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Smart & Resilient Logistics Corridors Future Gateway to the Green Trade

Mapping the Research Landscape of Renewable Energy Solutions for Sustainable Maritime Transport: A Bibliometric Analysis (2016–2025)

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ABSTRACT

The relationships among documents on Maritime Renewable Energy Solutions (MRES) for sustainable shipping are explored to 1) map the evolution and current status of this literature stream; 2) highlight the top contributing documents, authors, journals, affiliations, and countries; 3) identify collaboration patterns and the social and intellectual structure of the scientific community; and 4) uncover thematic clusters and future research directions in support of maritime decarbonization. A total of 513 publications from 2016 to October 2025 were retrieved from the Web of Science Core Collection and analysed using Biblioshiny and VOSviewer through co-authorship, co-citation, co-word, and direct citation analyses. The results revealed a rapidly growing and highly multidisciplinary field, with an annual growth rate of 43.62% and strong international collaboration, especially among European and Asian institutions. China, together with leading universities such as Shanghai Maritime University, has emerged as a key contributor, while journals such as Sustainability, Journal of Marine Science and Engineering, Energies, and Journal of Cleaner Production play central roles in shaping the knowledge base. Thematic and correspondence analyses showed well-established motor themes related to energy efficiency, regulatory frameworks, and environmental performance, alongside emerging themes focused on hydrogen, green ammonia, and other alternative fuels. Overall, the findings indicate the need for more integrated, cross-disciplinary, and policy-oriented research that links technological innovation, regulatory development, and implementation challenges to accelerate progress toward zero-emission maritime transport.

1. INTRODUCTION

Maritime transport is fundamental to global trade, accounting for approximately 80% of the world's cargo. As an integral element of the blue economy, a concept introduced at the 2012 Rio+20 UN Conference, it promotes sustainable ocean-based economic growth while prioritizing environmental stewardship (Silver et al. 2015; Notteboom et al. 2022). Although the shipping industry is more energy-efficient per ton-kilometer than most other transport modes, it still accounts for approximately 2.8% of global greenhouse gas (GHG) emissions (Morante 2022), a figure projected to increase by up to to 17% by 2050 (Sinay 2022). In addition to emissions, maritime activities contribute to air and noise pollution, waste discharge, port congestion, and the degradation of marine ecosystems (Jägerbrand et al. 2019).

The International Maritime Organization (IMO), a specialized agency of the United Nations, spearheads global initiatives to promote safe and environmentally sustainable shipping. Since 2003, the IMO has implemented policies aimed at reducing GHG emissions, which amounted to 1.06 gigatons of CO_2 in 2018, representing 2.89% of total anthropogenic emissions (Oberthür 2003; Aakko-Saksa et al. 2023). These initiatives align with the 2015 Paris Agreement and United Nations Sustainable Development Goal 13, both of which advocate for an urgent reduction of 43% by 2030 and the achievement of net-zero emissions by 2050 (Ezinna et al. 2021; Tracker 2021; Anantharaman et al. 2025).

In 2018, IMO introduced its initial GHG reduction strategy, which aimed to decrease the carbon intensity of international shipping by at least 40% by 2030 and 70% by 2050, relative to 2008 levels, and to halve the total annual emissions by 2050. The 2023 revised strategy enhanced these targets, advocating for a 20–30% reduction by 2030, 70–80% by 2040, and complete decarbonization by the mid-century. Additionally, it encourages the adoption of at least 5% zero or near-zero emission fuels by 2030, reflecting a global commitment to achieving net-zero maritime operations (Joung et al. 2020).

This study aims to examine maritime renewable energy solutions (MRES) in line with IMO targets for achieving net-zero greenhouse gas emissions by 2050. It provides a comprehensive assessment of the current approaches, challenges, and technological advancements driving the transition toward sustainable shipping. While maritime emissions have gained increasing attention, significant gaps remain in our understanding of the broader impacts of decarbonization strategies and their integration within existing international regulations. This study addresses these gaps by analyzing the IMO's evolving policies, emerging low- and zero-emission technologies, and their potential for large-scale adoption across the global maritime sector.

We performed a bibliometric analysis of the MRES scholarly literature to identify the following: 1) the authors, journals, institutions, countries, and documents that have contributed more to the field; 2) the MRES structure of the scientific community and its collaboration patterns; 3) main MRES themes, how they have evolved, and current trends; and 4) aspects that have been neglected and should be addressed or incorporated in future research. The following research questions (RQ) guided this study:

RQ1: How has the Research Landscape of MRES evolved? (Lechuga Sancho et al. 2020);

RQ2: Which have been the most productive authors, countries, and affiliations? (Fosso Wamba 2020; Lechuga Sancho et al. 2020; Xiao et al. 2021);

RQ3: Which have been the most influential sources and documents? (Fosso Wamba 2020; Lechuga

Sancho et al. 2020; Xiao et al. 2021);

RQ4: What is the social structure of the field? (Zupic and Čater 2015);

RQ5: How has the structure of this field developed over time? (Zupic and Čater 2015); and

RQ6: What has been the dynamics of the conceptual structure of the field (Zupic and Čater, 2015)?

Next, Section 3 describes the methodology; Section 4 presents the results of related bibliometric analyses; Section 5 introduces the discussion; and finally, Section 6 outlines the limitations and future research directions.

3. METHODOLOGY

Bibliometric analysis offers a systematic and reliable approach to explore large bodies of literature, revealing

research structures and emerging trends (Feng et al. 2017). This study follows the five-step science mapping

framework proposed by Zupic and Čater (2015) (Figure 1).

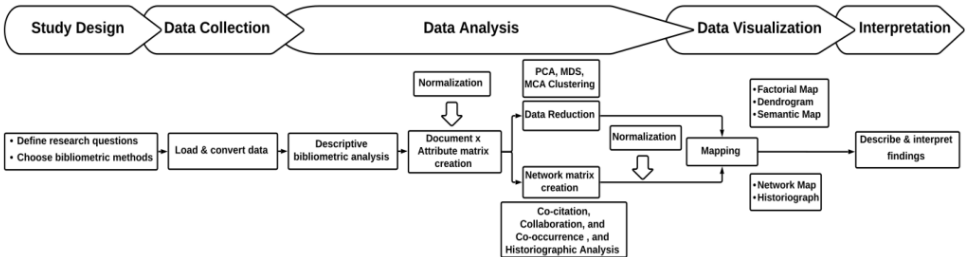

Figure 1: Methodological phases

To address the six research questions, we conducted co-authorship, co-citation, co-word, and direct citation analyses. Data were retrieved from the Web of Science Core Collection (WoS) on 25 October 2025, using a set of keywords related to sustainable and green maritime energy solutions such as "Sustainable," "Clean energy," "Alternative energy sources," "Low-carbon energy," and "Decarbonization technologies." Twenty-eight keyword combinations were used in the maritime transport industry. The keywords were validated against previous review studies to ensure comprehensive coverage of the literature search. Metadata, including titles, authors, affiliations, abstracts, keywords, and references, were exported for analysis.

