce greenhouse gas emissions and enhance ecological performance. These studies collectively assess viable pathways to decarbonization—through fuel alternatives, voluntary initiatives, and economic frameworks—connecting technical innovation with policy and operational strategies for sustainable shipping. They link through a shared emphasis on balancing environmental impact with practical and economic feasibility in the maritime sector. Park et al. [70] conduct a lifecycle analysis of zero-carbon fuels like ammonia and hydrogen for short-route ferries in West Scotland, finding significant GHG reductions (e.g., 25.7% with hydrogen fuel cells) and offering a roadmap for clean shipping policies. Jang et al. [71] extend this lifecycle approach to hydrogen fuel cells across 2000 ships, showing steam methane reforming could outperform diesel if optimised, providing quantified environmental indicators that align with Park's focus on alternative fuels. Pereda and Lucchesi [72] propose frameworks to evaluate the cost-effectiveness of environmental policies like fuel taxes and speed reduction, complementing Park and Jang by integrating economic analysis into the adoption of clean technologies. Christodoulou and Cullinane [73] analyse Stena Line's voluntary sustainability initiatives, such as methanol conversion and ferry electrification, revealing significant emission reductions and linking to Pereda's policy focus by highlighting the role of economic incentives in scaling such efforts.

Subcluster 5.3: *Environmental Sustainability and Climate Adaptation*

The theme of environmental sustainability and climate adaptation focuses on how the maritime sector can respond to climate change through deep adaptation strategies and by addressing carbon emissions within global shipping networks. These studies collectively highlight the urgency of moving beyond incremental changes to confront disruptive climate impacts and reduce environmental footprints, linking adaptation needs with emission management across ports and shipping operations. They connect by emphasising the systemic shifts required—whether in strategic planning, operational emissions, or stakeholder-driven green initiatives—to achieve resilience and sustainability.

Monios and Wilmsmeier [74] introduce the concept of deep adaptation, arguing that the maritime sector must prepare for severe climate disruptions rather than relying on minor adjustments, challenging traditional growth forecasts and urging a paradigm shift in maritime economics. Tran and Lam [75] quantify CO2 emissions in CMA-CGM's global container shipping network, revealing that 1.23 million tonnes of CO2 are emitted annually, concentrated in key hubs, and linking to Monios' call for adaptation by showing where green policies could have the greatest impact. Satta et al. [76] explore green strategies in Italian ports from a stakeholder perspective, identifying energy efficiency and renewable energy as key focuses that align with Monios' adaptation needs and Tran's emission insights, demonstrating how stakeholder collaboration can drive sustainable port operations.

3.6 Cluster 6: Operational Risks, Social, and Environmental Challenges

This cluster integrates research on managing risks, addressing social dynamics, and tackling environmental sustainability within maritime and port operations. It explores how the industry navigates operational vulnerabilities, community expectations, and ecological pressures amidst market volatility and technological shifts. By combining risk assessment, stakeholder engagement, and eco-efficiency strategies, this cluster reveals the interconnected challenges of ensuring reliability, fostering social acceptance, and advancing sustainable practices. Together, these efforts provide a comprehensive lens on balancing operational resilience with broader societal and environmental responsibilities in a rapidly evolving maritime landscape.

Subcluster 6.1: *Risk, Reliability, and Sustainability in Shipping*

The subcluster examines how risk analysis, reliability frameworks, and eco-efficiency intersect to enhance safety, resilience, and sustainability in container-handling operations and broader shipping networks. These studies collectively address vulnerabilities—cyber threats, natural hazards, operational risks, and cargo damage—while proposing quantitative tools and digital solutions to mitigate them, linking reliability with sustainable outcomes. They connect through a shared focus on systemic risk management, with overlapping concerns about operational stability and supply chain resilience.

Zhang et al. [77] developed a hybrid SgDT framework to analyse risks in automated container terminal operations, identifying critical factors like equipment malfunctions and communication failures, offering a foundation for safer, more reliable handling processes. Talley [78] investigates cargo damage risk in container ship accidents, finding that licensed operators and larger ships reduce risk and severity, providing insights that align with Zhang's emphasis on operational reliability. Tusher et al. [79] propose an MCDM framework to assess cybersecurity risks in autonomous shipping, ranking navigational systems as most vulnerable, connecting to Zhang's focus on technology-related risks in automated systems. Siddiqui and Verma [80] present a risk assessment methodology for intercontinental oil transport, incorporating location-specific costs, which complements Talley's accident focus by broadening the scope to global shipping risks. Verschuur et al. [19] offer a systemic risk framework for port and supply-chain networks under natural hazards, emphasising resilience strategies that tie into Siddiqui's network perspective and Zhang's operational stability concerns. Urciuoli and Hintsa [81] model the benefits of digital ecosystems in mitigating sea transport risks, showing significant savings (e.g., €3448–€79,242 per scenario), linking to Tusher's digital focus and Verschuur's resilience goals by enhancing supply chain sustainability through technology.

