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SELECTION OF ALTERNATIVE MARINE FUEL TECHNOLOGY BASED ON LITERATURE REVIEW BY APPLYING APPROPRIATE MULTI-CRITERIA DECISION-MAKING METHOD

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Abstract

The use of alternative fuel in ships can help alleviate high carbon emissions and adverse environmental consequences produced by the maritime industry. Due to the complexity of assessing many performance factors and lack of information, it is challenging for decision-makers to select the best sustainable alternative energy source for shipping from various options. Nevertheless, alternative energy decisions can be supported, and contradicting impacts can be analyzed with MCDM methodologies. This study focuses on applying decision-making processes for sustainable energy development concerns. A systematic review of published papers in the Scopus database on alternative fuel technologies and MCDM approaches from 2001 to 2021 has been conducted. All the selected articles were sorted by application area and process. In classifying the scientific journal articles and in-depth analysis, a SWOT analysis of MCDM techniques is offered. Convincing data support the conclusion that MCDM methods help decision-makers select appropriate fuel technology and are widely utilized in practice.

Keywords: MCDM; alternative fuel; sustainability; green shipping.

■ 1.0 INTRODUCTION

The maritime industry transports around 90 percent of international trade (by tonne-miles), consumes annually 330 metric tons of low-quality fossil fuels, e.g., Low Sulfur Heavy Fuel Oil (LSHFO) and Marine Diesel Oil (MDO) resulted in 31% of NOx, 4-9% of SOx, and 3-6% of CO2 emission pollutant to the atmosphere (Moshiul, Mohd Zaki & Abu Husain, 2019; Moshiul et al., 2021; Prussi et al., 2021). With the expansion of global trade, emissions from shipping are predicted to increase 250 percent by 2050 unless curbs are implemented (Cames et al., 2015). Hence, the shipping sector's decarbonization is inevitable and one of the most challenging tasks to achieve. In conjunction with the UN Paris Climate Agreement and Sustainable Development Goals, International Maritime Organisation (IMO) adopted the initial strategy for curbing Green House Gas (GHG) emissions from ships on 13 April 2018 with an ambitious target of plunging 70% carbon intensity and at least 50% of the total annual GHG emissions reduction from shipping by 2050, compared to 2008, while making strenuous attempts to phase them out as soon as feasible this century (IMO, 2018). Studies projected that while technical measures (i.e., engine up-gradation, ship's hull profile, propeller modification, etc.) can reduce a maximum of 20% air pollution from ships, only appropriate alternate fuel and energy sources can potentially reduce it 100% (DNV GL, 2019). Hence, alternative marine fuels adoption is an absolute certainty towards green shipping practice implementation.

Today, sustainability measurement is widely employed as a primary preventative tool for averting the environment's decline. However, contrasting goals are apparent in the energy sector. For example, the objectives to be met are frequently contradictory - lower energy prices for end-users, reduce energy dependency, including fossil fuel use, and assure energy security. When confronted with determining preferences and decisions must be made on several conflicting indicators of competing relevance, multi-criteria decision-making (MCDM) methods are advantageous.

Applying MCDM methodologies appears to be a flexible and transparent approach to resolving complex problems. It is a subfield of operations research that analyzes quantitative and qualitative criteria explicitly

considering selecting an appropriate transportation strategy that promotes efficiency while reducing costs and adverse environmental consequences. No one solution optimizes all objectives concurrently in a nontrivial multi-objective optimization problem. MCDM methods are increasingly being employed in decision-making about alternative fuels since they provide substantial benefits (Castro & Parreiras, 2020; Ha, Yang & Lam, 2019; Tripathy, Khambete, Chauhan, 2019; Wang et al., 2019). Moreover, MCDM approaches can assist energy policymakers in selecting the best solution independent of the evaluation process. As a result, MCDM techniques are increasingly being applied to address energy policy concerns in making decisions, setting goals, and looking.

