Assessing Success Factors to Adoption of Alternative fuels in Maritime Transport

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ABSTRACT

There is increasing pressure on the maritime transportation industry to reduce its environmental effect and change to alternative fuels. The adoption of alternative fuels in maritime transport is influenced by crucial success variables that are examined in this research article. The study identifies and assesses important drivers in the technological, economic, regulatory, and social domains through a thorough examination of the body of existing literature and empirical data analysis. The importance of technological elements in encouraging adoption is studied, encompassing developments in fuel technology, vessel retrofitting, and infrastructural compatibility. Economic factors that affect stakeholders' decision-making processes are examined, including cost competitiveness, investments in new technology, and financial incentives. The study assesses worldwide policies, industry standards, and regulatory frameworks that control the use of alternative fuels. It emphasizes the significance of consistent and supporting rules. The impact of social elements on acceptability and implementation in the marine industry is evaluated. These aspects include stakeholder participation, public awareness, and collaboration. The results indicate that the effective adoption of alternative fuels in maritime transport requires a cooperative approach that integrates technological innovation, economic feasibility, strong regulatory support, and active stakeholder participation. Policymakers, business executives, and researchers can use the research's practical insights to promote sustainable practices and a greener maritime sector.

1. INTRODUCTION

The maritime transport is an irreplaceable element of the world trade supporting the exchange of goods and commodities between countries that are separated by oceans. But, at the same time this industry creates significant pollution in terms of environmental pollution present mainly fossil fuels. As the effects of climate change and air pollution grow, the demand for an alternative sustainable solution has been higher. One of the most important measures to prevent these environmental impacts is adoption of alternative fuels, including ammonia, hydrogen, biofuels, and liquefied natural gas (LNG). The goal of this paper is to evaluate the primary drivers behind successful alternative fuel uptake in maritime segments, and by extension, assess the cost factors that drive those changes. The purpose of this paper is to use the ENTROPY method (as MCDM method) and ARAS method as well for a structured and objective evaluation of factors following this.

Nowadays, the sea industry could be a critical donor to worldwide outflows. Concurring to the Universal Oceanic Organization (IMO), sea transport accounts for roughly 2.5% to 3% of worldwide CO2 outflows. The industry's outflows of NOx and SOx are especially concerning, with ships contributing approximately 15% of worldwide NOx and 13% of worldwide SOx emanations. These poisons have serious natural and security impacts, contributing to corrosive rain, breathing issues, and climate alter. In reaction to these challenges, worldwide controls have ended up more rigid. The IMO has actualized directions such as the 2020 Sulfur Cap, which limits the sulfur substance in marine powers to 0.5%, down from the past 3.5%. Moreover, the IMO's starting GHG technique points to decrease CO2 outflows per transport work by at slightest 40% by 2030 [18], compared to 2008 levels, and to divide add up to yearly GHG outflows by 2050. In spite of these endeavors, the selection of elective powers has been moderate, prevented by components such as high costs, need of foundation, and mechanical challenges.

The long run of the sea industry pivots on the productive selection of elective powers. Progressed biofuels, LNG, hydrogen, and smelling salts are being investigated for their potential to altogether diminish outflows. For occurrence, LNG can decrease CO2 emanations by up to 20%, NOx by up to 85%, and for all targets and purposes distribute with SOx and particulate matter outflows. Hydrogen and smelling salts, when delivered from renewable sources, offer the potential for zero-carbon shipping, which adjusts with worldwide decarbonization targets. Be that as it may, transitioning to these elective fills requires significant assumption in modern advances and framework. The advancement of fuel cells, half variety energy frameworks, and other imaginative innovations will be basic. Additionally, building a strong supply chain and refuel framework for these elective powers is fundamental for their broad appropriation. Administrative systems are anticipated to ended up progressively rigid, driving the industry towards more maintainable improves. Collaboration among industry partners, policymakers, and analysts will be imperative in overcoming the challenges related with this move. By tending to the financial, mechanical, and administrative barriers, the oceanic industry can make noteworthy strides towards supportability. The productive selection of elective fills will not as it were decrease the natural effect of sea transport but too upgrade the industry's long-term viability and resilience.

This research adds to current literature on the problems encountered in the implementation of success factors for adopting alternative fuels in these nations by addressing the following research questions:

I. What are the key findings from the assessment of success factors for adopting alternative fuels in maritime transport?
II. What are the main barriers (e.g., technological, financial, or governmental) to the adoption of alternative fuels in maritime transport?
III. How do these findings contribute to the overall understanding and future direction of the maritime industry’s shift towards alternative fuels?

This investigation endeavors to answer the above questions through the accompanying objectives:

I. The use of alternative fuels in maritime transportation is dependent upon several key elements, such as regulatory backing, financial incentives, technological progress, stakeholder cooperation, and heightened environmental consciousness
II. High initial prices, technological constraints, inadequate infrastructure, a lack of standardized rules, and uncertainty about future government policies are the primary barriers to the use of alternative fuels in maritime transportation.

III. In order to help policymakers and industry stakeholders handle the financial, technological, and regulatory issues and enable a more strategic and successful transition towards alternative fuels in the maritime industry, these findings emphasize the crucial areas that require attention.

The subsequently section of this paper are structured are follows. Introduction to Section 1. Related to research papers Literature reviewe in Section 2. In Section 3 is Factors. Methodology is in Section 4

2. LITERATURE REVEIVW

a) *Technological Advancements and Compatibility & Integrations*

Compatibility and technological progress are essential for making it easier to integrate alternative fuels into the marine sector [1]. Engine technology advancements are increasing efficiency and lowering emissions. One example is the creation of dual-fuel engines, which can run on both traditional fuels and fuel alternatives like LNG or biofuels [2]. Securing compatibility with current vessels and infrastructure is crucial to facilitate the extensive integration of alternative fuels. Combined integration is ensured by building standard procedures for fuel handling and storage and adapting older ships with new fuel systems [14]. To enable the safe and effective use of alternative fuels, new materials and safety regulations are also being developed. Fuel management and operational efficiencies can be optimized through the use of digitalization and automation. Predictive analytics and real-time monitoring systems facilitate improved decision-making, maintenance scheduling, and environmental regulation compliance. The sustainability and viability of alternative fuels in the maritime industry will be progressively improved as these technologies advance [11]. In general, in order to get over technical barriers and realize the full potential of alternative fuels, technology improvements and compatibility initiatives are critical. The marine sector can significantly lower emissions and operating costs while moving toward a more sustainable future by investing in innovation and making sure that it works with the current infrastructure
[19].

b) *Cost-Effectiveness and Financial Incentives*

Using alternative fuels in the maritime sector is very cost-effective and is encouraged by a number of financial incentives. When considering operating expenses, alternative fuels like LNG, biofuels, hydrogen, and ammonia are frequently less expensive than conventional marine fuels. Long-term financial benefits are also provided by them, including lower fuel and maintenance costs, improved energy efficiency, and stable fuel prices. Alternative fuels are made even more appealing by financial incentives [16]. To reduce the upfront costs of fuel technology upgrades and infrastructure development, governments offer grants, subsidies, and tax breaks. By providing financial advantages for utilizing cleaner fuels, emissions reductions are encouraged by emissions trading programs and carbon credits. Cost reductions and improved operational efficiency are also achieved through practical incentives such as reduced port fees and preferential berthing for ships using alternative fuels [15]. In conclusion, the marine industry's shift to alternative fuels is supported by a mix of financial incentives and cost-effectiveness. By lowering operating expenses and encouraging sustainability and loyalty to environmental laws, these actions set the sector up for long-term financial and ecological gains [19, 15].