The data collection process is shown in Figure 2. Using the selected keywords, an initial search of the WoS Core Collection identified 1,412 papers. After removing duplicates, 883 studies were included. Excluding non-English publications reduced the number to 860, and papers published before 2016 were removed, leaving 779 publications. Editorial materials were then excluded, resulting in 772 papers. Finally, a relevancy check based on abstracts and keywords identified 513 papers that met the inclusion criteria. These publications formed the final dataset for bibliometric analysis.

Biblioshiny and VOSviewer were used to analyze the data. Biblioshiny is part of the bibliometrix R-package software, an open-source software with a set of tools for conducting quantitative bibliometrics analyses, developed by Aria and Cuccurullo (2017). The data were imported from WOS in Plain Text format using Biblioshiny. In terms of visualization, we used conceptual structure mapping and network mapping (Zupic and Čater 2015).

VOSviewer is a software that constructs and visualizes bibliometric networks, helping in conducting thematic analysis, co-occurrence analysis, co-citation analysis, and cluster analysis (Van Eck and Waltman 2010; Van Eck and Waltman 2014).

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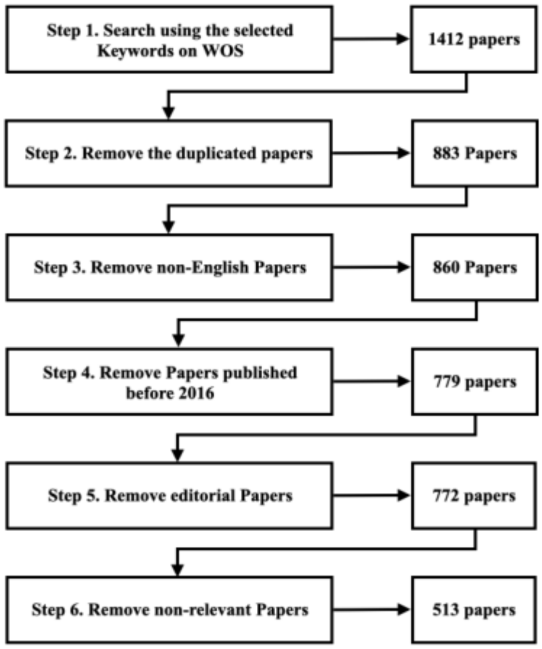


Figure 2: Data selection

4. RESULT

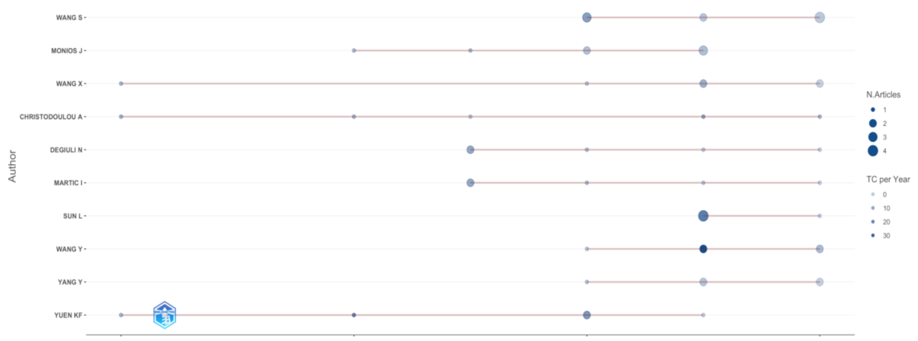
Dataset

Five hundred and thirteen MRES papers, published in 212 different WOS sources (journals) from 2016 to October 2025, were collected (Figure 3). The dataset contains 457 articles (89% of the collection) and 56 review papers (11%) authored by 1880 researchers. Thirty-seven single-authored papers (7.2% of the collection) were written by 35 authors (1.86% of the authors). Co-authors per document were, on average, 4.341. At the time of data collection, each document had been cited 14.38 times on average. Over this ten-year period, the field demonstrated an impressive annual growth rate of 43.62%, indicating increasing scholarly attention to maritime decarbonization, green propulsion systems, and sustainable energy transitions.. International collaboration was also significant, with 31.77% of publications involving cross-border co-authorship, particularly between European and Asian institutions, reflecting the global dimension of maritime sustainability challenges. The dataset contained 25,969 references and 2,001 author keywords, illustrating the depth and diversity of the field.

Figure 3: General characteristics of the dataset

Authors

One thousand eighty hundred seventy-eight authors contributed to the database. Of these, 1,660 (88.4%) contributed only one document. The concentration by the author in the MRES field is relatively high. For example, the proportion of authors who authored a single paper was much higher than would be expected if Lotka's law (Lotka 1926) applied (more than 88% in the dataset versus the expected 66%). These results may be associated with MRES being a relatively new, multidisciplinary research area. Figure 4 shows the production of authors with 5 or more MRES papers over time. According to Table 1, Wang X. and Monios J. published the most articles in the field, with 9 and 7 papers, respectively. Monios J. was also the author with the highest h- and g-indices within the field. Balcombe P., Brierley J., Hawkes A., Lewis C., Skatvedt L., Speirs J., and Staffell I. were the most cited authors and top authors in terms of global citations per article. Their review paper was cited globally 444 times.



Note: Bubbles represent papers published by the author; bubble size is proportional to the number of documents produced in the year, and color intensity is proportional to the total number of citations per year.

Figure 4: Production over time of the authors with 5 or more publications

Table 1: Authors with more publications, more citations, a higher cite-ratio, or a higher h-index

Author	TP	Rank	TC	Rank	h-index	Rank	g-index	m-index	TCA	Rank	LC	Rank	PY-start
Wang, S.	9	1	51	-	4	3	7	1.33	6	-	0	-	2023
Monios, J.	7	2	67	-	5	1	7	1	10	-	13	6	2021
Wang, X.	6	3	72	-	4	3	6	0.57	12	-	0	-	2019
Christodoulou, A.	5	4	137	-	5	1	5	0.71	27	-	12	7	2019
Degiuli, N.,	5	4	62	-	3	10	5	0.75	12	-	10	10	2022
Martić, I.	5	4	62	-	3	-	5	0.75	12	-	10	10	2022
Sun, L.	5	4	47	-	3	-	5	1.50	9	-	0	-	2024
Wang, Y.	5	4	86	-	4	3	5	1.33	17	-	2	-	2023
Yang, Y.	5	4	16	-	2	-	4	0.67	3	-	0	-	2023
Yuen, K. F.	5	4	197	-	4	3	5	0.57	39	-	0	-	2019
Balcombe, P.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Brierley, J.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Hawkes, A.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Lewis, C.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Skatvedt, L.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Speirs, J.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Staffell, I.	1	-	444	1	1	-	1	0.14	444	1	0	-	2019
Lindstad, E.	4	-	354	8	4	3	4	0.50	89	-	0	-	2018
Rialland, A.	3	-	303	9	3	-	3	0.50	101	-	0	-	2020
Afrane, S.	2	-	266	10	3	-	2	0.40	133	9	28	1	2021
Cullinane, K.	4	-	195	-	4	3	4	0.57	49	-	12	7	2019
Li, X.	4	-	91	-	4	3	4	0.80	23	-	1	-	2021
Ampah, J. D.	2	-	266	10	2	-	2	0.4	133	9	28	1	2021
Liu, H.	2	-	266	10	2	-	2	0.4	133	9	28	1	2021
Yusuf, A. A.	2	-	266	10	2	-	2	0.4	133	9	28	1	2021
Jin, C.	1	-	250	-	1	-	1	0.2	250	8	26	5	2021
Psaraftis, H. N.	4	-	94	-	2	-	4	0.2	24	-	12	7	2016