■ 2.0 STUDY DESIGN

Systematic Literature Reviews (SLRs) are organized reviews that follow a defined search strategy to assure objectivity, thoroughness, and process repeatability. The procedure entails locating, assessing, and interpreting accessible research relevant to a specific subject (Castro & Parreiras, 2020). In this SLR, the search begins with Scopus, recognized as Elsevier's primary scientific database for transdisciplinary research literature and computational methodologies (Anjum et al. 2020; Yesmin et al., 2021). According to the Scopus website, its archive has over 25,000 actives, including 6,000 open access journals from more than 5,000 international publishers. This study limits source materials from the Scopus database.

2.1 Data Mining Strategy and Study Flow

A search of publications in the online Scopus database was conducted on 1 August 2021. Key themes of the investigation were "alternative fuel,"; "multi-criteria decision making," and "shipping" during the period of 2001–2021. The search was limited to only the papers published in English. The SLR has been conducted for research trend analysis. Publications were examined to understand better the MCDM methodologies utilized to grasp alternative fuel selection topics better. The scholarly articles then focused mainly on the studies concerning the shipping sector to identify the most used MCDM techniques. Since the primary goal of this study is to compare MCDM approaches, the results are limited to the shipping industry. Figure 1 illustrates the logical structure of the research.

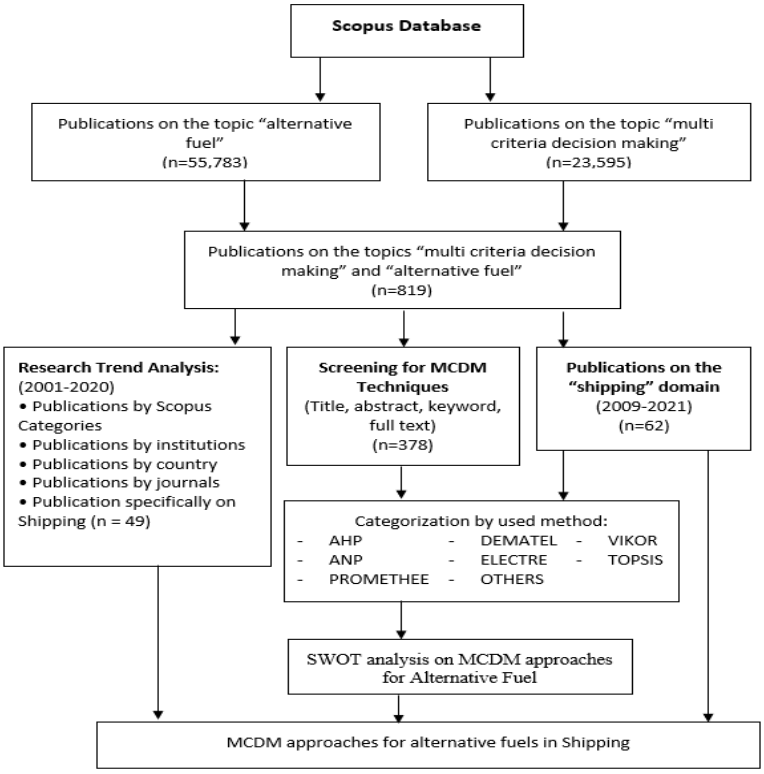

Figure 1: The Logical Flow of The Study

The following sections provide an overview of multi-criteria decision methods and a detailed analysis of

the topics "multi-criteria decision making" for "alternative fuel" in "Shipping" from the Scopus database. These were refined to papers focusing on the deployment of widely held MCDM techniques. Every manuscript was analyzed using its MCDM method and carefully vetted in Section 3.

■ 3.0 RESULT AND DISCUSSION

3.1 Basic Science Research

More than 55,000 publications on alternative fuel energy have been published in Scopus-indexed journals over two decades (Figure 2). In addition, there is a significant annual increase trend, with over 5,000 publications in the Scopus database on the topic of "alternative fuel" in 2020.

