Alternative Marine Fuel

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While the marine sector contributes significantly to the global economy, its environmental impact is a cause for apprehension due to growing concerns about ship emissions. The International Maritime Organization (IMO) has set decarbonization strategies consistent with sustainable development goals. The impending legislation aimed at reducing greenhouse gas (GHG) emissions from maritime shipping by at least half by 2050 and to zero by the end of the century. A growing body of research has focused on alternative marine fuel selection.

alternative marine fuel | bibliometric analysis | biblioshiny | decarbonization | maritime shipping | VOSviewer

1. Introduction

Global climate change appears to be one of the most perplexing problems that humanity has ever encountered [1]. The Intergovernmental Panel on Climate Change (IPCC) believes that human-induced greenhouse gas (GHG) concentrations are responsible for at least half of the observed global warming since 1950. The International Maritime Organization (IMO), an international regulating authority for shipping, adopted the international convention for the prevention of pollution from ships (MARPOL). It has six regulation annexes to protect the environment from pollution caused by oil, harmful liquids, dangerous substances, sewage, garbage, and air pollution caused by ships. IMO is steadily tightening environmental standards. A target has been established to cut GHG emissions by at least 50% by 2050. Thus, a long-term shift to zero-carbon ship technologies is anticipated, switching to alternative fuel with zero carbon emissions. To meet the low carbon maritime transportation target of 2050 and zero carbon by the end of this century, the reliance on fossil fuels as the principal marine fuel source must be gradually phased out [2]. Det Norske Veritas and Germanischer Lloyd (DNV-GL) now known as Det Norske Veritas (DNV) projected that while all other technical measures can reduce a maximum of 20% air pollution from ships, only appropriate alternate fuel and energy sources can potentially reduce it to 100%. Therefore, Alternative Marine Fuels (AMF) adoption is an absolute solution. As a result, AMF had become a significant interest for the maritime shipping industry, and it has recently attracted the attention of researchers. Therefore, research trend analysis on AMF is needed to understand scientific studies' state of the art in this phenomenon of interest.

There have been only a few bibliometric investigations on AMF, which is the motivation of this research. A bibliometric survey of AMF was conducted by Kołakowski et al. [3] who analyzed 234 articles published between 1992 to 2019 extracted from the Web of Science (WoS) database. The research focused only on "alternative fuels and renewable energy systems" from technology and legal framework perspective. Another bibliometric survey by

Ampah et al. [4] considered the time frame of two decades, 2000–2020. The research collected 583 articles from the scientific database from the WoS Core Collection and Scopus databases. Bibliometric analysis should provide an updated overview of a field because scholarly databases add new scientific papers each day. Both the studies mentioned above-analyzed documents published in 2019, 2020. Hence, there is a knowledge gap regarding the updated status of research progress and trend in AMF literature. Consequently, the research aims to conduct a bibliometric knowledge mapping of AMF literature extracted from the Scopus database.

This research contributes significantly to the body of knowledge by providing updated bibliometric findings in AMF research. Firstly, it considered 749 documents for analysis published between 1973 and 2022 and presents overall research publication, citation trends, how the topics have evolved with time, and trending topics. Secondly, it offers several bibliometric indicator results and discussions such as co-authorship analysis of authors and countries, author keyword co-occurrence to understand the nature of affiliation, and the keywords that appaired repeatedly. Thirdly, ranking the most productive authors, nations, and institutes provides researchers with information to search for potential collaboration. This research identifies top-ranked journals that could be targeted for publication on AMF related topics. Finally, another set of findings such as thematic maps, structural maps, subject area, and clusters presents state-of-the-art of research and highlights research gaps for future endeavors.

In summary, identifying trends in AMF can be beneficial not only for investigators and research organizations but also for industry players. This data could be extremely helpful for current and prospective investors and governing bodies in this sector. The latter can help identify state-of-the-art research gaps in the maritime-related AMF selection challenge and contribute to the growth of optimal solutions via further assessments.

2. Bibliometric Analysis

Bibliometric analysis is a systematic method for determining the research trends in a particular field of study using scholarly publications published in scientific databases. Additionally, this analytical approach enables researchers to assess and analyze the current state of scientific research in a particular field. The bibliometric analysis aims to ascertain the progress and problems associated with a specific contemporary phenomenon of interest by examining the features of scientific publications. Additionally, this research guides future research within that subject area.

