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RESEARCH ARTICLE

The Impact of Imo Regulations on Ship Emission Research: A Bibliometric Analysis

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ABSTRACT

The regulation of ship emissions has become an important issue in the context of global environmental sustainability, climate change mitigation, and maritime policy. This study examines the impact of International Maritime Organization (IMO) regulations on academic research related to ship engine emissions using a bibliometric methodology. A dataset consisting of 1,275 publications from 1995 to 2025 was extracted from the Scopus database and analyzed using the Biblioshiny package in RStudio. The average age of the studies was 5.77, while international collaboration was determined to be 28.08%. Outcomes show a 185.19% increase in post 2018 academic outputs following the implementation of key IMO initiatives such as MARPOL Annex VI, the Energy Efficiency Design Index (EEDI), and the Ship Energy Efficiency Management Plan (SEEMP). It demonstrates that Europe and Asia are the dominant contributors to the formation of regulations, while Africa and South America are relatively underrepresented, highlighting global inequalities. Simultaneity and thematic network analyses identify two further interconnected clusters: technical and environmental studies addressing emission reduction mechanisms, and policy-focused research highlighting governance, compliance, and sustainability challenges. Highly cited studies emphasize the fundamental importance of emission reduction technologies and regulatory frameworks, while more recent contributions increasingly focus on adopting green fuels and strategies to achieve long-term decarbonization. The findings show that IMO regulations not only guide technological innovation and industry practices but also actively shape the course of academic research.

Keywords: IMO, Ship emissions, Bibliometric analysis, Decarbonization, Maritime policy

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1. Introduction

It is inevitable to raise awareness and take precautions against the consequences that directly affect life on our planet, such as environmental pollution, global warming and climate change. On a global scale, there is a strong link between transportation and the amount of ship emissions generated (Jimenez et al., 2022). Greenhouse gases in particular are seen as an important factor in climate change, and it is known that maritime transportation causes a 3.1% share of greenhouse gases (Zincir & Arslanoglu, 2024). In the 60-year period after the 1950s, there

was a growth of approximately 6% in global trade (Hoang et al., 2022), and this growth gradually increased after 2010. With the increase in the world population, maritime transport, which is an effective means of transportation, has a share of 90% (Bendl et al., 2024a), indicating the importance of the pollution problem caused by maritime transport. Due to this increase, exhaust emissions from ship engines have become an important agenda item due to their disruption of the ecosystem balance, negative impact on climate change and endangering human health (Toscano & Murena, 2019).

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States, environmental organizations, and the maritime industry, especially IMO, are addressing this issue and have recently been organizing studies to raise awareness. According to the IMO's 2020 report, as part of carbon-neutral ship initiatives, maritime transport volume is expected to increase by 40% to 115% by 2050 ([Fourth Greenhouse Gas Study 2020, n.d.](#)). 70% of the pollution caused by the maritime sector is caused by the exhaust gas emissions of ship engines. These pollutants caused by ship engines mainly consist of emissions resulting from combustion reactions such as nitrogen oxides (NOx), carbon dioxide, sulfur oxides (SOx), particulate matter (PM) and carbon monoxide (CO) ([Bendl et al., 2024b](#)). It is accepted that emissions have negative effects not only on the environment but also on human health and are a vital issue that should be taken into consideration especially in special areas such as ports, inland waters and straits. According to IMO, between 2012 and 2018, the share of greenhouse gas emissions from maritime transport in total global emissions increased from 2.76% to 2.89% ([Han et al., 2023](#)).

Preventing ship-based pollution has led to the tightening of inspections and regulations by legal organizations such as IMO. Ships are subject to either flag state inspection by the country they are affiliated with or port state inspection in the ports. These regulations are not only include issues related to environmental risks, but are also very important developments in terms of life safety, economic improvements and encouraging the shift to alternative energy sources.

IMO strategies include comprehensive titles in technical and social terms. In this context, it presents reports on many subjects such as emission regulations, cyber security, digitalization, autonomous ships, incentives for developing countries, education and feedback mechanisms ([Kaya & Kahramanoğlu, 2025](#)). IMO plans to carry the process it initiated with the Geneva Convention in 1948 to zero emission level by 2050. IMO, which started its operations in 1958, has continued to protect the maritime environment and update its training certification systems over the years. It has focused on ballast water management and emission restrictions since the 2000s. It has determined special regions and has carried out plans according to the processes dating back to 2030 and 2050, most recently in 2023. [Fig. 1](#) demonstrates the IMO's plans for the period 2011 to 2050. In line with the decarbonization targets, the plan is to reduce greenhouse gas emissions from international transport to zero by 2050, as illustrated by actions undertaken and planned between 2011 and 2050. The transport sector is targeted to reach 70-80% by 2040, and the plan is to increase the

use of zero-emission technologies, using alternative fuels, and international energy demand to between 5–10%.