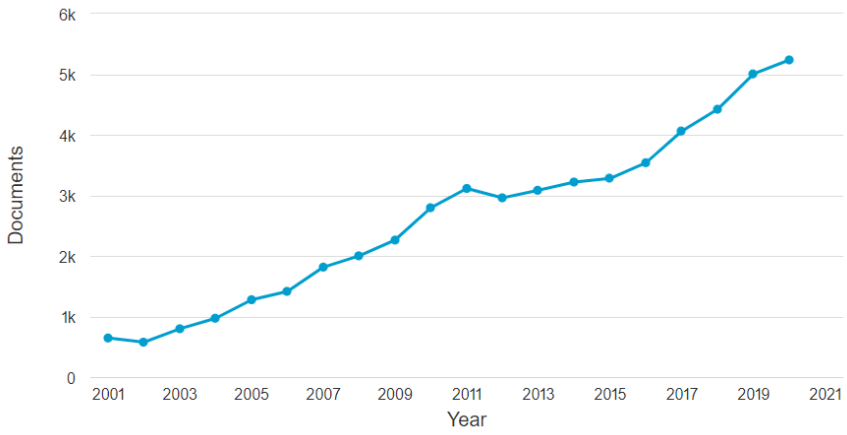

Figure 2: The Publications on "Alternative Fuel"

Multi-criteria decision analysis is gaining popularity due to its acceptance and wide range of applications. In the Scopus database, more than 23,000 scholarly articles have been written and published on the topic of "multi-criteria decision making" since 2000. Approximately half of all articles on this topic were published in the previous five years (Figure 3).

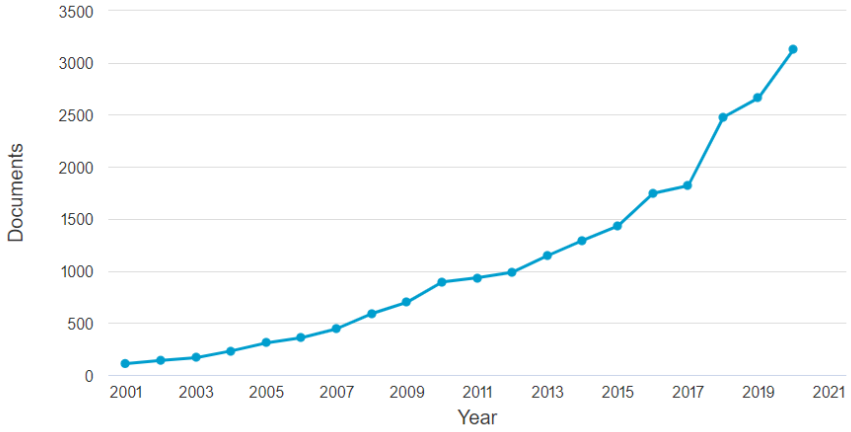

Figure 3: The Publications on "Multi-Criteria Decision Making"

Figure 4 illustrates the growing number of articles utilizing MCDM approaches for alternative fuel choices in the energy segment. This demonstrates the significance of MCDM methods for selecting viable alternative fuels in scientific and practical domains. The Scopus database has 819 publications on "multi-criteria decision making" and "alternate fuel." Over 60% of all papers on these topics have been published in the last five years.

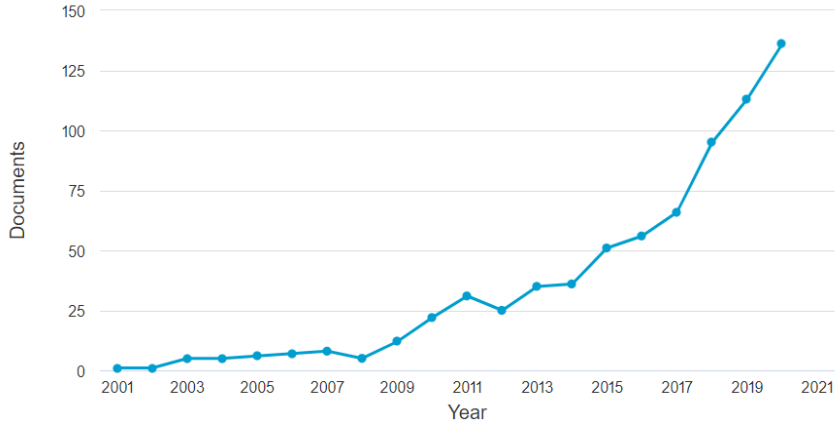

Figure 4: Publications on Topics "Alternate Fuel" and "Multi-Criteria Decision Making"

Most papers on alternative fuels that apply MCDM methods fall into the category of energy (396), environmental science (392), and engineering (390), as illustrated below pie chart in Figure 5. Other's category includes multidisciplinary, agriculture, biology, and medicine.