Bibliometrics, or the statistical analysis of bibliographers, appears to have been launched in 1969 as a technique of “illuminating scientific and technological processes through the numbering of documents.” Nowadays, bibliometrics is widely used to assess the qualities of articles, books, and other forms of literary production, determine the influence of academics and institutions, discover patterns of research collaboration, and identify and forecast trends in specific research fields. Given the rapid growth of scholarly outputs, bibliometrics is viewed as a critical and efficient method for researching libraries of published information—both qualitative data (e.g., hotspots and future research trends) and quantitative data such as temporal and geographic distribution of outputs, leading researchers, and mainstream journals [1]. The mathematical and statistical approaches employed in bibliometrics are based on three standard models: the Bradford dispersion law of literature, Lotka’s law, and Zipf’s law.

3. GHG Emission Control Initiatives and Scientific Studies on Alternative Marine Fuel

The international shipping decarbonization timeline (see **Figure 1**) presents the chronological exhibition of IMO's initiatives towards GHG emission control. The illustration begins with that Annex VI established restrictions on the amount of NOx emitted by marine diesel engines in 1997. IMO's first GHG study that reported, as of 1996, that maritime shipping caused around 1.8 percent of global CO_2 emission. The second GHG study published in 2009 presents an estimation holding international maritime shipping accountable for 2.7 percent of the total CO_2 emission worldwide. In the meantime, in 2005, Annex VI came to play its role in controlling global sulphur cap, sulphur emission control area (ECA), and NOx Tier 1. Further reduction of ECA sulphur cap and NOx Tier 2 occurred in 2010 and 2011, respectively. IMO's third and fourth GHG studies were approved in 2014 and 2020. In 2018, considering 2008 as base year, IMO's initial GHG strategy came in action, while in 2015 and 2016, the ECA sulphur cap further reduction to 0.10 percent m/m, energy efficiency design index (EEDI), data collection system (DCS) NOx Tier II and III were made mandatory [5]. During its 72nd session in April 2018, the IMO's Marine Environment Protection Committee (MEPC 72) approved the Initial IMO Strategy for decreasing GHG emissions from ships. The IMO Strategy established phase–by–phase targets for reducing GHG emissions from international shipping by 2050 in comparison to 2008. From the year of its announcement to 2023 it has been prioritized by IMO. Several potential short-term measures include enhancing current energy efficiency frameworks; establishing technological and operational efficiency solutions for newbuild and existing ships; and optimizing and reducing ship speeds [6]. Furthermore, to reduce CO_2 emissions per ton–mile of cargo transportation by at least 40% by 2030 through mid-term measures, with a goal of 70% by 2050, and to reduce average yearly GHG emissions by at least 50% by 2050, while pursuing efforts to phase out GHG emissions from international shipping as soon as possible during this millennium [7]. Beyond 2030, targets are defined for the mid-term (by 2030), and long-term (by 2050). Under short-term measure, ship energy efficiency existing ship index (EEXI), carbon intensity indicator (CII) has been introduced and EEDI phase 3 applies for newbuild large container ships.