c) *Emissions Reduction and Sustainability Alignment*

When compared to traditional fuels, the use of alternative fuels in the maritime sector significantly reduces emissions of greenhouse gases and air pollutants [4]. Fuels with reduced carbon dioxide emissions, such as LNG, biofuels, hydrogen, and ammonia, help to mitigate the effects of climate change. In addition, they emit very little particulate matter (PM), nitrogen oxides (NOx), and sulfur oxides (SOx), improving air quality and lowering health dangers.
Alternative fuels support sustainability objectives by encouraging energy efficiency and the use of renewable resources, in addition to lowering emissions [19]. While hydrogen and ammonia can be created using renewable energy sources, making them carbon-neutral or even carbon-negative possibilities, biofuels are derived from sustainable biological sources. These fuels help in the maritime sector's efforts to switch to greener energy sources and promote international sustainability projects [3]. In general, the use of alternative fuels in maritime transportation not only complies with broad sustainability goals but also enhances environmental performance by lowering emissions [11]. Alternative fuels are essential to developing a more environmentally friendly and sustainable marine sector since they encourage cleaner air and lessen dependency on fossil fuels [5].

d) *Supportive Regulations and Compliance Incentives*

Regulations that are beneficial and incentives for compliance greatly aid the maritime industry's shift to alternative fuels. Important international laws, like the 2020 sulfur quota imposed by the International Maritime Organization (IMO), require a decrease in the sulfur content of maritime fuels, which encourages the use of cleaner substitutes like LNG and biofuels [6]. In addition to lowering air pollution, these laws lay the groundwork for later actions that will focus on carbon intensity and greenhouse gas emissions. Emissions reduction credits and emissions trading programs also offer financial incentives for cutting emissions. Ships that utilize alternative fuels to reduce their emissions can earn credits or sell extra allowances, which incentivizes them to adopt cleaner technologies [20, 18]. In order to save costs and improve operational efficiency, port authorities are also making a contribution by providing operational incentives like lowered port fees and priority berthing for ships using alternative fuels.

e) *Fuel Availability and Logistical Support*

The availability of these fuels and the logistical support necessary to guarantee their smooth integration into shipping operations are prerequisites for the broad use of alternative fuels in the marine sector [12]. The industry is facing difficulties in building a strong and dependable supply chain for substitutes including LNG, hydrogen, biofuels, and ammonia as demand for greener fuels rises [9, 13]. The availability of fuel is progressively increasing as major ports worldwide build the infrastructure required to provide alternative fuels. The production and distribution of hydrogen and biofuels are seeing growth in investment, while LNG bunkering facilities are proliferating [8]. In order to guarantee that ships can obtain alternative fuels wherever they operate, this growing infrastructure is essential. Additionally, logistical support is changing to satisfy industrial demands

[9]. An effective supply chain requires coordinated efforts from fuel producers, port authorities, and transportation firms. Purchasing fueling stations, storing facilities, and transportation networks are essential parts of this infrastructure. Furthermore, cutting-edge logistics management systems and digital platforms are being created to optimize fuel distribution and guarantee prompt, economical delivery [7]. In addition to providing support for the current fleet, the development of alternative fuel infrastructure also stimulates investment in new ships built to run on these fuels. The maritime industry will be in a better position to switch to sustainable energy sources, lessening its environmental impact and coordinating with the global decrease of emissions, as logistical assistance improves and fuel availability becomes more reliable [19].

f) *Industry Collaboration and Training & Education*

The adoption of alternative fuels in the maritime sector is greatly aided by industry collaboration. Overcoming obstacles and promoting sustainable practices require collaboration between shipowners, fuel providers, technology developers, and regulatory agencies [21, 12]. Through the sharing of best practices, resources, and information, collaborative initiatives aim to expedite the development and application of alternative fuel technology. Maritime workers must be adequately trained and educated in order to make the switch to alternative fuels. Thorough training programs guarantee that engineers, crew members, and operational personnel with the abilities and know-how required to handle, store, and use alternative fuels safely [9, 11, 12]. This entails putting best practices for fuel economy and emissions reduction into practice as well as comprehending the special characteristics of fuels like LNG, hydrogen, and biofuels [16]. Education programs also encourage a sustainable culture in the maritime sector and increase public knowledge of the advantages of alternative fuels. The maritime sector can successfully manage the hurdles of switching to cleaner energy sources while optimizing the environmental and financial benefits of alternative fuels by cultivating a staff that is well-trained and encouraging industry collaboration.

3. FACTORS

The table below (Table 1) defines some of the success factors required for successful adoption of alternative fuels in maritime industry.

S.NO	FACTORS	DESCRIPTION	REFERENCES
I	Decarbonization	The procedure for lowering the amount of carbon dioxide (CO2) released into the atmosphere as a result of human activity, especially when fossil fuels like coal, oil, and natural gas are burned [21].	A Comparative Review of Alternative Fuels for the Maritime Sector: Economic, Technology, and Policy Challenges for Clean Energy Implementation by (Yifan Wang and Laurence A. Wright)
II	Regulatory compliance (RE) Opportunity cost	Regulations designed to guarantee safe, secure, and ecologically conscious shipping activities.	Alternative Fuel Selection Framework toward Decarbonizing

	(OC) Impact on the ecosystem	When making decisions, it refers to the possible gains or profits from selecting one option over another. When making decisions, it alludes to the potential rewards or gains from choosing one course of action over another [20].	Maritime Deep-Sea Shipping (Alam Md Moshiul, Roslina Mohammad and Fariha Anjum Hira)
III	Safety Global Availability Supply Capacity Durability Adaptability	When evaluating new naval technologies, safety at sea and onboard ships is a critical consideration. The simplicity and widespread use of a fuel on a worldwide scale is referred to as global availability. (LNG is widely used these days.) Global availability and fuel supply capacity are closely correlated. This is because there will be a huge supply of a fuel if a significant number of ships use that particular type of fuel. The ability of an alternative fuel to be used over a longer amount of time is referred to as durability. The viability of adapting modern ships with alternative fuel systems (i.e., how simple it is to adapt the new fuels) [18].	Assessment of Selected Alternative Fuels for Spanish Navy Ships According to Multi-Criteria Decision Analysis (Rocio Maceiras Victor Alfonsin, Miguel. Alvarez-Feijoo and Lara Llopis)
IV	Fuel availability Vessel safety	Fuel accessibility in the marine supply chain, including both conventional and renewable fuels, as well as the potential and difficulties associated with switching to more environmentally friendly fuel sources. Ensuring the safe and effective transportation of cargo across international waters [9].	Green fuels - A new challenge for marine industry Author links open overlay panel Turcanu Andra Luciana Marcu, Carmen Gasparotti, Eugen Rusu
V	Reliability	A criterion used to assess an alternative energy source's resistance and robustness to changes in external circumstances as well as its	Selection of sustainable alternative energy source for shipping: Multi-criteria decision

	Energy storage efficiency Infrastructure	independence from those conditions is called reliability. Fuel power density and refuel frequency are used to measure the energy storage efficiency criterion. The facilities necessary to establish alternative energy sources, such as marine fuels for ship propulsion, are referred to as infrastructure [19].	making under incomplete information (panelJingzheng Ren a, Marie Lützen b)
VI	Air pollution	How significantly reduce its environment and adverse impacts of air pollution on human health and the environment [16].	A Comprehensive Multicriteria Evaluation Approach for Alternative Marine Fuels (Eleni Strantzali, Georgios. Livanos and Konstantinos Aravossis)

VII	Acquisition cost GHG emission reduction Technical maturity Capital cost Public acceptance	Total cost of purchasing products and services The potential for alternative energy sources to reduce greenhouse gas emissions. GHG mostly consists of N2O, CH4, and CO2. Because of the cumulative learning curve effects, the alternative energy technology is implemented to a faultless level in the shipping industry. Initial investment cost per installed engine capacity for the alternative propulsion technology engine and associated on-board infrastructure, including fuel tanks, pipes, sensors, and alarm systems The extent to which the general public and society as a whole accept the alternative energy source. Public perceptions of the environmental and safety effects of energy sources are influenced in part by information disseminated through social media and governmental channels [3]	Towards a prioritization of alternative energy sources for sustainable shipping (Ziaul Haque Munim Mohammed Mojahid Hossain Chowdhury, Hasan Mahbub Tusher, Theo Notteboom c,d,e)

Table 1.

4. METHODOLOGY

A thorough data collection strategy is needed to assess the success factors for the use of alternative fuels in maritime transport, ensuring that every relevant factor are taken into explanation. The work at hand entails the collection of qualitative and quantitative data from several sources in order to get the intricate interactions between technological, economic, regulatory, and environmental aspects that impact the adoption of alternative fuels within the maritime sector.