The impact of IMO regulations on academic studies is a subject worth examining. Because it offers solution and suggestion perspectives to the maritime community, which requires studies on these restrictions. In the evolving maritime industry, innovative impacts particularly in the areas of alternative fuel utilization and energy efficiency have increasingly manifested over time ([Karvounis et al., 2022](#); [Kim et al., 2020](#); [Ozsari et al., 2025](#); [Wang et al., 2025](#)). Chu Van et al. searched a comprehensive examination of the marine oil refining industry, with particular attention to the anticipated composition of future marine fuel blends, while also analyzing the contextual framework and global implications of the latest IMO regulations imposed on ship emissions. The study predicted that LNG and biofuels will be widely used on ships, along with a shift to low-sulfur fuels compared to HFO ([Chu Van et al., 2019](#)).

According to the statistical analysis conducted by Cariou and Randrianarisoa, a total of 117 countries and 75 different civil society organizations actively participated in 28 MEPC meetings. However, despite this numerical diversity, the researchers emphasize that the early stages of the decision-making process did not achieve a sufficient level of representativeness and inclusiveness. In particular, they highlight that participation in IMO workshops was uneven in terms of both geographical distribution and economic capacity. This imbalance not only amplified the influence of dominant stakeholders in shaping policy outcomes but also led to the marginalization of economically disadvantaged countries, effectively excluding them from the process ([Malnes, 1995](#); [Prehn, 2021](#)). Consequently, the lack of genuinely inclusive global representation in these decision-making mechanisms constitutes a significant limitation, not only from the perspective of fairness and equity but also in terms of the legitimacy and effectiveness of the decisions adopted ([Agné et al., 2015](#); [Cariou & Randrianarisoa, 2023](#)). It appears that IMO is gradually implementing its regulations, particularly in coastal and near-coastal areas ([Jeong et al., 2023](#)). The fact that 70% of ship emissions occur 400 km inland clearly demonstrates the dangerous extent of greenhouse gas emissions released in coastal areas and ports ([Murcia González, 2021](#)). In this context, Roy and Chakraborty, in their compilation study, determined that the regulations implemented by IMO regarding greenhouse gas reduction have produced significant positive results for the environment and human health. They also stated that IMO should have a regular monitoring and tracking system, promote

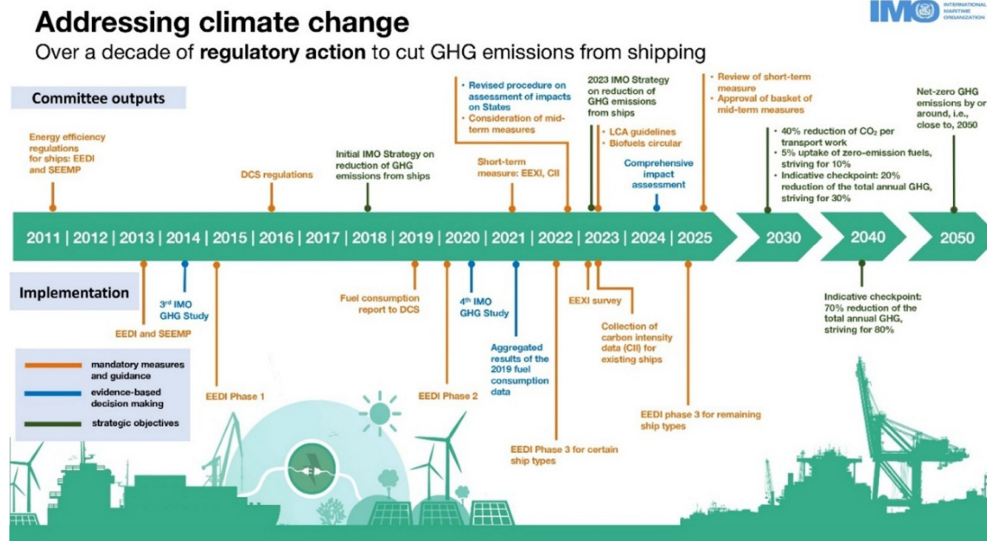


Fig. 1. IMO's plans for the period 2011 to 2050 (IMO's work to cut GHG emissions from ships, n.d.).

clean fuels such as LNG, NH₃, methanol, and hydrogen, require ships to use port electricity during their stays, and increase international participation and collaboration (Roy & Chakraborty, 2025).

In addition to the IMO's greenhouse gas emission neutralization targets, its core strategies include the construction of sustainable ships, taking into account environmental and economic conditions. The IMO's initial strategy target of reducing CO₂ by 50% has evolved into a carbon neutrality target by 2050, and energy efficiency and sustainability targets are also of significant importance (Kim et al., 2020). The Ship Energy Efficiency Management Plan (SEEMP), implemented by the IMO on January 1, 2013, and expanded in 2023, aims to increase the environmental performance and efficiency of ships. Within this scope, the management plan includes the management and monitoring of items such as oil fuel records, speed optimization, and heat recovery systems, among the IMO's efficiency sub-topics (SEEMP - Ship Energy Efficiency Management Plan, n.d.; Tadros et al., 2023).

