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Sustainable aviation fuel supplier evaluation for airlines through LOPCOW and MARCOS approaches with interval-valued fuzzy neutrosophic information

Fatih Ecer[a], Gökhan Tanrıverdi[b,c], Mehmet Yaşar[d], Ömer Faruk Görçün[e,*]

[a] Sub-Department of Operations Research, Faculty of Economics and Administrative Sciences, Afyon Kocatepe University, Afyonkarahisar, Turkey
[b] Department of Aviation Management, Ali Cavit Çelebioğlu School of Civil Aviation, Erzincan Binali Yıldırım University, Yalnızbağ Campus, Erzincan, 24000, Turkey
[c] Transport & Logistics Section, Faculty of Technology, Policy and Management, Delft University of Technology, 2628 BX, Delft, The Netherlands
[d] Department of Aviation Management, School of Civil Aviation, Kastamonu University, Kuzeykent Campus, Kastamonu, Turkey
[e] Department of Business Administration, Faculty of Economic, Administration, and Social Sciences, Kadir Has University, İstanbul, Turkey

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ABSTRACT

In line with the 2050 net zero emission target, sustainable aviation fuel (SAF) is recognized as one of the most effective decarbonization solutions for the aviation industry, which has been identified among the critical areas for mitigating climate change. However, although sustainability issues and decarbonization have attracted scholars' attention in various terms for the airline industry, we identified some significant theoretical and managerial gaps as follows: (i) the number of studies evaluating sustainable suppliers by airlines via multi-criteria decision-making (MCDM) approaches are very few, (ii) the extant literature has no paper addressing airlines' SAF supplier selection process, and (iii) no widely established criteria set in the literature to evaluate the SAF suppliers for airlines. We propose a novel model for the decision-making process of airlines' sustainable SAF supplier selection, including 39 criteria from 5 aspects considering the triple bottom of sustainability. The proposed model involves the combination of the logarithmic percentage change-driven objective weighting (LOPCOW) and measurement alternatives and ranking according to the compromise solution (MARCOS) approaches' extended forms based on the interval-valued fuzzy neutrosophic numbers (IVFNN). A comprehensive sensitivity and comparison control is further exploited to display the developed framework's robustness and practicality. Our results suggest that airlines prioritize the green initiatives of SAF suppliers over the economic aspect in the process of sustainable SAF supplier selection. We provide some managerial and policy insights for practitioners and policy-makers in the airline industry and some directions for further research.

1. Introduction

Today, one of the most important strategic tasks for businesses to increase their performance and provide a competitive advantage is to build their supply chains by considering the triple bottom of sustainability since the performance of businesses is closely related to the performance and practices of their suppliers (Chai et al., 2023; Luthra et al., 2017). This importance arises from the suppliers' influence on economic, social, and environmental dimensions, including cost efficiency, product quality, environmental impact, delivery reliability, societal benefits, and the buyer-supplier relationship (Chan and Kumar, 2007). Accordingly, the increased interest of researchers and practitioners in the triple bottom of sustainability has begun to shape research on supply chain management recently (Luthra et al., 2017; Kuo et al., 2010; Li et al., 2019; Liu et al., 2019).

Businesses must establish long-term relationships with socially, economically, and environmentally powerful suppliers to gain and sustain competitive advantage (Liu et al., 2019). At this point, the criteria considered while determining sustainable suppliers have become crucial. On the one hand, these criteria may be tangible and intangible and have conflicting and incompatible features (Guarnieri and Trojan, 2019; Mina et al., 2021). Additionally, while the price was previously a pivotal determinant among the supplier selection criteria, the triple bottom of sustainability has taken its place among the selection criteria

* Corresponding author.
E-mail addresses: fatihecer@gmail.com (F. Ecer), gtanriverdi@erzincan.edu.tr (G. Tanrıverdi), myasar@kastamonu.edu.tr (M. Yaşar), omer.gorcun@khas.edu.tr (Ö.F. Görçün).

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with the rise in sustainability pressures in different dimensions recently (Çebi and Bayraktar, 2003; Kannan et al., 2015; Mina et al., 2021).

With the increasing threats of global warming and climate change, initiatives related to environmental sustainability have gained importance. Most industries and organizations from different countries and regions have prioritized solutions to curb and mitigate this dangerous trend since environmental deterioration has become a concern in recent years (Mina et al., 2021; Undavalli et al., 2023). In line with the motivation to keep global warming to 1.5 °C, one of the ten critical solutions proposed for managing climate change has been revealed as the decarbonization of the airline industry (World Resources Institute, 2023). Concordantly, while discussions on sustainability in the airline industry were previously conducted outside of the environmental aspect (Tanrıverdi et al., 2020), as in the other critical industries, studies addressing the environmental aspects of the airline industry have increased significantly in recent years, due to the rising pressures regarding climate change. As a response to the environmental pressures, the International Civil Aviation Authority (ICAO) has designed a global market-based measure called Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and created the 2050 net zero emission target to gradually reduce and eliminate the adverse impacts of the airline industry (ICAO, 2023). Sustainable aviation fuel (SAF), one of the decarbonization solutions determined within the scope of CORSIA, stands out as the most effective solution in the airline industry. Recently started to be utilized in the airline industry, SAF is a liquid fuel that can cut carbon dioxide (CO_2) emissions by up to 80%, and today, it is expressed that SAF is about three times more expensive than fossil jet fuels due to insufficient production. SAF can be obtained from various feedstocks, comprising waste fats and oil, non-food plants, and green, municipal, and animal waste. It is emphasized that SAFs must constitute 65% of the total emission reduction; thus, the SAF production capacity of 450 billion liters must be achieved by 2050. In line with this anticipation, the target for 2030 is that 10% of the fuel to be used on all flights to be operated throughout that year will consist of SAFs. The International Air Transport Association (IATA) predicts that SAF production capacity will increase to 30 billion liters by 2030. For the period post-2030, with the development of SAF production technologies and the expected increase in producers and refineries, SAF amount is expected to follow an upward trend more rapidly (Cui and Chen, 2024; Cui et al., 2024; IATA, 2023a; IATA, 2021b).

The extant literature has several studies related to the decarbonization of the airline industry (Ryley et al., 2020; Watson et al., 2024). For example, Pérez-Calderón et al. (2021) analyzed how the European aviation industry has adapted to the decarbonization plan in the Emissions Trading Scheme (ETS) scope and forecasted the future impacts of ETS on European aviation. Tanrıverdi et al. (2023) investigated the relationship between the economic and environmental sustainability performance of 56 leading airlines across the periods before, during, and early-stage recovery of the COVID-19 pandemic. To encourage the decarbonization of air transport, Avogadro et al. (2021) examined the potential effects of a policy that bans short-to medium-haul flights on routes that can be more efficiently operated by other types of transportation, such as high-speed trains. In another study, Hamdan et al. (2022) explained the relationship between air traffic flow management and emission policies through the effects of SAFs. However, no paper in the extant literature was carried out on the decision-making process of airlines for selecting SAF suppliers.

The mandatory adoption of SAF usage by airlines soon necessitates airlines to take rapid action to initiate the transition to SAF usage. Hence, leading airlines have already made offtake agreements with global SAF suppliers as a strategic move to gain an advantage in green competition in the long term. However, the sustainable supplier selection problem for airlines concerning SAF is not merely a strategic move to gain a competitive edge in green practices or comply with impending regulations; it is crucial for the airline industry and global sustainability. The significance of SAF in the airline industry is extremely high, as it is predicted to contribute substantially to the decarbonization of flight operations. Additionally, constructing a supply chain that considers sustainability enhances business performance and provides a competitive advantage. The sustainable supplier selection problem can be modeled and addressed using multi-criteria decision-making methods (Çebi and Bayraktar, 2003; Ecer and Pamucar, 2020) since this problem simultaneously impacts businesses in different aspects associated with suppliers' actions (Ecer, 2022). Based on this premise, the present study aims to test the proposed integrated decision-making model, interval-valued fuzzy neutrosophic numbers-based logarithmic percentage change-driven objective weighting (IVFNN LOPCOW) and measurement alternatives and ranking according to the compromise solution-based interval-valued fuzzy neutrosophic numbers (IVFNN MARCOS), for airlines' sustainable SAF supplier selection, considering the triple bottom line of sustainability. The model comprises five distinct aspects and incorporates a total of 39 criteria. The model is applied and tested through evaluation of some leading global SAF suppliers by decision makers. Here are the present study's significant contributions: The study illustrates a novel framework by identifying the significant aspects and criteria for the airlines' sustainable SAF supplier selection decision and exposing the relative significance of the criteria. The study integrates IVFNN LOPCOW and IVFNN MARCOS methods as a unique methodology to weight criteria and rank alternative SAF suppliers. It verifies the practicality of the suggested appraisal framework and integrated method considering the sustainable SAF supplier selection process for airlines. The study is novel and essential since there is no other study in the literature that deals with the airlines' decision of sustainable SAF supplier selection and even fuel supplier selection, and it has the potential to shed light on the strategic choices of airlines to ensure their long-term viability. The study is also expected to provide foresight for current and possible SAF suppliers to increase their revenues and market shares by enabling them to learn about what airlines consider when selecting SAF suppliers and to contribute to regulators to determine policies and strategies for SAF production and supply.

The present study continues as follows. In the second part of the study, after presenting the criteria and methods used in the extant literature on sustainable supplier selection, background on MCDM methods under the IVFNN environment is given. In the third part, the suggested procedure used in the current work is introduced, while in the fourth part, an application on sustainable SAF supplier selection of airlines is carried out, and the results are given. Whereas the results obtained are discussed in the fifth part, the sixth part includes managerial and policy insights, and in the last section, with suggestions for future studies, the conclusions and restrictions of the study are given.

2. Literature review

In this section, the extant literature is summarized under four subheadings: sustainable supplier selection criteria, methodologies used in the sustainable supplier selection studies, background on MCDM methods under IVFNN environment, and under the research gaps subheading, the studies conducted on supplier selection in the airline industry, which is the context of the study.

2.1. Sustainable supplier selection evaluation criteria

Çebi and Bayraktar (2003) identified four chief factors for supplier assessment in the food industry: logistics, technology, business, and relationship. In the study, an integrated model was created for the implementation and solution processes to select suitable suppliers. Kuo et al. (2010) used the main criteria of quality, cost, delivery, service, environment, and corporate social responsibility in green supplier selection in a case study of a Taiwanese digital camera manufacturer. Kannan et al. (2013) used the criteria of cost, quality, delivery, technological capability, and environmental capability in their research on selecting suitable suppliers in the green supply chain within the Iranian automotive industry. Ávila et al. (2012) adopted the main criteria of quality, financial, synergies, cost, and production and the sub-criteria related to these criteria for selecting suitable suppliers in their research in the context of large companies, SMEs, and micro enterprises. Kannan et al. (2015) used 11 main criteria and 60 sub-criteria, with environmental sustainability being the dominant factor in green supplier selection. The model presented in the study was applied as a case study on a plastic materials manufacturer in Singapore, and the findings highlighted the importance of green supplier selection for possible risks that may be faced in the future. Rezaei et al. (2016) conducted a case study on a company producing edible oil. The research consisted of preselection, selection, and aggregation stages, and supplier evaluation was conducted for the case study company using the best-worst method (BWM) in the selection part. Luthra et al. (2017), in their research in the context of the Indian automotive industry, determined 22 sustainable supplier selection criteria from three different aspects (economic, environmental, and social) formed in line with the literature and expert opinion. The results of the proposed model revealed that environmental cost, product quality, product price, occupational health and safety system, and environmental competence were the top five criteria with the highest scores among the 22 criteria. Gupta and Barua (2017) investigated the supplier selection of SMEs based on green innovation capabilities in the automotive industry and proposed a framework consisting of 7 main and 42 criteria under these criteria. It is stated that the proposed framework is suitable for companies that are considering transforming their activities into green supply chain management. Lo et al. (2018) aimed to address the green supplier selection problem with an integrated method in line with supplier performance, environmental protection, and supplier risk criteria. The research results show that the criteria and integrated method used can efficiently appraise the green suppliers' achievements and improve order allocation to qualified suppliers. Li et al. (2019a) conducted supplier selection based on sustainable supply chain practices in line with economic, environmental, and social criteria. Their research, which analyses a Chinese energy company as a case study in this context, draws attention to decision makers' choices in sustainable supplier selection under conditions of uncertainty. Govindan et al. (2020) used circularity, quality, and on-time delivery factors in their research in the context of the automotive industry. The results show that the suggested model is cost-effective and environmentally friendly for closed-loop supply chain network designs. Tirkolaee et al. (2020), in their research on sustainable, reliable supplier selection, proposed a two-stage process through 21 criteria under the main economic, environmental, and social criteria. Optimal supplier selection policies were determined through sensitivity analyses of key parameters such as product purchase price, wholesaler demand, and supply chain reliability. Mina et al. (2021) developed a hybrid approach to achieve sustainable development goals in line with the main criteria of delivery, quality, circularity, and capability in their research in the petrochemical industry. According to the results, the researchers believe the proposed approach is efficient and feasible. Rahimi et al. (2021) used a fuzzy approach to select a suitable supplier based on delivery, cost, quality, technical capability, and pay-off criteria. The study outcomes indicate that the supplier with the highest weight is the best alternative. The suggested procedure assists decision-makers in better understanding each criterion's weight, even if they are not experts. Menon and Ravi (2022) added the ethical criterion to the main economic, social, and environmental criteria commonly used in previous research. The results of the research show that economic factors are still dominant in the selection of sustainable suppliers. Tong et al. (2022) evaluated criteria such as quality, delivery, cost, and service, which were used as the main criteria in previous studies under the main criterion of product and service capability. In addition, the degree of cooperation and risk factors are the other main criteria used in the research to select suitable suppliers. Table 1 shows the criteria commonly used in the selection of sustainable suppliers.

Existing studies have established various criteria for sustainable supplier selection, including economic, environmental, and social aspects. However, many of these studies focus on specific industries and do not comprehensively address the unique challenges of the airline industry in selecting SAF suppliers. For instance, while Kannan et al. (2013) and Luthra et al. (2017) provided valuable insights into green supplier selection, their methodologies primarily target the automotive and manufacturing sectors, which differ significantly from the airline industry's needs. These studies often lack the depth required to address the complexities of SAF supplier evaluation, such as the critical role of environmental impact, the technical capabilities necessary for SAF production, and the stringent regulatory compliance standards specific to aviation. Furthermore, whereas previous research has explored MCDM methods, such as the analytic hierarchy process (AHP) and technique for order of preference by similarity to ideal solution (TOPSIS), these approaches often fall short in handling the inherent uncertainty and vagueness associated with sustainable supplier selection. This limitation underscores the necessity for advanced methodologies to manage such uncertainties effectively.

2.2. Sustainable supplier selection methodologies

A review of sustainable supplier selection research shows that many studies employ mathematical, analytical, qualitative, artificial intelligence, and hybrid models (Chai et al., 2023; Ecer and Torkayesh, 2024). Among the methods used, studies using AHP in different ways stand out. In this context, it can be seen that AHP is used together with other methods (Luthra et al., 2017; Z. Lu et al., 2019), integrated with other methods (Ecer, 2022; Gupta et al., 2016), or fuzzy methods (Azadnia et al., 2015; Xu et al., 2019; Laosirihongthong et al., 2019). Another analytical method used in sustainable supplier selection is ANP (Hashemi et al., 2015; Kannan, 2018; Coşkun et al., 2022). Other commonly used methods include TOPSIS (Zhao and Guo, 2014; Govindan and Sivakumar, 2016; Yu, Shao et al., 2019; Gidiagba et al., 2023; Ecer et al., 2024), DEMATEL (Yazdani et al., 2017; Giri et al., 2022), ELECTRE (Lo et al., 2018; Çalı and Balaman, 2019; Yu, Zhao et al., 2019), VIKOR (Akman, 2015; Rostamzadeh et al., 2015), PROMETHEE I/II (Roy et al., 2020; Coşkun et al., 2022; Tong et al., 2022), SWARA and WASPAS (Debnath et al., 2023; Yazdani et al., 2016), and BWM (Cheraghalipour and Farsad, 2018; Jafarzadeh Ghoushchi et al., 2019; Liu et al., 2019; Oroojeni Mohammad Javad et al., 2020; Gidiagba et al., 2023).

In addition to these studies, Chai et al. (2023) applied the cumulative prospect theory method in the context of e-bike sharing. In another study, DEA and GEP methods were applied in the context of the textile industry (Fallahpour et al., 2017). Jain and Singh (2020) conducted supplier selection in the Indian iron and steel industry using the Fuzzy Kano model. Kilic and Yalcin (2020) used two-stage GP and IF-TOPSIS methods in the Turkish manufacturing industry. A Fermatean fuzzy PSI-CoCoSo framework is developed by Pamucar et al. (2024). Tavana et al. (2017) applied dynamic DEA and GP with a hybrid approach in their research in the US microprocessor, microchip, and micro-memory parts manufacturing sector. Stević et al. (2019) proposed sustainable supplier selection in the lime manufacturing industry in Bosnia and Herzegovina with FUCOM and interval rough SAW models. Osiro et al. (2018) introduced HFLTS-QFD in the Brazilian automotive industry, Ecer (2021) employed a FUCOM-MAIRCA model in the Turkish automotive industry, and Vahidi et al. (2018) used Hybrid SWOT-QFD models in the Iranian automotive industry. Qin et al. (2017) adopted the TODIM method with IT2FSs in the automotive industry, and Mao et al. (2019) conducted the TODIM method with fuzzy TOPSIS and IVIFN in the polymer industry.

On the other hand, Moheb-Alizadeh and Handfield (2019) applied MCDM methods integrated with mathematical models using the Benders decomposition algorithm, and Wang et al. (2019) proposed discrete Choquet integral multi-criteria methods. Information on the different methodologies used in the existing literature on sustainable supplier

Table 1
Common criteria used in the sustainable supplier selection studies.