I. *Data Collection Explanation*:

The first step in data collection is conducting a thorough literature review. This involves reviewing previous research papers, publications, and reports on alternative fuels for marine transportation.

The evaluation of the literature lays the groundwork for understanding the present state of knowledge and aids in identifying the critical success factors that have already been studied. Academic journals, industry studies, and government publications are essential sources. The focus of primary data collecting can be guided by identifying gaps in the current research, which is another benefit of this step.

II. *Surveys and Questionnaires*:

Surveys and Questionnaires work effectively for gathering quantitative data from a sizable sample of participants. A wide range of people, including ship owners, operators, and marine experts, can get these. The questions should to be created with the purpose of gathering data on the different kinds of alternative fuels that are currently in use, as well as the variables that affect fuel selection, cost concerns, regulatory compliance, and environmental impact. Surveys can also be used to determine how well-known and accepted alternative fuels are in the sector.

III. *Case Studies*:

Case studies of particular ports or maritime enterprises that have embraced alternative fuels offer in-depth perspectives on practical implementations. Through the analysis of these cases, scholars can distinguish the elements that facilitated the effective execution, the obstacles encountered, and the results attained. Case studies provide real-world examples and insights that can be helpful for other industry participants thinking about making comparable changes.

IV. *Data from Maritime Database*:

Quantitative information on fuel consumption, emissions, fleet characteristics, and shipping routes can be found in maritime databases, including those maintained by the International Maritime Organization (IMO) and the shipping industry. These databases can be used for long-term trend analysis, performance comparisons between various fuel types, and evaluations of the effects of regulatory changes on fuel consumption. Information obtained from these sources is useful for comparing against global standards and comprehending the larger industry trends

V. *Method*:

Two strategies used in Multi-Criteria Decision Making (MCDM) to assess and rank options based on many criteria are the ENTROPY method and the ARAS (Additive Ratio Assessment) method [17]. Here's a quick rundown of each technique:

(a) ENTROPY Method

Based on the quantity of information each criterion offers, the weights of the criteria are determined using the ENTROPY approach. It includes the following steps and gauges the disarray or ambiguity in the decision-making process:

(i) A matrix of decision criteria Construction: With the use of the following equation, the decision matrix—which is denoted by D and comprises of xij values-is produced.

In accordance with the jth criterion in equation, the values of the ith alternative are expressed by the xij values. The variables i and j represent the number of choice possibilities (i = 1, 2..., m) and evaluation criteria (j = 1, 2..., n).

$$D = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Factors	Decarbonization	Regulatory Co	Opportunity c	Impact on the	Safety	Global Availal	Supply Capaci	Durability	Adaptability	Fuel availabil	Vessel Safety	Reliability	Energy storage	Infrastructure	Air pollution	Acquisition co	GHG Emission	Technical mat	Capital Cost	Public acceptanc
Decarbonization	6	3.75	3.25	4.75	3.75	3.5	3.5	2.75	3.25	3.75	3.25	3.25	3.25	3.5	4.25	3	4.25	3.25	2.5	3.5
Regulatory Compliance	3.75	6	3.25	2.75	3.75	3	3	3.25	3.5	3.5	3.75	3.75	3.25	3.25	4	3.25	3.75	3.5	3.25	3.25
Opportunity cost	3.5	3	6	3	3	3.25	3.5	2.5	3.25	3	3.25	2.75	2.5	2.75	3	3.25	3	3.5	3.5	3
Impact on the ecosystem	4.75	3	3.25	6	4	3.75	3	3.75	3	3.5	3.75	3	3	3.5	4.5	2.5	4.25	3.25	2.75	3.25
Safety	3.5	3.75	3	4.25	6	2.75	2.5	3.75	3.75	3.5	4.75	4	3.75	3.5	3.5	2.75	3.75	3.5	3	3.75
Global Availability	3.75	3.25	3.5	3.75	2.75	6	4	3	3	4.25	3.5	3.25	3	3.5	2.5	2.75	2.5	3	3.25	3.25
Supply Capacity	3.5	3.25	3.25	3	2.5	3.75	6	3	3.5	4	3.75	3.75	3.25	3.75	2.75	3.25	2.5	3.5	3.25	3
Durability	2.75	3.25	3	3.5	4	3	2.75	6	3.5	2.75	4	4	3.5	3.75	3.5	3.25	3	3.5	3.5	3.75
Adaptability	3.75	3.5	3.75	3.5	3.5	3.25	3.5	3.5	6	3	4	4	3.5	3.75	3	3	3.25	4.25	3	3.75
Fuel availability	3.75	3.5	3.25	4	4	4.25	3.5	3	3.5	6	3.75	3.5	3.5	3.75	3.75	2.75	3.75	3.25	3.25	3
Vessel Safety	3.5	4.25	3	4	4.5	3.5	3.5	3.75	4	4.25	6	3.75	3.75	3.5	3.75	3.25	3.5	3.5	3.5	4.25
Reliability	3.75	4	3	3.5	4.25	2.75	3.5	3.75	3.5	4.25	4	6	3.75	3.75	4.25	2.75	3.75	4	3	3.5
Energy storage efficiency	3.5	3.25	3	3.25	3.75	3	3.75	3.75	3.75	4	3.75	3.75	6	4	3	3	2.75	3.75	3.75	3.75
Infrastructure	3.5	3.25	3	3.25	3.75	3.25	4	4	4	3.5	3.25	3.5	3.75	6	3.25	3.25	3.5	3.5	3.25	3.75
Air pollution	4.75	4	3.25	4.75	3.75	3	2.75	3.25	3.75	4	3.75	3.5	3.25	3	6	3	4.25	3.5	3.25	3.75
Acquisition cost	3.25	3	3.25	2.75	2.75	2.75	3.25	2.75	3.25	3	3	2.75	3	3.25	3.25	6	3.5	2.75	3.75	3.25
GHG Emission reduction	4.25	4	3.25	4.25	3.75	2.5	2.75	3.5	3.5	3.75	3.25	3.5	2.75	3.25	4.25	3	6	3.75	3	3.5
Technical maturity	3.25	4	3.25	3.25	3.5	3.25	3.5	3.5	3.75	3.5	3.5	3.75	3.75	3.75	3.5	3	3.5	6	3.25	3.5
Capital Cost	2.75	3.25	4.25	2.75	3.25	3.25	4	3.25	3.25	3.25	3.5	2.5	3.5	3.5	3.5	3.75	3.25	3.25	6	3.75
Public acceptance	3.5	3.5	3	3.5	3.75	3.5	3	3.25	3.25	3	3.75	3.5	3.75	3.5	3.5	3.25	3.25	3.5	3.25	6

Table 2. Creation of decision matrix

(ii) Normalization of Decision Matrix: Equation (ii) is used to normalize the values of the criterion that have distinct elements in the problem, converting them to values in the interval [0, 1].