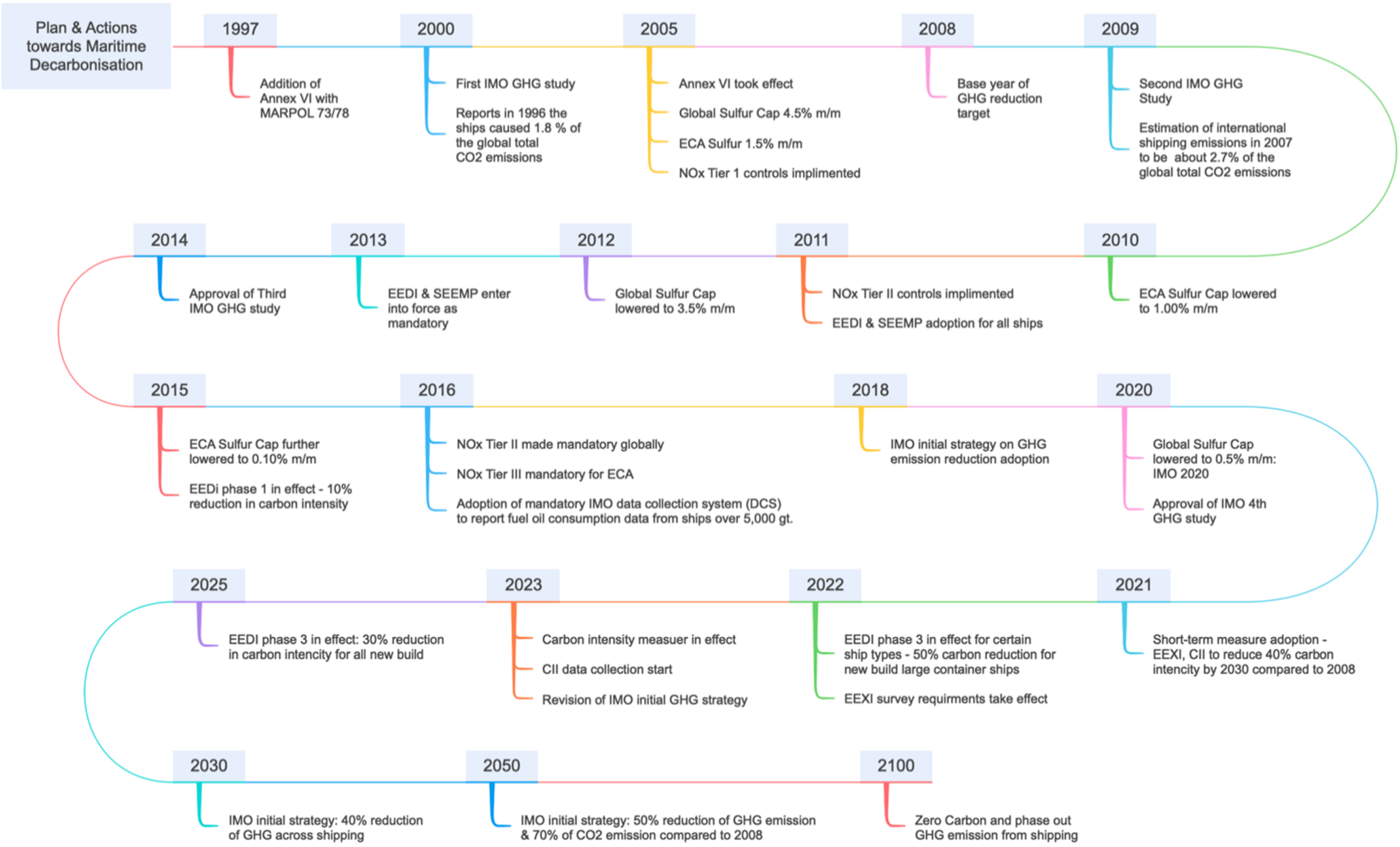

Figure 1. International shipping decarbonization timeline.

Mid-term and long-term measures include signing a program for AMF with low-carbon (in the mid-term) and zero-carbon (in the long-term) fuels, operational energy efficiency measures for newbuild and existing ships, and market-based measures [6].

IMO's ambitious initial strategy has influenced the scientific literature on AMF since 2018. Consequently, there has been noticeable progress in knowledge development in this research area. Understandably, recent studies on AMF are decarbonizing, GHG emission control focused aimed at the short-, mid-, and long-term targets set by IMO. However, the studies mostly discussed several AMFs or fuel groups [8] such as biofuels [9], green hydrogen, or liquid hydrogen [10]. Existing studies applied several methods to address AMF related gaps, such as multi-criteria decision-making (MCDM), bibliometric review, traditional systematic review, etc.

Some of the studies applied the MCDM method to address the AMF related decision-making issue. The method is also known as multi-criteria decision analysis (MCDA). Xing et al. [11] emphasize AMF along with technological and operational measures considering the target of low carbon shipping by 2050. The researchers carried out a technical review to determine the most promising AMF considering the simultaneous reduction of SOx, NOx, CO_2 emissions, as well as sustainability. A qualitative ranking of the potential of different marine fuel options is presented based on a multi-dimensional decision-making framework. Ren and Lützen [12] used the MCDA technique to evaluate LNG, nuclear, and wind power based on ten criteria: technical maturity, reliability, energy storage efficiency, infrastructure, capital cost, bunker price, NOx and GHG reduction, social acceptability, and safety. Technological, economic, environmental, and social aspects are among the dimensions considered in this research. The analysis concluded by naming nuclear power followed by LNG as the most sustainable AMFs. Similarly, under the four (technological, economic, environmental, social) dimensions and methods like Ren and Lützen [12], another study by Ren and Liang [13] ranks LNG, fossil methanol, and hydrogen based on 11 criteria. The findings revealed that hydrogen or LNG is the most environmentally friendly AMF.