	Tuzkaya et al. (2009)	Koc et al. (2023)	Nayeri et al. (2023)	H.-W. Lo (2023)	Hajiaghaei-Keshteli et al. (2023)	Luthra et al. (2017)	Lo et al. (2018)	Masoomi et al. (2022)	Fu (2019)	Z. Lu et al. (2019)	Roy et al. (2020)	Lou et al. (2022)	Menon and Ravi (2022)	Rahimi et al. (2021)	Govindan et al. (2020)	Mina et al. (2021)	Kuo et al. (2010)	Kannan et al. (2013)	Kannan et al. (2015)	Li et al. (2019a)	Tirkolaee et al. (2020)	Tong et al. (2022)	Çebi and Bayraktar, (2003)	Ávila et al. (2012)	Rezaei et al. (2016)	H. Gupta and Barua (2017)	Suraraksa and Shin (2019)	Haeri and Rezaei (2019)
Product Quality		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓													✓	✓
Quality control and assurance			✓												✓	✓	✓	✓	✓								✓	
On-time delivery		✓	✓		✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
Product cost			✓	✓	✓	✓		✓			✓	✓	✓	✓			✓	✓	✓		✓	✓		✓			✓	✓
Eco-design	✓	✓		✓	✓	✓		✓					✓		✓		✓	✓	✓	✓		✓			✓	✓	✓	
After-sale services		✓	✓		✓										✓	✓						✓	✓					
Past Experience															✓	✓						✓	✓					
Flexibility				✓	✓	✓	✓			✓	✓		✓			✓			✓	✓	✓	✓	✓	✓			✓	
Company reputation		✓					✓		✓	✓		✓									✓	✓					✓	
Environmental management system	✓	✓			✓	✓		✓			✓		✓				✓	✓	✓						✓	✓	✓	
Pollution control	✓	✓			✓	✓		✓					✓		✓			✓	✓						✓			✓
Resource consumption	✓		✓			✓		✓					✓					✓							✓	✓		✓
Green image	✓				✓			✓					✓						✓						✓			✓
Environmentally friendly materials	✓	✓			✓										✓	✓			✓			✓				✓		
Green packaging	✓	✓			✓	✓					✓					✓			✓			✓						
Technical capability		✓				✓								✓		✓	✓	✓	✓							✓	✓	✓
Financial capability		✓				✓						✓				✓						✓					✓	
Research and Development	✓	✓				✓										✓		✓	✓						✓	✓	✓	
Transportation cost						✓				✓	✓						✓	✓	✓		✓	✓		✓			✓	
Corporate Social Responsibility	✓	✓		✓	✓								✓						✓			✓						
Production facilities and capacity					✓	✓					✓	✓				✓			✓					✓		✓	✓	
Green logistics	✓	✓					✓								✓					✓						✓		
Environmental costs	✓					✓					✓														✓			
Clean technology	✓			✓	✓										✓	✓			✓									
Recycling	✓	✓	✓	✓	✓											✓			✓						✓	✓		
Customized Service					✓							✓										✓	✓					
Order fulfillment rate					✓												✓	✓	✓			✓					✓	
Human rights		✓				✓					✓		✓				✓		✓	✓	✓							
Safety Systems & Occupational Health		✓	✓	✓		✓					✓		✓								✓	✓					✓	
Rejection ratio																	✓	✓	✓								✓	

selection and the areas and countries in which the research has been carried out is given in Table 2. The acronyms of the methods presented in Table 2 are listed in Appendix A1.

2.3. Background on MCDM methods under the IVFNN environment

In literature, neutrosophic fuzzy sets with MCDM methods have been applied successfully to solve the challenging real-world problem such as clean vehicle selection with neutrosophic fuzzy MARCOS (Pamucar et al., 2021), forklift selection using improved FUCOM-MOORA model with neutrosophic fuzzy sets (Chakraborty and Saha, 2022), water treatment plants' assessment via single-valued neutrosophic fuzzy MARCOS and GMDH methodology (Majumder, 2023), failure evaluation through neutrosophic fuzzy BWM (Yucesan and Gul, 2021), subcontractor evaluation utilizing improved DEMATEL with single-valued neutrosophic sets (Abdullah et al., 2021), container vessel assessment with Type-2 neutrosophic fuzzy GRA model (Hashemkhani Zolfani et al., 2022a), and COVID-19 vaccine selection using neutrosophic AHP-TOPSIS framework (Hezam et al., 2021).

However, MCDM models based on IVFNN knowledge are rare. In one of those papers, Ecer et al. (2023) conducted a sustainability evaluation for micro-mobility solutions in urban transportation through an IVFNN approach, including LOPCOW, CoCoSo, and Delphi methods. Yazdani et al. (2021) performed a sustainable supplier selection via a CRITIC and CoCoSo integrated model with IVFNN information. Yiğit (2023) evaluated training programs for human resources through the IVFNAHP approach. Wang et al. (2018) proposed a technology evaluation model by extending the VIKOR method with neutrosophic fuzzy sets.

2.4. The research gaps

The airline industry consists of a structure with different supplier stakeholders performing various functions at the center of which airline companies are located. Airline companies primarily depend on these companies to which they supply different services through outsourcing, and the sustainability of airline operations is closely related to airline-supplier relations.

The extant literature includes various studies on the relationships between the airline industry and the supply chain. Alshurideh et al. (2019) investigated the connection between supply chain integration and customer relationship management through the triangulation method for Emirates Airlines logistics. Rajaratnam and Sunmola (2021) aimed to understand the distinctive features, practical difficulties, and new developments in the airline catering supply chain with qualitative and exploratory research. Choy et al. (2007) developed a performance measurement model for managing supplier relations with maintenance logistics providers in their study on Dragon Airlines. Zkik et al. (2023) presented an efficient airline supply chain management model based on blockchain and machine learning.

There are limited studies on supplier selection in the airline industry in the extant literature. Fu (2019) introduced an assessment model consisting of qualitative and quantitative criteria for choosing the best catering supplier to increase customer satisfaction. On the other hand, Chan et al. (2007) investigated the selection of an airline company as an essential supplier of maintenance and repair for airlines through a model consisting of tangible and intangible criteria, as a case study on an airline through a multi-criteria decision-making approach. In another study, Gorener et al. (2017) offered a comprehensive solution to the issue of supplier performance evaluation and selection in the aircraft maintenance sector. Rezaei et al. (2014) applied a model that they developed in two stages: the first stage is to reduce the number of potential suppliers, and the second stage, where alternative suppliers are evaluated against the main criteria and sub-criteria, and the most suitable supplier is selected as KLM Airlines, one of the largest carriers in Europe in the airline retail industry. Liou et al. (2014) put forth a brand-new fuzzy integral-based methodology for selecting and

Table 2
Methods, scopes, and countries of sustainable supplier selection studies.

Authors	Methodology	Scope	Country
Akman (2015)	Fuzzy c means, VIKOR	Automobile industry	Turkey
Azadnia et al. (2015)	Fuzzy AHP, Rule-based weighted fuzzy method, MOMP	Packaging films in the food industry	Iran
Chai et al. (2023)	IFSs, IVTFNs, Cumulative prospect theory	E-bike sharing	N/A
Cheraghalipour and Farsad (2018)	BWM, RMCGP	Plastic industry	Iran
Coşkun et al. (2022)	Materiality analysis, ANP, PROMETHEE, Cluster analysis	Chemical manufacturer	Transnational
Çalı and Balaman (2019)	ELECTRE I, VIKOR with IFSs	Automobile industry	N/A
Debnath et al. (2023)	SWARA, WASPAS, ARAS, EDAS	Healthcare testing facilities	Emerging economies
Ecer (2022)	AHP, IT2FSs	Home appliance manufacturing	Turkey
Fallahpour et al. (2017)	DEA, GEP	Textile company	N/A
Ghadimi et al. (2018)	MAS	Healthcare electronic devices	Several countries
Gidiagba et al. (2023)	Delphi, BWM, TOPSIS	Oil and Gas (O&G) industry	Nigeria
Giri et al. (2022)	Pythagorean fuzzy DEMATEL	N/A	N/A
Govindan and Sivakumar (2016)	Fuzzy TOPSIS, MOLP	Paper industry	South India
Gupta et al. (2016)	AHP, Fuzzy MOILP	Automobile part manufacturing	India
Hashemi et al. (2015)	ANP, Improved GRA	Automobile industry	Iran
Jafarzadeh Ghoushchi et al. (2019)	Fuzzy BWM, Piecewise linear value function	Oilseed industry	N/A
Jain and Singh (2020)	Fuzzy Kano Model	Iron and Steel Industry	India
Kannan (2018)	Fuzzy Delphi, ISM, ANP, COPRAS Grey	Textile company	India
Kannan et al. (2014)	Fuzzy TOPSIS	Electronics company	Brazil
Kilic and Yalcin (2020)	Two-phase GP, IF-TOPSIS	Manufacturing industry	Turkey
Laosirihongthong et al. (2019)	Fuzzy AHP	Cement manufacturing	South-East Asia
Li et al. (2019b)	TOPSIS with Rough Set Theory	Photovoltaic energy	China
Liu et al. (2019)	BWM, AQM	Watch manufacturer	N/A
Lu et al. (2018)	ELECTRE with Rough Set Theory	Solar air-conditioner manufacturer	N/A
Lu et al. (2019)	Fuzzy AHP, Cloud model, Possibility degree	Straw biomass industry	China
Luthra et al. (2017)	AHP, VIKOR	Automobile industry	India
Mao et al. (2019)	Fuzzy TOPSIS, TODIM, IVIFN	Polymer manufacturer	N/A
Mohammed et al. (2019)	Fuzzy AHP, Fuzzy TOPSIS, FMOO	Metal industry	Saudi Arabia
Moheb-Alizadeh and Handfield (2019)	DEA, ε-constraint method, Benders decomposition algorithm	Automobile industry	Iran
Mousakhani et al. (2017)	IT2FSs TOPSIS, IT2FSs Hamming Distance	Battery industry	Iran
Oroojeni Mohammad	BWM, Fuzzy TOPSIS	Iron and steel manufacturing	Khouzestan-Iran

(continued on next page)

Table 2 (*continued*)

Authors	Methodology	Scope	Country
Javad et al. (2020)			
Osiro et al. (2018)	HFLTS-QFD	Automobile industry	Brazil
Park et al. 2018)	MAUT, AHP, MOILP	Bi-cycle industry	Globally
Qin et al. (2017)	An extended novel TODIM method with IT2FSs	Automobile industry	N/A
Rostamzadeh et al. (2015)	Intuitionistic fuzzy VIKOR	Computer disk manufacturing	Malaysia
Roy et al. (2020)	Fuzzy AHP, PROMETHEE	Garment company	Bangladesh
Shang et al. (2022)	Integrated BWM, Fuzzy Shannon entropy, Fuzzy MULTIMOORA	Forklift truck manufacturer	China
Stević et al. (2019)	FUCOM, Interval Rough SAW	Lime manufacturing	Bosnia Herzegovina
Tavana et al. (2017)	GP, Dynamic DEA	Semiconductor equipment	The United States
Tong et al. (2022)	PROMETHEE II	SMEs	China
Vahidi et al. (2018)	Hybrid SWOT, QFD	Automobile industry	Iran
Wang et al. (2018)	Fuzzy AHP, Green DEA	Food Processing industry	Vietnam
Wang et al. (2019)	Discrete Choquet Integral Multi-Criteria	Manufacturing company	N/A
Xu et al. (2019)	AHP Sort II with IT2FSs	Material supplier	China
Yazdani et al. (2016)	QFD, SWARA, WASPAS	Stainless steel industry	Iran
Yazdani et al. (2017)	DEMATEL, QFD, COPRAS, MOORA	Dairy products	Iran
Yu, Zhao et al. (2019)	TOPSIS, ELECTRE with Entropy Measure Method	Home appliances manufacturing	China
Yu, Shao et al. (2019)	TOPSIS with Entropy Measure Method, GCA	Home appliances manufacturing	China
Zhao and Guo (2014)	Fuzzy TOPSIS, Fuzzy Entropy	Thermal power equipment	China

improving suppliers in the airline industry by applying the proposed model to a real case. Bakır et al. (2021) sought to address the issue of choosing ground-handling suppliers as a business-to-business (B2B) marketing decision in the airline industry. Yusriza et al., 2023 evaluated the effects using Bayesian network (BN) modelling to assess supply chain performance in airline catering. Borjalilu et al. (2021) create an Entropy and Vikor-based multi-criteria supplier selection model for airlines using the literature and expert opinions and test the model on a real case.

Upon reviewing the literature on supplier evaluation and selection in the airline industry, the authors observed that most supplier selection issues pertain to catering services and maintenance providers. The authors found no prior studies on selecting or evaluating sustainable aviation fuel (SAF) or fossil jet fuel suppliers for airline companies. Therefore, this study appears to be novel in addressing this particular issue. Additionally, the study introduces a new multi-criteria decision-making methodology, distinct from existing approaches, by implementing the IVFNN LOPCOW-IVFNN MARCOS integrated model.

3. The proposed framework

Traditional MCDM methods, despite their widespread application, exhibit several drawbacks when applied to the complex problem of SAF supplier selection. For example, methods like AHP and TOPSIS assume a level of precision in the decision-making process that is often unattainable in real-world scenarios, particularly in sustainability, where criteria can be highly subjective and interdependent. These methods also generally require a linear and hierarchical structure of criteria, which may not adequately capture the dynamic and multifaceted nature of sustainability metrics. Moreover, existing methods frequently neglect the integration of fuzzy logic principles, crucial for dealing with the ambiguities and uncertainties of sustainable supplier selection. Although some studies have introduced fuzzy set theory to enhance traditional MCDM methods, they often do not fully exploit the potential of advanced fuzzy systems, such as interval-valued fuzzy neutrosophic sets, which offer a more robust framework for capturing the nuances of expert judgments. Our proposed framework addresses these limitations by integrating IVFNN with the LOPCOW and MARCOS approaches. This combination allows for a more flexible and comprehensive evaluation of SAF suppliers by accommodating the inherent uncertainties and providing a more nuanced analysis of the criteria. The IVFNN approach enhances the robustness of the decision-making process by allowing experts to express their preferences more flexibly, capturing the uncertainty and hesitation that typically accompany complex sustainability assessments. Additionally, integrating LOPCOW and MARCOS methods ensures a balanced criteria weighting, reflecting objective data and subjective judgments. It is essential in the multifaceted context of SAF supplier selection.

Supplier evaluations use interval values better to capture the uncertainty and variability in expert assessments. Traditional methods often require a single, precise value, which may not adequately represent the inherent uncertainties and subjectivities of the decision-making process. Interval values provide a more accurate representation of different experts' diverse perspectives and uncertainty levels. This approach makes the evaluation process more flexible and realistic. The methodology used in this study is based on Interval-Valued Fuzzy Neutrosophic Numbers (IVFNN), which are superior to traditional MCDM methods because they manage uncertainty and subjectivity more effectively. IVFNN can better integrate uncertainties and conflicting information, resulting in more robust and reliable decision-making outcomes. The primary reasons for choosing this methodology are:

- ✓ Uncertainty Management: IVFNN minimizes the impact of uncertainties by effectively incorporating them into the decision-making process.
- ✓ Flexibility: This fuzzy extension handles the variability of expert opinions and evaluation criteria more flexibly.
- ✓ Reliability: IVFNN-based models provide more dependable results, particularly advantageous in complex and critical decision scenarios.

This part demonstrates the proposed IVFNN-based decision-making framework and its basic procedure. The fundamental procedure of the model is illustrated in Fig. 1.

3.1. Preliminary information

Neutrosophic set theory is a novel fuzzy set based on neutrosophy and generalizes the classical and fuzzy forms of the neutrosophy. The classical fuzzy theory (FSs), developed by Zadeh (1965), is based on membership functions describing the degree of membership for each element. Atanassov (1999) developed fuzzy interval sets (IFSs) to overcome the weakness of the FSs. IFS is based on describing the membership $\mu_E(x)$ and non-membership $y_E(x)$ degrees separately in a fuzzy set. An IF set can be demonstrated as $I = \{(x, \mu_E(x), y_E(x)) | x \in X\}$, as a generalization of the classical fuzzy theory. Afterwards, Smarandache (1999, 2001) developed the notion of the neutrosophic set (NS). It is an extended form of the IFS theory, and the neutrosophic constituents' number is independent of <1, or >1, or $=1$. The neutrosophic aggregation operators (NAOs) provide finer conclusions than IFOs when the parameters' total number equals 1 (as in IFS), as the IFOs disregard the indeterminacy. Contrarily, the NAOs regard ambiguity at the same level as membership in truth and non-membership in misstatement is identified (Smarandache, 2019). Moreover, NS is more applicable and robust

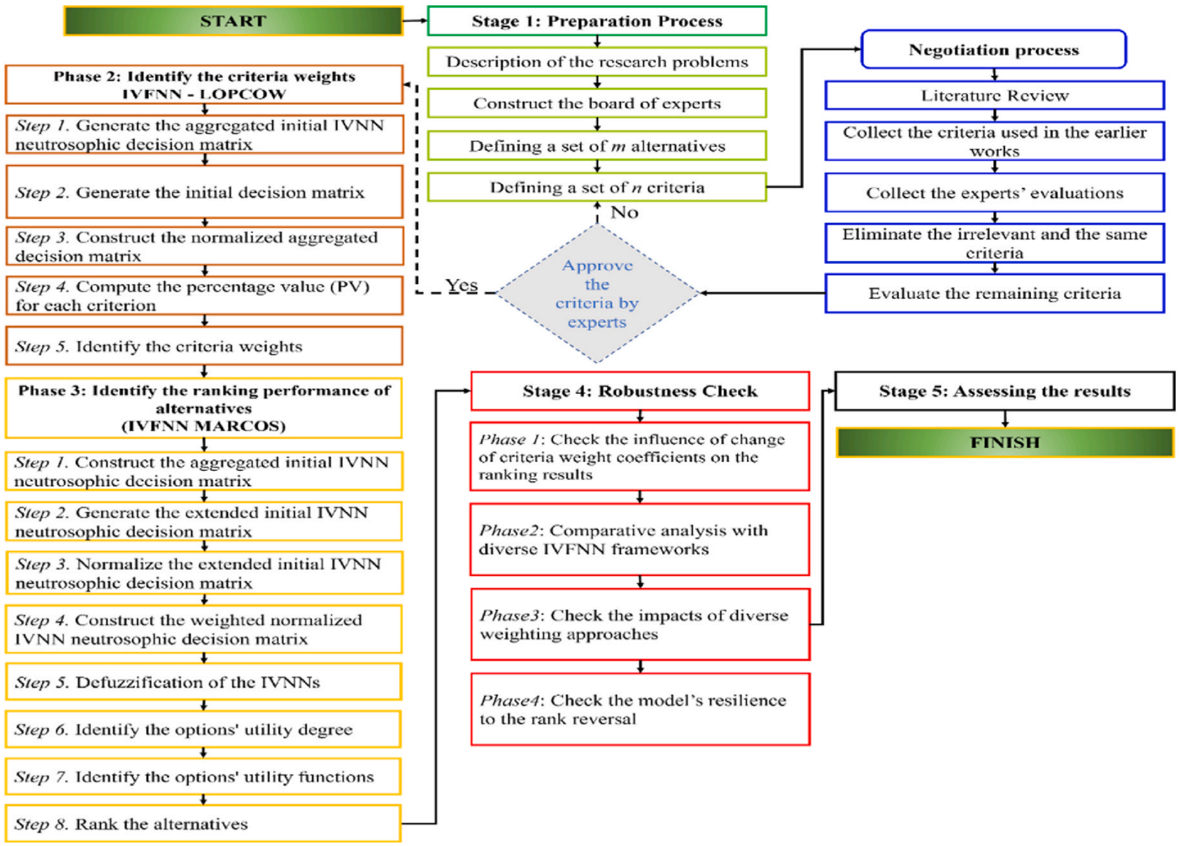

Fig. 1. The suggested model and its fundamental algorithm.

since, aside from independent constituents, it also deals with partly and partially dependent components, while IFS cannot. In this part, some basic notions and operations, apart from several properties and descriptions of neutrosophic and interval-valued neutrosophic sets, have been exhibited, respectively.