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Factors	Decarbonizati	Regulatory	Opportuni	Impact on	Safety	Global Ava	Supply Cap	Durability	Adaptabilit	Fuel availa	Vessel Saf	Reliability	Energy sto	Infrastruct	Air polluti	Acquisition	GHG Emiss	Technical	Capital Co	Public accept
Decarbonization	0.08	0.051546	0.04797	0.064407	0.050505	0.052045	0.050542	0.039711	0.044983	0.050847	0.043046	0.045296	0.046595	0.048276	0.058219	0.046875	0.059649	0.045139	0.037175	0.0482759
Regulatory Compliance	0.05	0.082474	0.04797	0.037288	0.050505	0.04461	0.043321	0.046931	0.048443	0.047458	0.049669	0.052265	0.046595	0.044828	0.054795	0.050781	0.052632	0.048611	0.048327	0.0448276
Opportunity cost	0.04666667	0.041237	0.088561	0.040678	0.040404	0.048327	0.050542	0.036101	0.044983	0.040678	0.043046	0.038328	0.035842	0.037931	0.041096	0.050781	0.042105	0.048611	0.052045	0.0413793
Impact on the ecosystem	0.06333333	0.041237	0.04797	0.081356	0.053872	0.055762	0.043321	0.054152	0.041522	0.047458	0.049669	0.041812	0.043011	0.048276	0.061644	0.039063	0.059649	0.045139	0.040892	0.0448276
Safety	0.04666667	0.051546	0.04428	0.057627	0.080808	0.040892	0.036101	0.054152	0.051903	0.047458	0.062914	0.055749	0.053763	0.048276	0.047945	0.042969	0.052632	0.048611	0.04461	0.0517241
Global Availability	0.05	0.044674	0.051661	0.050847	0.037037	0.089219	0.057762	0.043321	0.041522	0.057627	0.046358	0.045296	0.043011	0.048276	0.034247	0.042969	0.035088	0.041667	0.048327	0.0448276
Supply Capacity	0.04666667	0.044674	0.04797	0.040678	0.03367	0.055762	0.086643	0.043321	0.048443	0.054237	0.049669	0.052265	0.046595	0.051724	0.037671	0.050781	0.035088	0.048611	0.048327	0.0413793
Durability	0.03666667	0.044674	0.04428	0.047458	0.053872	0.04461	0.039711	0.086643	0.048443	0.037288	0.05298	0.055749	0.050179	0.051724	0.047945	0.050781	0.042105	0.048611	0.052045	0.0517241
Adaptability	0.05	0.04811	0.055351	0.047458	0.047138	0.048327	0.050542	0.050542	0.083045	0.040678	0.05298	0.055749	0.050179	0.051724	0.041096	0.046875	0.045614	0.059028	0.04461	0.0517241
Fuel availability	0.05	0.04811	0.04797	0.054237	0.053872	0.063197	0.050542	0.043321	0.048443	0.081356	0.049669	0.04878	0.050179	0.051724	0.05137	0.042969	0.052632	0.045139	0.048327	0.0413793
Vessel Safety	0.04666667	0.058419	0.04428	0.054237	0.060606	0.052045	0.050542	0.054152	0.055363	0.057627	0.07947	0.052265	0.053763	0.048276	0.05137	0.050781	0.049123	0.048611	0.052045	0.0586207
Reliability	0.05	0.054983	0.04428	0.047458	0.057239	0.040892	0.050542	0.054152	0.048443	0.057627	0.05298	0.083624	0.053763	0.051724	0.058219	0.042969	0.052632	0.055556	0.04461	0.0482759
Energy storage efficiency	0.04666667	0.044674	0.04428	0.044068	0.050505	0.04461	0.054152	0.054152	0.051903	0.054237	0.049669	0.052265	0.086022	0.055172	0.041096	0.046875	0.038596	0.052083	0.055762	0.0517241
Infrastructure	0.04666667	0.044674	0.04428	0.044068	0.050505	0.048327	0.057762	0.057762	0.055363	0.047458	0.043046	0.04878	0.053763	0.082759	0.044521	0.050781	0.049123	0.048611	0.048327	0.0517241
Air pollution	0.06333333	0.054983	0.04797	0.064407	0.050505	0.04461	0.039711	0.046931	0.051903	0.054237	0.049669	0.04878	0.046595	0.041379	0.082192	0.046875	0.059649	0.048611	0.048327	0.0517241
Acquisition cost	0.04333333	0.041237	0.04797	0.037288	0.037037	0.040892	0.046931	0.039711	0.044983	0.040678	0.039735	0.038328	0.043011	0.044828	0.044521	0.09375	0.049123	0.038194	0.055762	0.0448276
GHG Emission reduction	0.05666667	0.054983	0.04797	0.057627	0.050505	0.037175	0.039711	0.050542	0.048443	0.050847	0.043046	0.04878	0.039427	0.044828	0.058219	0.046875	0.084211	0.052083	0.04461	0.0482759
Technical maturity	0.04333333	0.054983	0.04797	0.044068	0.047138	0.048327	0.050542	0.050542	0.051903	0.047458	0.046358	0.052265	0.053763	0.051724	0.047945	0.046875	0.049123	0.083333	0.048327	0.0482759
Capital Cost	0.03666667	0.044674	0.062731	0.037288	0.043771	0.048327	0.057762	0.046931	0.044983	0.044068	0.046358	0.034843	0.050179	0.048276	0.047945	0.058594	0.045614	0.045139	0.089219	0.0517241
Public acceptance	0.04666667	0.04811	0.04428	0.047458	0.050505	0.052045	0.043321	0.046931	0.044983	0.040678	0.049669	0.04878	0.053763	0.048276	0.047945	0.050781	0.045614	0.048611	0.048327	0.0827586

Table 3. Normalization of Decision Matrix

(iii) Finding the entropy values for the criterion: Using Eq. (iii), one may determine the entropy value, or eij, which is the value that corresponds to the uncertainty measure of the criterion j. In this case, eij is $0 \leq eij < 1$, and k is a constant coefficient defined as $k = (\ln(m)) - 1$.