Notes: All measures concern only the authors' MRES papers (in the dataset); **TP** = total no. of publications; **TC** = total no. of citations; **h-index**: the author has published h papers that have h or more citations; **g-index**: considering all papers of the author ranked in decreasing order of the citations they have received, the top g articles received (altogether) at least g2 citations; **TCA** = no. of citations per article; **LC** = no. of local citations; **PY-start** = year of the first paper. local citations mean the citations by papers also in the dataset, **h-index** is a quantitative metric based on analysis of publication data using publications and citations to provide "an estimate of the importance, significance, and broad impact of a scientist's cumulative research contributions." (Hirsch 2005), the **g-index** is an improvement to the h-index, and it gives more weight to highly cited articles (Egghe 2006), and the **m-index** is another variant of the h-index that displays h-index per year since first publication.

Notes: TP = total number of publications; TC = total number of citations; TCA = citations per article; LC = local citations; PY-start = year of the first paper.

Author collaboration networks

Thirty-five out of the 513 papers in the dataset were written by single authors; the other 478 were co-written by 1843 authors. On average, each paper was written by four authors. MRES research has been developed in small co-authorship networks and isolated clusters, and most of the collaborative production involved authors from the same affiliation; moreover, only one of the identified research collaboration clusters is international (Table 2).

Table 2: Papers published by the author's collaboration networks

Cluster	Authors	Affiliation	Title	Year	No. of WOS citations	Total No. of WOS citations
1	Wang, S. Yang, Y.	The Hong Kong Polytechnic University, **Hong Kong**	An Efficient Ranking-Based Data-Driven Model for Ship Inspection Optimization	2024	4	6
			Joint Ship Scheduling and Speed Optimization for Naval Escort Operations to Ensure Maritime Security	2024	2	
			Carbon Dioxide Storage Site Location and Transport Assignment Optimization for Sustainable Maritime Transport	2025	0	
2	Melnyk, O. Onishchenko, O.	Odesa National Maritime University, **Ukraine**	Technical and Operational Measures to Reduce Greenhouse Gas Emissions and Improve the Environmental and Energy Efficiency of Ships	2022	9	41
			Study of Environmental Efficiency of Ship Operation in Terms of Freight Transportation Effectiveness Provision	2022	6	
			Integral Approach to Vulnerability Assessment of Ship's Critical Equipment and Systems	2023	19	
			Enhancing Shipboard Technical Facility Performance Through the Utilization of Low-Sulfur Marine Fuel Grades	2024	5	
			Development of Strategies for Reducing Nitrous Oxide Emissions from Marine Diesel Engines	2024	1	
			Chemical Methods and Nanotechnology Integration in Ship Ballast Water Management for Maritime Transport Sustainability	2024	1	
			Pulse-Driven Surface Hardening and Advanced Electrospark Alloying for Maritime Applications	2024	0	
3	Fomin, O. Kucera, P.	State University of Infrastructure and Technologies, **Ukraine** Brno University of Technology, **Czech Republic**	Ensuring the Environmental Friendliness of Drillships During Their Operation in Special Ecological Regions of Northern Europe	2022	13	44
			Use of Biofuels in Marine Diesel Engines for Sustainable and Safe Maritime Transport	2024	31	
			Pulse-Driven Surface Hardening and Advanced Electrospark Alloying for Maritime Applications	2025	0	
4	Camarero-Orive, A. Gonzalez-Cancelas, N.	Universidad Politécnica de Madrid, **Spain**	Optimizing Sustainable Port Logistics in Spanish Ports with Emerging Technologies	2025	2	5
			Enhancing Sustainability in Port Infrastructure Through Innovation: A Case Study of the Spanish Port System	2025	2	
			Bayesian Networks Applied to the Maritime Emissions Trading System: A Tool for Decision-Making in European Ports	2025	1	
5	Cullinane, K. Christodoulou, A.	University of Gothenburg, **Sweden**	Identifying the Main Opportunities and Challenges from the Implementation of a Port Energy Management System: A SWOT/PESTLE Analysis	2019	57	118
			Potential for, and Drivers of, Private Voluntary Initiatives for the Decarbonisation of Short Sea Shipping: Evidence from a Swedish Ferry Line	2021	37	
			The Prospects for, and Implications of, Emissions Trading in Shipping	2024	24	
6	Fuentes-Blasco, M. Gil-Saura, I.	University of Valencia, **Spain** Pablo de Olavide University, Seville, **Spain**	How to Increase Company Loyalty: Using Relational Variables and Sustainable Practices to Segment the Maritime Transport Sector	2022	4	4
			Increased Loyalty in Maritime Shipping in Panama with a Customer Focus	2022	0	
			Managing Sustainable Practices and Logistics Value to Improve Customer Loyalty: Importers vs. Freight Forwarders	2023	0	
7	Lucchesi, A. Pereda, PC.	University of São Paulo, **Brazil**	Alternative Frameworks for Cost-Effectiveness Analysis of Environmental Policies in Maritime Transport	2022	3	10
			Carbon Tax in the Shipping Sector: Assessing Economic and Environmental Impacts	2025	3	
			Sustainable Shipping: Modeling Technological Pathways Toward Net-Zero Emissions in Maritime Transport (Part I)	2025	2	
			Sustainable Shipping: Modeling Economic and Greenhouse Gas Impacts of Decarbonization Policies (Part II)	2025	2	
8	Cigolotti, V. Minutillo, M.	Italian National Agency for New Technologies, **Italy** University of Salerno, **Italy**	A Framework for the Replacement Analysis of a Hydrogen-Based Polymer Electrolyte Membrane Fuel Cell Technology on Board Ships: A Step Towards Decarbonization in the Maritime Sector	2022	45	57
			Towards the Design of a Hydrogen-Powered Ferry for Cleaner Passenger Transport	2024	5	
			On the Identification of Regulatory Gaps for Hydrogen as Maritime Fuel	2025	2	
			Techno-Economic Assessment of a Green Liquid Hydrogen Supply Chain for Ship Refueling	2025	5	
9	Degiuli, N. Martić, I.	University of Zagreb, **Croatia**	Slow Steaming as a Sustainable Measure for Low-Carbon Maritime Transport	2024	3	3
			The Detrimental Impact of Biofilm on Ship Fuel Consumption and CO_2 Emissions	2025	0	
	Degiuli, N. Martić, I. Farkas, A.		Is Slow Steaming a Viable Option to Meet the Novel Energy Efficiency Requirements for Containerships?	2022	26	59
			Energy Savings Potential of Hull Cleaning in the Shipping Industry	2023	20	
			Optimization of Maintenance Schedule for Containerships Sailing in the Adriatic Sea	2023	13	
10	Altarriba, E. Tanhuanpää, T. Rahiala, S.	South-Eastern Finland University of Applied Sciences, **Finland**	Comparing Fuels and Emission Reduction Technologies for Sustainable Shipping: A Sustainability Index Weighting Life Cycle Emissions and Costs	2025	2	5
			Developing Sustainable Shipping and Maritime Transport: Multi-Criteria Analysis Between Emission Abatement Methods	2024	3	
			Improving the Environmental Performance of Shipping and Maritime Transport – Highlights of the Maritime Emissions Workshop	2022	0	
11	Palombo, A. Buonomano, A. Giuzio, G. F. Del Papa, G.	University of Naples, **Italy** CNR-Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili, **Italy**	Nuclear Lead-Cooled Fast Reactor (LFR) for Naval Propulsion and Shore Connection: An Energy, Economic and Environmental Analysis	2025	0	10
			Green Hydrogen Production: Energy and Economic Modelling of Self-Sufficient Solar-Powered Electrolyser Based on Seawater Desalination	2025	1	
			Reducing Carbon Footprint in Ports Through Electrification and Flexible Energy Management of Ships	2025	4	
			Design and Retrofit Towards Zero-Emission Ships: Decarbonization Solutions for	2025	5	