3.1.1. *Neutrosophic sets (NSs)*

Here, some fundamental notions and features of the neutrosophic set introduced by Majumdar and Samanta (2014) and Smarandache (2019) are presented.

Definition 1. Let U be a universal set, with a generic element of U denoted by u. A neutrosophic set (NS), the truth-membership function T_U, indeterminacy-membership function I_U and falsity-membership function F_U are used to describe a neutrosophic set N in U, $T_N(u), I_N(u)$, $F_N(u)$ are realistic standard or non-standard subsets of [0ˉ, 1⁺] for each $u \in U$ and all membership functions:

$$T_N(u), I_N(u), F_N(u) \subseteq]0^-, 1^+[\tag{1}$$

Definition 2. A neutrosophic N's complement can be described by N˜ and can be shown as:

$$T_{N^\sim}(u) = \{1^+\} \ominus T_N(u), I_{N^\sim}(u) = \{1^+\} \ominus I_N(u), F_{N^\sim}(u) = \{1^+\} \ominus F_N(u), \text{for all } u \in U. \tag{2}$$

Definition 3. The other neutrosophic set M consists of an NS N, and N ⊆ M, if and only if;

$$\begin{aligned} inf\ T_N(u) \le inf\ T_M(u), sup\ T_N(u) \le sup\ T_M(u)\ inf\ I_N(u) \\ \ge inf\ I_M(u), sup\ I_N(u) \\ \ge sup\ I_M(u) inf\ F_N(u) \\ \ge inf\ F_M(u), sup\ F_N(u) \\ \ge sup\ F_M(u) \text{for all } u \in U. \end{aligned} \tag{3}$$

Definition 4. Two different NSs, N and M are equal only when N ⊆ M and M ⊆ N.

Definition 5. Two different neutrosophic sets N and M and the union of NS X, expressed as X = N ∪ M, whose truth-membership function, indeterminacy-membership function, and falsity-membership functions can be determined as follows:

$$\begin{aligned} T_X(u) &= T_N(u) \oplus T_M(u) \ominus T_N(u) \odot T_M(u) \\ I_X(u) &= I_N(u) \oplus I_M(u) \ominus I_N(u) \odot I_M(u) \\ F_X(u) &= F_{AN}(u) \oplus F_M(u) \ominus F_N(u) \odot F_M(u) \\ &\text{for all } u \in U. \end{aligned} \tag{4}$$

Definition 6. Two differences between NS N and M and the intersection set define X, represents as $X = A \cap B$, whose truth-membership function, indeterminacy-membership function, and falsity-membership functions can be expressed as follows:

$$\begin{aligned} T_X(u) &= T_N(u) \ominus T_N(u) \odot T_M(u), \\ I_X(u) &= I_N(u) \ominus I_N(u) \odot I_M(u), \\ F_X(u) &= F_N(u) \ominus F_N(u) \odot F_M(u), \\ &\text{for all } u \in U. \end{aligned} \tag{5}$$

Definition 7. Two intersections of two NS N and M is a neutrosophic set X, represents as $X = A \cap B$, whose truth-membership function, indeterminacy-membership function, and falsity-membership functions can be depicted as follows:

$$\begin{array}{l} T_X(u) = T_N(u) \odot T_M(u), \\ I_X(u) = I_N(u) \odot I_M(u), \\ F_X(u) = F_N(u) \odot F_M(u), \\ \quad \textit{for all } u \in U. \end{array} \tag{6}$$

3.1.2. Interval valued NSs (IVNSs)

In this part, brief and preliminary information on critical arguments presented by (Majumdar and Samanta, 2014) regarding the characteristics of the interval-valued neutrosophic set (IVNS) is given.

Definition 1. Let U be a universal set, with the generic object of U denoted by u ∈ U. An interval-valued neutrosophic set can be defined as N. Accordingly, an interval-valued neutrosophic set β is the subset of U (N ⊂ U), represent as follows:

$$N = \{\langle u, T_N(u), I_N(u), F_N(u)\rangle : u \in U\} \tag{7}$$

An interval-valued neutrosophic set (IVNS), the truth-membership function $T_N(u)$, the indeterminacy-membership function $I_N(u)$ and falsity-membership function $F_N(u)$ are used to describe an INVNS N in U. Where $T_N(u) : U \rightarrow [0,1]$, $I_N(u) : U \rightarrow [0,1]$ and $F_N(u) : U \rightarrow [0,1]$, *for all* $u \in U$. .

Definition 2. The interval-valued neutrosophic functions can be described as:

$$T_N(u) = [\textit{inf } T_N(u), \textit{sup}_N\ (u)] \subseteq [0,1], I_N(u) = [\textit{inf } I_N(u), \text{sup}_N\ (u)] \subseteq [0,1], \\ F_N(u) = [\textit{inf } F_N(u), \textit{sup } F_N(u)] \subseteq [0,1], \textit{for all } u \in U \tag{8}$$

The sum of all membership functions should satisfy the following equation:

$$0 \leq T_N(u) + I_N(u) + F_N(u) \leq 3, \textit{for all } u \in U. \tag{9}$$

Definition 3. When the universal set N is continuous, an IVNS A can be represented as follows:

$$N = \int_u \frac{\langle T_N(u), I_N(u), F_N(u)\rangle}{u}, u \in U \tag{10}$$

When the universal set U is discrete, an IVNS N can be expressed as follows:

$$N = \sum_{i=1}^{t} \frac{\langle T_N(u_i), I_N(u_i), F_N(u_i)\rangle}{u_i}, u \in U \tag{11}$$

Definition 4. The complement of an IVNS N is denoted by N^{ω} Furthermore, it is identified as follows:

$$\left.\begin{array}{r} T_{N^{\omega}}(u) = F_N(u) \\ \textit{inf } I_{N^{\omega}}(u) = 1 - \textit{sup } I_N(u) \\ \textit{sup } I_{N^{\omega}}(u) = 1 - \textit{inf } I_N(u) \\ F_{N^{\omega}}(u) = T_N(u) \end{array}\right. \text{for all } u \in U. \tag{12}$$

Definition 5. Two different interval-valued neutrosophic sets N and M are equal only when N ⊆ M and M ⊆ N.

Definition 6. The union of two interval-valued neutrosophic sets N and M can describe an interval-valued neutrosophic set X, which can be represented as follows:

$$\left.\begin{array}{r} \textit{inf } T_X(u) = \textit{max}\{\textit{inf } T_N(u), \textit{inf } T_M(u)\} \\ \textit{sup } T_X(u) = \textit{max}\{\textit{sup } T_N(u), \textit{sup } T_M(u)\} \\ \textit{inf } I_X(u) = \textit{min}\{\textit{inf } I_N(x), \textit{inf } I_M(u)\} \\ \textit{sup } I_X(u) = \textit{min}\{\textit{sup } I_N(u), \textit{sup } I_M(u)\} \\ \textit{inf } F_X(u) = \textit{min}\{\textit{inf } F_N(u), \textit{inf } F_M(u)\} \\ \textit{sup } F_X(u) = \textit{min}\{\textit{sup } F_N(u), \textit{sup } F_M(u)\} \end{array}\right. \textit{for all } u \in U. \tag{13}$$

Definition 7. The intersection of two different IVNSs, N and M, written as X = N ∩ M, is expressed as follows:

$$\left.\begin{array}{r} \textit{inf } T_X(u) = \textit{min}\{\textit{inf } T_N(u), \textit{inf } T_M(u)\} \\ \textit{sup } T_X(u) = \textit{min}\{\textit{sup } T_N(u), \textit{sup } T_M(u)\} \\ \textit{inf } I_X(u) = \textit{max}\{\textit{inf } I_N(u), \textit{inf } I_M(u)\} \\ \textit{sup } I_X(u) = \textit{max}\{\textit{sup } I_N(u), \textit{sup } I_M(u)\} \\ \textit{inf } F_X(u) = \textit{max}\{\textit{inf } F_N(u), \textit{inf } F_M(u)\} \\ \textit{sup } F_X(u) = \textit{max}\{\textit{sup } F_N(u), \textit{sup } F_M(u)\} \end{array}\right. \text{for all } u \in U. \tag{14}$$

Definition 8. Some arithmetic operations for two different interval-valued neutrosophic sets N and M can be expressed as follows (Zavadskas et al., 2020):

$$\begin{array}{c} N = \langle [\textit{inf } T_N, \textit{sup } T_N], [\textit{inf } I_N, \textit{sup } I_N], [\textit{inf } F_N, \textit{sup } F_N]\rangle, \\ M = \langle [\textit{inf } T_M, \textit{sup } T_M], [\ \textit{inf } I_M, \textit{sup } I_M], [\ \textit{inf } F_M, \textit{sup } F_M]\rangle \\ \lambda > 0. \end{array} \tag{15}$$

$$N \oplus M = \left\langle \begin{array}{c} [(\textit{inf } T_N \oplus \textit{inf } T_M \ominus \textit{inf } T_N \odot \textit{inf } T_M), (\textit{sup } T_N \oplus \textit{sup } T_M \ominus \textit{sup } T_N \odot \textit{sup } T_M)], \\ [(\text{ inf } I_N \odot \textit{inf } I_M), (\text{ supI } I_N \odot \textit{sup } I_M)], [(\textit{inf } F_N \odot \textit{inf } F_M), (\text{ sup } F_N \odot \textit{sup } F_M)] \end{array} \right\rangle \tag{16}$$

$$\lambda N = \langle [1 \ominus (1 \ominus \textit{inf } T_N)^{\lambda}, 1 \ominus (1 \ominus \textit{sup } T_N)^{\lambda}], [(\textit{inf } I_N)^{\lambda}, (\textit{sup}_N\ )^{\lambda}], [(\textit{inf } F_{N1})^{\lambda}, (\textit{inf } F_N)^{\lambda}]\rangle \tag{17}$$

$$N_1 \odot N_2 = \left\langle \begin{array}{c} [(\textit{inf } T_N \odot \textit{inf } T_M), (\textit{sup } T_N \odot \textit{sup } T_M)], \\ [(\textit{inf } I_N \oplus \textit{inf } I_M - \textit{inf } I_N \odot \textit{inf } I_M), (\textit{sup } I_N \oplus \textit{sup } I_M \ominus \textit{sup } I_N \odot \textit{sup } I_M)], \\ [(\textit{inf } F_{N1} \oplus \textit{inf } F_{N2} - \textit{inf } F_N \odot \textit{inf } F_M), (\textit{sup } F_N \oplus \textit{sup } F_M \ominus \textit{sup } F_N \odot \textit{sup } F_M)] \end{array} \right\rangle \tag{18}$$

3.2. IVFNN-LOPCOW

The LOPCOW technique is a novel weighting multi-criteria method offered by Ecer and Pamucar (2022). It is based on prioritizing the evaluation factor in a specific hierarchical structure for an assessment procedure. LOPCOW has many precious advantages. For example, it can

Table 3
Interval Neutrosophic values for evaluating alternatives (Yazdani et al., 2021).

Linguistic variable	Abbreviation	IVFNNs	Deneutrosophication values
Certainly low	CL	< [0.1,0.2], [0.1,0.2], [0.8,0.9] >	0.261
Very low	VL	< [0.2,0.3], [0.3,0.4], [0.7,0.8] >	0.400
Low	L	< [0.3,0.4], [0.4,0.5], [0.6,0.7] >	0.478
Below average	BA	< [0.4,0.5], [0.5,0.6], [0.5,0.6] >	0.556
Average	A	< [0.5,0.5], [0.6,0.7], [0.4,0.5] >	0.578
Above average	AA	< [0.5,0.6], [0.5,0.6], [0.4,0.5] >	0.661
High	H	< [0.6,0.7], [0.4,0.5], [0.3,0.4] >	0.794
Very high	VH	< [0.7,0.8], [0.2,0.3], [0.2,0.3] >	0.889
Certainly high	CH	< [0.8,0.9], [0.1,0.2], [0.1,0.2] >	1.000

overcome an issue, such as the availability of negative or zero values in raw data, and enables criterion importance levels to be obtained rationally. Besides, it can provide logical results for the identification of the weights of the criteria, avoiding the influence of the characteristics of the criteria to be benefited or to be costly, and helps to eliminate dimensional gaps resulting from the data structure (Ulutaş et al., 2024). Ecer et al. (2023) introduced the IVFNN-LOPCOW methodology very recently. The methodology's details are illustrated below (Ecer et al., 2023):

Step 1. Generate the aggregated initial IVFNN neutrosophic decision matrix (AI-NDM): Suppose there is m number of options $(i = 1, 2, \ldots, m)$, n number of criteria $(j = 1, 2, \ldots, n)$, and k number of experts $(k = 1, 2, \ldots, l)$ in a group decision-making problem. Specialists evaluate the factors by considering IVNS-based linguistic terms given in Table 3 (Karaşan et al., 2019).

In this respect, assessing of i th option $(i = 1, 2, \ldots, m)$ by considering j th criterion $(j = 1, 2, \ldots, n)$ by k th specialists is described as $x_{ij}^{(k)} = \langle \left[T_{ij}^{(k)L}, T_{ij}^{(k)U}\right], \left[I_{ij}^{(k)L}, I_{ij}^{(k)U}\right], \left[F_{ij}^{(k)L}, F_{ij}^{(k)U}\right] \rangle$.

In a group decision-making process, the interval-valued neutrosophic weighted arithmetic average operator (INWAA) is applied to aggregate the analysts' appraisals (Karasan and Kahraman, 2018) using Eq. (19).

$$\partial_{ij} = \langle \left[1 - \prod_{k=1}^{l} \left(1 - T_{ij}^{(k)L}\right)^{\omega_k}, 1 - \prod_{k=1}^{l} \left(1 - T_{ij}^{(k)U}\right)^{\omega_k}\right], \left[\prod_{k=1}^{l} \left(I_{ij}^{(k)L}\right)^{\omega_k}, \prod_{k=1}^{l} \left(I_{ij}^{(k)U}\right)^{\omega_k}\right], \left[\prod_{k=1}^{k} \left(F_{ij}^{(k)L}\right)^{\omega_k}, \prod_{k=1}^{l} \left(F_{ij}^{(k)U}\right)^{\omega_k}\right] \rangle \tag{19}$$
$$(i = 1, 2, \ldots, n)(j = 1, 2, \ldots, m)(k = 1, 2, \ldots, l)$$

where $\omega_k \in [0, 1]$ and, the DMs weights' sum is (ω_k) $\sum_{k=1}^{l} \omega_k = 1$ and $\partial_{ij} = \langle \left[T_{ij}^L, T_{ij}^U\right], \left[I_{ij}^{(L}, I_{ij}^{(U}\right], \left[F_{ij}^L, F_{ij}^U\right] \rangle$.

Step 2. Generate the initial decision matrix: Herein, the members of AI-NDM are transformed to numerical (definite) scores by applying the mathematical expression of deneutrosophication (Yazdani et al., 2021) presented in Eq. (20). Next, the initial decision matrix is formed.

$$DN(\partial_{ij}) = \left(\frac{T_{ij}^L + T_{ij}^U}{2} + \left(1 - \frac{\left(I_{ij}^L + I_{ij}^U\right)}{2}\right)\left(I_{ij}^U\right) - \left(\frac{F_{ij}^L + F_{ij}^U}{2}\right)\left(1 - F_{ij}^U\right)\right) \tag{20}$$

Step 3. Build the normalized aggregated decision matrix (NADM): the normalized values of elements are identified with the help of Eq. (21) by considering the criteria characteristics, e.g., cost or benefit (Ecer and Pamucar, 2022).

$$\wp_{ij} = \frac{\partial_{\max} - \partial_{ij}}{\partial_{\max} - \partial_{\min}}, j \in \text{Cos}\,t$$
$$\wp_{ij} = \frac{\partial_{ij} - \partial_{\min}}{\partial_{\max} - \partial_{\min}}, j \in Benefit \tag{21}$$

Step 4. Compute the percentage value (PV): The PVs regarding each factor are identified by employing Eq. (22) (Ecer and Pamucar, 2022).

$$PV_{ij} = \left| \ln\left(\frac{\sqrt{\frac{\sum_{i=1}^{m} \wp_{ij}^2}{m}}}{\sigma}\right) * 100 \right| \tag{22}$$

where σ symbolizes the deviation value, and "m" denotes the number of options.