The aim of this study is to investigate the impact of IMO regulations on the academic research landscape by employing a bibliometric approach. The bibliometric study presents data by year and by keywords. In addition, the number of citations to the studies and the countries of origin of the researchers and authors are analyzed. This allows the impact of these regulations on academic studies to be assessed in relation to the dates of the IMO regulations. The search focused on the impact of IMO regulations, particularly on emissions. Before beginning the study, a comprehensive literature review was conducted to examine the relevant studies. The analysis revealed

that ship emissions have become increasingly significant with the growing maritime industry, and a focus on solution-oriented efforts was emphasized. It was understood that the IMO's sanctions and restrictions, the most powerful reference in this regard, are directly determinative. In this context, the study seeks to identify the extent to which IMO's regulatory framework, particularly in the areas of environmental protection, energy efficiency, and emission reduction, has influenced the direction, intensity, and thematic orientation of scholarly outputs. By systematically mapping publication trends, citation networks, and collaborative patterns, the research aims to reveal how regulatory interventions have shaped scientific discourse, prioritized research agendas, and fostered knowledge production within the maritime domain. Ultimately, this study aspires to contribute to a deeper understanding of the interplay between global maritime governance and academic knowledge creation, while also highlighting potential gaps and emerging research frontiers.

2. Methods

Bibliometric analysis offers a highly effective methodological approach for systematically examining the volume, scope, and impact of academic output on a specific topic. Using keywords, titles, and abstracts as basic units of analysis, this method provides a comprehensive overview of the research environment (Lee et al., 2020). Such an approach facilitates the identification of thematic orientations, comparative dimensions, and temporal distributions of publications, thereby offering clear insights into



Fig. 2. Initial data for bibliometric analysis.

the evolution of research interests and the intensity of academic engagement with the topic (Elçiçek, 2024; Kaya & Başhan, 2025). The clear visibility of trends across years provides insights into potential future research topics. This study employs a bibliometric methodology to analyze the influence of IMO regulations on academic research output.

Bibliometric data was obtained from the Scopus database, which is widely recognized as a comprehensive source of peer-reviewed scientific publications. The data was analyzed using the RStudio program via Biblioshiny. Biblioshiny is a unique software interface developed for bibliometric analysis. It provides a graphical user interface for the R-based bibliometrix package, offering a variety of visualizations. This enables it to present effective data such as annual number of publications and growth rates, citation counts, and the interconnection of key words of focus (Aria & Cuccurullo, 2017). To ensure relevance, the search was limited to the period 1995–2025, which coincides with the period when IMO's regulatory frameworks on greenhouse gas emissions, sulfur limits, and energy efficiency came to the fore. The search string included combinations of keywords such as “ship* emission*”, “ship* engine emission*”, “ship* exhaust emission*”, “vessel* emission*”, “marine* emission*”, “IMO regulations”, “green ship*”, “maritime”, “Marpol”, “Annex VI”, “alternative fuel*”, “zero carbon”, “marine environment control”, “MARPOL”, “marine pollution”. Only journal articles, conference proceedings, and review papers published in English were considered. Fig. 2 shows the data used as a basis for bibliometric analysis. The study analyzed a total of 1,275 works, including 970 articles, 221 conference papers, and 84 review studies. The analysis, covering the years 1995 to 2025, included studies in English, which is the most common and generally accepted language in the literature.

In this study, several methodological refinements were implemented prior to data collection in order to

address potential limitations inherent in bibliometric analysis. To broaden the scope of the assessment, multiple databases were systematically searched and cross-validated against the primary source, with the comparison revealing only negligible overlaps. The dataset obtained from the selected database was subsequently subjected to a rigorous data-cleaning procedure, during which duplicate records and beyond the scope of the research were carefully identified and removed to ensure data integrity and originality. In addition, a number of recurrent publications with overlapping content, particularly those concentrated within specific regional contexts, were excluded to enhance the representativeness and reliability of the dataset. During the database search, duplicate studies that did not directly address IMO regulations, were irrelevant, did not fall within the scope of ship emissions and efficiency, and were removed through manual screening. A structured graphical representation of the research is illustrated in the Fig. 3.

3. Result and discussion

The bibliometric analysis clearly demonstrates that the regulations and strategic directives of the IMO have significantly influenced academic output and research trends in the maritime field. The findings reveal a marked increase in the number of publications particularly addressing emission control, alternative fuels, energy efficiency, and safety management, which coincides with the implementation of IMO regulations. This indicates that the IMO's role as an international standard-setting authority directly shapes the academic research agenda. Furthermore, the geographical distribution analysis shows that universities and research centers in Europe and Asia are at the forefront of scholarly contributions, whereas Africa and South America provide relatively limited input. This disparity suggests that although IMO regulations are applied globally, the level of academic