Note: Table 2 lists the papers published by collaboration networks with a minimum of three papers with a given author.

Countries and affiliations

The research output of universities and other research organizations is an important indicator of a country's scientific expertise, innovation, and development (Nath and Jana 2021). Regarding international collaboration, researchers from 59 countries have published papers in MRES (Table 3 lists countries with 23 or more papers). Among these countries, China was the leading country in the number of publications (87 articles). Furthermore, China is also the most cited country, with 1208 citations.

Furthermore, the author's affiliation can be an important driver of citations (Schwert 1993; Lukka and Kasanen 1996). The articles in the dataset were developed in 689 different organizations; the top 10 organizations with seventeen or more publications are listed in Table 3. All 10 organizations in the Table are universities; cumulatively, they contributed 192 papers to the field (37.4% of the total).

Table 3: The top ten research areas, affiliations, countries, and journals based on the number of publications

Ranking	Research areas	TP	%
1st	Environmental Sciences	119	23.2%
2nd	Energy Fuels	103	20%
2nd	Green Sustainable Science Technology	103	20%
4th	Environmental Studies	88	17.2%
5th	Engineering Marine	77	15%
6th	Transportation	67	13%
6th	Oceanography	59	11.5%
8th	Engineering Ocean	57	11.11%
9th	Transportation Science Technology	39	7.6%
10th	Economics	31	6%
Ranking	**Affiliation**	**TP**	**%**
1st	Shanghai Maritime University	25	5%
2nd	Maritime University of Szczecin	20	4%
2nd	Nanyang Technological University	20	4%
4th	Gdynia Maritime University	19	4%
4th	University of A Coruña	19	4%
4th	University of Aveiro	19	4%
7th	The Hong Kong Polytechnic University	18	4%
7th	Universidad Politécnica de Madrid	18	4%
9th	Shanghai Jiao Tong University	17	3%
9th	Technical University of Denmark	17	3%
Ranking	**Countries**	**TP**	**%**
1st	China	87	17%
2nd	Italy	55	10.7%
2nd	Spain	42	8.2%
4th	UK	40	8%
5th	Poland	34	6.6%
6th	Germany	25	4.9%
7th	Greece	24	4.7%
8th	Finland	23	4.5%
8th	France	23	4.5%
8th	Turkiya	23	4.5%
Ranking	**Journals**	**TP**	%
1st	Sustainability	49	10%
2nd	Journal of Marine Science and Engineering	37	7%
3rd	Energies	18	4%
4th	Journal of Cleaner Production	16	3%
5th	Ocean Engineering	13	3%
6th	Transportation Research Part D: Transport and Environment	12	2%
7th	Energy Conversion and Management	11	2%
7th	International Journal of Hydrogen Energy	11	2%
9th	Maritime Economics & Logistics	10	2%
10th	Applied Sciences (Basel)	8	2%
10th	Marine Policy	8	2%
10th	Renewable & Sustainable Energy Reviews	8	2%

Country and affiliation collaboration networks

Figure 5 shows the country collaboration network (that includes countries with at least three collaborated papers, resulting in 3 clusters) and Figure 6 the affiliation collaboration network (6 clusters with two collaborations between affiliations in the same cluster) identified in the MRES literature.

Note: Nodes represent the countries or institutions and edges the nodes depends on the total occurrence frequency of the items; the thickness of the links the co-authorships; the size of the nodes depends on the total indicates the collaboration frequency; and the distance between the nodes is indicative of the occurrence frequency of the items; the thickness of the links strength of the collaboration (the closer the nodes, the more intense the collaboration). indicates the collaboration frequency, and the distance between the nodes is indicative of the strength of the collaboration (the closer the nodes, the more intense the collaboration)

.Figure 5: Country collaboration network

Authors from 71 countries were involved in international collaborations, and the number of such collaborations was 253. China (26 international collaborations), the United Kingdom (UK) (25 international collaborations), and Italy (22 international collaborations) were the countries with the most international collaborations. The strongest collaboration link was between China and Singapore (9 papers), followed by those between China and the UK (7 papers) and Australia (5 papers).

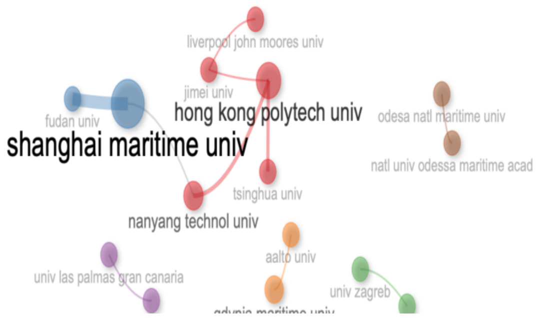


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Figure 6: Affiliation collaboration network

535 of 689 organizations in the dataset (77.6%) had at least one publication developed in collaboration with another organization. Shanghai Maritime University was the most active in collaborating with other institutions; most of the partner affiliations are Chinese, with Fudan University, Shanghai, China, emerging as the most frequently partnered institution. There is also notable cooperation with French affiliations—such as the University of Le Havre Normandie, the University of Paris-Nanterre, Paris Nanterre University, and the Université du Littoral Côte d'Opale (ULCO)—as well as strong ties with Belgian institutions including the Antwerp Maritime Academy, Ghent University, and the University of Antwerp.

Sources

Two hundred and twelve sources have published MRES research. Out of these, 154 journals (72.6%) published only one paper in the field. Table 3 lists the twelve with the highest number of publications. Three main types of journals have contributed to the area: 1) journals mainly focused on sustainability-related issues - e.g., Sustainability, Journal of Cleaner Production (JCP), etc.; 2) journals mainly focused on Sustainable Transport and Maritime Policy – e.g., Transportation Research Part D: Transport and Environment, Maritime Economics & Logistics, Marine Policy, etc.; 3) journals mainly focused on Energy and Environmental Engineering – e.g., Energies, Energy Conversion and Management, International Journal of Hydrogen Energy, Renewable & Sustainable Energy Reviews, etc.; and 4) Maritime Engineering and Ocean Technology – e.g., Journal of Marine Science and Engineering, Ocean Engineering.