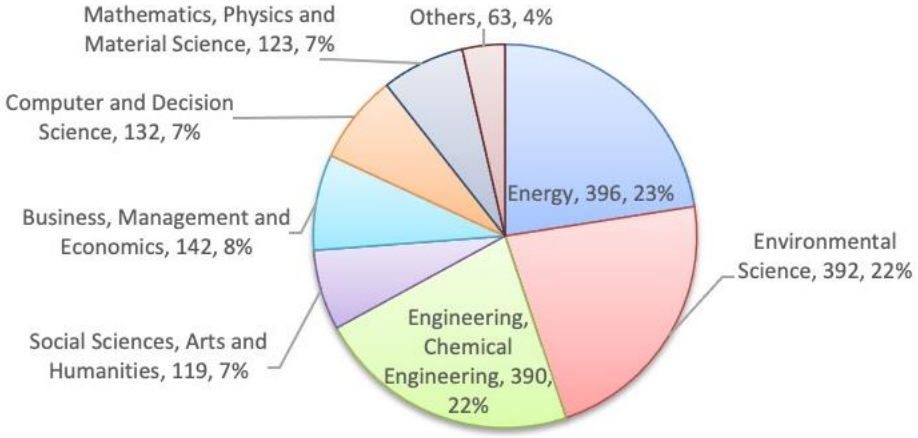

Figure 5: The Publications by The Scopus Categories on The Topics Of "Multi-Criteria Decision Making" and "Alternative Fuel," 2002–2020

Table 1 shows the highest top 10 institutions based on publications number on the topics. Among other higher education institutions, the University of Tehran (22), Hong Kong Polytechnic University (14), and Istanbul Teknik Universitesi (13) are pioneers in this field (Table 1).

Table 1: The Publications by Journals on The Topics of "Multi-Criteria Decision Making" and "Alternative Fuel," 2002–2020

Institutions	Number of Publications
University of Tehran	22
Hong Kong Polytechnic University	14
İstanbul Teknik Üniversitesi	13
Iran University of Science and Technology	12
Delft University of Technology	10
Imperial College London	10
University of Central Florida	9
Ghulam Ishaq Khan Institute of Engineering Sciences and Technology	9
K.S.Rangasamy College of Technology	9
Vellore Institute of Technology, Chennai	9

Figure 6 depicts the distribution of alternative fuel selections addressed by various countries utilizing MCDM techniques. Scientists from the United States (136), Iran (78), India (76), Turkey (68), China (62), and the United Kingdom (53) have published most papers on this subject. The figure does not include countries with less than 20 publications.