$$e_{ij} = -k \bullet \sum_{j=1}^{n} P_{ij} \bullet \ln(P_{ij})$$

Factors	Decarbonizat	Regulatory	Opportunit	Impact on	Safety	Global Ava	Supply Cap	Durability	Adaptabilit	Fuel availa	Vessel Safe	Reliability	Energy sto	Infrastruct	Air pollutio	Acquisition	GHG Emiss	Technical	Capital Co	Public accept
Decarbonization	-0.20205829	-0.15285	-0.14569	-0.17664	-0.15079	-0.15383	-0.15086	-0.12811	-0.13951	-0.15147	-0.1354	-0.14017	-0.14287	-0.14632	-0.16555	-0.14345	-0.16817	-0.13984	-0.12238	-0.1463156
Regulatory Compliance	-0.14978661	-0.2058	-0.14569	-0.12264	-0.15079	-0.13873	-0.13599	-0.14357	-0.14665	-0.14465	-0.14912	-0.15426	-0.14287	-0.13919	-0.15913	-0.15134	-0.15497	-0.147	-0.14642	-0.1391866
Opportunity cost	-0.14302051	-0.13148	-0.21468	-0.13025	-0.12965	-0.14642	-0.15086	-0.11991	-0.13951	-0.13025	-0.1354	-0.12501	-0.11931	-0.12411	-0.13117	-0.15134	-0.13337	-0.147	-0.15383	-0.131792
Impact on the ecosystem	-0.17475842	-0.13148	-0.14569	-0.20412	-0.15737	-0.16097	-0.13599	-0.1579	-0.1321	-0.14465	-0.14912	-0.13273	-0.13532	-0.14632	-0.17176	-0.12666	-0.16817	-0.13984	-0.13072	-0.1391866
Safety	-0.14302051	-0.15285	-0.13803	-0.16445	-0.20329	-0.13072	-0.11991	-0.1579	-0.15355	-0.14465	-0.17402	-0.16094	-0.15716	-0.14632	-0.14564	-0.13523	-0.15497	-0.147	-0.13873	-0.1531981
Global Availability	-0.14978661	-0.13886	-0.15307	-0.15147	-0.12207	-0.21561	-0.1647	-0.13599	-0.1321	-0.16445	-0.14238	-0.14017	-0.13532	-0.14632	-0.11555	-0.13523	-0.11754	-0.13242	-0.14642	-0.1391866
Supply Capacity	-0.14302051	-0.13886	-0.14569	-0.13025	-0.11418	-0.16097	-0.21192	-0.13599	-0.14665	-0.15807	-0.14912	-0.15426	-0.14287	-0.1532	-0.12352	-0.15134	-0.11754	-0.147	-0.14642	-0.131792
Durability	-0.12121586	-0.13886	-0.13803	-0.14465	-0.15737	-0.13873	-0.12811	-0.21192	-0.14665	-0.12264	-0.15565	-0.16094	-0.15014	-0.1532	-0.14564	-0.15134	-0.13337	-0.147	-0.15383	-0.1531981
Adaptability	-0.14978661	-0.14598	-0.16019	-0.14465	-0.14399	-0.14642	-0.15086	-0.15086	-0.20665	-0.13025	-0.15565	-0.16094	-0.15014	-0.1532	-0.13117	-0.14345	-0.14084	-0.16703	-0.13873	-0.1531981
Fuel availability	-0.14978661	-0.14598	-0.14569	-0.15807	-0.15737	-0.17452	-0.15086	-0.13599	-0.14665	-0.20412	-0.14912	-0.14734	-0.15014	-0.1532	-0.1525	-0.13523	-0.15497	-0.13984	-0.14642	-0.131792
Vessel Safety	-0.14302051	-0.16592	-0.13803	-0.15807	-0.1699	-0.15383	-0.15086	-0.1579	-0.16021	-0.16445	-0.20125	-0.15426	-0.15716	-0.14632	-0.1525	-0.15134	-0.14803	-0.147	-0.15383	-0.1662874
Reliability	-0.14978661	-0.15949	-0.13803	-0.14465	-0.16373	-0.13072	-0.15086	-0.1579	-0.14665	-0.16445	-0.15565	-0.20751	-0.15716	-0.1532	-0.16555	-0.13523	-0.15497	-0.16058	-0.13873	-0.1463156
Energy storage efficiency	-0.14302051	-0.13886	-0.13803	-0.13758	-0.15079	-0.13873	-0.1579	-0.1579	-0.15355	-0.15807	-0.14912	-0.15426	-0.21102	-0.15985	-0.13117	-0.14345	-0.12562	-0.1539	-0.16097	-0.1531981
Infrastructure	-0.14302051	-0.13886	-0.13803	-0.13758	-0.15079	-0.14642	-0.1647	-0.1647	-0.16021	-0.14465	-0.1354	-0.14734	-0.15716	-0.20622	-0.13854	-0.15134	-0.14803	-0.147	-0.14642	-0.1531981
Air pollution	-0.17475842	-0.15949	-0.14569	-0.17664	-0.15079	-0.13873	-0.12811	-0.14357	-0.15355	-0.15807	-0.14912	-0.14734	-0.14287	-0.13179	-0.20537	-0.14345	-0.16817	-0.147	-0.14642	-0.1531981
Acquisition cost	-0.1360161	-0.13148	-0.14569	-0.12264	-0.12207	-0.13072	-0.14357	-0.12811	-0.13951	-0.13025	-0.12817	-0.12501	-0.13532	-0.13919	-0.13854	-0.22192	-0.14803	-0.12471	-0.16097	-0.1391866
GHG Emission reduction	-0.16266558	-0.15949	-0.14569	-0.16445	-0.15079	-0.12238	-0.12811	-0.15086	-0.14665	-0.15147	-0.1354	-0.14734	-0.12748	-0.13919	-0.16555	-0.14345	-0.20837	-0.1539	-0.13873	-0.1463156
Technical maturity	-0.1360161	-0.15949	-0.14569	-0.13758	-0.14399	-0.14642	-0.15086	-0.15086	-0.15355	-0.14465	-0.14238	-0.15426	-0.15716	-0.1532	-0.14564	-0.14345	-0.14803	-0.20708	-0.14642	-0.1463156
Capital Cost	-0.12121586	-0.13886	-0.1737	-0.12264	-0.13695	-0.14642	-0.1647	-0.14357	-0.13951	-0.13758	-0.14238	-0.11697	-0.15014	-0.14632	-0.14564	-0.16624	-0.14084	-0.13984	-0.21561	-0.1531981
Public acceptance	-0.14302051	-0.14598	-0.13803	-0.14465	-0.15079	-0.15383	-0.13599	-0.14357	-0.13951	-0.13025	-0.14912	-0.14734	-0.15716	-0.14632	-0.14564	-0.15134	-0.14084	-0.147	-0.14642	-0.2062202
SUM Pij*ln(Pij)	-2.97878127	-2.98092	-2.97911	-2.97368	-2.97747	-2.97511	-2.97577	-2.97711	-2.98297	-2.9791	-2.983	-2.97836	-2.9788	-2.98293	-2.9758	-2.97584	-2.97482	-2.98194	-2.9784	-2.9822795
Eij	0.99434161	0.995057	0.99445	0.992637	0.993903	0.993115	0.993338	0.993785	0.995739	0.994448	0.995749	0.994201	0.994349	0.995727	0.993346	0.993359	0.993018	0.995395	0.994214	0.9955094

Table 4. The entropy values

Where m is number of alternative (Factors)
m = 20

(iv) Determining the differences' degrees: Equation (iv) is utilized to compute dj values for every criterion by utilizing the entropy values of the criteria.

$$d_j = 1 - e_j$$

dj	0.005658	0.0049	0.0056	0.0074	0.0061	0.0069	0.0067	0.0062	0.0043	0.0056	0.0043	0.0058	0.0057	0.0043	0.0067	0.0066	0.007	0.0046	0.0058	0.00449

sum dj	0.11431984

(v) Figuring out the criteria the entropy weights: Using Eq. (v), divide each criterion's differentiation degree by the overall differentiation degree to obtain the wj values of the criteria.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

Weight(Wj)	0.049496	0.0432	0.0486	0.0644	0.0533	0.0602	0.0583	0.0544	0.0373	0.0486	0.0372	0.0507	0.0494	0.0374	0.0582	0.0581	0.0611	0.0403	0.0506	0.03928

(b) ARAS (Additive Ratio Assessments) Method

The ARAS method, introduced by Zavadskas and Turskis (2010), for ranking and assessing options, the ARAS approach is a somewhat easy-to-use and efficient MCDM technique. The following processes are involved:

(i) Creating the first decision matrix: This involves deciding on the problem's decision matrix options as well as the evaluation criteria that will be taken into account while assessing them. Subsequently, the first decision matrix is constructed as per Eq. (iv), which displays the decision options' scores based on the criteria. In this case, j = 1, 2, …, n, and i = 0, 1, …, m are the number of assessment criteria and choices, respectively. Which has been created in table 2.

$$X = \begin{bmatrix} x_{01} & x_{02} & \cdots & x_{0n} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

(ii) Creating the normalized decision matrix: The optimal value series is determined and the various metric values are integrated prior to the creation of the normalized decision matrix. Whether the decision criterion is benefit- or cost-based determines the ideal value series. Eq. (vii) is used to calculate the optimal value of the criterion if it is benefit-based, or if it needs to be maximized; if it is cost-based, or if it needs to be minimized, Eq. (viii) is used to calculate the ideal value of the criterion.

$$\overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}$$

$$\overline{x_{ij}} = \frac{1/x_{ij}}{\sum_{i=0}^{m} 1/x_{ij}}$$

The normalized decision matrix displayed in Eq. (ix) is the result of computing the optimal value series of the criterion.

$$\overline{X} = \begin{bmatrix} \overline{x}_{01} & \overline{x}_{02} & \cdots & \overline{x}_{0n} \\ \overline{x}_{11} & \overline{x}_{12} & \cdots & \overline{x}_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ \overline{x}_{m1} & \overline{x}_{m2} & \cdots & \overline{x}_{mn} \end{bmatrix}$$