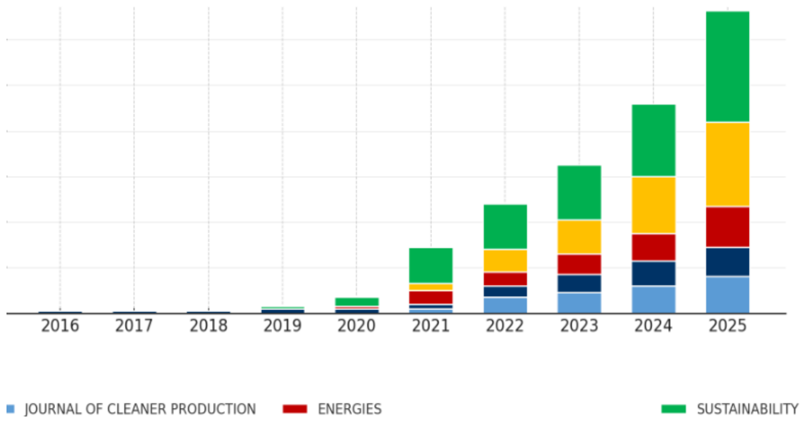


Figure 7: Source growth

Figure 7 presents the evolution of the number of papers published by the journals with more publications in the field; five exhibited the highest growth in the period under analysis: Sustainability (49 papers), Journal of Marine Science and Engineering (37), Energies (18), Journal of Cleaner Production (16), and Ocean Engineering (13), one handered thirty-three out of the 513 papers in the dataset (29.9%) were published in these journals. Ocean Engineering was somehow a pioneer; then, after 2022, the number of MRES papers published in the Sustainability and Journal of Marine Science and Engineering has increased significantly.

Sources' co-citation

Co-citation of journals occurs when two journals receive a citation from a third source, and the strength of the relationship between two sources can be assessed by the frequency of co-citations (Pelit and Katircioglu 2021). Mapping the co-citation relationships among journals reveals the intellectual structure of a research area (i.e., its subfields and the connections between them). To analyze the co-citation of the sources, in VOSviewer, the minimum number of journal local citations was set to 50, and the number of journals selected was 63, which generated the map presented in Figure 8. Journals were grouped into four clusters: 1) the green, centered around the International Journal of Hydrogen Energy (652 citations, 62 links), comprises journals on Energy and sustainability engineering; 2) the yellow, centered around the Ocean Engineering (600 citations, 62 links), includes journals focusing on Ocean and energy policy/engineering interface; 3) the red, with Transportation Research Part D: Transport and Environment (891 citations, 62 links) as the center, aggregates journals on Maritime transport and logistics research; finally, 4) the blue, with Science of the Total Environment (202 citations, 61 links) as the central journal, aggregates journals on Environmental and pollution studies. The central journals in each cluster are linked with the highest number of other sources in the graph and have been frequently cited, which indicates their influence.

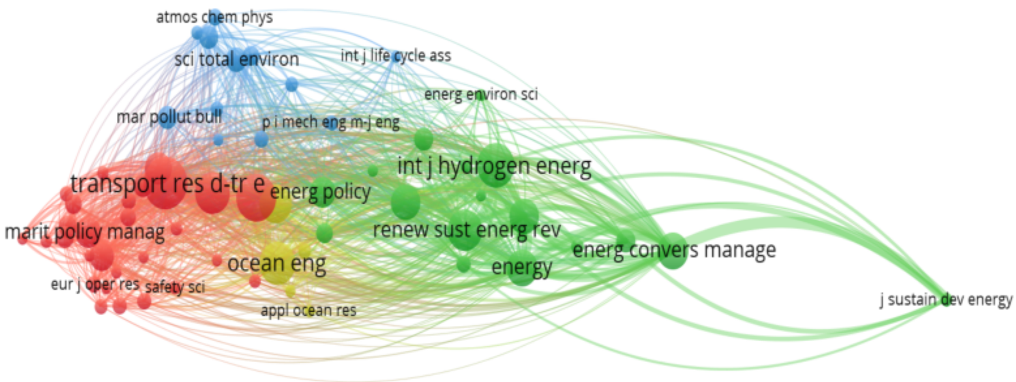
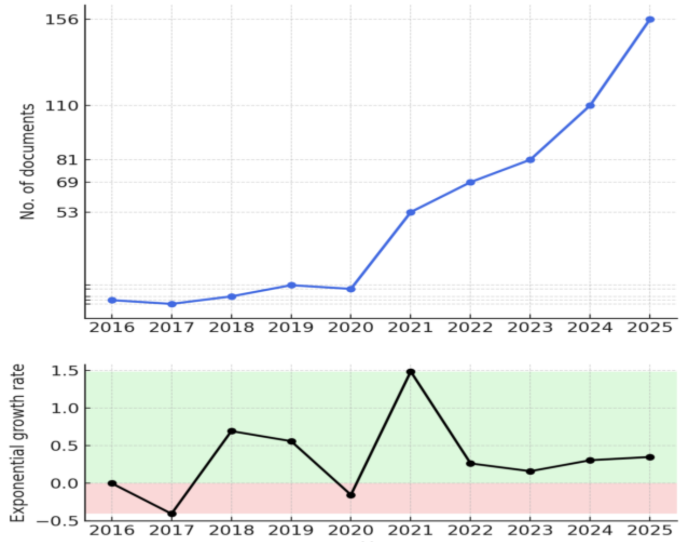


Figure 8: Source Co-citation network of cited sources

Documents

By analyzing the quantity of published literature over time, one can realize the current situation of research and the trend of future development in a certain field (Aria and Cuccurullo 2017). During the period under analysis, the number of MRES papers published each year has increased (Figure 9), totaling 513 papers. The highest output was observed in 2025, which recorded the largest number of documents in the dataset with 156. The exponential growth rate indicates a generally positive trend, with a few fluctuations reflecting short periods of slower activity or temporary decline. Nonetheless, the overall pattern suggests sustained growth in research interest and output throughout the decade.



Observation: The exponential growth rate, r, was computed using the following formula: $r = \frac{\ln(N(t)) - \ln(N(0))}{t}$,
where ln is the logarithm value, N(0) is the initial number of publications, N(t) is the final number of publications, and t is time.

Figure 9: Evolution of the number of documents

In WOS, documents in the dataset are linked to several research areas (WOS categories): Environmental Sciences (23.2%), Energy Fuels and Green Sustainable Science Technology (20%), Environmental Studies (17.2%), and Engineering Marine (15%) (Table 3).