Subcluster 6.2: *Environmental, Social, and Operational Challenges*

The theme of environmental, social, and operational challenges in port and maritime systems explores the interplay of sustainability, social acceptance, and operational resilience, addressing economic, environmental, and governance issues amid market shocks and disruptions. These studies collectively examine how ports and shipping adapt to global pressures—through economic revitalisation, infrastructure upgrades, stakeholder engagement, and emissions management—linking operational performance with social and environmental outcomes. They connect by highlighting the multifaceted challenges of balancing profitability, community relations, and ecological goals in a dynamic industry.

Zeien and Hillmann [82] argue that maritime economics is key to revitalising the US marine industry, showing how competitive markets and minimal government intervention enhance performance, setting a foundational economic context for operational challenges. Musso and Sciomachen [83] analyse the impact of megaships on an Italian port terminal, using simulation to demonstrate that higher dwell times enable a 40% rail modal split, addressing operational efficiency and sustainability in line with Zeien's market-driven focus. Moeremans and Dooms [23] propose a social license to operate model for Flemish ports, finding that positive community perceptions of economic, environmental, and social impacts boost acceptance, linking social sustainability to operational legitimacy. Felício et al. [84] extend this by showing how sustainable port practices—communication, community participation, and local investment—shape positive perceptions, reinforcing Moeremans' stakeholder engagement insights. Van den Berghe et al. [85] question the inevitability of port-city land-use conflicts in Amsterdam, suggesting that the 'port-out, city-in' narrative may self-perpetuate, offering a governance perspective that complements Musso's infrastructure focus. Crotti et al. [21] examine merger waves in container shipping, showing that vertical integration stabilises alliances when extended to terminal operations, connecting operational resilience to Zeien's competitive market thesis. Jeong and Yun [86] use the

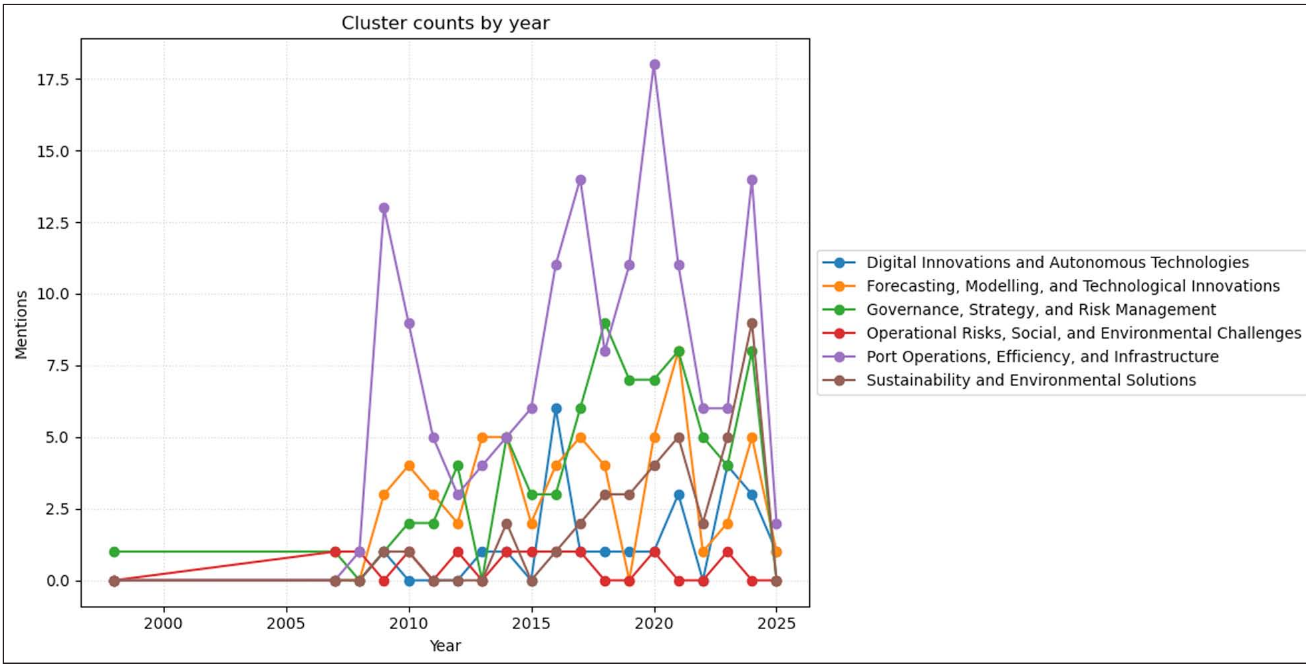

Figure 3 Cluster changes by year

Logarithmic Mean Divisia Index to identify transport scale and capacity as key drivers of a 15.7% emissions rise in shipping from 2007-2018, highlighting energy intensity as critical for decoupling emissions from growth, tying environmental challenges to Musso and Felício's sustainability efforts.