Step 5: Identify the criteria weight values: Eq. (23) is employed to determine the criteria weight values (Ecer and Pamucar, 2022).

$$\omega_j = \frac{PV_{ij}}{\sum_{i=1}^{n} PV_{ij}} \tag{23}$$

3.3. IVFNN-MARCOS

The MARCOS approach is a novel decision-making procedure developed by Stević et al. (2020). It provides many advantages for addressing extraordinarily intricate assessment problems. It considers ideal and anti-ideal solutions, identifies the utility degree concerning them better, and can consider many options and criteria with fewer computations. These abilities of the technique make it more stable and consistent than many popular MCDM frameworks (Hashemkhani Zolfani et al., 2022b). Aside from the traditional form of the MARCOS approach, extended forms of the method based on various fuzzy sets, such as the classical fuzzy sets (Görçün and Doğan, 2023), spherical fuzzy sets (Jafarzadeh Ghoushchi et al., 2023), q-rung orthopair fuzzy sets (Krishankumar et al., 2023), interval type-2 fuzzy sets (Gong et al., 2021), dual hesitant fuzzy sets (Saha et al., 2022), intuitionistic fuzzy sets (Ecer and Pamucar, 2021; Salimian et al., 2022; Ecer et al., 2022), fuzzy ZE-numbers (Haseli et al., 2023), and Pythagorean probabilistic hesitant fuzzy sets (Qahtan et al., 2023) have successfully been employed in previous studies. To the authors' information, the present article proposes an extension of the MARCOS method based on IVFNNs (IVFNN-MARCOS) for the first time in the literature. The fundamental algorithm of the model is presented as follows:

Step 1. Construct the aggregated initial IVFNN neutrosophic decision matrix: Suppose there is m number of options $(i = 1, 2, \ldots, m)$, n number of criteria $(j = 1, 2, \ldots, n)$, and k number of experts $(k = 1, 2, \ldots, l)$ in a group decision-making problem. Each expert executes linguistic appraisal for each option by considering each criterion. Then, these linguistics appraisals are transformed to the IVFNNs corresponding in linguistic scale, and the k number of IVFNN matrices is obtained as presented in Eq. (24). Afterwards, these matrices are aggregated with the aid of the INWAA operator as given in Eq. (19). Finally, the aggregated initial neutrosophic decision matrix is generated.

$$\left[x_{ij}^{(k)}\right]_{mxn} = \begin{pmatrix} \langle [T_{11}^{(k)L}, T_{11}^{(k)U}], [I_{11}^{(k)L}, I_{11}^{(k)U}], [F_{11}^{(k)L}, F_{11}^{(k)U}] \rangle & \cdots & \langle [T_{1n}^{(k)L}, T_{1n}^{(k)U}], [I_{1n}^{(k)L}, I_{1n}^{(k)U}], [F_{1n}^{(k)L}, F_{1n}^{(k)U}] \rangle \\ \vdots & \ddots & \vdots \\ \langle [T_{m1}^{(k)L}, T_{m1}^{(k)U}], [I_{m1}^{(k)L}, I_{m1}^{(k)U}], [F_{m1}^{(k)L}, F_{m1}^{(k)U}] \rangle & \cdots & \langle [T_{mn}^{(k)L}, T_{mn}^{(k)U}], [I_{mn}^{(k)L}, I_{mn}^{(k)U}], [F_{mn}^{(k)L}, F_{mn}^{(k)U}] \rangle \end{pmatrix} \tag{24}$$

where $x_{ij}^{(k)} = \langle \left[T_{ij}^{(k)L}, T_{ij}^{(k)U}\right], \left[I_{ij}^{(k)L}, I_{ij}^{(k)U}\right], \left[F_{ij}^{(k)L}, F_{ij}^{(k)U}\right] \rangle (i = 1, 2, \ldots, m), (j = 1, 2, \ldots n)$.

Step 2. Generate the extended initial IVFNN neutrosophic decision matrix: In this phase, the aggregated initial IVFNN neutrosophic decision matrix is extended by adding the ideal and anti-ideal solutions. In this regard, characteristics of the criteria (min or max) are considered. Depending on the nature of the criteria, AAI and AI are described by implementing Eqs. (25) and (26):

$$AI = \left(\left[max\ T_{ij}^L, max\ T_{ij}^U\right], \left[min\ I_{ij}^L, min\ I_{ij}^U\right], \left[min\ F_{ij}^L, min\ F_{ij}^U\right]\right) \tag{25}$$

$$AAI = \left(\left[min\ T_{ij}^L, min\ T_{ij}^U\right], \left[max\ I_{ij}^L, max\ I_{ij}^U\right], \left[max\ F_{ij}^L, max\ F_{ij}^U\right]\right) \tag{26}$$

Step 3. Normalize the extended initial IVFNN neutrosophic decision matrix: Herein, the elements of the extended initial IVFNN matrix are normalized by applying Eq. (27).

$$\eta_{ij} = \begin{cases} \langle \left[T_{ij}^L, T_{ij}^U\right], \left[I_{ij}^L, I_{ij}^U\right], \left[F_{ij}^L, F_{ij}^U\right] \rangle, j \in Benefit \\ \langle \left[F_{ij}^L, F_{ij}^U\right], \left[1 - I_{ij}^U, 1 - I_{ij}^L\right], \left[T_{ij}^L, T_{ij}^U\right] \rangle, j \in \mathrm{Cos}\ t \end{cases} \tag{27}$$

Step 4. Construct the weighted normalized IVFNN neutrosophic decision matrix: The elements of the normalized IVFNN matrix are weighted by implementing Eq. (28). For this purpose, the elements of the matrix are multiplied by weight coefficients identified by using the IVFNN LOPCOW approach.

$$S_{ij} = \eta_{ij}.w_j \tag{28}$$

Step 5. Defuzzification of the IVFNNs and computing the score values of alternatives: In this phase, the weighted normalized IVFNN matrix elements are defuzzified by implementing Eq. (29).

$$\varsigma_i = \left[\frac{T_{ij}^L + T_{ij}^U}{2}\right] + \left(1 - \left[\frac{I_{ij}^L + I_{ij}^U}{2}\right].I_{ij}^U\right) - \left(\left[\frac{F_{ij}^L + F_{ij}^U}{2}\right].\left(1 - F_{ij}^U\right)\right) \tag{29}$$

Step 6. Identify the options' utility degree: the utility degree of each option is computed by implementing Eqs. (30) and (31). It denotes the degree of utility for each option regarding ideal and anti-ideal solutions.

$$K_i^- = \frac{\varsigma_i}{\varsigma_{aai}} \tag{30}$$

$$K_i^+ = \frac{\varsigma_i}{\varsigma_{ai}} \tag{31}$$

where ς_i denotes the elements of the vector demonstrating the score value of each option, while ς_{aai} is the anti-ideal ς_{ai} is the ideal solution.

Step 7. Identify the options' utility functions: The utility function of each option is calculated by applying Eq. (32). It denotes the utility function for each option regarding ideal and anti-ideal solutions (Stević et al., 2020).

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \tag{32}$$

where $f(K_i^+)$ demonstrates the utility function concerning the anti-ideal solution Eq. (33) while $f(K_i^-)$ symbolizes the utility function with the ideal solution Eq. (34).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{33}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{34}$$

Step 8. Rank the alternatives: The alternatives are ranked by considering their utility function. The option with the highest value is identified as the best option.

4. Sustainable SAF supplier selection for airlines

The proposed hybrid IVFNN model is applied to address the airline industry's sustainable SAF supplier selection problem. In this connection, the researchers designed a five-stage research process to solve the problem comprehensively.

4.1. The preparation process

The preparation process of the present study was conducted in three phases. In the first step, the criteria pool, including 46 criteria from 6 different aspects, was created by benefiting from the related literature

Table 4
Main criteria, sub-criteria, their descriptions, and references for the proposed framework of sustainable SAF supplier selection.

	Sub-Factors		Description	Type	References
Economy	***E₁***	Payment flexibility	Facilitating the payment of the purchased product and service by the supplier	Max	Ávila et al. (2012); Yilmaz et al. (2011); Rahmi (2019); Ramadhanti and Pulansari (2022)
	E₂	Price	The charge paid to the supplier by the customer for the service received	Min	Roy et al. (2020); Kannan et al. (2015); Luthra et al. (2017); Ávila et al. (2012)
	E₃	Price performance value	The general performance of the supplier's deliveries and product quality concerning its cost	Max	Kannan et al. (2015); Gupta et al. (2017); Kuo et al. (2010); Gurel et al. (2015)
	E₄	Firm size	Supplier's size as measured by the number of employees, revenue, total assets, industry background, and other indicators	Max	Tong et al. (2022); Lou et al. (2022); Yang et al. (2017); Nair et al. (2015); Park and Krishnan (2001)
	E₅	Financial stability	Situation and stability of the supplier's finance	Max	Tong et al. (2022); Luthra et al. (2017); Mina et al. (2021); Lo et al. (2018), Amiri et al., 2021; Mishra et al., (2019)
	E₆	Technological capability	A set of management and technical skills to exploit technology and deal with the technological aspect associated with the supplier domain	Max	Rahimi et al. (2021); Hashemi et al. (2015); Vahidi et al. (2018); Haeri and Rezaei (2019); Gao et al. (2020); Luthra et al. (2017); Mina et al. (2021)
	E₇	Alternative supplier availability	The presence of different SAF suppliers to be taken service at the airport where airlines are provided fuel supply in terms of customer bargaining power	Max	Önder and Dağ (2013)
	E₈	R&D investments	The ability of the supplier's R&D investments to meet its current and future product development and innovation needs	Max	Kannan et al. (2013); Gupta et al. (2017); Van Hemel and Cramer, 2002; Horbach (2008); Halila and Rundquist (2011); Testa et al. (2011); Horbach et al. (2012) Zailani et al. (2012)
Delivery Capability	***D₁***	On-time and efficient delivery	Supplier's on-time delivery rate of the given purchase order	Max	Çebi and Bayraktar (2003); Kannan (2018); Govindan et al. (2020); Roy et al. (2020); Tirkolaee et al. (2020); Lu et al. (2019); Mina et al. (2021)
	D₂	Delivery reliability	The ratio of the total number of deliveries made within a time to the number of deliveries done without any errors considering safety risks	Max	Mina et al. (2021); Hendiani et al. (2020); Mina et al. (2014); Parkouhi and Ghadikolaei, 2017; Cavalcante et al. (2019)
	D₃	Distribution network	Availability of the supplier at different airports	Max	Mina et al. (2021); Parkouhi and Ghadikolaei, 2017; Parkouhi et al. (2019)
	D₄	Deliver flexibility	The ability of responsiveness to schedule and change orders in response to changing orders	Max	Sarkis (2003); Roy et al. (2020); Lu et al. (2019); Kuo et al. (2010); Luthra et al. (2017); Lo et al. (2018)
	D₅	Order fulfillment rate	Suppliers' ability to meet customer demand	Max	Guo et al. (2017); Kannan et al. (2015); Kannan et al. (2013); Kuo et al. (2010)
	D₆	Labor intensive	Dependence on labor by suppliers considering employee productivity, turnover rates, or strikes during production activities	Min	Çebi and Bayraktar (2003); Lo et al. (2018)
	D₇	Facilities and capacity	Supplier's SAF facilities and capacity adequacy in terms of fuel availability/stock management, a sufficient number of qualified personnel to serve the aircraft, and sufficient equipment	Max	Rezaei et al. (2015), Govindan et al. (2015); Ávila et al. (2012)
Quality	***Q₁***	Quality control and assurance systems	Implementing appropriate systems by suppliers to control and improve product quality and obtaining quality assurance	Max	Kuo et al. (2010); Kuo and Lin (2012); Kannan et al. (2013); Sari and Timor (2016); Govindan et al. (2020); Yazdani et al. (2017); Mina et al. (2021); Á vila et al. (2012)
	Q₂	Previous customer satisfaction	The condition demonstrating past customer satisfaction with the supplier	Max	Bafrooei et al. (2014); Çebi and Bayraktar (2003); Govindan et al. (2020); Mina et al. (2021)
	Q₃	Product quality	Efficient combustion and long shelf life of the fuel, together with its continuous availability in appropriate standards and quality	Max	Kuo et al. (2010); Büyüközkan and Çifçi, 2012; Lo et al. (2018); Luthra et al. (2017); Fu (2019); Lu et al. (2019); Tirkolaee et al. (2020)
	Q₄	Quality of after-sales service	Providing conditions for the use of grantees' rights in case of possible decreases in fuel quality and efficiency	Max	Jinturkar et al. (2014); Mina et al. (2014); Parkouhi et al. (2019); Kuo et al. (2010), Amindoust et al. (2012), Kannan et al. (2015); Wu et al. (2019); Mina et al. (2021); Govindan et al. (2020)
	Q₅	Customized service	A service that allows the supplier to personalize their customer requests	Max	Vanpoucke et al. (2014); Tong et al. (2022)
	Q₆	Quality certification	The appropriate standard level to which the product is certified by the certification body (e.g. Compliance with the RSB-CORSIA standard by ICAO certification)	Max	Suraraksa and Shin (2019); Tong et al. (2022)
	Q₇	Drop-in fuel or not	The ability to use the fuel in the aircraft/engine configuration without the need for additional equipment modifications	Max	Zhang and Hu (2013); Bauen et al. (2020); Kargbo et al. (2021)
	Q₈	Type of SAF	Compliance of fuel with sustainability criteria (e.g. no ILUC effect)	Max	Bauen et al. (2020); Ng et al. (2021)
Social	***S₁***	Information disclosure	Providing a limited amount of information to customers and other stakeholders to prevent critical information leakage	Max	Chiou et al. (2008); Kuo et al. (2010); Kannan et al. (2015); Lo et al. (2018)
	S₂	Relational reliability	It refers to the practice of trust and communication between the buyer and the supplier.	Max	Javed et al. (2022); Sawik (2014); Çebi and Bayraktar (2003); Tirkolaee et al. (2020); Gupta et al. (2017)
	S₃	Corporate social responsibility	The voluntary undertaking of social and environmental responsibilities for the benefit of society by companies	Max	Tong et al. (2022); Guo et al. (2017); Menon and Ravi (2022); Hutchins and Sutherland (2008); Sarkis and Dhavale (2015); Amindoust et al. (2012); Xu et al. (2013)

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Table 4 (*continued*)

		Sub-Factors	Description	Type	References
	S_4	Suppliers' reward and monitor system	Whether suppliers have systems for promoting their performance improvements	Max	Lou et al. (2022); Heide et al. (2007); Noshad and Awasthi (2018); Yawar and Seuring (2018)
	S_5	Corporate irregularities	Suppliers' amount of tax arrears, their number of economic disputes, negative news coverage about them, and their greenwash behaviours	Min	Yoon (2018); Liu et al. (2019); Tong et al. (2022)
	S_6	Supplier reputation	The supplier's reputation in the industry and its past working experience are positive and reliable in the short and long term.	Max	Lo et al. (2018); Govindan et al. (2015); Lou et al. (2022); Mina et al. (2021); Fu (2019); Çebi and Bayraktar (2003)
	S_7	Practices compatible with human rights	Related to whether the supplier provides specific standards of protection in labour matters and related legal rights	Max	Sarkis and Dhavale (2015); Govindan et al. (2013); Azadnia et al. (2012); Menon and Ravi (2022);
	S_8	Collaborations with social, environmental, and research groups	Suppliers' actions in collaboration with social and environmental groups and research groups	Max	Rondinelli and London (2003); Mohnen and Hoareau (2003); Gupta et al. (2017)
Environmental	E_1	Compliance with the environmental regulations and standards	Within the scope of environmental management systems, it refers to suppliers' compliance with standards and regulations such as RSB-CORSIA and ISO14001 and having green-related certificates	Max	Govindan et al. (2013); Menon and Ravi (2022); Roy et al. (2020); Kannan et al. (2013); Kuo et al. (2010); Luthra et al. (2017)
	E_2	Green design and purchasing	The supplier's investments in obtaining new products to minimize adverse environmental effects by designing and purchasing products that can be recycled and reused	Max	Tseng and Chiu (2013); Zhang et al. (2020), Gupta et al. (2017); Kannan et al. (2013); Mina et al. (2021)
	E_3	Waste management and pollution prevention/ control	Control over the amount of waste and pollution released into the environment by the supplier	Max	Bai and Sarkis (2010); Menon and Ravi (2022); Kannan et al. (2015); Luthra et al. (2017); Rezaei et al. (2016)
	E_4	Green logistics	Integrating the concept of environmental protection into logistics management by suppliers	Max	Govindan et al. (2013); Gupta et al. (2017); Lo et al. (2018); Li et al. (2019)
	E_5	Green production capabilities	Suppliers' level of capability of clean or eco-friendly production systems	Max	Amin and Zhang (2012); Kannan et al. (2015); Luthra et al. (2017); Rezaei et al. (2016); Amindoust et al. (2012)
	E_6	Internal management support	Suppliers' decisions made by senior management to achieve and maintain green development and support felt at all levels.	Max	Govindan et al. (2015); Li et al. (2019); Awasthi et al. (2010), Gupta et al. (2017); Humphreys et al. (2003); Mina et al. (2014); Kannan (2018)
	E_7	Green Image	How the stakeholders perceive the supplier in light of green initiatives such as carbon emission reduction per unit fuel (%), past environmental record, green marketing	Max	Menon and Ravi (2022); Mafakheri et al. (2011); Lu et al. (2019); Kannan et al. (2015)
	E_8	Green R&D and innovation	The ability of suppliers to contribute to R&D projects that generate new, cleaner technologies, processes, practices, and techniques and innovate available ones	Max	Luthra et al. (2017); Kannan et al. (2015)

and experts via an online Google Form. The experts consulted on airlines' selection of sustainable SAF suppliers are from academia (3 experts) and industry (4 experts). The academic experts' titles and experiences were associate professor (8 years), associate professor (10 years), and full professor (15 years). Additionally, the industry experts' positions and experiences were, respectively, supply and logistics manager from an aviation fuel supplier (10 years), cost control and fuel contract manager from an airline (9 years), fuel contract specialist from an airline (9 years), CEO from an airline (22 years).