Figure 10 shows the average number of citations per year of the papers published each year. In 2019, the influence of the review by Balcombe et al. (2019) is visible. The number of global citations indicates the influence a paper has had in general, and local citations are an indicator of the importance of a paper in the field of MRES. The most globally cited (444 citations) was the review " How to decarbonise international shipping: Options for fuels, technologies and policies" by Balcombe et al. (2019). The review by Ampah et al. (2021), titled " Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector ", was the second most globally cited (250 citations) since the year of its publication (50 citations per year); this paper ranked at the top in terms of local citations (26). The article titled "Energy efficiency of integrated electric propulsion for ships – A review" (Nuchturee et al. 2020) was the third most globally cited (185 citations).

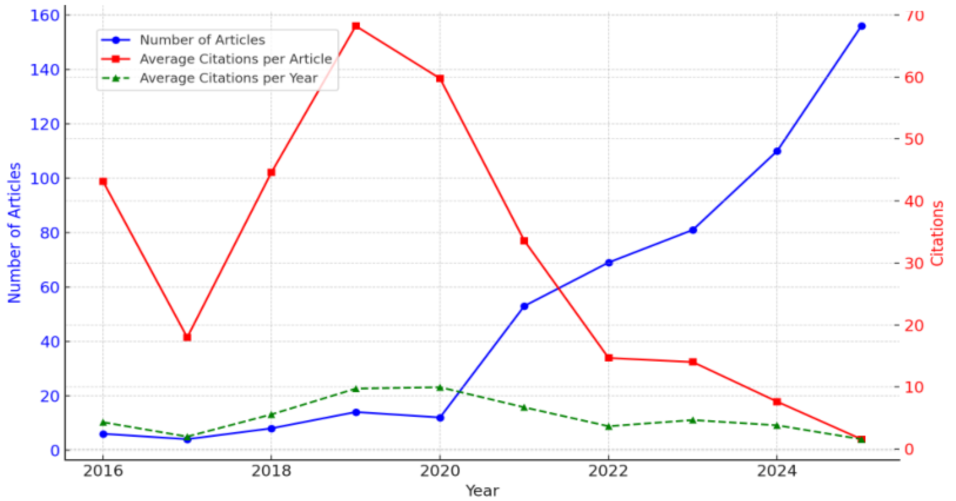
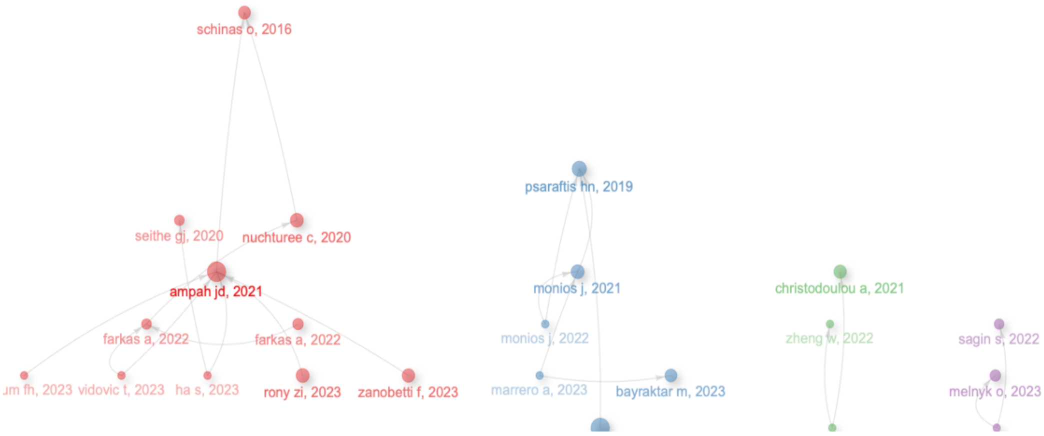


Figure 10: Number of articles per year and number of citations the documents published each year received



Note: Each node represents an article, and each oriented edge represents a direct citation; documents represented in the same color addressed similar topics.

Figure 11: Historical direct citation network map

Figure 11 shows the historical direct citation networks, i.e., a chronological network map of the most relevant direct citations in the bibliographic collection (Garfield 2004) of the 23 most locally cited papers in the dataset. The earliest node is the paper by Schinas and Butler (2016) (7 local citations). Four thematic clusters reflect distinct thematic orientations within the maritime decarbonization literature. 1) The red cluster concentrates on alternative marine fuels, ship-level energy-efficiency measures, and life-cycle emissions assessments, highlighting technical pathways for reducing environmental impacts; 2) The blue cluster turns toward governance structures, regulatory frameworks, and market instruments that shape policy-driven decarbonization efforts; 3) The green cluster emphasizes firm-level strategies, including voluntary initiatives and the adoption of emerging fuels such as green ammonia; and 4) The purple cluster addresses operational and equipment-related dimensions, focusing on ship performance and environmental compliance in specialized operating contexts. The papers most locally cited

in each cluster (theme) were: (i) the article "Reviewing Two Decades Of Cleaner Alternative Marine Fuels: Towards Imo's Decarbonization Of The Maritime Transport Sector" by Ampah et al. (2021) (red group); (ii) the article "The Prospects For, And Implications Of, Emissions Trading In Shipping" by Christodoulou and Cullinane (2024) (blue group); (iii) the article "Potential For, And Drivers Of, Private Voluntary Initiatives For The Decarbonisation Of Short Sea Shipping: Evidence From A Swedish Ferry Line" by Christodoulou and Cullinane (2021) (green group), and (iv) the article "Integral Approach To Vulnerability Assessment Of Ship's Critical Equipment And Systems" by Melnyk et al. (2023) (purple group).

Keywords

Keyword analysis is useful to assess the accuracy of the process used to select the articles in the dataset. Furthermore, the keywords defined by authors are usually correlated to publication content and sufficient to derive topical aspects of the research area (Song et al. 2019). The thematic map analysis of a research area can provide knowledge regarding the potential for future research development of the various themes in the field. This analysis takes clusters of authors' keywords and their interconnections to obtain themes that are characterized by properties of density (which measures the cohesiveness among the nodes) and centrality (the degree of correlation among different topics) (Esfahani et al. 2019). These two properties assess if a certain topic has been well developed and is important. Increasing the number of relations between a node (theme) and other nodes increases its centrality and importance in the network. Similarly, cohesiveness in a node (i.e., the density of a research area) delineates its ability to develop and sustain itself.

In Figure 12, the upper-left quadrant (strong density, low centrality), the map shows niche but internally cohesive themes, including carbon footprint, fuel consumption, and optimization. These topics appear methodologically mature within their subdomains yet remain relatively peripheral to the broader development of maritime decarbonization research. The upper-right quadrant (high centrality, high density) presents motor themes that are structurally important to the field. Concepts such as energy, energy efficiency, IMO regulations, and efficiency analysis occupy this space, indicating that regulatory frameworks and energy-performance evaluations form well-developed and influential research cores in maritime sustainability studies. In the lower-right quadrant (high centrality, low density), the map displays basic and transversal themes with broad relevance but lower structural maturity. Topics such as maritime transport, sustainability, decarbonization, shipping, and alternative fuels represent foundational concepts that support the field's conceptual structure but remain in a process of development and consolidation. Finally, the lower-left quadrant (low centrality, low density) contains emerging or declining themes. Keywords such as hydrogen, renewable energy, ship, and green hydrogen appear here, suggesting early-stage research fronts that may gain prominence as alternative fuels evolve technologically and operationally within the maritime sector.