Figure 3 presents cluster changes by year and shows how attention to each theme rises, stabilises, or declines across the study period. The pattern confirms a clear post-2010 pivot: digital innovations and autonomous technologies expand from a marginal presence to a persistent growth path, while sustainability and environmental solutions accelerate in parallel as decarbonization and regulatory pressures intensify. Governance, strategy, and risk management remain a constant backbone but increasingly intersect with digital and green agendas, indicating stronger policy coordination and institutional adaptation. Port operations, efficiency, and infrastructure dominate early years and continue at substantial levels, though their focus progressively absorbs data-driven and environmental considerations. Forecasting, modelling, and technological innovations show cyclical peaks aligned with market shocks and technology waves, and operational, social, and environmental risk topics maintain steady, lower-volume activity that anchors resilience concerns. Taken all together, the year-by-year trajectory in Figure 3 demonstrates not merely growth in volume but a reorganisation of the field toward a digital–green core, with governance providing the connective tissue between methodological advances and operational practice.

4 Discussion

The findings of this study provide a comprehensive and structured overview of the maritime economy research landscape, revealing six main clusters and 26 subclusters that encapsulate the diverse and interdisciplinary nature of the field.

Our results answer the CRQ by revealing a stable six-cluster structure with twenty-six subclusters that map the field's dominant themes and their interconnections. The network map and hierarchy show how governance and strategy, forecasting and modelling, port operations and infrastructure, digital and autonomous technologies, sustainability, and operational/social–environmental risks form the backbone of maritime-economy research, with visible cross-links among technology, policy, and green-transition topics.

RQ1 (Structure). We demonstrate the field's intellectual organisation through SNA+BSP communities that persist under parameter variation. Cluster synopses, exemplar papers, and the subcluster taxonomy offer fine-grained resolution while preserving macro coherence.

RQ2 (Evolution). Temporal analyses show a clear trajectory. Before ~2010, activity concentrated on efficiency, port performance, and classical economics. From 2010–2016, digital methods and governance reforms rise; after 2017, sustainability (alternative fuels, lifecycle emissions, adaptation) and autonomy/AI accelerate. Recent years exhibit stronger coupling among digital ports, green corridors, and regulatory instruments, indicating convergence toward a green-digital governance paradigm. Several subclusters expand or merge (e.g., smart-port analytics integrating with policy/governance), while peripheral niches with sparse literature remain small or fall below the minimum size threshold.

RQ3 (Method) and the human-in-the-loop contribution. The hybrid pipeline improves rigor in three ways: (i) accuracy—BSP yields cleaner communities; dual independent reviewers rate coherence/anchors/boundaries on a 1–5 rubric; disagreements are arbitrated; stability checks confirm results; (ii) interpretability, LLMs generate concise, consistent labels and descriptors from titles/abstracts without determining membership; (iii) replicability, we reveal data, code, parameters, seeds, agreement metrics (target ≥0.80), and a change log of merges/splits. This audited, human-in-the-loop layer ties structure to meaning and operationalises RQ3.

4.1 Limitations and Further Research

The corpus relies on Web of Science and may miss items from Scopus, Dimensions, Google Scholar, and grey literature. Citation-based structure can underweight emerging or practice-oriented work with sparse links. Human adjudication, while raising coherence, introduces some subjectivity. Future studies should broaden sources, add full-text and multimodal features, and combine citation communities with modern topic/embedding methods (e.g., BERTopic, transformer embeddings). Longitudinal network models and forecasting can track the pace of change in fuels, autonomy, and regulation. Semi-automated validation (agreement metrics + rule-based checks) can further standardise labels. Finally, linking clusters to policy outcomes and operational KPIs, especially within the EU Green Deal and Sustainable Blue Economy frameworks, would translate thematic maps into actionable evidence for governance and industry.

The methodological challenges encountered during this study, particularly the limitations of automated clustering based on citation networks, highlight the importance of a hybrid approach that combines computational tools with human expertise.

Our present analysis was cross-sectional, focusing on publications up to 2025. A longitudinal extension using temporal network analysis and trend forecasting would allow researchers to monitor how key maritime themes evolve in response to global challenges such as decarbonization, digital transition, and geopolitical uncertainty.

Future studies should therefore aim to integrate multi-source datasets, multimodal analytics, and dynamic visualisation dashboards to support real-time mapping of the maritime knowledge ecosystem. Such developments would not only refine bibliometric precision but also strengthen the evidence base for EU policy initiatives, including the Green Deal, Sustainable Blue Economy Strategy (2021), and forthcoming maritime innovation frameworks.

Taken together, these findings provide a validated thematic map, a temporal view of shifting priorities, and a transparent methodological template that support evidence-based decisions for scholars, policymakers, and industry in the maritime economy.

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