In the second stage, two experts from different airlines checked the criteria pool for suitability to the study. These experts also were among the practitioners mentioned below. As a result of the check in the second stage, one aspect and seven criteria were eliminated, and the multi-criteria decision-making questionnaire created and used for data collection in the third stage was composed of 5 main criteria and 39 sub-criteria. The criteria used in the study, along with their definitions and references, are shown in Table 4. The research data were collected in the third stage from four experts out of seven in the first stage between 18 and March 31, 2023. Three experts who contributed to the study in the first stage did not participate in the second stage, citing their unavailability. The decision-makers who contributed to the second stage included one academic expert specializing in sustainable aviation fuels in the aircraft airframe engine maintenance department and three experts from the airline industry. Whereas the academic expert has ten years of academic background as an associate professor, the experts from the airline industry have 9, 9, and 10 years of industry experience as cost control and a fuel contract manager (airline), fuel contract officer (airline), and supply and logistics manager (aviation fuel supplier).

Decision-makers have evaluated three world-leading SAF supplier companies (SAF1, SAF2, and SAF3) by following the suggested model in the present work. While two of these companies were United Kingdom-based, the other was from France-based. These companies have a long history in the energy sector and offer a diverse range of products and services to meet energy supply and demand on a global scale. The companies provide a comprehensive range of services, encompassing crude oil extraction and refining, as well as natural gas production and distribution. The first company is a pioneer in extracting oil and natural gas directly from fields and is renowned for its renewable energy investments. The second company is distinguished by its refinery and distribution networks, which strongly emphasize environmental sustainability and carbon footprint reduction projects. The third company is also an essential player in the global market due to its extensive network of petrol stations and petrochemical products.

Additionally, these companies have taken significant steps towards sustainability and environmental responsibility by investing in renewable energy projects. Their common objective is reducing dependence on fossil fuels by investing in alternative energy sources, including solar, wind, and biofuels. Furthermore, they have developed and implemented carbon capture and storage technologies to reduce carbon emissions. These companies endeavor to ensure the continuity of renewable energy production by establishing offshore wind farms and developing energy storage solutions. In addition to their commitment to sustainability, these companies also support projects designed to protect biodiversity and improve water and air quality.

Table 5
The aggregated initial IVFNN matrix.

	E1	E2	E3	E4	E5
SAF1	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF3	< [0.650, 0.749], [0.278, 0.398], [0.238, 0.350] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
	E6	E7	E8	D1	D2
SAF1	< [0.709, 0.814], [0.200], [0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF2	< [0.678, 0.779], [0.238], [0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF3	< [0.634, 0.737], [0.299], [0.405], [0.263, 0.366] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
	D3	D4	D5	D6	D7
SAF1	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.613, 0.701], [0.331, 0.441], [0.283, 0.387] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >
SAF2	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.629, 0.737], [0.238, 0.341], [0.263, 0.371] >
SAF3	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.700, 0.800], [0.200, 0.300], [0.200, 0.300] >	< [0.650, 0.762], [0.266, 0.383], [0.238, 0.350] >
	Q1	Q2	Q3	Q4	Q5
SAF1	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.634, 0.749], [0.000, 0.000], [0.000, 0.000] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.654, 0.766], [0.251, 0.366], [0.234, 0.346] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186], [0.291] >	< [0.628, 0.729], [0.336, 0.440], [0.271, 0.372] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >

Table 5 (*continued*)

	Q6	Q7	Q8	S1	S2
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.560, 0.664], [0.398, 0.505], [0.336, 0.440] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.617, 0.737], [0.168, 0.278], [0.263, 0.383] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >
	S3	S4	S5	S6	S7
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.628, 0.745], [0.221, 0.331], [0.255, 0.372] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
SAF2	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.654, 0.770], [0.186, 0.291], [0.230, 0.346] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >
SAF3	< [0.606, 0.692], [0.372, 0.479], [0.291, 0.394] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.654, 0.770], [0.186, 0.291], [0.230, 0.346] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >
	S8	EV1	EV2	EV3	EV4
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.659, 0.749], [0.263, 0.371], [0.238, 0.341] >
SAF3	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
	EV5	EV6	EV7	EV8	
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	
SAF2	< [0.634, 0.722], [0.313,	< [0.737, 0.843], [0.168,	< [0.692, 0.789], [0.221,	< [0.659, 0.762], [0.251,	

(*continued on next page*)

Table 5 (*continued*)

	E1	E2	E3	E4	E5
	0.421], [0.263, 0.366] >	0.278], [0.157, 0.263] >	0.335], [0.200, 0.308] >	0.357], [0.238, 0.341] >	
SAF3	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	

4.2. *Identifying the criteria weights*

Here, the fundamental procedure of the IVFNN-LOPCOW approach has been followed to identify the criteria weight coefficients as follows:

Step 1. In this step, experts performed linguistic appraisals for each criterion by considering the linguistic terms in Table 1. Next, the IVFNN initial matrices were obtained. The experts' linguistic assessments are demonstrated in Appendix A1. Then, these linguistic assessments were transformed into IVFNNs by considering IVN numbers corresponding to Table 1, and the initial IVFNN matrices were obtained as presented in Appendix A2. Afterwards, these matrices were aggregated using the INWAA operator. Table 5 represents the IVFNN initial decision matrix.
Step 2. Afterwards, the initial IVFNN decision matrix elements were transformed to numerical values by employing the formula of deneutrosophication given in Eq. (20), and the initial decision matrix was constructed, as shown in Table 6.
Step 3. Next, the initial decision matrix elements were normalized by implementing Eq. (21), and the normalized decision matrix was formed, as shown in Table 7.
Steps 4–5. In the fourth step of the procedure, the criteria' percentage values were computed using Eq (22). Finally, the criteria weights were acquired using Eq. (23). Table 8 demonstrates the results obtained following the suggested framework.

Once the results obtained are evaluated in general, it has been noticed that there are slight differences among the relative significances of the criteria. Hence, 12 of the criteria are identified as the most influential factors. In addition, environmental criteria have been identified as the most critical factors with relative importance, with a score of 23.89%. The second influential criterion set is the social factors, with a score of 22.28%. The remaining criteria groups are ranked as delivery (21.75%), economic (16.74%), and quality (15.33%).

4.3. *Computing the alternatives' preference ratings*

The IVFNN-MARCOS approach has been implemented to identify the preference ratings of the options. The following procedure is presented as follows:

Step 1. In the first step of the IVFNN-MARCOS approach, the same procedure is followed as in the second phase of the model, and the initial IVFNN decision matrix is constructed.
Step 2. The extended initial IVFNN neutrosophic decision matrix was formed by using Eqs. (25) and (26). The extended initial IVFNN matrix is demonstrated in Table 9.
Step 3. In the third step of the IVFNN-MARCOS technique, the matrix elements were normalized by implementing Eq. (27). The normalized IVFNN matrix is presented in Table 10.
Step 4. The elements of the normalized IVFNN matrix were weighted by applying Eq. (28). The weighted normalized IVFNN matrix is presented in Table 11.
Step 5. Next, the IVFNNs were defuzzified by employing Eq. (29).

Table 7
The normalized decision matrix.

Criteria	SAF1	SAF2	SAF3	Criteria	SAF1	SAF2	SAF3
E1	1.000	0.552	0.000	Q6	0.000	1.000	0.000
E2	0.000	0.422	1.000	Q7	0.808	0.000	1.000
E3	1.000	0.509	0.000	Q8	0.000	1.000	0.000
E4	1.000	0.000	0.000	S1	0.000	1.000	0.543
E5	0.000	0.000	1.000	S2	1.000	0.000	0.397
E6	1.000	0.514	0.000	S3	1.000	0.881	0.000
E7	1.000	0.771	0.000	S4	1.000	1.000	0.000
E8	1.000	0.526	0.000	S5	1.000	0.000	0.000
D1	1.000	1.000	0.000	S6	0.681	0.000	1.000
D2	1.000	1.000	0.000	S7	0.000	1.000	0.691
D3	1.000	0.731	0.000	S8	1.000	1.000	0.000
D4	1.000	1.000	0.000	EV1	1.000	1.000	0.000
D5	0.000	1.000	1.000	EV2	1.000	0.442	0.000
D6	1.000	0.178	0.000	EV3	1.000	1.000	0.000
D7	1.000	0.000	0.598	EV4	1.000	0.000	1.000
Q1	1.000	1.000	0.000	EV5	1.000	0.000	0.303
Q2	1.000	0.204	0.000	EV6	0.340	1.000	0.000
Q3	0.000	1.000	0.840	EV7	1.000	0.000	1.000
Q4	1.000	0.000	0.000	EV8	1.000	0.000	0.844
Q5	1.000	1.000	0.000				

Table 6
The initial decision matrix.

Criteria	Direction	SAF1	SAF2	SAF3	Criteria	Direction	SAF1	SAF2	SAF3
E1	Max	0.806	0.791	0.772	Q6	Max	0.822	0.859	0.822
E2	Min	0.822	0.791	0.748	Q7	Max	0.807	0.671	0.839
E3	Max	0.832	0.791	0.748	Q8	Max	0.832	0.859	0.832
E4	Max	0.832	0.822	0.822	S1	Max	0.832	0.881	0.859
E5	Max	0.832	0.832	0.859	S2	Max	0.832	0.694	0.748
E6	Max	0.822	0.786	0.748	S3	Max	0.822	0.809	0.717
E7	Max	0.832	0.822	0.789	S4	Max	0.832	0.832	0.807
E8	Max	0.859	0.806	0.748	S5	Min	0.729	0.745	0.745
D1	Max	0.859	0.859	0.822	S6	Max	0.822	0.786	0.839
D2	Max	0.859	0.859	0.832	S7	Max	0.809	0.852	0.839
D3	Max	0.832	0.809	0.748	S8	Max	0.822	0.822	0.807
D4	Max	0.822	0.822	0.809	EV1	Max	0.859	0.859	0.822
D5	Max	0.806	0.832	0.832	EV2	Max	0.832	0.806	0.786
D6	Min	0.722	0.786	0.800	EV3	Max	0.832	0.832	0.822
D7	Max	0.806	0.726	0.774	EV4	Max	0.822	0.766	0.822
Q1	Max	0.859	0.859	0.822	EV5	Max	0.822	0.745	0.768
Q2	Max	0.881	0.773	0.746	EV6	Max	0.822	0.852	0.807
Q3	Max	0.691	0.859	0.832	EV7	Max	0.822	0.806	0.822
Q4	Max	0.809	0.748	0.748	EV8	Max	0.832	0.768	0.822
Q5	Max	0.822	0.822	0.809					

Table 8
The outcomes of the applied model.

Criteria	$\sqrt{\frac{\sum_{i=1}^{m} k_{ij}^2}{m}}$	σ	PV_j	ω_j	Rank	Criteria	$\sqrt{\frac{\sum_{i=1}^{m} k_{ij}^2}{m}}$	σ	PV_j	ω_j	Rank
E1	0.659	0.501	27.49	0.029	22	Q6	0.577	0.577	0.00	0.000	34
E2	0.627	0.502	22.18	0.023	28	Q7	0.742	0.531	33.56	0.035	16
E3	0.648	0.500	25.90	0.027	26	Q8	0.577	0.577	0.00	0.000	34
E4	0.577	0.577	0.00	0.000	34	S1	0.657	0.501	27.19	0.028	23
E5	0.577	0.577	0.00	0.000	34	S2	0.621	0.504	20.98	0.022	29
E6	0.649	0.500	26.09	0.027	25	S3	0.769	0.546	34.26	0.036	13
E7	0.729	0.524	33.03	0.034	17	S4	0.816	0.577	34.66	0.036	1
E8	0.652	0.500	26.55	0.028	24	S5	0.577	0.577	0.00	0.000	34
D1	0.816	0.577	34.66	0.036	1	S6	0.699	0.511	31.30	0.033	20
D2	0.816	0.577	34.66	0.036	1	S7	0.702	0.512	31.52	0.033	19
D3	0.715	0.517	32.35	0.034	18	S8	0.816	0.577	34.66	0.036	1
D4	0.816	0.577	34.66	0.036	1	EV1	0.816	0.577	34.66	0.036	1
D5	0.816	0.577	34.66	0.036	1	EV2	0.631	0.501	23.06	0.024	27
D6	0.586	0.533	9.47	0.010	33	EV3	0.816	0.577	34.66	0.036	1
D7	0.673	0.503	29.04	0.030	21	EV4	0.816	0.577	34.66	0.036	1
Q1	0.816	0.577	34.66	0.036	1	EV5	0.603	0.513	16.25	0.017	31
Q2	0.589	0.528	10.89	0.011	32	EV6	0.610	0.508	18.16	0.019	30
Q3	0.754	0.537	33.91	0.035	15	EV7	0.816	0.577	34.66	0.036	1
Q4	0.577	0.577	0.00	0.000	34	EV8	0.755	0.538	33.95	0.035	14
Q5	0.816	0.577	34.66	0.036	1						

Steps 6, 7, and 8. Afterwards, following the suggested approach's remaining steps, the alternatives' utility degrees and utility functions were computed, and options were ranked as presented in Table 12.

When the outcomes concerning the ranking performance of the alternatives are evaluated in general, the SAF2 option is the best sustainable SAF supplier, and SAF3, and SAF1 alternatives follow the best alternative, respectively.

4.4. Robustness check

In this section, the proposed IVFNN model's robustness and stability have been tested with the help of extensive sensitivity and comparative analyses. In the first phase, we changed the criteria weights and examined their impacts on the overall ranking results. In this connection, we formed 390 scenarios and changed the criteria weights in each scenario by following the fundamental procedure suggested by Görçün (2022), Görçün et al. (2021), and Görçün and Doğan (2023). After the comprehensive assessments concerning the impacts of the changes in the criteria weights on the ranking results, it has been observed that there is no change in the ranking performance of all alternatives, as presented in Fig. 2.

Although the analysis results prove that the suggested IVFNN model is entirely consistent and stable, slight differences among the criteria weights and significant gaps between the ranking performances of the alternatives may be accepted as the main reason. Nonetheless, it does not reduce the trustworthiness of the model. In the second stage, we compared the assessment results of the suggested framework with the outcomes of the extended form of some popular MCDM tools based on IVFNN sets.

For this purpose, three popular MCDM frameworks' extended forms with IVFNNs, such as IVFNN-WASPAS (Alimohammadlou and Khoshsepehr, 2022), IVFNN-CoCoSo (Ecer et al., 2023), and IVFNN-TOPSIS (Chi and Liu, 2013) were implemented. When evaluated, the suggested model's ranking results are identical to other IVFNN approaches except for IVFNN-TOPSIS. The ranking results of the implemented IVFNN methodologies are illustrated in Table 13 as follows:

To ensure the reliability and robustness of the proposed IVFNN model, we compared its results with three popular MCDM methods extended with IVFNN sets: IVFNN-WASPAS, IVFNN-CoCoSo, and IVFNN-TOPSIS. Each of these methods has unique characteristics and computational steps that distinguish them from one another and the proposed IVFNN-LOPCOW & MARCOS model:

IVFNN-WASPAS (Alimohammadlou and Khoshsepehr, 2022): Weighted Aggregated Sum Product Assessment (WASPAS) combines two methods: Weighted Sum Model (WSM) and Weighted Product Model (WPM). When extended with IVFNNs, it incorporates uncertainty and hesitancy in decision-making using interval-valued fuzzy numbers. IVFNN-WASPAS utilizes the aggregation of weighted sums and products of criteria, making it robust against variations in criteria weights and capable of handling complex decision-making scenarios with high reliability.

IVFNN-CoCoSo (Ecer et al., 2023): Combined Compromise Solution (CoCoSo) is based on compromise solutions, integrating the power of score functions to derive final rankings. When enhanced with IVFNNs, vagueness and hesitancy in the evaluation process are managed effectively. IVFNN-CoCoSo method combines different compromise solutions to balance the trade-offs among criteria, ensuring stable ranking results even under varying conditions.

IVFNN-TOPSIS (Chi and Liu, 2013): Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) ranks alternatives based on their distance to an ideal solution. The IVFNN extension allows the method to account for imprecise and uncertain data. IVFNN-TOPSIS measures the geometric distance between each alternative and the ideal and anti-ideal solutions, providing a transparent and interpretable ranking but may show sensitivity to extreme values.

The results from these methods were compared with the proposed IVFNN-LOPCOW & MARCOS model, as shown in Table 13. The comparison demonstrates that the proposed model's ranking results are consistent with other IVFNN approaches except for minor differences in the IVFNN-TOPSIS method.

In the next phase, we examined the impacts of diverse weighting approaches (see Table 14). In this connection, we applied some popular and reliable weighting techniques (i.e., CRITIC and MEREC) extended form with IVFNN sets. At the end of the evaluation, it was noted that there was no change in the ranking performance of the alternatives, even though slight changes in some criteria's weights exist. Table 15 denotes the ranking performance of the alternatives with diverse weighting approaches.

In the final stage of the robustness check, we tested the resistance of the suggested approach to the rank reversal problem. For this purpose, we formed three scenarios and eliminated the worst option in each scenario. Then, we repeated the computations for the remaining alternatives. The acquired results of the test are shown in Table 16.

As understood from Table 16, there is no change in the ranking results of the alternatives. It proves the proposed IVFNN framework is

Table 9
The extended initial IVFNN neutrosophic decision matrix.