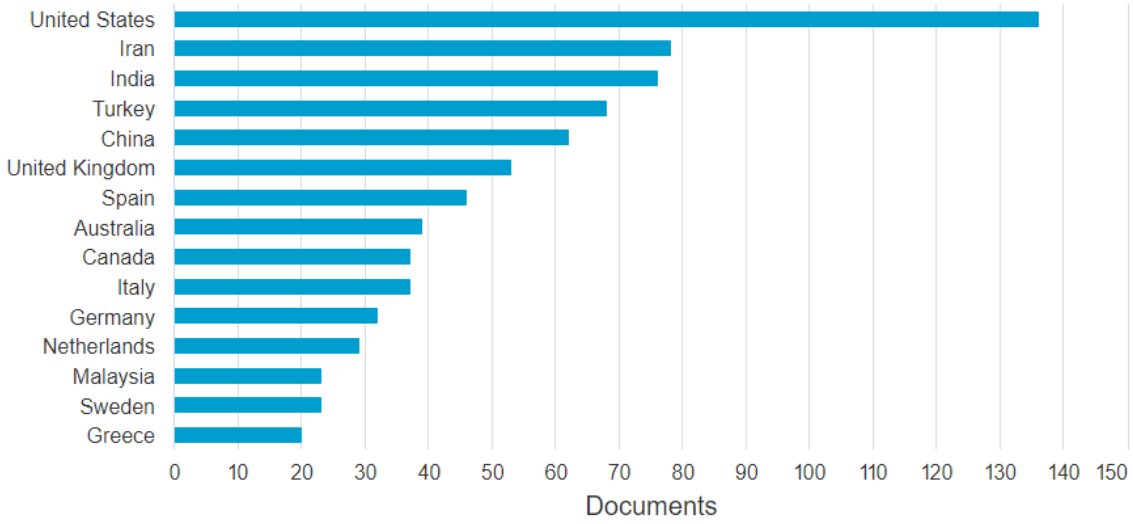

Figure 6: The Publications by Country on "Multi-Criteria Decision Making" and "Alternative Fuel," 2002–2020

Energy (48), Journal of Cleaner Production (46), Sustainability Switzerland (37), Energy Policy (31), and Renewable and Sustainable Energy Reviews (31) is the most renowned scholarly publications that publish works on this topic (31) (Table 2). The table lists the top 10 journals with more than 12 publications.

Table 2: The publications by journals on "multi-criteria decision making" and "alternative fuel," 2002–2020

Journals	Number of Publications
Energy	48
Journal Of Cleaner Production	46
Sustainability Switzerland	37
Energy Policy	31
Renewable And Sustainable Energy Reviews	31
Applied Energy	23
Energies	19
Renewable Energy	18
International Journal of Hydrogen Energy	14
Sustainable Energy Technologies and Assessments	13

The initial analysis of scientific publications revealed aspects of the development of alternative fuels in energy fuels. Additional comprehensive study is conducted on the scientific articles pertaining specifically to maritime shipping. Figure 7 depicts the evolution of Scopus-indexed articles on the topics of "multi-criteria decision making" and "alternative fuel" in the "Shipping" sector. It illustrates the MCDM methods' increasing popularity year after year, i.e., the number of publications on the topics mentioned above is constantly growing and has risen exponentially over the last four years. It is worth noting that scientists began using MCDM approaches for alternative fuel selection in the shipping sector very recently, with scholarly publications in the Scopus database dating only from 2009.

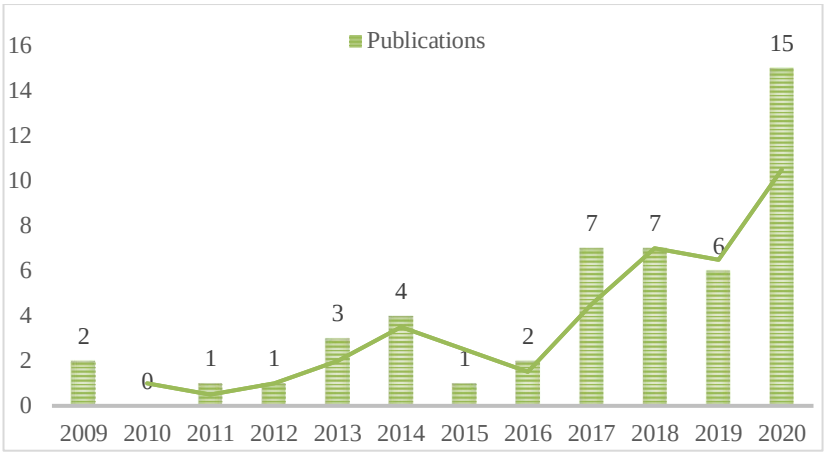

Figure 7: The Publications on "Multi-Criteria Decision Making," "Alternate Fuel," and "Shipping"

As per the research trend analysis, alternative fuel seems to be a promising area of research. The number of publications in the first quarter of 2021 is 15, which is already equivalent to the complete publication of the year 2020. The territories and journals most studies mostly employ MCDM methodologies to aid in decision-making on proper fuel selection.