Factors	Decarbonizatio	Regulatory Co	Opportunity co	Impact on the e	Safety	Global Availab	Supply Capac	Durability	Adaptability	Fuel availabilit
Decarbonization	0.08	0.05154639	0.04797048	0.06440678	0.0505051	0.05204461	0.05054152	0.039711	0.0449827	0.05084746
Regulatory Compliance	0.05	0.08247423	0.04797048	0.037288136	0.0505051	0.04460967	0.0433213	0.046931	0.04844291	0.04745763
Opportunity cost	0.046666667	0.04123711	0.088560886	0.040677966	0.040404	0.04832714	0.05054152	0.036101	0.0449827	0.04067797
Impact on the ecosystem	0.063333333	0.04123711	0.04797048	0.081355932	0.0538721	0.05576208	0.0433213	0.054152	0.04152249	0.04745763
Safety	0.046666667	0.05154639	0.044280443	0.057627119	0.0808081	0.04089219	0.03610108	0.054152	0.05190311	0.04745763
Global Availability	0.05	0.04467354	0.051660517	0.050847458	0.037037	0.08921933	0.05776173	0.043321	0.04152249	0.05762712
Supply Capacity	0.046666667	0.04467354	0.04797048	0.040677966	0.03367	0.05576208	0.0866426	0.043321	0.04844291	0.05423729
Durability	0.036666667	0.04467354	0.044280443	0.047457627	0.0538721	0.04460967	0.03971119	0.086643	0.04844291	0.03728814
Adaptability	0.05	0.04810997	0.055350554	0.047457627	0.047138	0.04832714	0.05054152	0.050542	0.08304498	0.04067797
Fuel availability	0.05	0.04810997	0.04797048	0.054237288	0.0538721	0.06319703	0.05054152	0.043321	0.04844291	0.08135593
Vessel Safety	0.046666667	0.05841924	0.044280443	0.054237288	0.0606061	0.05204461	0.05054152	0.054152	0.05536332	0.05762712
Reliability	0.05	0.05498282	0.044280443	0.047457627	0.0572391	0.04089219	0.05054152	0.054152	0.04844291	0.05762712
Energy storage efficiency	0.046666667	0.04467354	0.044280443	0.044067797	0.0505051	0.04460967	0.05415162	0.054152	0.05190311	0.05423729
Infrastructure	0.046666667	0.04467354	0.044280443	0.044067797	0.0505051	0.04832714	0.05776173	0.057762	0.05536332	0.04745763
Air pollution	0.063333333	0.05498282	0.04797048	0.06440678	0.0505051	0.04460967	0.03971119	0.046931	0.05190311	0.05423729
Acquisition cost	0.043333333	0.04123711	0.04797048	0.037288136	0.037037	0.04089219	0.04693141	0.039711	0.0449827	0.04067797
GHG Emission reduction	0.056666667	0.05498282	0.04797048	0.057627119	0.0505051	0.03717472	0.03971119	0.050542	0.04844291	0.05084746
Technical maturity	0.043333333	0.05498282	0.04797048	0.044067797	0.047138	0.04832714	0.05054152	0.050542	0.05190311	0.04745763
Capital Cost	0.036666667	0.04467354	0.062730627	0.037288136	0.043771	0.04832714	0.05776173	0.046931	0.0449827	0.0440678
Public acceptance	0.046666667	0.04810997	0.044280443	0.047457627	0.0505051	0.05204461	0.0433213	0.046931	0.0449827	0.04067797

Factors	Vessel Safety	Reliability	Energy storage	Infrastructure	Air pollution	Acquisition cos	GHG Emissio	Technical ma	Capital Cost	Public acce
Decarbonization	0.04304636	0.0452962	0.046594982	0.04827586	0.058219178	0.046875	0.0596491	0.04513889	0.0371747	0.048276
Regulatory Compliance	0.04966887	0.0522648	0.046594982	0.04482759	0.054794521	0.05078125	0.0526316	0.04861111	0.0483271	0.044828
Opportunity cost	0.04304636	0.0383275	0.035842294	0.03793103	0.04109589	0.05078125	0.0421053	0.04861111	0.0520446	0.041379
Impact on the ecosystem	0.04966887	0.0418118	0.043010753	0.04827586	0.061643836	0.0390625	0.0596491	0.04513889	0.0408922	0.044828
Safety	0.06291391	0.0557491	0.053763441	0.04827586	0.047945205	0.04296875	0.0526316	0.04861111	0.0446097	0.051724
Global Availability	0.04635762	0.0452962	0.043010753	0.04827586	0.034246575	0.04296875	0.0350877	0.04166667	0.0483271	0.044828
Supply Capacity	0.04966887	0.0522648	0.046594982	0.05172414	0.037671233	0.05078125	0.0350877	0.04861111	0.0483271	0.041379
Durability	0.05298013	0.0557491	0.050179211	0.05172414	0.047945205	0.05078125	0.0421053	0.04861111	0.0520446	0.051724
Adaptability	0.05298013	0.0557491	0.050179211	0.05172414	0.04109589	0.046875	0.045614	0.05902778	0.0446097	0.051724
Fuel availability	0.04966887	0.0487805	0.050179211	0.05172414	0.051369863	0.04296875	0.0526316	0.04513889	0.0483271	0.041379
Vessel Safety	0.0794702	0.0522648	0.053763441	0.04827586	0.051369863	0.05078125	0.0491228	0.04861111	0.0520446	0.058621
Reliability	0.05298013	0.0836237	0.053763441	0.05172414	0.058219178	0.04296875	0.0526316	0.05555556	0.0446097	0.048276
Energy storage efficiency	0.04966887	0.0522648	0.086021505	0.05517241	0.04109589	0.046875	0.0385965	0.05208333	0.0557621	0.051724
Infrastructure	0.04304636	0.0487805	0.053763441	0.08275862	0.044520548	0.05078125	0.0491228	0.04861111	0.0483271	0.051724
Air pollution	0.04966887	0.0487805	0.046594982	0.04137931	0.082191781	0.046875	0.0596491	0.04861111	0.0483271	0.051724
Acquisition cost	0.0397351	0.0383275	0.043010753	0.04482759	0.044520548	0.09375	0.0491228	0.03819444	0.0557621	0.044828
GHG Emission reduction	0.04304636	0.0487805	0.039426523	0.04482759	0.058219178	0.046875	0.0842105	0.05208333	0.0446097	0.048276
Technical maturity	0.04635762	0.0522648	0.053763441	0.05172414	0.047945205	0.046875	0.0491228	0.08333333	0.0483271	0.048276
Capital Cost	0.04635762	0.0348432	0.050179211	0.04827586	0.047945205	0.05859375	0.045614	0.04513889	0.0892193	0.051724
Public acceptance	0.04966887	0.0487805	0.053763441	0.04827586	0.047945205	0.05078125	0.045614	0.04861111	0.0483271	0.082759

Table 5. The normalized decision matrix

(iii) Creating the weighted normalized decision matrix: The normalized decision matrix is weighted by considering the importance weights (wj) for the criteria, which are established in accordance with the opinions of experts or the decision maker's subjective opinions. Equation (x) is utilized to create the weighted decision matrix**.**

$$\hat{x}_{ij} = \overline{x}_{ij} \bullet w_{ij}$$

Weights	0.049496092	0.04323955	0.048550399	0.064403686	0.0533314	0.06022343	0.05827554	0.054366	0.03726968
Factors	Decarbonizatio	Regulatory Co	Opportunity co	Impact on the e	Safety	Global Availal	Supply Capac	Durability	Adaptability
Decarbonization	0.003959687	0.00222884	0.002074222	0.004148034	0.0026935	0.0031343	0.00294533	0.002159	0.00167649
Regulatory Compliance	0.002474805	0.00356615	0.002328986	0.002401493	0.0026935	0.00268655	0.00252457	0.002551	0.00180545
Opportunity cost	0.002309818	0.00178307	0.004299666	0.002619811	0.0021548	0.00291043	0.00294533	0.001963	0.00167649
Impact on the ecosystem	0.003134753	0.00178307	0.002328986	0.005239622	0.0028731	0.00335818	0.00252457	0.002944	0.00154753
Safety	0.002309818	0.00222884	0.002149833	0.003711399	0.0043096	0.00246267	0.00210381	0.002944	0.00193441
Global Availability	0.002474805	0.00193166	0.002508139	0.003274764	0.0019752	0.00537309	0.0033661	0.002355	0.00154753
Supply Capacity	0.002309818	0.00193166	0.002328986	0.002619811	0.0017957	0.00335818	0.00504914	0.002355	0.00180545
Durability	0.001814857	0.00193166	0.002149833	0.003056446	0.0028731	0.00268655	0.00231419	0.00471	0.00180545
Adaptability	0.002474805	0.00208025	0.002687291	0.003056446	0.0025139	0.00291043	0.00294533	0.002748	0.00309506
Fuel availability	0.002474805	0.00208025	0.002328986	0.003493081	0.0028731	0.00380594	0.00294533	0.002355	0.00180545
Vessel Safety	0.002309818	0.00252602	0.002149833	0.003493081	0.0032322	0.0031343	0.00294533	0.002944	0.00206337
Reliability	0.002474805	0.00237743	0.002149833	0.003056446	0.0030526	0.00246267	0.00294533	0.002944	0.00180545
Energy storage efficiency	0.002309818	0.00193166	0.002149833	0.002838129	0.0026935	0.00268655	0.00315572	0.002944	0.00193441
Infrastructure	0.002309818	0.00193166	0.002149833	0.002838129	0.0026935	0.00291043	0.0033661	0.00314	0.00206337
Air pollution	0.003134753	0.00237743	0.002328986	0.004148034	0.0026935	0.00268655	0.00231419	0.002551	0.00193441
Acquisition cost	0.002144831	0.00178307	0.002328986	0.002401493	0.0019752	0.00246267	0.00273495	0.002159	0.00167649
GHG Emission reduction	0.002804779	0.00237743	0.002328986	0.003711399	0.0026935	0.00223879	0.00231419	0.002748	0.00180545
Technical maturity	0.002144831	0.00237743	0.002328986	0.002838129	0.0025139	0.00291043	0.00294533	0.002748	0.00193441
Capital Cost	0.001814857	0.00193166	0.003045597	0.002401493	0.0023344	0.00291043	0.0033661	0.002551	0.00167649
Public acceptance	0.002309818	0.00208025	0.002149833	0.003056446	0.0026935	0.0031343	0.00252457	0.002551	0.00167649