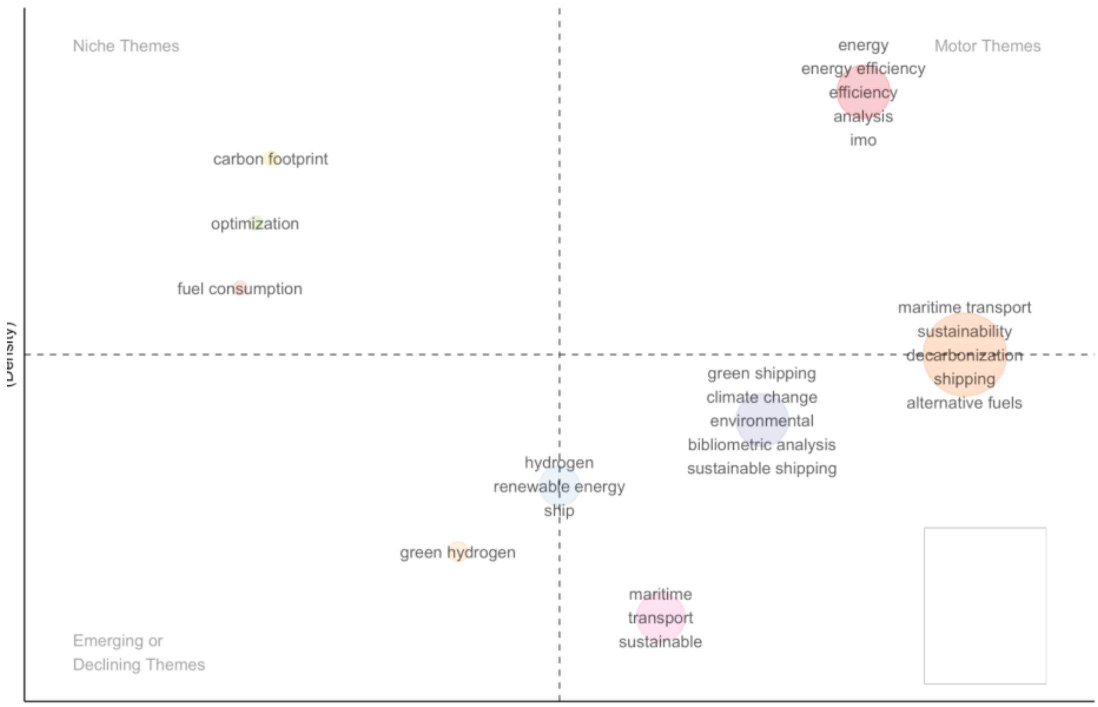


Figure 12: Thematic map of authors' keywords

Correspondence

Multiple correspondence analysis (MCA) compresses large data with multiple variables into a low-dimensional space to form an intuitive two-dimensional (or three-dimensional) graph to reveal the similarity between the keywords (Mori et al. 2016). In this study, we used a hierarchical clustering method to analyse and detail the keywords that are common to the articles. Figure 13 presents a world map that depicts the close or alienated relationship between the keywords in the field of MRES.

The first identifiable cluster (red) concerns transport, maritime transportation, and green ports, forming a compact group that highlights research dealing with port-related environmental initiatives and broader maritime transport dynamics. The second cluster (blue) is the dominant structure, bringing together research on sustainable maritime logistics, port management, environmental impacts, optimization, renewable energy, bibliometric analysis, and green shipping. A third cluster (yellow green) emerges around energy, efficiency, greenhouse gases, LNG, IMO, and the EEDI framework, indicating a regulatory and performance-oriented research stream. The fourth cluster (green) relates to green ammonia and green hydrogen, representing an emerging strand of research examining alternative future fuels for shipping. Finally, a fifth cluster (pink) clusters around ammonia and technoeconomic analysis, which appears distinct from the green-ammonia cluster above, suggesting a methodological focus on cost- and feasibility-oriented evaluations of ammonia as a maritime fuel.

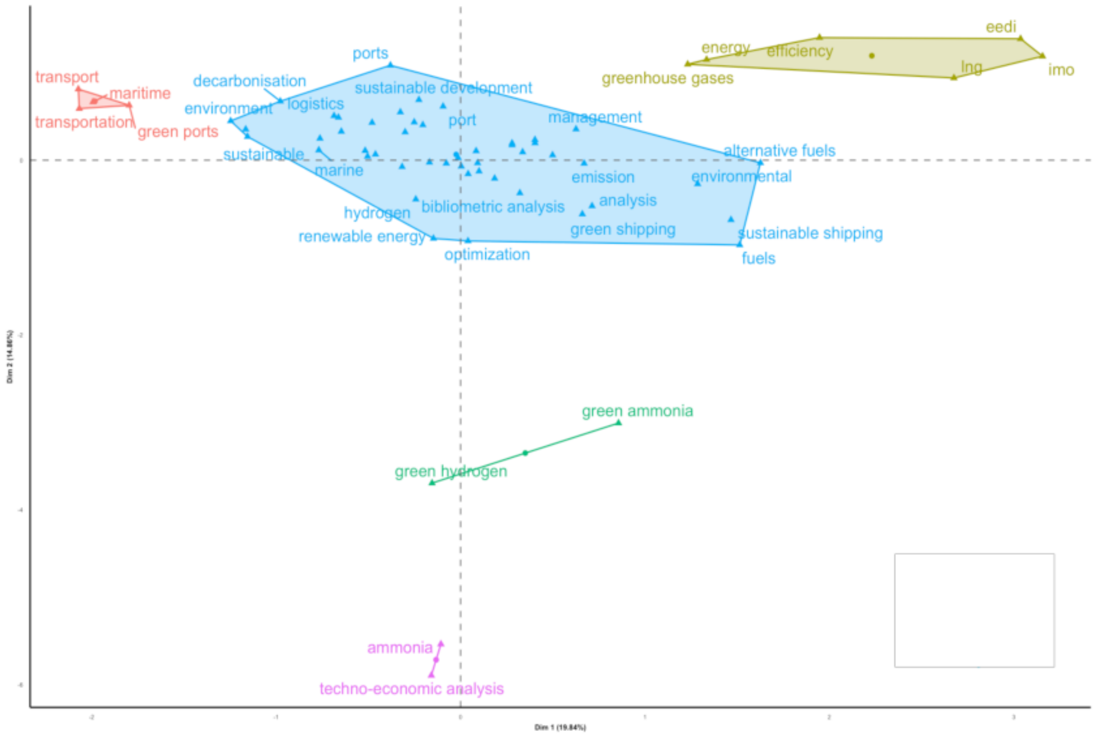


Figure 13: Multiple correspondence analysis (MCA) of high-frequency keywords (Word map)

5. DISCUSSION

Initially, we addressed the research question: How has the literature in the field evolved? The research landscape concerning MRES has demonstrated a significant and sustained upward trajectory over the analysis period from 2016 to October 2025. The final dataset, comprising 513 papers, revealed an impressive annual growth rate of 43.62%, highlighting the increasing scholarly engagement with maritime decarbonization and sustainable energy transitions. The annual publication output exhibits exponential growth, culminating in the highest volume of documents in 2025, with 156 papers. The field is inherently multidisciplinary, focusing primarily on Environmental Sciences (23.2%), Energy Fuels (20%), and Green Sustainable Science Technology (20%). Reflecting the global nature of shipping, international collaboration is notable, accounting for 31.77% of publications, particularly between institutions in European and Asian regions.