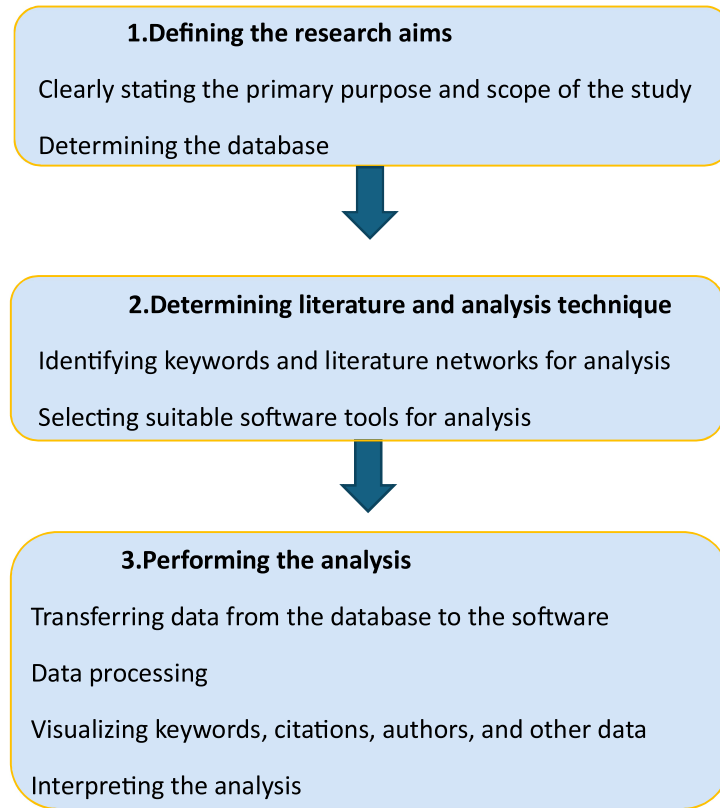


Fig. 3. Structured graphical representation of the research.

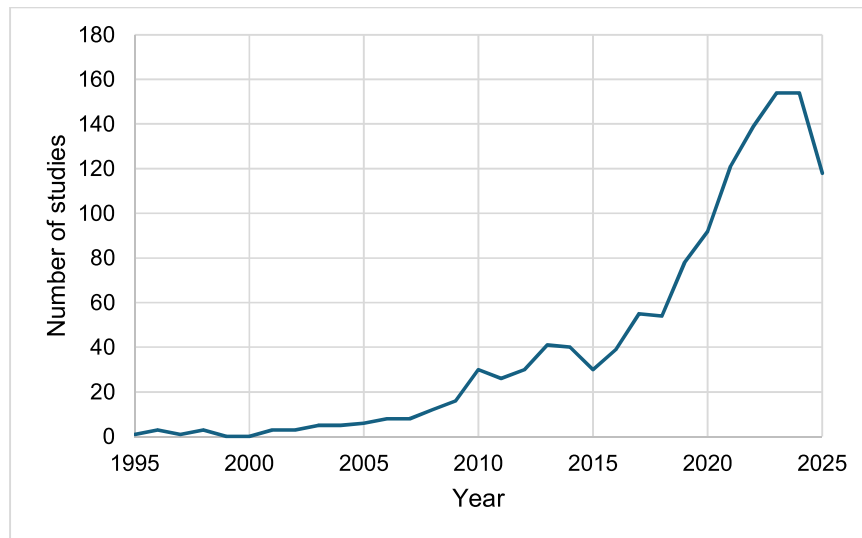


Fig. 4. Trends in maritime research publications related IMO regulations between 1995 and 2025.

production is closely related to regional research capacity and funding opportunities.

Fig. 4 illustrates the distribution of publications between 1995 and 2025. Although initially there were limited studies on the topic, the maximum number of studies was produced in 2023 and 2024, reaching

154. By mid-2025, this number had reached 118. The data reveal that scientific output in the maritime field has shown a remarkable upward trend, particularly after 2010. The period between 1995 and 2005 is characterized by relatively low and stable production, while around 2010 a noticeable increase emerged,