4.2 Analysis of MCDM Approaches

Further screening of the publications was undertaken based on the research objective of identifying an appropriate MCDM approach. After screening the title, abstract, keywords, and full text, 378 articles were relevant and maintained for further research. Throughout the review, the following MCDM approaches were discovered (shown in Table 3: 1) Analytic Hierarchy Process (AHP), 2) Analytic Network Process (ANP), 3) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), 4) Elimination EtChoix Traduisant la REalite' (ELECTRE), 5) Preference ranking organization method for enrichment of evaluations (PROMETHEE), 6) VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), 7) Decision making trial and evaluation laboratory (DEMATEL) and others. Figure 8 shows the percentage distributions of the publications according to the MCDM technique.

Table 3: Number of papers based on MCDM techniques

	MCDM Techniques							
	AHP	ANP	TOPSIS	ELECTRE	PROMETHEE	VIKOR	DEMATEL	OTHERS
Number of Publication	140	29	91	8	43	30	11	26

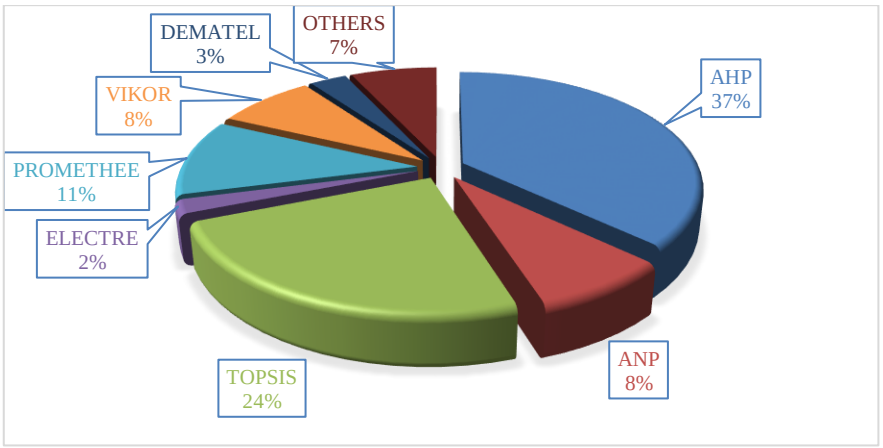

Figure 8: Percentage distribution of publications according to MCDM methods

Other MCDM techniques such as weighted sum method (WSM), stepwise weight assessment ratio analysis (SWARA), aggregate performance index (API), and Measuring attractiveness by a categorical-based evaluation technique (MACBETH) are also applied to resolve alternative fuel technology issues in a negligible amount totaling to 7%.

MCDM Method	Method's decision-making principal	Strengths	Weaknesses	Opportunities	Threats	Application domain
AHP	AHP is a systematic methodology for organizing and analyzing complicated judgments, as well as a precise method for quantifying decision criterion weights. Through pair-wise comparisons, the relative magnitudes of factors are estimated using the expertise of individual experts.	-Adaptable, intuitive, and checks inconsistencies -Problems are organized hierarchically, so each aspect significance becomes apparent. -Decision-making without prejudice	- Ranking inaccuracies - The technique of additive aggregation utilized may result in missing critical information. - Extra pairwise comparisons are required.	Recommended to integrate sensitivity analyses	Different criterion hierarchies may affect how weights are allocated	Natural resources and environment, Energy, Transportation, and supply chain, manufacturing, construction, performance-type problems, resource management, corporate policy and strategy, public policy, political strategy.
ANP	ANP constructs the decision issue by arranging several goals, criteria, and alternatives and comparing each requirement pair-wise to determine the optimal alternative.	-not necessary for elements to be independent. -Prediction is accurate because feedback improves priorities.	- Time-consuming - Uncertainty – not backed up - Difficult to persuade decision making	Integrating sensitivity analyses is recommended.	Different criterion hierarchies may influence weight allocation.	Construction, manufacturing, health, safety and medicine, transportation, and supply chain.
TOPSIS	The technique appraises the optimal option by directing distances to a positive and negative resolution.	The approach is relatively straightforward, and it remains constant regardless of the number of choice criteria and possibilities.	Correlations between criteria are not considered while calculating Euclidean distance. Additionally, vector normalization may be required to solve a multi-dimensional problem.	The method is easily adaptable to address a variety of energy sustainability challenges.	Not observed	Supply chain management, engineering, manufacturing systems, business, and marketing, environmental, human resources, and water resources management.
ELECTRE	ELECTRE technique develops solutions by determining outranking connections between two alternatives. It determines optimal choice based on the greatest advantages and the fewest possible conflicts.	Even when data is missing, the approach can yield a solution.	Time-consuming Without software, the process is computationally complex due to the complicated evaluation techniques involved.	Beneficial to apply and compare various methodologies' outcomes to ensure the assessment's strength and dependability.	Probable calculation errors due to complex computation procedure	Energy, economics, environmental, water management, and transportation problems.