Balcombe et al. [14] provided an overview to a suggest research direction, identifying research gaps. The research covers environmental, economic, and policy aspects and a cost comparison and life cycle emissions. Liquefied natural gas (LNG), nuclear power, renewable energy, biofuels (i.e., straight vegetable oil—SVO, hydrotreated vegetable oil—HVO, bioethanol, etc.) are some of the potential AMFs. The research prioritizes LNG for SOx, NOx, CO_2 emission reduction. However, LNG is combustion efficient, GHG reduction is threatened due to methane slip during upstream and downstream activity, and liquefaction is related to 8 to 12 percent energy loss. To address this issue regarding LNG, dual-fuel ships might need selective catalytic reduction (SCR) for NOx lessening. LNG needs to be combined with other measures to obtain a 50 percent reduction in GHG emissions. Another potential AMF hydrogen produced from nuclear power onshore is mentioned and from renewables such as electricity from solar and wind. Subsidies for LNG are recommended to accelerate the implementation until nuclear, renewables, and hydrogen take over. Large-scale production of biofuels is linked to “sustainability reasons” because they come from food sources. While the research mention wastes and residues from forest-based industries, non-food cellulosic material, it reminds people that the availability of these fuels is limited. The concluding remark states a need for combined effort in terms of fuels, technology, and policy to achieve the decarbonization target.

Ben Brahim et al. [15] specifically focused on the Danish maritime sector towards CO_2 neutrality by 2050. The evaluation has been conducted based on emissions from well to tank, regulation, and carbon pricing data. The research looks into “fuel technologies” and AMFs, namely hydrogen, methanol, LNG, and ammonia. The environmental and technological benefits and drawbacks were explored qualitatively and in light of the literature. The research employed a cost minimization model at the system level and the anticipated remaining CO_2 budget to determine how to restrict CO_2 emissions and achieve carbon neutrality by 2050. The assessment concluded that hydrogen, methanol, and ammonia are the most economically viable AMFs. In contrast, LNG is not considered a long-term solution due to methane leakage and expensive fuel and technological costs, and battery options are evaluated solely for short sea shipping.

Research trend analysis of AMF was conducted by Kołakowski et al. [3] and Ampah et al. [4] last year. Kołakowski et al. [3] analysed the research output on AMF considering technological and legal framework perspectives. The bibliometric technique was used to analyse 234 articles from the Web of Science. The findings show that scientists have focused their efforts on AMFs, whereas renewable energy sources have become a major research topic lately. Prospective technologies’ environmental benefits are being studied more than their economical features. Ampah et al. [4] conducted a bibliometric analysis of 583 scientific papers published between 2000 and 2020 using the Web of Science Core Collection and Scopus databases. According to the findings, the United States is making substantial contributions to the sector. The most investigated alternative shipping fuel has been discovered as liquefied natural gas. On the other hand, recent developments reveal that researchers are increasingly interested in methanol, ammonia, and hydrogen fuels. The research community has primarily focused on the potential of different AMFs as a replacement for conventional marine fuels to limit emissions from the shipping sector from an environmental, technical, and economic perspective, as evidenced by the frequently used keywords and relevant articles. To recapitulate, there is significant gaps that are the motivation of this research. Past studies used diverse methods such as MCDA, systematic review, and bibliometric review. However, only a few bibliometric studies on AMF have been conducted until the year 2021. Bibliometric studies analyses meta data extracted from scholarly databases, which are continuously updating new studies. A thorough, updated search of Scopus revealed no studies that conduct a comprehensive review of published research on AMF using bibliometric methods in the current year, 2022. Research trend analysis is required to suggest a future research direction. The present research fills this knowledge gap, conducting a bibliometric review of the AMF literature. Besides, few studies provided empirical finding on considerable criteria in choosing appropriate AMF. However, a comprehensive list of criteria could be beneficial for further research. It can be a significant input for MCDM-based assessment, which in turn will support management decision making.

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