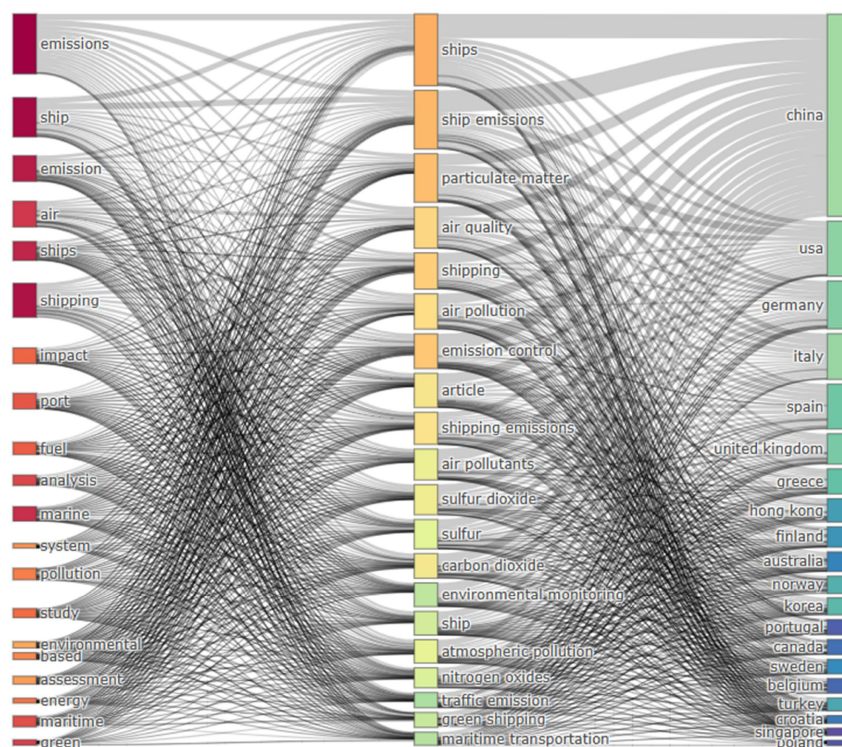


Fig. 5. The connection between the keywords, the topics and the contributing countries.

which became more pronounced in the subsequent years. After 2015, the number of publications began to rise more sharply, reaching its peak between 2020 and 2022. This rapid growth corresponds with the implementation of major IMO environmental regulations, such as MARPOL Annex VI, EEDI, SEEMP, and the 2020 global sulfur cap. The concentration of academic studies during this period can be interpreted as a response to these regulatory frameworks, reflecting heightened scholarly interest driven by international policy measures. However, a decline in the number of studies is observed after 2023. This downturn may be attributed to various factors, including the impact of the COVID-19 pandemic on research processes, fluctuations in funding opportunities, or the fact that the initial impact phase of IMO regulations on the academic agenda had already passed. Although a decrease was observed in the last year due to the 2025 deadline not being reached, it is clear that this increase is continuing gradually. Nevertheless, the overall trajectory since 1995 demonstrates a steady upward trend, underscoring the pivotal role of IMO policies as a driver of academic research in the maritime sector.

As illustrated in the Sankey diagram in Fig. 5, the keywords are presented on the left, the most frequently employed expressions in article titles are positioned in the middle, and the countries of af-

filiation of the most prolific authors are displayed on the right. It illustrates the interconnections between keywords, thematic focuses, and contributing countries in maritime research. The analysis reveals that emissions, ship emissions, air pollution, and emission control are the most prominent themes, reflecting the strong influence of IMO environmental regulations, particularly MARPOL Annex VI. Geographically, China, the United States, and Germany lead in publication output, followed by Italy, Spain, and the United Kingdom, indicating that countries with strong maritime industries or regulatory commitments dominate the research landscape. In contrast, nations such as Turkey, Greece, and Finland contribute more selectively to specific themes.

Fig. 6 presented the temporal distribution of academic publications authored by different researchers between 2007 and 2025. The size and color intensity of the markers reflect the relative impact of the publications. Darker colors and larger circles indicate higher influence or concentration. A notable increase can be observed after 2015, suggesting that research interest in this field has grown rapidly, particularly over the last decade. Jalkanen and Sddiek, with 20 published works, stand out in terms of both publication output and overall research impact. In contrast, the authors who contributed fewer works but had a significant impact. The diversity of author names



Fig. 6. Annual variation in the publication output of the most prolific authors.

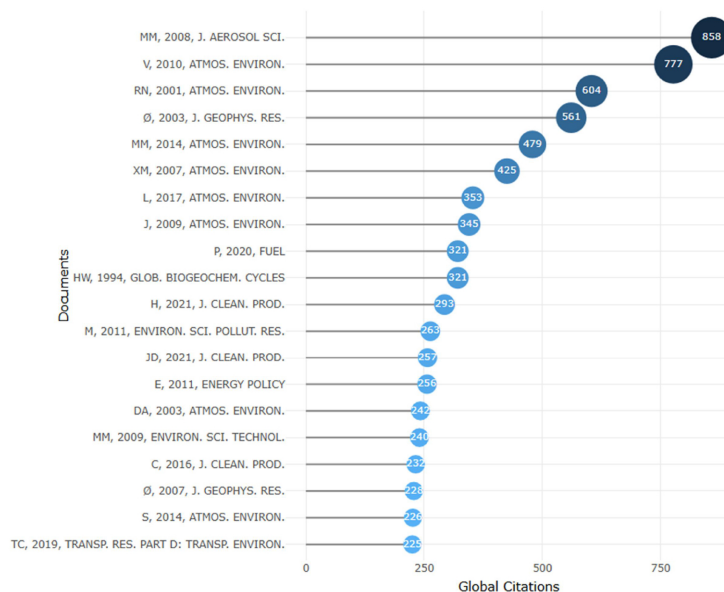


Fig. 7. Academic journals by citation count.

indicates that the field has evolved into a global research domain, with significant contributions from Europe, Asia, and Latin America. The impact of the IMO's intensive work in recent years is evident, as can be seen in the graph, which clearly shows the rapid growth in their work in recent years.