PROMETHEE	PROMETHEE is an outranking methodology that solves a choice problem by evaluating options while taking their divergence from decision criteria into account.	The technique does not necessitate score normalization.	Weights assigned to criteria must be reviewed using a different tool. Furthermore, it is necessary to define the Preference function.	Advantageous to apply and compare various approaches' outcomes to ensure the assessment's strength and dependability.	Calculation errors are conceivable due to highly complex computation procedures.	Environmental, hydrology, water management, business, and finance, chemistry, logistics, and transportation, manufacturing and assembly, energy, agriculture.
VIKOR	The technique determines the optimal solution by comparing alternatives in terms of their degree of similarity to the ideal solution.	It is a modernized version of the TOPSIS approach.	When confronted with a conflicting issue, the method gets challenging.	Beneficial to apply and compare various methodologies' outcomes to ensure the assessment's strength and dependability.	Probable calculation mistakes	Civil engineering and infrastructure, supply chain management, energy
DEMATEL	DEMATEL is regarded as an efficient tool for identifying the components of a complicated system's cause-effect chain. It is concerned with examining the interdependence of elements and identifying the key ones using a visual structural model.	It is a useful technique for gathering a group of ideas and analyzing structural problems.	Traditional DEMATEL is only capable of solving one group's perception.	It employs digraphs, which are more useful than graphs with no direction.	Faulty outcome occurs due to vast range of obstacles.	Safety measurement, Construction, manufacturing, asportation, and supply chain, supervisory control systems, Marketing strategy, and customer behavior

Table 4: MCDM Techniques – SWOT analysis and area of applications (multiple sources including Aghelie et al., 2016; Pommiera et al., 2007; Yannis et al., 2020)

It should be mentioned that each MCDM technique has distinct advantages and disadvantages depending on the application area. Thus, based on the phenomenon of interest in this study, a more detailed investigation was conducted in the shipping area to ascertain the most often employed MCDM methodologies.

3.1 Analysis of Articles in Shipping Alternative Fuel

Articles about the shipping industry can be discovered in the Scopus database only as of 2009 for alternative fuel technologies that utilize MCDM methodologies. From 2009 to 2021, an analysis of published articles in shipping on alternative fuel technology reveals that AHP is the most frequently used technique, followed by TOPSIS, as illustrated in Figure 9.