	E1	E2	E3	E4	E5
SAF1	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF3	< [0.650, 0.749], [0.278, 0.398], [0.238, 0.350] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
ID	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
AID	< [0.650, 0.749], [0.278, 0.398], [0.238, 0.350] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >

	E6	E7	E8	D1	D2
SAF1	< [0.709, 0.814], [0.200], [0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF2	< [0.678, 0.779], [0.238], [0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF3	< [0.634, 0.737], [0.299], [0.405], [0.263, 0.366] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
AID	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >

	D3	D4	D5	D6	D7
SAF1	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.613, 0.701], [0.331, 0.441], [0.283, 0.387] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >
SAF2	< [0.729, 0.832], [0.168, 0.271],	< [0.709, 0.814], [0.200, 0.308],	< [0.729, 0.832], [0.168, 0.271],	< [0.678, 0.779], [0.238, 0.341],	< [0.629, 0.737], [0.238, 0.341],

Table 9 (*continued*)

	E1	E2	E3	E4	E5
	[0.168, 0.271] >	[0.186, 0.291] >	[0.168, 0.271] >	[0.221, 0.322] >	[0.263, 0.371] >
SAF3	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.700, 0.800], [0.200, 0.300], [0.200, 0.300] >	< [0.650, 0.762], [0.266, 0.383], [0.238, 0.350] >
ID	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.613, 0.701], [0.331, 0.441], [0.283, 0.387] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >
AID	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.700, 0.800], [0.200, 0.300], [0.200, 0.300] >	< [0.629, 0.737], [0.266, 0.383], [0.263, 0.371] >

	Q1	Q2	Q3	Q4	Q5
SAF1	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.634, 0.749], [0.000, 0.000], [0.000, 0.000] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.654, 0.766], [0.251, 0.366], [0.234, 0.346] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186], [0.291] >	< [0.628, 0.729], [0.336, 0.440], [0.271, 0.372] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
ID	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.755, 0.859], [0.000, 0.000], [0.000, 0.000] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
AID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.628, 0.729], [0.336, 0.440], [0.271, 0.372] >	< [0.634, 0.749], [0.168, 0.271], [0.168, 0.271] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >

	Q6	Q7	Q8	S1	S2
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.560, 0.664], [0.398, 0.505], [0.336, 0.440] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.617, 0.737], [0.168, 0.278], [0.263, 0.383] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >
ID	< [0.755, 0.859], [0.141,	< [0.722, 0.832], [0.178,	< [0.755, 0.859], [0.141,	< [0.779, 0.881], [0.119,	< [0.729, 0.832], [0.168,

(*continued on next page*)

Table 9 (*continued*)

	E1	E2	E3	E4	E5
	0.245], [0.141, 0.245] >	0.291], [0.168, 0.278] >	0.245], [0.141, 0.245] >	0.221], [0.119, 0.221] >	0.271], [0.168, 0.271] >
AID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.560, 0.664], [0.398, 0.505], [0.336, 0.440] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.617, 0.737], [0.299, 0.405], [0.263, 0.383] >

	S3	S4	S5	S6	S7
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.628, 0.745], [0.221, 0.331], [0.255, 0.372] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
SAF2	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.654, 0.770], [0.186, 0.291], [0.230, 0.346] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >
SAF3	< [0.606, 0.692], [0.372, 0.479], [0.291, 0.394] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.654, 0.770], [0.186, 0.291], [0.230, 0.346] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.628, 0.745], [0.221, 0.331], [0.255, 0.372] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >
AID	< [0.606, 0.692], [0.372, 0.479], [0.291, 0.394] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.654, 0.770], [0.186, 0.291], [0.230, 0.346] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >

	S8	EV1	EV2	EV3	EV4
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.659, 0.749], [0.263, 0.371], [0.238, 0.341] >
SAF3	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
AID	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.659, 0.749], [0.263, 0.371], [0.238, 0.341] >

	EV5	EV6	EV7	EV8

Table 9 (*continued*)

	E1	E2	E3	E4	E5
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	
SAF2	< [0.634, 0.722], [0.313, 0.421], [0.263, 0.366] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	
SAF3	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	
AID	< [0.634, 0.722], [0.313, 0.421], [0.263, 0.366] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	

maximally resilient and stable and does not influence change. Hence, this model's ability makes it a more robust and reliable procedure for practitioners to address real-life decision-making problems.

5. Discussion

When the research results are evaluated in terms of different aspects of the study, we see that the ranking of aspects is as follows through the aggregation of weightings assigned to each criterion in each aspect: environmental (0.2389), social (0.2228), delivery capability (0.2175), economic (0.1674), and quality (0.1533). At this point, it can be noted that airlines not only take steps to decarbonize their flight operations by giving importance to environmental efforts but also consider how much green initiatives the potential suppliers pay attention to their operations in the process of SAF supplier selection. The social aspect that follows the environmental criteria indicates that the criteria included in this aspect are the second most crucial for airlines in selecting sustainable SAF suppliers. The lower rankings of the economic and quality aspects demonstrate that airlines focus less on price and quality in selecting SAF suppliers, as these fuels are still in the early stages of development with a relatively low production level, and their quality is very close since there are limited producers in the SAF market.

When the research results are further analyzed, we can evaluate that airline operators prioritize factors related to the environmental dimension in the suppliers they want to work with. These factors include compliance with environmental regulations and standards, waste management and pollution prevention/control, green logistics, and green image. That indicates that airlines aim to achieve high performance and gain a competitive advantage in future environmental competition by attracting environmentally conscious customers in international markets. Here, it should also be emphasized that SAF suppliers must invest to meet airline expectations to survive and succeed in future supplier competition. The prominence of delivery factors such as on-time and efficient delivery, delivery reliability, order fulfillment rate, and delivery flexibility highlight the strong desire of airlines to ensure smooth ground operations without any surprises in the operational processes related to SAF supply.

Table 10
The normalized IVFNN matrix.

	E1	E2	E3	E4	E5
SAF1	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.186, 0.291], [0.692, 0.800], [0.709, 0.814] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.221, 0.331], [0.619, 0.737], [0.669, 0.766] >	< [0.669, 0.766], [0.263, 0.381], [0.221, 0.331] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF3	< [0.650, 0.749], [0.278, 0.398], [0.238, 0.350] >	< [0.263, 0.366], [0.595, 0.701], [0.634, 0.737] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
ID	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.263, 0.366], [0.595, 0.701], [0.634, 0.737] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
AID	< [0.650, 0.749], [0.278, 0.398], [0.238, 0.350] >	< [0.186, 0.291], [0.692, 0.800], [0.709, 0.814] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >

	E6	E7	E8	D1	D2
SAF1	< [0.709, 0.814], [0.200], [0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF2	< [0.678, 0.779], [0.238], [0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
SAF3	< [0.634, 0.737], [0.299], [0.405], [0.263, 0.366] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >
AID	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.678, 0.789], [0.211, 0.322], [0.211, 0.322] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >

	D3	D4	D5	D6	D7
SAF1	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.283, 0.387], [0.559, 0.669], [0.613, 0.701] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >
SAF2	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.221, 0.322], [0.659, 0.762], [0.678, 0.779] >	< [0.629, 0.737], [0.238, 0.341], [0.263, 0.371] >
SAF3	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.200, 0.300], [0.700, 0.800], [0.700, 0.800] >	< [0.650, 0.762], [0.266, 0.383], [0.238, 0.350] >
ID	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.283, 0.387], [0.559, 0.669], [0.613, 0.701] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >
AID	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.200, 0.300], [0.700, 0.800], [0.700, 0.800] >	< [0.629, 0.737], [0.266, 0.383], [0.263, 0.371] >

Table 10 (*continued*)

	Q1	Q2	Q3	Q4	Q5
SAF1	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.634, 0.749], [0.000, 0.000], [0.000, 0.000] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141], [0.245] >	< [0.654, 0.766], [0.251, 0.366], [0.234, 0.346] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186], [0.291] >	< [0.628, 0.729], [0.336, 0.440], [0.271, 0.372] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
ID	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.755, 0.859], [0.000, 0.000], [0.000, 0.000] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
AID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.628, 0.729], [0.336, 0.440], [0.271, 0.372] >	< [0.634, 0.749], [0.168, 0.271], [0.168, 0.271] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >

	Q6	Q7	Q8	S1	S2
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >
SAF2	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.560, 0.664], [0.398, 0.505], [0.336, 0.440] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.779, 0.881], [0.119, 0.221], [0.119, 0.221] >	< [0.617, 0.737], [0.168, 0.278], [0.263, 0.383] >
SAF3	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.634, 0.737], [0.299, 0.405], [0.263, 0.366] >
ID	< [0.755, 0.859], [0.141,	< [0.722, 0.832], [0.178,	< [0.755, 0.859], [0.141,	< [0.779, 0.881], [0.119,	< [0.729, 0.832], [0.168,

(*continued on next page*)

Table 10 (*continued*)

	E1	E2	E3	E4	E5
	0.245], [0.141, 0.245] >	0.291], [0.168, 0.278] >	0.245], [0.141, 0.245] >	0.221], [0.119, 0.221] >	0.271], [0.168, 0.271] >
AID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.560, 0.664], [0.398, 0.505], [0.336, 0.440] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.617, 0.737], [0.299, 0.405], [0.263, 0.383] >
	S3	**S4**	**S5**	**S6**	**S7**
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.255, 0.372], [0.669, 0.779], [0.628, 0.745] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
SAF2	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.230, 0.346], [0.709, 0.814], [0.654, 0.770] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >
SAF3	< [0.606, 0.692], [0.372, 0.479], [0.291, 0.394] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.230, 0.346], [0.709, 0.814], [0.654, 0.770] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.255, 0.372], [0.669, 0.779], [0.628, 0.745] >	< [0.722, 0.832], [0.178, 0.291], [0.168, 0.278] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >
AID	< [0.606, 0.692], [0.372, 0.479], [0.291, 0.394] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.230, 0.346], [0.709, 0.814], [0.654, 0.770] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.687, 0.794], [0.238, 0.350], [0.206, 0.313] >
	S8	**EV1**	**EV2**	**EV3**	**EV4**
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
SAF2	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.659, 0.749], [0.263, 0.371], [0.238, 0.341] >
SAF3	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.755, 0.859], [0.141, 0.245], [0.141, 0.245] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >
AID	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.678, 0.779], [0.238, 0.341], [0.221, 0.322] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.659, 0.749], [0.263, 0.371], [0.238, 0.341] >
	EV5	**EV6**	**EV7**	**EV8**	

Table 10 (*continued*)

	E1	E2	E3	E4	E5
SAF1	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	
SAF2	< [0.634, 0.722], [0.313, 0.421], [0.263, 0.366] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	
SAF3	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	
ID	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.737, 0.843], [0.168, 0.278], [0.157, 0.263] >	< [0.709, 0.814], [0.200, 0.308], [0.186, 0.291] >	< [0.729, 0.832], [0.168, 0.271], [0.168, 0.271] >	
AID	< [0.634, 0.722], [0.313, 0.421], [0.263, 0.366] >	< [0.692, 0.800], [0.211, 0.322], [0.200, 0.308] >	< [0.692, 0.789], [0.221, 0.335], [0.200, 0.308] >	< [0.659, 0.762], [0.251, 0.357], [0.238, 0.341] >	

Table 11
The weighted normalized IVFNN matrix.

	Si						
Alternative	T^L	T^U	I^L	I^U	F^L	F^U	Score (S_i)
SAF1	0.694	0.802	0.000	0.000	0.000	0.000	0.748
SAF2	0.678	0.786	0.222	0.334	0.212	0.321	0.793
SAF3	0.666	0.775	0.242	0.355	0.224	0.334	0.784
AI	0.706	0.814	0.000	0.000	0.000	0.000	0.760
AAI	0.645	0.752	0.265	0.377	0.242	0.351	0.762

On the other hand, the results strongly indicate airlines' preference to work with suppliers that can provide flexibility and offer customized services in SAF supply, allowing for adjustments to their planning. This approach allows airlines to manage their operations and is expected to help prevent any potential direct and indirect costs that airlines may incur due to disruptions in operations. Criteria found to be of lower importance as a result of the analysis, such as information disclosure and corporate misconduct, demonstrate airlines' trust in their suppliers. In contrast, the lower emphasis on price and price performance criteria can be attributed to the current low production level of SAF and the absence of significant price differences among the three alternative suppliers in the study. This indicates that there is currently no price competition among suppliers due to the low production of SAF. In other words, airlines are willing to bear the costs regardless of the price now, considering that in the future, they will stand out in the competition.

Furthermore, the current insufficient number of SAF producers worldwide demonstrates that airlines supply SAF from similar

Table 12
The utility degrees, utility functions, and ranking performance of the options.

	S_i						
AAI	0.762	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Rank
SAF1	0.748	0.982	0.984	0.501	0.499	0.655	3
SAF2	0.793	1.040	1.043	0.501	0.499	0.694	1
SAF3	0.784	1.029	1.031	0.501	0.499	0.687	2
AI	0.760						

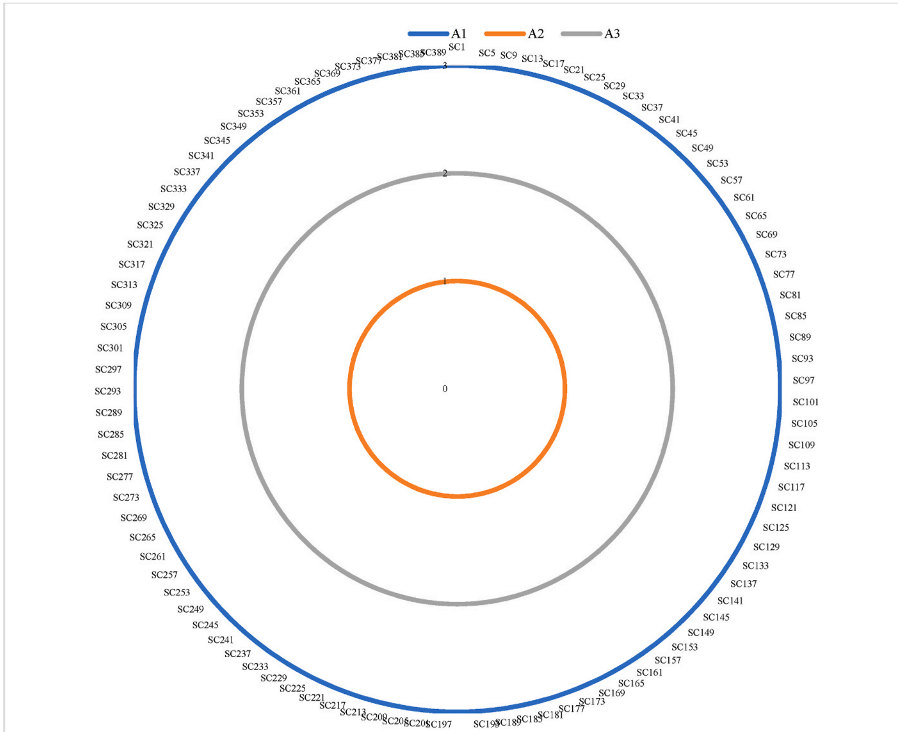

Fig. 2. Performance of options based on 390 scenarios.

Table 13
The ranking results of the implemented IVFNN approaches.

	IVFNN-LOPCOW & MARCOS (The proposed model)	IVFNN-WASPAS (Alimohammadlou and Khoshsepehr, 2022)	IVFNN-CoCoSo (Ecer et al., 2023)	IVFNN-TOPSIS (Chi and Liu, 2013)
SAF1	3	3	3	2
SAF2	1	1	1	1
SAF3	2	2	2	3

producers. As a result, when making decisions on sustainable SAF suppliers that are almost identical in quality and price, the focus on price performance is diminished. The criteria of company size, financial stability, after-sales service quality, quality certification, and the type of fuel provided ranking significantly lower can be attributed to the similarity in the quality of SAF suppliers and their products. Furthermore, it can be noted that all three alternative suppliers have a significant level of company size and financial stability, and they do not differentiate themselves significantly in terms of service quality.

Table 15
The ranking results of the alternatives with diverse IVFNN weighting approaches.

	IVFNN-LOPCOW & MARCOS (The proposed model)	IVFNN-MEREC & MARCOS	IVFNN-CRITIC & MARCOS
SAF1	3	3	3
SAF2	1	1	1
SAF3	2	2	2

Table 16
The results of the test for the model's resilience to the rank reversal.

Scenarios	The ranking results
Scenario 1 (Original)	SAF2 > SAF3 > SAF1
Scenario 2	SAF2 > SAF3
Scenario 3	SAF2

Table 14
Comparison between the implemented IVFNN approaches.

Approach	Full Form	Characteristics	Advantages	Drawbacks
IVFNN-WASPAS	Interval-Valued Fuzzy Neutrosophic Numbers - Weighted Aggregated Sum Product Assessment	Combines weighted sum and product of criteria, robust against variations in criteria weights	High reliability, handles complex scenarios effectively	It may require extensive data for accurate results
IVFNN-CoCoSo	Interval-Valued Fuzzy Neutrosophic Numbers - Combined Compromise Solution	Balances trade-offs among criteria, stable rankings under varying conditions	Manages vagueness and hesitancy effectively, stable under varying conditions	Potentially complex calculations require detailed input
IVFNN-TOPSIS	Interval-Valued Fuzzy Neutrosophic Numbers - Technique for Order Preference by Similarity to Ideal Solution	Measures geometric distance to ideal and anti-ideal solutions, transparent and interpretable rankings	Provides transparent and interpretable rankings, handles imprecise data	Sensitive to extreme values, may require normalization
IVFNN-LOPCOW & MARCOS	Interval-Valued Fuzzy Neutrosophic Numbers - Logarithmic Percentage Change-driven Objective Weighting & Measurement Alternatives and Ranking According to Compromise Solution	Flexible and comprehensive, accommodates uncertainties, balanced weighting of criteria	Handles uncertainties well, provides nuanced analysis, balanced approach	Requires detailed input, potentially complex calculations

Last, considering the supplier ranking, it is observed that supplier SAF2 (0.694) in the first place has only slight performance score differences compared to other SAF suppliers (SAF3: 0.687, SAF2: 0.655). That is because all three alternative SAF suppliers evaluated in the research are leading global suppliers of fossil jet fuel and SAF. The fact that the SAF2 supplier ranks first among closely competing suppliers with similar business volumes and comparable qualifications can be attributed to its higher evaluations regarding certain high-value criteria by decision-makers. Therefore, the SAF2 supplier has secured the top position in the research results due to its slightly higher performance than other alternative suppliers in the SAF market.