The citations of the documents in which academic studies are published are at least as important as the context of the subject. Fig. 7 shows the ranking of academic journals by citation count. Examination of the data reveals that certain articles exert a notably

dominant influence within the literature. The most cited study is a study by Viana et al. (2008), published in the Journal of Aerosol Science, which has received 858 global citations.. This is followed by Eyring et al. (2010), with 777 citations and Colville et al. (2001), with 604 citations, indicating that these publications have become foundational references in the field and have generated widespread scholarly impact. Lower-cited publications, in the range of between 200 and 350 citations demonstrate that recent studies can achieve substantial impact within a relatively short

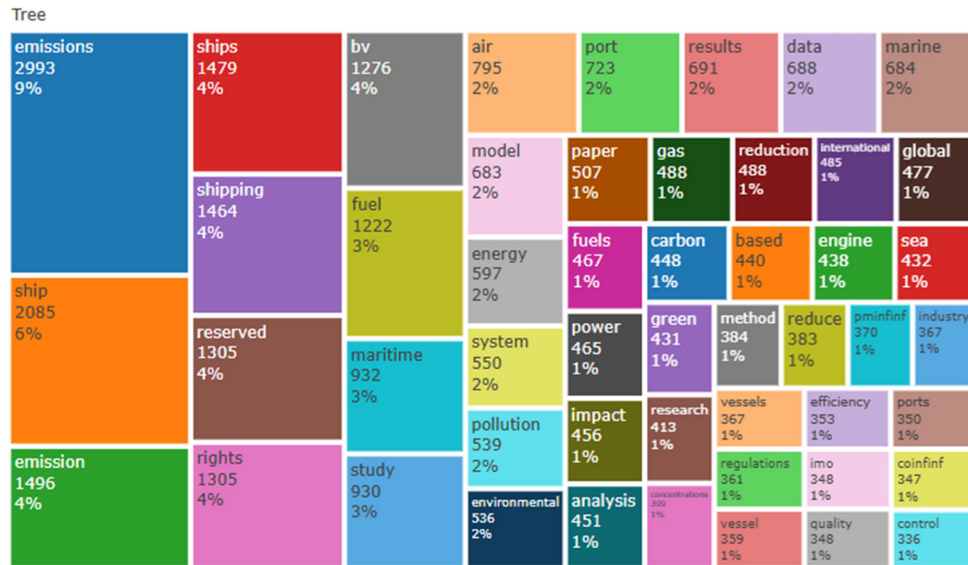


Fig. 8. Most frequently mentioned words in the abstracts.

timeframe. This reflects the rapid academic attention given to emerging trends in the field. Graph highlights the interplay between highly cited, seminal works that form the core literature of the domain and more recent studies that are rapidly gaining citations. This distribution provides valuable insights into both the historical development of the research area and its current scholarly trajectories.

Abstracts are the most important section for researchers searching through articles, ensuring they can be quickly and easily understood. Furthermore, they must be written in the clearest and most compelling terms to ensure the study is understood. Fig. 8 shows the most frequently emphasized words in the abstracts of the analyzed studies. The size of the boxes in the figure represents the frequency of specific keywords in the literature. The colors indicate different thematic clusters, while each box contains the total occurrence and percentage share of the corresponding keyword. A review of keywords reveals a focus on studies related to ship exhaust emissions. While emissions account for 13%, this figure rises to approximately 20% when emission types and pollution are added. This demonstrates that the study's targeted approach has been achieved. The most frequently used words are "emission" and "ship," used 4489 and 3564 times, respectively. Medium-sized words include "reserved/rights" which are used 1305 times, and "fuel," used a total of 1689 times. These terms suggest that the research also addresses issues related to energy efficiency as well as legal and regulatory dimensions. Smaller words, such as "system," "analysis," "green," and "method," which

comprised the first 1%, indicate that the research is not confined solely to emission measurements but also encompasses systemic approaches, methodological developments, and environmental sustainability. This visualization reveals the conceptual intensities within the literature, illustrating that maritime and environmental research is particularly concentrated on emission reduction, fuel consumption, and environmental regulations. Furthermore, the prominence of keywords such as green, efficiency, and energy highlights the increasing attention directed toward sustainability and green logistics perspectives in recent years.