In addressing the second research question regarding the most productive authors, countries, and affiliations, it is evident that China emerges as the leading nation,

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contributing 87 articles (17%) and also excelling in citations with a total of 1208. Italy and Spain follow in terms of publication volume. Concerning individual author productivity, Wang X. (9 papers) and Monios J. (7 papers) are the most prolific, with Monios J. also achieving the highest h- and g-indices. A distinguished group of authors, including Balcombe P., Brierley J., and Staffell I., is recognized as the most cited overall, primarily due to their singular review paper, which garnered 444 global citations. Shanghai Maritime University is identified as the most productive institutional affiliation, contributing

25 papers (5%), followed by the Maritime University of Szczecin and Nanyang Technological University, each with 20 papers. Notably, all institutions listed among the top 10 most productive affiliations are universities.

In addressing the third research question, which concerns the identification of the most influential sources and documents, it is evident that the review titled "How to decarbonise international shipping: Options for fuels, technologies and policies" (Balcombe et al. 2019) emerges as the most influential document, having garnered 444 global citations. The paper "Reviewing two decades of cleaner alternative marine fuels" (Ampah et al. 2021) ranks as the second most globally cited with 250 citations and holds the highest number of local citations (26), underscoring its significance within the MRES field. The journal Sustainability is identified as the leading publishing source, having disseminated 49 MRES papers, accounting for 10% of the total, followed by the Journal of Marine Science and Engineering with 37 papers. An analysis of source co-citation, which elucidates the intellectual structure, positions Transportation Research Part D: Transport and Environment at the center of the cluster, emphasizing its focus on Maritime Transport and Logistics research, with 891 local citations, thereby indicating its substantial influence.

In addressing the fourth research question concerning the social structure of the field, it is observed that the social structure of MRES research is characterized by an average of 4.341 co-authors per document. However, most collaborations occur within small co-authorship networks and isolated clusters. A significant proportion of collaborative efforts involve authors affiliated with the same institution. Conversely, the field demonstrates considerable international scope, with researchers from 59 countries contributing to published papers. Overall, international collaboration encompasses authors from 71 countries. Notably, China (26 collaborations), the United Kingdom (25), and Italy (22) are the countries with the highest number of international collaborations, with the most robust inter-country link identified between China and Singapore, resulting in nine joint publications. At the institutional level, Shanghai Maritime University emerges as the most active collaborator, predominantly engaging with other Chinese institutions, such as Fudan University.

To elucidate the impact of authors' scientific contributions within the field on the broader scientific community and address the fifth research question: how has the structure of this field evolved over time? —The temporal evolution of the MRES research structure reveals a progressive thematic diversification and methodological maturation in alignment with regulatory milestones. The historical direct citation network identifies four distinct thematic clusters that have emerged chronologically: alternative marine fuels and life-cycle assessments, governance and regulatory frameworks, firm-level voluntary decarbonization strategies, and operational ship performance compliance. Source growth analysis indicates significant momentum post-2022, with Sustainability and Journal of Marine Science and Engineering experiencing notable increases in publications, while Ocean Engineering provided earlier foundational contributions. The field's transition from technical assessments to policy-oriented and strategic management perspectives reflects a maturation beyond purely engineering solutions. Furthermore, the emergence of specialized clusters around alternative fuels—particularly green hydrogen and ammonia—signifies the field's responsiveness to the IMO's 2023 revised strategy, indicating a dynamic adaptation to evolving regulatory landscapes and technological possibilities.

In addressing the sixth research question concerning the dynamics of the conceptual structure within the field, the analysis, conducted through a thematic map based on keyword centrality and density, elucidates established, foundational, and emerging themes. Motor Themes, characterized by high density and high centrality, are structurally significant and well-developed, encompassing areas such as Energy, Energy Efficiency, IMO Regulations, and Efficiency Analysis. Basic and Transversal Themes, marked by high centrality but low density, serve as foundational concepts that underpin the field's structure while still being in development; these include Maritime Transport, Sustainability, Decarbonization, Shipping, and Alternative Fuels. Emerging Themes, identified by low centrality and low density, such as Hydrogen, Renewable Energy, Ship, and Green Hydrogen, represent nascent research fronts anticipated to gain prominence as alternative fuel technologies advance. This emerging focus is further elaborated by Multiple Correspondence Analysis (MCA), which identifies a specific cluster concentrating on green ammonia and green hydrogen.

6. CONCLUSION

This bibliometric analysis reveals that research on Maritime Renewable Energy Solutions has expanded rapidly over the past decade, forming a highly multidisciplinary and increasingly collaborative field that reflects the urgency of international decarbonization targets in the shipping industry. The results indicate that scientific production is concentrated in a limited set of leading countries, universities, authors, and journals, yet characterized

by growing international co-authorship networks and diversified thematic clusters that span technical, regulatory, economic, and managerial perspectives. At the conceptual level, well-established motor themes such as energy efficiency, IMO regulations, and environmental performance coexist with emerging fronts focused on hydrogen, green ammonia, and other alternative fuels, underscoring a progressive shift from isolated technological solutions toward more integrated, policy-oriented, and system-wide pathways for achieving zero-emission maritime transport.

7. LIMITATIONS, AND FUTURE RESEARCH

Limitations of this study must be acknowledged to provide a clear understanding of its scope. One key limitation is the study's temporal range, spanning from 2016 to October 2025, which may not fully encapsulate recent developments in the field. Secondly, reliance on a specific database for data collection may omit relevant information from other sources. Furthermore, an exclusive focus on English-language papers may create a regional bias. Finally, the choice of keywords to search for relevant documents may be a limitation: while the selection of keywords was broad, the resulting dataset may not include all relevant literature on the topic; it is possible that some related articles using new or specific terms may not have been captured. In planning for future research, it is imperative to address these limitations. Thus, future research should extend the timeframe to include more recent cases, ensure a comprehensive analysis of the current situation, and diversify data sources. Maritime Renewable Energy Solutions research should encourage further studies:

- In the context of developing countries.
- Conduct integrated techno-economic and life-cycle assessments of green hydrogen and green ammonia across different ship types and routes, comparing them systematically with LNG, methanol, and conventional fuels in terms of costs, emissions, and operational constraints.

• Explore infrastructure and supply-chain requirements, including port-side production, storage, and bunkering systems, as well as their interaction with port energy hubs and national power grids.

• Investigate safety, risk, and regulatory gaps, focusing on onboard handling, crew training, and the alignment of alternative fuel standards with evolving IMO GHG strategies and regional.

• Analyze deployment scenarios in real corridors (e.g., green shipping corridors) through case studies and simulation models.

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