Weights	0.04856965	0.03718589	0.0507299	0.049429231	0.03738031	0.05820438	0.058090969	0.0610732	0.04028556	0.0506137	0.039281
Factors	Fuel availabili	Vessel Safety	Reliability	Energy storage	Infrastructur	Air pollution	Acquisition co	GHG Emissio	Technical ma	Capital Cost	Public acce
Decarbonization	0.00246964	0.00160072	0.0022979	0.002303154	0.00180457	0.003388611	0.002723014	0.003643	0.00181845	0.0018815	0.001896
Regulatory Compliance	0.002305	0.00184698	0.0026514	0.002303154	0.00167567	0.003189281	0.002949932	0.0032144	0.00195833	0.002446	0.001761
Opportunity cost	0.00197571	0.00160072	0.0019443	0.001771657	0.00141787	0.002391961	0.002949932	0.0025715	0.00195833	0.0026342	0.001625
Impact on the ecosystem	0.002305	0.00184698	0.0021211	0.002125988	0.00180457	0.003587941	0.002269178	0.003643	0.00181845	0.0020697	0.001761
Safety	0.002305	0.00233951	0.0028281	0.002657486	0.00180457	0.002790621	0.002496096	0.0032144	0.00195833	0.0022579	0.002032
Global Availability	0.00279893	0.00172385	0.0022979	0.002125988	0.00180457	0.001993301	0.002496096	0.0021429	0.00167857	0.002446	0.001761
Supply Capacity	0.00263429	0.00184698	0.0026514	0.002303154	0.00193346	0.002192631	0.002949932	0.0021429	0.00195833	0.002446	0.001625
Durability	0.00181107	0.00197011	0.0028281	0.00248032	0.00193346	0.002790621	0.002949932	0.0025715	0.00195833	0.0026342	0.002032
Adaptability	0.00197571	0.00197011	0.0028281	0.00248032	0.00193346	0.002391961	0.002723014	0.0027858	0.00237797	0.0022579	0.002032
Fuel availability	0.00395143	0.00184698	0.0024746	0.00248032	0.00193346	0.002989951	0.002496096	0.0032144	0.00181845	0.002446	0.001625
Vessel Safety	0.00279893	0.00295517	0.0026514	0.002657486	0.00180457	0.002989951	0.002949932	0.0030001	0.00195833	0.0026342	0.002303
Reliability	0.00279893	0.00197011	0.0042422	0.002657486	0.00193346	0.003388611	0.002496096	0.0032144	0.00223809	0.0022579	0.001896
Energy storage efficiency	0.00263429	0.00184698	0.0026514	0.004251977	0.00206236	0.002391961	0.002723014	0.0023572	0.00209821	0.0028223	0.002032
Infrastructure	0.002305	0.00160072	0.0024746	0.002657486	0.00309354	0.002591291	0.002949932	0.0030001	0.00195833	0.002446	0.002032
Air pollution	0.00263429	0.00184698	0.0024746	0.002303154	0.00154677	0.004783922	0.002723014	0.003643	0.00195833	0.002446	0.002032
Acquisition cost	0.00197571	0.00147758	0.0019443	0.002125988	0.00167567	0.002591291	0.005446028	0.0030001	0.00153868	0.0028223	0.001761
GHG Emission reduction	0.00246964	0.00160072	0.0024746	0.001948823	0.00167567	0.003388611	0.002723014	0.005143	0.00209821	0.0022579	0.001896
Technical maturity	0.002305	0.00172385	0.0026514	0.002657486	0.00193346	0.002790621	0.002723014	0.0030001	0.00335713	0.002446	0.001896
Capital Cost	0.00214036	0.00172385	0.0017676	0.00248032	0.00180457	0.002790621	0.003403768	0.0027858	0.00181845	0.0045157	0.002032
Public acceptance	0.00197571	0.00184698	0.0024746	0.002657486	0.00180457	0.002790621	0.002949932	0.0027858	0.00195833	0.002446	0.003251

Table 6. The weighted normalized decision matrix

The weighted normalized decision matrix shown in Eq. (xi) is obtained with the calculated $\hat{x}_{ij}$ weighted normalized values.

$$\widehat{X} = \begin{bmatrix} \widehat{x}_{01} & \widehat{x}_{02} & \cdots & \widehat{x}_{0n} \\ \widehat{x}_{11} & \widehat{x}_{12} & \cdots & \widehat{x}_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{x}_{m1} & \widehat{x}_{m2} & \cdots & \widehat{x}_{mn} \end{bmatrix}$$

(iv) Determining the optimality function: Eq. (xii) is used to determine the optimality function values for each decision alternative. The optimality function of the decision option is represented by Si in this case; the alternative with a higher Si value is the superior one.

$$S_i = \sum_{j=1}^{n} \widehat{x}_{ij}$$

(v) Determining the utility degree and the final alternative ranking: Equation (xiii), when used, is used to calculate the utility degree of alternatives (Ki). The optimality function value of a decision alternative divided by the optimality function value of the best alternative yields the degree of utility. The Ki ratios, which accept values in the [0,1] range, are used to compute the relative efficiency of the utility function values of the alternatives. From greatest to smallest, calculated values are ordered, and the best option with the highest value is selected. Here So is a maximum optimality function.

$$K_i = \frac{S_i}{S_o}$$

5. RESULTS AND DISCUSSION:

Factors	Si	Ki	Ranking
Decarbonization	0.05084624	0.95038472	6
Regulatory Compliance	0.049334	0.92211893	13
Opportunity cost	0.04550374	0.85052621	20
Impact on the ecosystem	0.05108657	0.95487691	5
Safety	0.05083819	0.95023427	7
Global Availability	0.04807553	0.89859636	18
Supply Capacity	0.04823847	0.90164201	17
Durability	0.04930195	0.92151983	14
Adaptability	0.05026745	0.93956637	11
Fuel availability	0.05143928	0.96146945	4
Vessel Safety	0.05350069	1	1
Reliability	0.05236221	0.97872024	3
Energy storage efficiency	0.05051514	0.94419607	9
Infrastructure	0.05051194	0.94413631	10
Air pollution	0.05256119	0.98243953	2
Acquisition cost	0.04602529	0.86027465	19
GHG Emission reduction	0.0506988	0.94762884	8
Technical maturity	0.05022563	0.93878469	12
Capital Cost	0.0492953	0.92139559	15
Public acceptance	0.04911764	0.91807483	16

Table 7. The utility degree and the final alternative ranking

So	=	0.05350069

High-Ranking Factors:

Vessel Safety: This factor comes in first place, highlighting how crucial it is to guarantee vessel safety when implementing alternative fuels. The high rating implies that in order for any alternative fuel to be accepted, it must adhere to strict safety regulations.