The word cloud provides a visual representation of the prevailing themes within the research field. A word cloud of the 75 most frequently used keywords by the authors is presented in Fig. 9. The size of the terms reflects their frequency of occurrence in the literature. Among the most dominant keywords are ships, ship emissions, shipping emissions, particulate matter, emission control, air pollution, and air quality respectively. This distribution indicates that the central focus of maritime transportation research lies in ship-generated emissions, air pollution, and regulatory measures aimed at pollution control. Other noteworthy terms include specific pollutants such as carbon dioxide, sulfur dioxide, nitrogen oxides, and greenhouse gases. These keywords suggest that the literature not only addresses general pollution effects but also engages in an in-depth examination of the environmental impacts of particular gases. Furthermore, the prominence of concepts such as green shipping, energy efficiency, and environmental

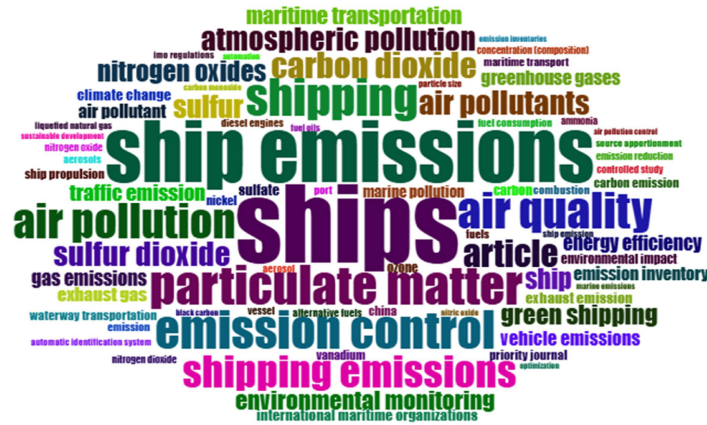


Fig. 9. Highly used keywords.

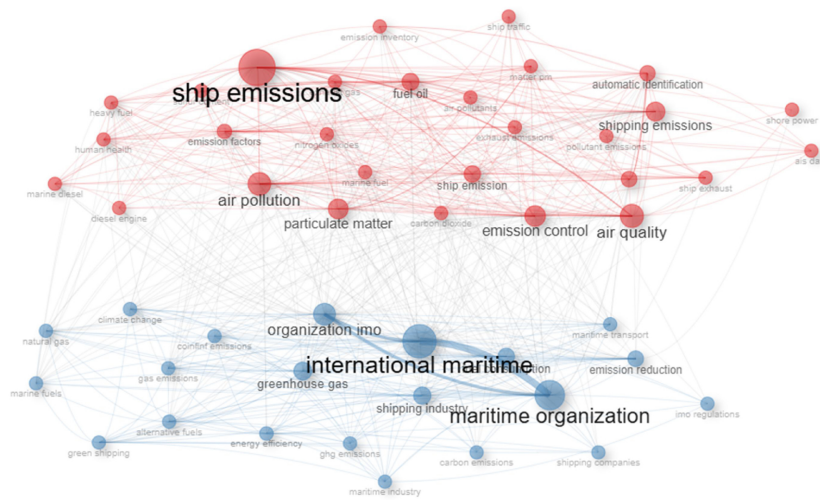


Fig. 10. Co-occurrence network analysis.

monitoring reflects the growing representation of environmental sustainability and green transition policies in recent scholarly discourse. At the same time, the inclusion of terms such as maritime transportation, marine pollution, and IMO highlights the relevance of institutional and policy-oriented dimensions, particularly the role of international regulations in shaping the academic debate.

Fig. 10 illustrates the relationships among co-occurring keywords in the literature. The size of the circles indicates the relative importance of a concept in the field, while the colors represent thematic clusters identified through community detection. The connecting lines illustrate co-occurrence relationships between concepts. The section highlighted in red represents the technical and environmental dimension, while the blue section represents the policy and regulatory dimension. The most dominant concept, ship emissions, occupies the central position within this network. Other significant concepts

connected to this cluster include air pollution, particulate matter, emission control, air quality, fuel oil, and shipping emissions. This structure represents research addressing the direct environmental impacts of maritime transportation, including emission factors and air pollution studies. At the center of this cluster is IMO. Surrounding concepts include greenhouse gas, climate change, energy efficiency, emission reduction, and alternative fuels. This cluster reflects scholarly work focused on international regulations, climate policies, and the promotion of green shipping practices. Examination of the network structure reveals a clear distinction between technical and environmental studies and policy and regulatory research. Nevertheless, concepts such as emission control and greenhouse gas act as bridges linking the two clusters, suggesting that technical research and international policy and regulatory studies are complementary domains. This finding demonstrates that academic research not only contributes to