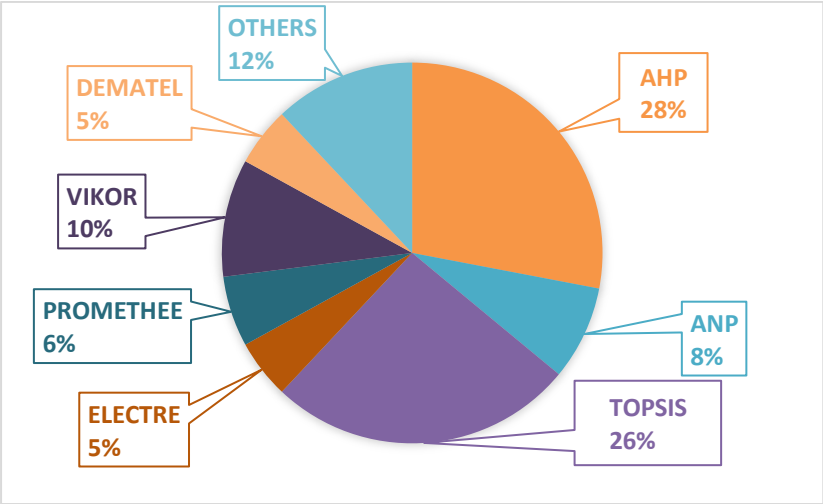

Figure 9: Percentage distribution of publications in shipping according to MCDM methods

Furthermore, Table 5 summarizes the significant studies in shipping that have used various types of MCDM approaches in dealing with alternate fuel oils. Additionally, the data indicate that AHP and TOPSIS are the most often used alternative fuel research in the shipping sector.

Source	AHP	ANP	TOPSIS	ELECTRE	PROMETHEE	VIKOR	DEMATEL
Wang, Chen & Tung (2021)	√	√					
Rehman & Ali (2021)	√						
Bui et al. (2021)	√		√				
Jeong et al. (2019)	√		√				
Sercan & Çelikoglu, (2019)	√		√				
Wang et al. (2019)	√					√	
Ramesh & Sakthivel, (2018)	√				√		
Sivaraja, Sakthivel & Warke, (2018)	√		√		√		
Özdemir & Güneroğlu, (2018)	√		√				
Sivaraja & Sakthivel, (2017)	√		√	√		√	
Osorio-Tejada, Llera-Sastresa & Scarpellini, (2017)	√						
Ren & Lützen (2015)	√					√	
Sakthivel et al., (2014)	√		√				
Sakthivel & Ilangkumaran, (2013)	√			√			

Sakthivel et al., (2013)	√		√				√	
Sakthivel et al., (2013)	√		√					
Tzeng & Huang, (2011)	√	√	√	√	√		√	√
Ramachandranpillai & Arock, (2021)		√						
Stokic, Vujanovic & Sekulic, (2020)		√	√					
Chen & Ren, (2018)		√	√					
Rehman & Ali, (2021)			√					
Aspen & Sparrevik, (2020)			√					
Ren & Liang, (2017)			√					
Dagkinis & Nikitakos, (2016)			√					
Strantzali et al., (2018)					√		√	
Lin, Chen & Tzeng, (2009)								√

Table 5: MCDM techniques used for alternative fuels in shipping

■ 4.0 CONCLUSIONS

MCDM approaches to rank energy sources, technologies, and aspects according to numerous goals and criteria give a solid solution strategy for complicated multi-dimensional alternative fuel technologies and decision-making. As a result, considerable research in the literature used MCDM approaches to tackle energy policy and decision-making challenges. This paper carried out a unique literature review to provide insight into different MCDM techniques application for alternative fuel and future research suggestions. The study further sheds light on the research trend of MCDM and alternative fuels specific to the shipping industry. The review of relevant scientific studies from the Scopus database from 2000 to 2021 has been analyzed by year of publication, journals, territories, and institutes involved. The finding showed that Studies on MCDM and alternative fuel, regardless of industry, utilize AHP and TOPSIS methods the most. Similarly, the shipping industry-focused studies are also using these two methods for alternative fuel selection. To researchers' best knowledge, this is one of the first studies of this kind specific to the shipping industry in determining the appropriate MCDM method for selecting alternative fuel oil.

However, there are certain limitations to this study that can be addressed by more research. The Scopus database was used exclusively for data extraction in this study. Additional scholarly databases may be considered in future studies. While a review of the existing literature demonstrates that MCDM methods are more applicable to complex decision-making in the alternative fuel sector, relatively few studies focus on the shipping sector. The current study fills this knowledge gap. AHP and TOPSIS may be used as an MCDM approach in alternative fuel research for the green shipping industry, according to the findings of this study.

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