6. Managerial implications

Using the proposed model for selecting sustainable SAF suppliers, this research provides valuable insights for airline companies and SAF suppliers. Firstly, airline companies can rank suppliers based on essential criteria, enabling them to identify the most suitable sustainable SAF supplier among potential options. This model simplifies the refueling process—a critical component of their operations—and allows airlines to collaborate with SAF suppliers with environmentally solid initiatives, thereby advancing their sustainability goals.

Correspondingly, airline companies can also be likely to minimize the difficulties and risks (such as the inability to access the product when needed) in the supply process. As the importance of SAF, which is expected to replace fossil jet fuels together with other alternative fuels in the coming years, increases in line with ICAO's net-zero 2050 global target, it becomes a critical issue for airline companies to select and work with the best sustainable SAF supplier. On the other hand, when the research results are evaluated from the SAF supplier perspective, the study suggests that if SAF suppliers adopt the prominent criteria (ones with high importance weights), they could have a chance to be preferred by airlines in the coming years, in case of a more competitive environment for SAF supply.

7. Conclusion

The airline industry is recognized as one of the ten critical sectors contributing to solving the global challenge posed by global warming and climate change threats. In this regard, SAFs produced from plant and animal waste are highlighted as the most effective solution offered within the industry, with the tremendous potential to decarbonize air transportation. However, SAF production is not yet at the desired level, and currently, the price of SAF is approximately three times that of jet fuels. Despite this situation, airlines aiming to gain an advantage in green competition in international markets are already strategizing and seeking to establish long-term relationships and agreements with global SAF suppliers by considering social, economic, and environmental factors together. This study presents a multi-criteria decision-making model for selecting sustainable SAF suppliers in the airline industry's sustainable aviation fuel procurement process.

In this study, based on expert opinions and a literature review, thirty-nine criteria were identified from five aspects: economy, delivery capability, quality, social, and environmental. These criteria were included in the research model following expert approval, and to determine the weights of the criteria, the IVFNN-LOPCOW method, which prioritizes the hierarchical structure of evaluation criteria, was used. In the subsequent stage, three major global SAF suppliers (SAF1, SAF2, and SAF3) were evaluated using the IVFNN MARCOS integrated ranking method. The analysis revealed that in the selection of sustainable SAF suppliers by airlines, environmental factors such as compliance with environmental regulations and standards, waste management and pollution prevention/control, green logistics, and green image, as well as delivery factors such as on-time and efficient delivery, delivery reliability, order fulfillment rate, and delivery flexibility, were prominent. Additionally, quality factors such as quality control and assurance systems, customized service, social factors such as reward and monitor systems, and collaborations with social, environmental, and research groups were identified as other significant factors. These 12 criteria from four dimensions had equal importance values after the weighting stage and shared the top position. In ranking the three significant suppliers dominating the global SAF supply, SAF2 ranked first, followed by SAF3 and SAF1. This result was influenced by the higher scores received by SAF2 compared to other alternatives regarding criteria with relatively high importance values during the alternative evaluation stage.

The present study, while prospectively addressing the issue of SAF supplier evaluation for airlines, has also several limitations. Firstly, in line with the proposed model, the evaluations regarding the selection of sustainable SAF suppliers for airlines are limited to the thoughts, experiences, and knowledge of the four decision-makers involved in the study. Some of the well-known measurement problems are that participants' responses often do not accurately reflect their true thoughts due to the influence of social desirability and demand characteristics (Furr and Verne, 2008). Managers working for different stakeholders of the airline industry, who face increasing environmental sustainability pressures due to global warming and climate change, are unlikely to criticize these pressures or publicly express opposing thoughts directly. Another significant limitation of the study, in this context, is that social desirability and demand characteristics may have contaminated the responses, thus, participants' evaluations of the criteria may have been partially influenced by these pressures. The third limitation is that this research on sustainable SAF supplier selection is conducted within the context of the airline industry. Although the airline industry has taken the forefront due to increasing environmental pressures, other modes of transportation also face similar challenges. Therefore, it is possible to use the proposed methodology in future research focusing on similar processes of the other transportation modes, such as sustainable maritime fuel supplier selection, while considering contextual differences. Additionally, considering contextual differences, the proposed model can be applied to different industries as a sustainable supplier selection model. In this regard, applying the proposed model in future research across different industries would be beneficial for testing the robustness of the model. Another limitation arising from the study is related to the methodology used. The IVFNN-LOPCOW method was used for criteria weighting, and the IVFNN-MARCOS method was employed for supplier ranking. In future research, various popular weighting methods (such as AHP, BWM, LBWA, LMAW, SWARA, etc.) and ranking methods (such as EDAS, MABAC, TOPSIS, VIKOR, CODAS, etc.) can be utilized, including the classical form or different fuzzy number sets and different levels (type one, type two).

CRediT authorship contribution statement

Fatih Ecer: Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Gökhan Tanrıverdi:** Writing – review & editing, Writing – original draft, Validation, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Mehmet Yaşar:** Writing – review & editing, Validation, Investigation, Formal analysis, Data curation. **Ömer Faruk Görçün:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Conceptualization.

Appendix A1. Expansions of the methods' acronyms given in Table 2

Acronyms	Expansions
AHP	Analytic hierarchy process
ANP	Analytical network process
ARAS	Additive ratio assessment
AQM	Alternative queuing method
BWM	Best-worst method
CoCoSo	Combined compromise solution
COPRAS	Complex proportional assessment
DEA	Data envelopment analysis
DEMATEL	Decision making trial and evaluation laboratory
EDAS	Evaluation based on distance from average solution
ELECTRE	Elimination and choice translating reality English
FMOO	Fuzzy multi-objective optimization model
FUCOM	Full consistency method
GA	Genetic algorithm
GCA	Grey correlation analysis
GRA	Grey relational analysis
GEP	Gene expression programming
GP	Goal programming
HFLTS	Hesitant fuzzy linguistic term sets
IFSs	Intuitionistic fuzzy sets
ISM	Interpretive structural modelling
IT2FSs	Interval type-2 fuzzy set
IVIFN	Interval-valued intuitionistic fuzzy numbers
MASS	Multi-agent systems
MAUT	Multi-attribute utility theory
MOILP	Multi-objective integer linear programming
MOLP	Multi-objective linear programming
MOMP	Multi-objective mathematical programming
MOORA	Multi-objective optimization model based on the ratio analysis
PROMETHEE	Preference ranking organization method for enrichment evaluation
QFD	Quality function deployment
RMCGP	Revised multi-choice goal programming
PSI	Preference selection index
SAW	Simple additive weighting
SWARA	Step-wise weight assessment ratio analysis
TODIM	Interactive and multicriteria decision making (an acronym in Portuguese)
TOPSIS	Technique for order of preference by similarity to ıdeal solution
VIKOR	Vlse kriterijumska optimizacija kompromisno resenje
WASPAS	Weighted aggregated sum product assessment

Appendix A2. Decision makers' evaluations of alternatives

		DM1			DM2			DM3			DM4		
Code	Criteria	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3
E1	Payment flexibility	VH	H	AA	A	A	A	VH	VH	VH	CH	CH	CH
E2	Price	VH	H	AA	CH	A	VH	VH	VH	VH	H	CH	H
E3	Price performance value	VH	H	AA	CH	A	VH	VH	VH	VH	VH	CH	H
E4	Firm size	VH	VH	VH	CH	CH	CH	VH	VH	VH	VH	H	H
E5	Financial stability	VH	VH	VH	CH	CH	CH	VH	VH	VH	VH	VH	CH
E6	Technological ability	VH	VH	AA	CH	H	VH	VH	VH	VH	H	VH	H
E7	Availability of alternative suppliers	VH	H	BA	VH	VH	VH	VH	VH	VH	CH	CH	CH
E8	R&D investments	VH	VH	AA	CH	A	VH	VH	VH	VH	CH	CH	H
D1	On time and efficient delivery	VH	VH	VH	CH	CH	CH	VH	VH	VH	CH	CH	H
D2	Delivery reliability	VH	VH	VH	CH	CH	CH	VH	VH	VH	CH	CH	VH
D3	Distribution network	VH	H	AA	CH	H	VH	VH	VH	VH	VH	CH	H
D4	Delivery flexibility	VH	H	H	CH	CH	CH	VH	VH	VH	H	VH	H
D5	Order fulfillment rate	VH	VH	VH	CH	CH	CH	VH	VH	VH	A	VH	VH
D6	Labor intensity of services	AA	H	VH	VH	VH	VH	VH	VH	VH	A	VH	VH
D7	Production facilities and capacity	VH	VH	AA	CH	L	AA	VH	VH	VH	A	VH	CH
Q1	Quality control and assurance systems	VH	VH	VH	CH	CH	CH	VH	VH	VH	CH	CH	H
Q2	Previous customer satisfaction	CH	H	H	CH	BA	H	VH	VH	VH	CH	CH	H
Q3	Product quality	VH	VH	VH	CH	CH	CH	VH	VH	VH	H	CH	VH
Q4	After-sales service quality	H	H	H	CH	AA	AA	VH	VH	VH	H	VH	VH
Q5	Special service	H	H	H	CH	CH	CH	VH	VH	VH	VH	VH	H
Q6	Quality certificate	VH	VH	VH	CH	CH	CH	VH	VH	VH	H	CH	H
Q7	Whether the fuel is drop-in or not	AA	AA	AA	CH	CH	CH	VH	VH	VH	VH	VH	VH
Q8	Type of fuel supplied	VH	VH	VH	CH	CH	CH	VH	VH	VH	VH	CH	VH
S1	Information disclosure (privacy)	VH	VH	VH	CH	CH	CH	VH	VH	VH	CH	CH	CH
S2	Relational reliability	VH	H	H	CH	CL	VH	VH	VH	VH	VH	CH	AA
S3	Corporate social responsibility	H	H	A	CH	H	H	VH	VH	VH	VH	CH	H

(*continued on next page*)

(*continued*)

		DM1			DM2			DM3			DM4		
Code	Criteria	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3	SAF1	SAF2	SAF3
S4	Rewarding and monitor system	VH	VH	AA	CH	CH	CH	VH	VH	VH	VH	VH	VH
S5	Institutional irregularities	VL	VL	VL	CH	CH	CH	VH	VH	VH	H	VH	VH
S6	Supplier reputation	VH	H	AA	CH	VH	CH	VH	VH	VH	H	VH	CH
S7	Practices in line with human rights	H	H	AA	CH	CH	CH	VH	VH	VH	H	CH	CH
S8	Collaborations with social, environmental and research groups	H	H	AA	CH	VH	VH	VH	VH	VH	VH	CH	CH
EV1	Compliance with environmental legislation and standards	VH	VH	VH	CH	CH	CH	VH	VH	VH	CH	CH	H
EV2	Green design and purchasing	VH	VH	H	CH	A	VH	VH	VH	VH	VH	CH	VH
EV3	Waste management and pollution prevention/control	VH	VH	H	CH	CH	CH	VH	VH	VH	VH	VH	VH
EV4	Green logistics practices	VH	VH	H	CH	A	VH	VH	VH	VH	H	VH	CH
EV5	Green production capabilities	VH	H	AA	CH	A	VH	VH	VH	VH	H	VH	VH
EV6	Enterprise management support	VH	H	AA	CH	CH	CH	VH	VH	VH	H	CH	VH
EV7	Green image	VH	VH	H	CH	A	VH	VH	VH	VH	H	CH	CH
EV8	Green R&D and innovation	VH	VH	H	CH	AA	CH	VH	VH	VH	VH	VH	VH

Data availability

Data will be made available on request.

References

Abdullah, L., Ong, Z., Mohd Mahali, S., 2021. Single-valued neutrosophic DEMATEL for segregating types of criteria: a case of subcontractors' selection. J. Math. 2021 (1), 6636029.

Alimohammadlou, M., Khoshsepehr, Z., 2022. Investigating organizational sustainable development through an integrated method of interval-valued intuitionistic fuzzy AHP and WASPAS. Environ. Dev. Sustain. 24 (2), 2193–2224.

Alshurideh, M., Alsharari, N.M., Al Kurdi, B., 2019. Supply chain integration and customer relationship management in the airline logistics. Theor. Econ. Lett. 9 (2), 392–414.

Amin, S.H., Zhang, G., 2012. An integrated model for closed-loop supply chain configuration and supplier selection: multi-objective approach. Expert Syst. Appl. 39 (8), 6782–6791.

Amindoust, A., Ahmed, S., Saghafinia, A., Bahreininejad, A., 2012. Sustainable supplier selection: a ranking model based on fuzzy inference system. Appl. Soft Comput. 12 (6), 1668–1677.

Amiri, M., Hashemi-Tabatabaei, M., Ghahremanloo, M., Keshavarz-Ghorabaee, M., Zavadskas, E.K., Banaitis, A., 2021. A new fuzzy BWM approach for evaluating and selecting a sustainable supplier in supply chain management. Int. J. Sustain. Dev. World Ecol. 28 (2), 125–142.

Atanassov, K.T., 1999. Intuitionistic fuzzy sets. In: Intuitionistic Fuzzy Sets. Studies in Fuzziness and Soft Computing, vol. 35, pp. 1–137.

Ávila, P., Mota, A., Pires, A., Putnik, G., Teixeira, J., 2012. Supplier's selection model based on an empirical study. Procedia Technol. 5, 625–634.

Avogadro, N., Cattaneo, M., Paleari, S., Redondi, R., 2021. Replacing short-medium haul intra-European flights with high-speed rail: impact on CO2 emissions and regional accessibility. Transport Pol. 114, 25–39.

Awasthi, A., Chauhan, S.S., Goyal, S.K., 2010. A fuzzy multicriteria approach for evaluating environmental performance of suppliers. Int. J. Prod. Econ. 126 (2), 370–378.

Bafrooei, A.A., Mina, H., Ghaderi, S.F., 2014. A supplier selection problem in petrochemical industry using common weight data envelopment analysis with qualitative criteria. Int. J. Ind. Syst. Eng. 18 (3), 404–417.

Bai, C., Sarkis, J., 2010. Integrating sustainability into supplier selection with grey system and rough set methodologies. Int. J. Prod. Econ. 124 (1), 252–264.

Bakır, M., Özdemir, E., Akan, Ş., 2021. A novel MADM approach to the ground-handling agent selection problem in B2B markets. J. Adv. Manag. Res. 18 (5), 684–707.

Borjalilu, N., Sazvar, Z., Nayeri, S., 2021. An integrated method for airline company supplier selection based on the entropy and vikor methods: a real case study. Internat. J. Aviation, Aerona. Aeros. 8 (4), 1.

Büyüközkan, G., Çifçi, G., 2012. Evaluation of the green supply chain management practices: a fuzzy ANP approach. Prod. Plann. Control 23 (6), 405–418.

Cavalcante, I.M., Frazzon, E.M., Forcellini, F.A., Ivanov, D., 2019. A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing. Int. J. Inf. Manag. 49, 86–97.

Çebi, F., Bayraktar, D., 2003. An integrated approach for supplier selection. Logist. Inf. Manag. 16 (6), 395–400.

Chai, N., Zhou, W., Jiang, Z., 2023. Sustainable supplier selection using an intuitionistic and interval-valued fuzzy MCDM approach based on cumulative prospect theory. Inf. Sci. 626, 710–737.

Chakraborty, S., Saha, A.K., 2022. Selection of Forklift unit for transport handling using integrated MCDM under neutrosophic environment. Facta Univ. – Ser. Mech. Eng. 22 (2), 235–256.

Chan, Felix T.S., Kumar, N., 2007. Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega 35 (4), 417–431.

Chan, F.T.S., Chan, H.K., Ip, R.W.L., Lau, H.C.W., 2007. A decision support system for supplier selection in the airline industry. Proc. IME B J. Eng. Manufact. 221 (4), 741–758.

Chi, P., Liu, P., 2013. An extended TOPSIS method for the multiple attribute decision making problems based on interval neutrosophic set. Neutrosophic Sets Syst. 1 (1), 63–70.

Choy, K.L., Chow, H.K.H., Lee, W.B., Chan, F.T.S., 2007. Development of performance measurement system in managing supplier relationship for maintenance logistics providers. Benchmarking 14 (3), 352–368.

Cui, Q., Chen, B., 2024. Cost-benefit analysis of using sustainable aviation fuels in South America. J. Clean. Prod. 435, 140556.

Cui, Q., Lei, Y., Li, Y., 2024. Co-benefit scenario analysis on replacing aviation kerosene with sustainable aviation fuels in Africa. Environ. Impact Assess. Rev. 104, 107318.

Ecer, F., 2021. Sustainable supplier selection: FUCOM subjective weighting method based MAIRCA approach. Mehmet Akif Ersoy Univer. J. Econ. Adminis. Sci. Faculty 8 (1), 26–48.

Ecer, F., 2022. Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: a case study of a home appliance manufacturer. Operat. Res. 22 (1), 199–233.

Ecer, F., Pamucar, D., 2020. Sustainable supplier selection: a novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model. J. Clean. Prod. 266, 121981.

Ecer, F., Pamucar, D., 2021. MARCOS technique under intuitionistic fuzzy environment for determining the COVID-19 pandemic performance of insurance companies in terms of healthcare services. Appl. Soft Comput. 104, 107199.

Ecer, F., Pamucar, D., 2022. A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: an application in developing country banking sector. Omega 112, 102690.

Ecer, F., Torkayesh, A.E., 2024. A stratified fuzzy decision-making approach for sustainable circular supplier selection. IEEE Trans. Eng. Manag. 71, 1130–1144.