Air Pollution: The ranking with the second-highest number emphasizes how urgent it is to reduce air pollution. This is in line with international environmental goals and air quality improvement regulatory frameworks.

Reliability: For vessels to operate consistently and dependably, reliability is third ranking. This high ranking means that alternative fuels need to prove to be just as reliable as traditional fuels, if not more so

Low-Ranking Factors:

Technical Maturity 12 ranking position & Adaptability is 11 ranking postion, These characteristics imply that, although crucial, technical maturity and adaptability are subordinated to the more pressing issues of environmental impact, safety, and dependability.

Regulatory Compliance 13 ranking position, which is ranked in the centre shows that while following laws is important, it is more of a standard expectation than a differentiator.

Durability 14 and Capital Costs 15 ranking position, For long-term viability and economic feasibility, respectively, durability and capital costs are essential. Their rankings point to a trade-off between upfront costs and long-term gains.

Public Acceptance is 16 ranking position, Although it depends on other elements like safety, dependability, and environmental effect, public acceptance is crucial for broad adoption.

Supply Capacity 17 and Global Availability 18 ranking, These variables draw attention to the distribution and logistical issues that need to be resolved in order to guarantee the viability of alternative fuels.

Opportunity Cost 20 and Acquisition Cost 19, ranking Lower rankings for these expenses imply that, while crucial, addressing safety, dependability, and environmental issues takes precedence above economic considerations.

The entropy weights in the given figure show in figure 1 which factors have the highest weights and which have the least. From this figure we can draw the conclusion which are the factors which will have the greatest impact in the maritime industry at the time of adopting alternative fuel.

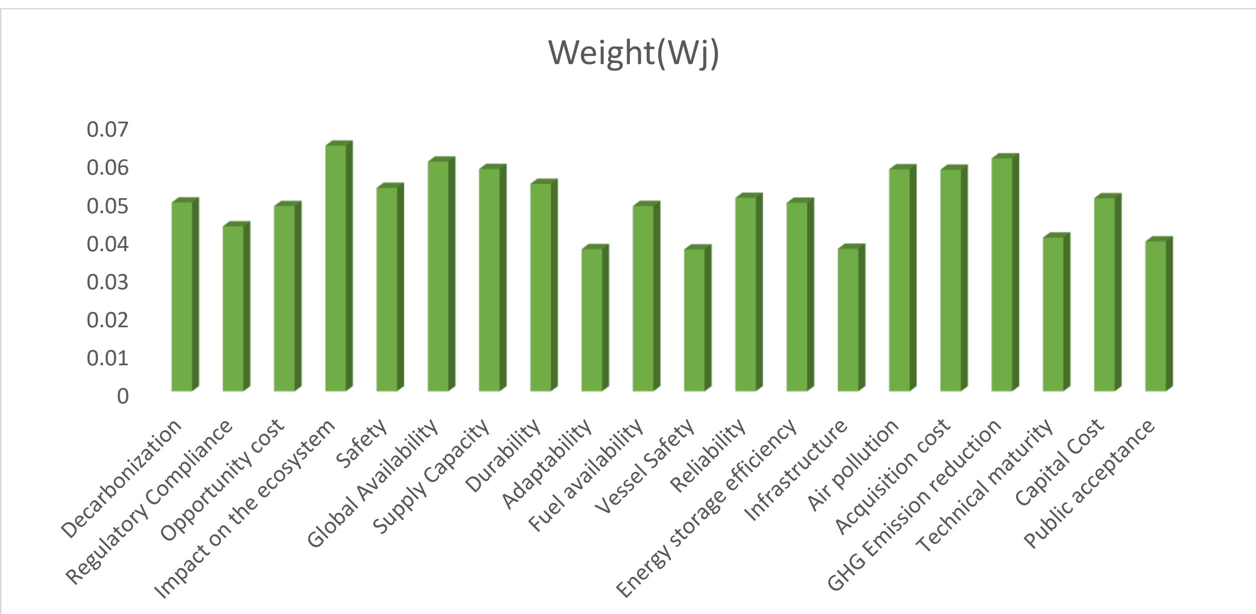

Figure 1. Figuring out the criteria the entropy weights

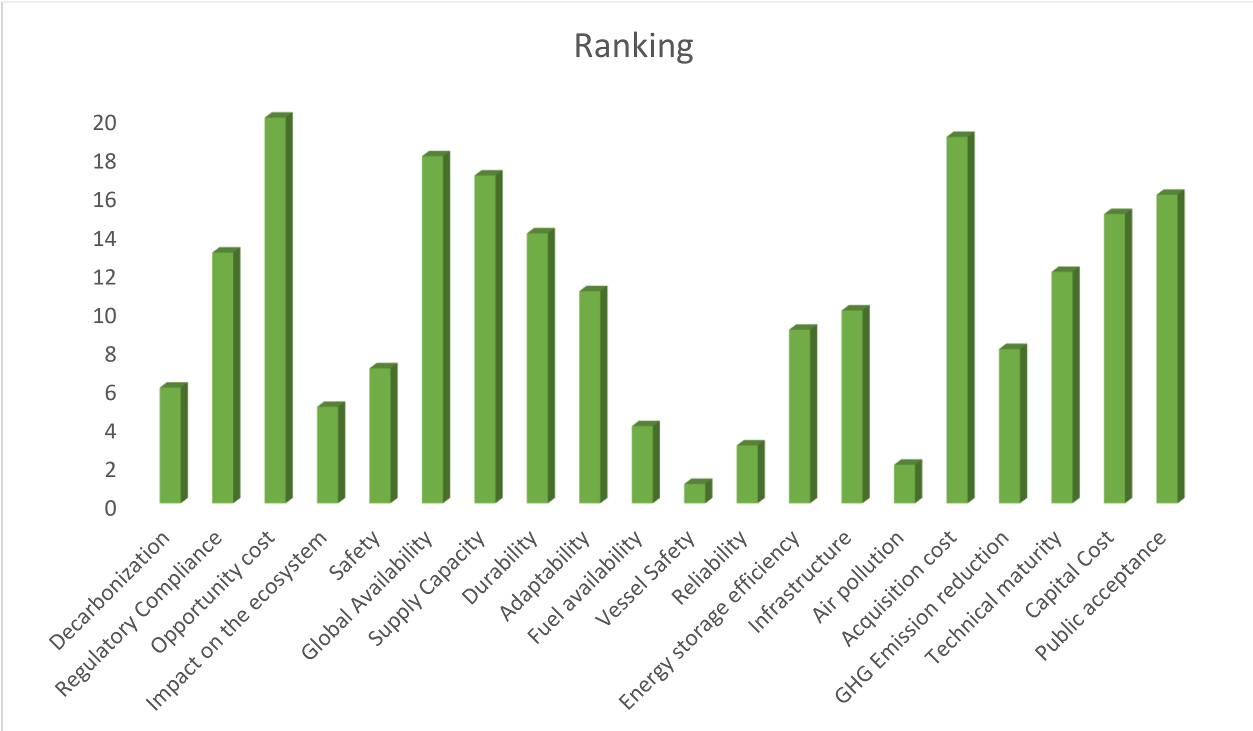

Figure 2. The utility degree and the final alternative ranking

The given above figure (Figure 2), we can find out what are the factors to be kept in mind when adopting alternative fuel and what benefits it will have for the maritime industry.

6. CONCLUSION

It takes a complex process to gather and evaluate data in order to determine what makes the use of alternative fuels in maritime transportation successful. To get a complete view of the dynamics of the industry, it combines quantitative and qualitative methodologies. Through the methodical collection of data from many sources and the application of rigorous analysis methodologies, scholars can discern the principal motivators, impediments, and prospects associated with the adoption of alternative fuels. This methodology guarantees a strong basis for formulating strategies aimed at supporting greener and more sustainable fuel alternatives within the maritime sector. This study also shows how useful MCDM techniques like ARAS and Entropy are for assessing and prioritizing options in the adoption of alternative fuels. These techniques' objective evaluation aids in decision-making by guaranteeing that all pertinent factors are sufficiently taken into account. The analysis's conclusions might help stakeholders prioritize important elements and make strategic choices that support their sustainability objectives.

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