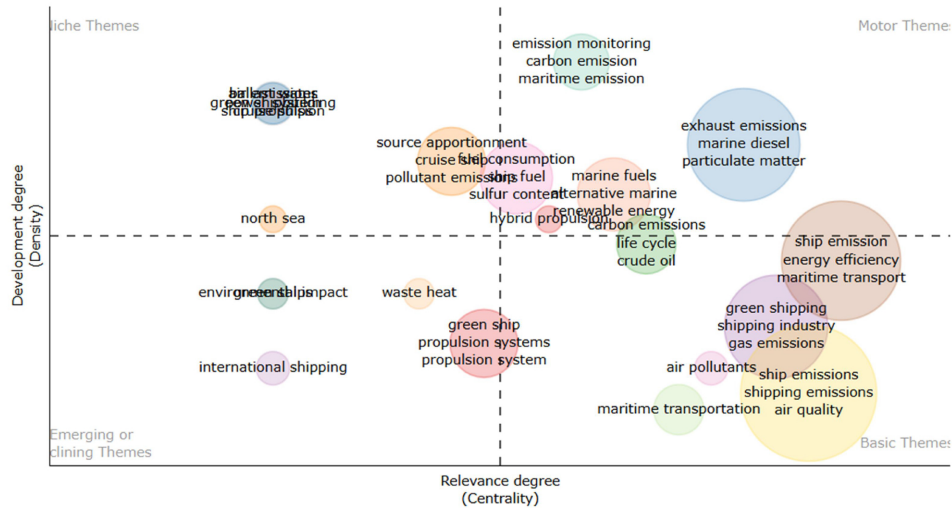


Fig. 11. Thematic map of study titles.

scientific and measurement based analyses but also plays a significant role in shaping policy development processes.

The thematic map contains significant data on the importance of the topics under study, as well as their developmental trajectories. Fig. 11 represents a bibliometric output known as a thematic map, in which key concepts are positioned along the dimensions of relevance degree and density development degree. The diagram illustrates both the level of development and the degree of importance of themes within the research field. The diagram is divided into four sections: Motor, Basic, Niche, and Emerging or Declining Themes, which reflect the relevance and maturity of the concepts. In the upper right section, where the Motor theme is located, exhaust emissions, marine diesel, and particulate matter are prominent. These concepts are positioned as both central and highly developed, and are currently demonstrates their role as the main driving forces in the literature. Basic themes include ship emissions, maritime emissions, maritime transport, air quality, energy efficiency and green shipping. These represent the fundamental building blocks of the field and are frequently referenced in a wide range of studies. Emissions and energy efficiency, in particular, have become indispensable axes of maritime research. The upper left section includes concepts such as air emissions, cruise ships, green shipbuilding, and ship propulsion. These emphasize more environmentally friendly and energy efficient approaches. The lower-left quadrant includes international shipping, environmental impact, and propulsion system. These themes point either to areas of research that are just beginning to gain attention or to those that are gradually losing prominence in the literature.

4. Conclusion

This study has revealed that the regulatory framework established by IMO has been a decisive factor in shaping the trajectory of academic research on ship emissions and maritime environmental policies over the past two decades. It has revealed the impact of IMO regulations on academic work. Key findings, such as the number of studies conducted, citations, and annual changes, are as follows:

- The analysis of 1,275 studies showed a significant increase in the number of studies, particularly after 2015, when regulations intensified. The number of studies, which was 54 in 2018, increased to 154 in 2024, showing a 185.19% increase.
- Although the average annual growth rate since 1995 has been determined to be 17.24%, the extremely low number of studies in the early years shows that the annual increase has been much higher in recent years. The average document age of 5.77 is indicative of this.
- The average number of citations to the studies was determined to be 27.59, indicating an upward trend in interest in the subject.
- It is encouraging that the keywords identified by the authors are consistent with those identified by the publishers and that researchers in leading countries such as China, the US, and Germany are the most prolific publishers.
- The keywords ships, emission control, and ship emissions ranked first, second, and third, with 706, 349, and 336 citations, respectively.

The bibliometric analysis demonstrated a significant rise in scholarly interest following the adoption of major IMO regulations. These measures not only stimulated research in areas such as emission reduction technologies, alternative fuels, and energy efficiency, but also redefined the thematic structure of maritime research by prioritizing sustainability and climate change mitigation. In addition, the thematic evolution observed across the years demonstrates that concepts such as exhaust emissions, particulate matter, ship efficiency, and green shipping have consolidated their status as core research themes, whereas emerging topics particularly related to alternative fuels, hybrid propulsion, and decarbonization strategies are likely to dominate the research agenda in the coming decades.

Finally, as the global maritime industry moves toward its 2050 decarbonization targets, continuous monitoring of regulatory impacts, supported by bibliometric and scientometric assessments such as this study, will be essential. Given the increasing convergence of technical and governance related research, policies should be designed to foster interdisciplinary collaboration between engineers, environmental scientists, economists, and legal experts. This integrative approach will accelerate the development of feasible solutions that are both technologically viable and economically sustainable. These assessments can help identify knowledge gaps, track research progress, and ensure that policies remain adaptive to scientific and technological developments.

Data availability statement

“The Impact of IMO Regulations on Ship Machinery Emission Research: A Bibliometric Analysis” Access to data is available for the study titled.

Conflict of interest

There are no conflicts of interest in the single-authored study “The Impact of IMO Regulations on Ship Emission Research: A Bibliometric Analysis.”

Ethical approval

There are no ethical issues with the publication of this manuscript.

Use of AI for writing assistance

No AI technologies utilized.

Financial disclosure

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Author contribution

The entire study, “The Impact of IMO Regulations on Ship Emission Research: A Bibliometric Analysis” was conducted by Halil İbrahim Sönmez.

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