Ecer, F., Böyükaslan, A., Hashemkhani Zolfani, S., 2022. Evaluation of cryptocurrencies for investment decisions in the era of industry 4.0: a borda count-based intuitionistic fuzzy set extensions EDAS-MAIRCA-MARCOS multi-criteria methodology. Axioms 11 (8). https://doi.org/10.3390/axioms11080404.

Ecer, F., Küçükönder, H., Kayapınar Kaya, S., Görçün, Ö.F., 2023. Sustainability performance analysis of micro-mobility solutions in urban transportation with a novel IVFNN-Delphi-LOPCOW-CoCoSo framework. Transport. Res. Pol. Pract. 172, 103667.

Ecer, F., Haseli, G., Krishankumar, R., Hajiaghaei-Keshteli, M., 2024. Evaluation of sustainable cold chain suppliers using a combined multi-criteria group decision-making framework under fuzzy ZE-numbers. Expert Syst. Appl. 245, 123063.

Fu, Y.K., 2019. An integrated approach to catering supplier selection using AHP-ARAS-MCGP methodology. J. Air Transport. Manag. 75, 164–169.

Furr, R., Verne, R., 2008. Psychometrics: an Introduction. Sage Publication, California.

Gao, H., Ju, Y., Gonzalez, E.D.S., Zhang, W., 2020. Green supplier selection in electronics manufacturing: an approach based on consensus decision making. J. Clean. Prod. 245, 118781.

Gong, X., Yang, M., Du, P., 2021. Renewable energy accommodation potential evaluation of distribution network: a hybrid decision-making framework under interval type-2 fuzzy environment. J. Clean. Prod. 286, 124918.

Görçün, Ö.F., 2022. A novel integrated MCDM framework based on Type-2 neutrosophic fuzzy sets (T2NN) for the selection of proper Second-Hand chemical tankers. Transport. Res. E Logist. Transport. Rev. 163, 102765.

Görçün, Ö.F., Doğan, G., 2023. Mobile crane selection in project logistics operations using Best and Worst Method (BWM) and fuzzy Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS). Autom. ConStruct. 147, 104729.

Görçün, Ö.F., Senthil, S., Küçükönder, H., 2021. Evaluation of tanker vehicle selection using a novel hybrid fuzzy MCDM technique. Decision Making: Applic. Manag. Eng. 4 (2), 140–162.

Gorener, A., Ayvaz, B., Kuşakcı, A.O., Altınok, E., 2017. A hybrid type-2 fuzzy based supplier performance evaluation methodology: the Turkish Airlines technic case. Appli. Soft Comput. J. 56, 436–445.
Govindan, K., Khodaverdi, R., Jafarian, A., 2013. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. J. Clean. Prod. 47, 345–354.
Govindan, K., Rajendran, S., Sarkis, J., Murugesan, P., 2015. Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. J. Clean. Prod. 98, 66–83.
Govindan, K., Mina, H., Esmaeili, A., Gholami-Zanjani, S.M., 2020. An integrated hybrid approach for circular supplier selection and closed loop supply chain network design under uncertainty. J. Clean. Prod. 242, 118317.
Guarnieri, P., Trojan, F., 2019. Decision making on supplier selection based on social, ethical, and environmental criteria: a study in the textile industry. Resour. Conserv. Recycl. 141, 347–361.
Guo, Z., Liu, H., Zhang, D., Yang, J., 2017. Green supplier evaluation and selection in apparel manufacturing using a fuzzy multi-criteria decision-making approach. Sustainability 9 (4), 650.
Gupta, H., Barua, M.K., 2017. Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS. J. Clean. Prod. 152, 242–258.
Gurel, O., Acar, A.Z., Onden, I., Gumus, I., 2015. Determinants of the green supplier selection. Proce. Social Behav. Sci. 181, 131–139.
Haeri, S.A.S., Rezaei, J., 2019. A grey-based green supplier selection model for uncertain environments. J. Clean. Prod. 221, 768–784.
Halila, F., Rundquist, J., 2011. The development and market success of eco-innovations: a comparative study of eco-innovations and "other" innovations in Sweden. Eur. J. Innovat. Manag. 14 (3), 278–302.
Hamdan, S., Jouini, O., Cheaitou, A., Jemai, Z., Granberg, T.A., Josefsson, B., 2022. Air traffic flow management under emission policies: analyzing the impact of sustainable aviation fuel and different carbon prices. Transport. Res. Pol. Pract. 166, 14–40.
Haseli, G., Yaran Ögel, İ., Ecer, F., Hajiaghaei-Keshteli, M., 2023. Luxury in female technology (FemTech): selection of smart jewelry for women through BCM-MARCOS group decision-making framework with fuzzy ZE-numbers. Technol. Forecast. Soc. Change 196, 122870.
Hashemi, S.H., Karimi, A., Tavana, M., 2015. An integrated green supplier selection approach with analytic network process and improved Grey relational analysis. Int. J. Prod. Econ. 159, 178–191.
Hashemkhani Zolfani, S., Görçün, Ö.F., Kundu, P., Küçükönder, H., 2022a. Container vessel selection for maritime shipping companies by using an extended version of the Grey Relation Analysis (GRA) with the help of Type-2 neutrosophic fuzzy sets (T2NFN). Comput. Ind. Eng. 171, 108376.
Hashemkhani Zolfani, S., Bazrafshan, R., Ecer, F., Karamaşa, Ç., 2022b. The suitability-feasibility-acceptability strategy integrated with Bayesian BWM-MARCOS methods to determine the optimal lithium battery plant located in South America. Mathematics 10 (14), 2401.
Hendiani, S., Mahmoudi, A., Liao, H., 2020. A multi-stage multi-criteria hierarchical decision-making approach for sustainable supplier selection. Appl. Soft Comput. 94, 106456.
Hezam, I.M., Nayeem, M.K., Foul, A., Alrasheedi, A.F., 2021. COVID-19 Vaccine: a neutrosophic MCDM approach for determining the priority groups. Results Phys. 20, 103654.
Horbach, J., 2008. Determinants of environmental innovation—new evidence from German panel data sources. Res. Pol. 37 (1), 163–173.
Horbach, J., Rammer, C., Rennings, K., 2012. Determinants of eco-innovations by type of environmental impact—the role of regulatory push/pull, technology push and market pull. Ecol. Econ. 78, 112–122.
Humphreys, P.K., Wong, Y.K., Chan, F.T.S., 2003. Integrating environmental criteria into the supplier selection process. J. Mater. Process. Technol. 138 (1–3), 349–356.
IATA, 2021. Developing sustainable aviation fuel - international air transport association. https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/.
IATA, 2022. 2022 SAF production increases 200% - more incentives needed to reach. Net Zero. Retrieved from. https://www.iata.org/en/pressroom/2022-releases/2022-12-07-01/.
ICAO International Civil Aviation Organization, 2023. Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA News. https://www.icao.int/environmental-protection/CORSIA/pages/default.aspx.
Jafarzadeh Ghoushchi, S., Shaffiee Haghshenas, S., Memarpour Ghiaci, A., Guido, G., Vitale, A., 2023. Road safety assessment and risks prioritization using an integrated SWARA and MARCOS approach under spherical fuzzy environment. Neural Comput. Appl. 35 (6), 4549–4567.
Kannan, D., 2018. Role of multiple stakeholders and the critical success factor theory for the sustainable supplier selection process. Int. J. Prod. Econ. 195, 391–418.
Kannan, D., Khodaverdi, R., Olfat, L., Jafarian, A., Diabat, A., 2013. Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. J. Clean. Prod. 47, 355–367.
Kannan, D., Govindan, K., Rajendran, S., 2015. Fuzzy axiomatic design approach based green supplier selection: a case study from Singapore. J. Clean. Prod. 96, 194–208.
Karaşan, A., Kahraman, C., 2018. A novel interval-valued neutrosophic EDAS method: prioritization of the united nations national sustainable development goals. Soft Comput. 22 (15), 4891–4906.
Karaşan, A., Boltürk, E., Kahraman, C., 2019. A novel neutrosophic CODAS method: selection among wind energy plant locations. J. Intell. Fuzzy Syst. 36 (2), 1491–1504.
Krishankumar, R., Mishra, A.R., Rani, P., Ecer, F., Ravichandran, K.S., 2023. Assessment of zero-carbon measures for sustainable transportation in smart cities: a CRITIC-MARCOS framework based on Q-rung fuzzy preferences. IEEE Internet Things J. 10 (21), 18651–18662.
Kuo, R.J., Wang, Y.C., Tien, F.C., 2010. Integration of artificial neural network and MADA methods for green supplier selection. J. Clean. Prod. 18 (12), 1161–1170.
Li, J., Fang, H., Song, W., 2019. Sustainable supplier selection based on SSCM practices: a rough cloud TOPSIS approach. J. Clean. Prod. 222, 606–621.
Liou, J.J.H., Chuang, Y.C., Tzeng, G.H., 2014. A fuzzy integral-based model for supplier evaluation and improvement. Inf. Sci. 266, 199–217.
Liu, H.C., Quan, M.Y., Li, Z.W., Wang, Z.L., 2019. A new integrated MCDM model for sustainable supplier selection under interval-valued intuitionistic uncertain linguistic environment. Inf. Sci. 486, 254–270.
Lo, H.W., Liou, J.J., Wang, H.S., Tsai, Y.S., 2018. An integrated model for solving problems in green supplier selection and order allocation. J. Clean. Prod. 190, 339–352.
Lou, Z., Ye, A., Mao, J., Zhang, C., 2022. Supplier selection, control mechanisms, and firm innovation: configuration analysis based on fsQCA. J. Bus. Res. 139, 81–89.
Lu, J., Wei, C., Wu, J., Wei, G., 2019. TOPSIS method for probabilistic linguistic MAGDM with entropy weight and its application to supplier selection of new agricultural machinery products. Entropy 21 (10), 953.
Luthra, S., Govindan, K., Kannan, D., Mangla, S.K., Garg, C.P., 2017. An integrated framework for sustainable supplier selection and evaluation in supply chains. J. Clean. Prod. 140, 1686–1698.
Mafakheri, F., Breton, M., Ghoniem, A., 2011. Supplier selection-order allocation: a two-stage multiple criteria dynamic programming approach. Int. J. Prod. Econ. 132 (1), 52–57.
Majumdar, P., Samanta, S.K., 2014. On similarity and entropy of neutrosophic sets. J. Intell. Fuzzy Syst. 26 (3), 1245–1252.
Majumder, P., 2023. An integrated trapezoidal fuzzy FUCOM with single-valued neutrosophic fuzzy MARCOS and GMDH method to determine the alternatives weight and its applications in efficiency analysis of water treatment plant. Expert Syst. Appl. 225, 120087.
Menon, R.R., Ravi, V., 2022. Using AHP-TOPSIS methodologies in the selection of sustainable suppliers in an electronics supply chain. Cleaner Mater. 5, 100130.
Mina, H., Kannan, D., Gholami-Zanjani, S.M., Biuki, M., 2021. Transition towards circular supplier selection in petrochemical industry: a hybrid approach to achieve sustainable development goals. J. Clean. Prod. 286, 125273.
Mishra, A.R., Rani, P., Pardasani, K.R., Mardani, A., 2019. A novel hesitant fuzzy WASPAS method for assessment of green supplier problem based on exponential information measures. J. Clean. Prod. 238, 117901.
Nair, A., Jayaram, J., Das, A., 2015. Strategic purchasing participation, supplier selection, supplier evaluation and purchasing performance. Int. J. Prod. Res. 53 (20), 6263–6278.
Pamucar, D., Ecer, F., Deveci, M., 2021. Assessment of alternative fuel vehicles for sustainable road transportation of United States using integrated fuzzy FUCOM and neutrosophic fuzzy MARCOS methodology. Sci. Total Environ. 788, 147763.
Pamucar, D., Ulutaş, A., Topal, A., Karamaşa, Ç., Ecer, F., 2024. Fermatean fuzzy framework based on preference selection index and combined compromise solution methods for green supplier selection in textile industry. Int. J. Syst. Sci.: Operat. Logis. 11 (1), 2319786.
Park, D., Krishnan, H.A., 2001. Supplier selection practices among small firms in the United States: testing three models. J. Small Bus. Manag. 39 (3), 259–271.
Parkouhi, S.V., Ghadikolaei, A.S., 2017. A resilience approach for supplier selection: using Fuzzy Analytic Network Process and grey VIKOR techniques. J. Clean. Prod. 161, 431–451.
Parkouhi, S.V., Ghadikolaei, A.S., Lajimi, H.F., 2019. Resilient supplier selection and segmentation in grey environment. J. Clean. Prod. 207, 1123–1137.
Pérez-Calderón, E., Milanés-Montero, P., Gutíerrez-Pérez, C., 2021. Climate change, where do we come from and where are we going? European aviation sector behaviour. Transport Pol. 114, 40–48.
Qahtan, S., Alsattar, H.A., Zaidan, A.A., Deveci, M., Pamucar, D., Ding, W., 2023. A novel fuel supply system modelling approach for electric vehicles under Pythagorean probabilistic hesitant fuzzy sets. Inf. Sci. 622.
Rahimi, M., Kumar, P., Moomivand, B., Yari, G., 2021. An intuitionistic fuzzy entropy approach for supplier selection. Complex Intelli. Syst. 7 (4), 1869–1876.
Rahmi, S.R., 2019. Analysis of supplier selection by using the AHP and PROMETHEE methods in regional public hospital padang (RSUD padang). In: Third Padang International Conference on Economics Education, Economics, Business and Management, Accounting and Entrepreneurship (PICEEBA 2019). Atlantis Press, pp. 32–41.
Rajaratnam, D., Sunmola, F., 2021. Supply chain management in airline catering service: characteristics, challenges and trends. In: Proceedings of the International Conference on Industrial Engineering and Operations Management, pp. 1831–1842.
Ramadhanti, V.I., Pulansari, F., 2022. Integration of fuzzy AHP and fuzzy TOPSIS for green supplier selection of mindi wood raw materials. Jurnal sistem dan manajemen industri 6 (1), 1–13.
Rezaei, J., Fahim, P.B.M., Tavasszy, L., 2014. Supplier selection in the airline retail industry using a funnel methodology: conjunctive screening method and fuzzy AHP. Expert Syst. Appl. 41 (18), 8165–8179.
Rezaei, J., Wang, J., Tavasszy, L., 2015. Linking supplier development to supplier segmentation using Best Worst Method. Expert Syst. Appl. 42 (23), 9152–9164.
Rezaei, J., Nispeling, T., Sarkis, J., Tavasszy, L., 2016. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. J. Clean. Prod. 135, 577–588.

Roy, S.A., Ali, S.M., Kabir, G., Enayet, R., Suhi, S.A., Haque, T., Hasan, R., 2020. A framework for sustainable supplier selection with transportation criteria. Int. J. Sustain. Eng. 13 (2), 77–92.
Ryley, T., Baumeister, S., Coulter, L., 2020. Climate change influences on aviation: a literature review. Transport Pol. 92, 55–64.
Saha, A., Simic, V., Senapati, T., Dabic-Miletic, S., Ala, A., 2022. A dual hesitant fuzzy sets-based methodology for advantage prioritization of zero-emission last-mile delivery solutions for sustainable city logistics. IEEE Trans. Fuzzy Syst. 31 (2), 407–420.
Salimian, S., Mousavi, S.M., Antucheviciene, J., 2022. An interval-valued intuitionistic fuzzy model based on extended VIKOR and MARCOS for sustainable supplier selection in organ transplantation networks for healthcare devices. Sustainability 14 (7), 3795.
Sarkis, J., 2003. A strategic decision framework for green supply chain management. J. Clean. Prod. 11 (4), 397–409.
Smarandache, F., 1999. A Unifying Field in Logics: Neutrosophic Logic, Neutrosophy, Neutrosophic Set, Neutrosophic Probability. American Research Press.
Smarandache, F., 2001. Neutrosophic logic, neutrosophic set, neutrosophic probability and statistics. In: Smarandache, F. (Ed.), Proceedings of the First International Conference on Neutrosophy, Neutrosophic Logic, Neutrosophic Set, Neutrosophic Probability and Statistics, pp. 1–149.
Smarandache, F., 2019. Neutrosophic set is a generalization of intuitionistic fuzzy set, inconsistent intuitionistic fuzzy set (picture fuzzy set, ternary fuzzy set), pythagorean fuzzy set, spherical fuzzy set, and q-rung orthopair fuzzy set, while neutrosophication is a generalization of regret theory, grey system theory, and three-ways decision. New Theory 29, 1–31.
Stević, Ž., Pamučar, D., Puška, A., Chatterjee, P., 2020. Sustainable supplier selection in healthcare industries using a new MCDM method: measurement of alternatives and ranking according to COmpromise solution (MARCOS). Comput. Ind. Eng. 140, 106231.
Tanrıverdi, G., Bakır, M., Merkert, R., 2020. What can we learn from the JATM literature for the future of aviation post Covid-19? - a bibliometric and visualization analysis. J. Air Transport. Manag. 89, 101916.
Tanrıverdi, G., Merkert, R., Karamaşa, Ç., Asker, V., 2023. Using multi-criteria performance measurement models to evaluate the financial, operational and environmental sustainability of airlines. J. Air Transport. Manag. 112, 102456.
Tirkolaee, E.B., Mardani, A., Dashtian, Z., Soltani, M., Weber, G.W., 2020. A novel hybrid method using fuzzy decision making and multi-objective programming for sustainable-reliable supplier selection in two-echelon supply chain design. J. Clean. Prod. 250, 119517.
Tong, L.Z., Wang, J., Pu, Z., 2022. Sustainable supplier selection for SMEs based on an extended PROMETHEE II approach. J. Clean. Prod. 330, 129830.
Tseng, M.L., Chiu, A.S., 2013. Evaluating firm's green supply chain management in linguistic preferences. J. Clean. Prod. 40, 22–31.
Ulutaş, A., Topal, A., Görçün, Ö.F., Ecer, F., 2024. Evaluation of third-party logistics service providers for car manufacturing firms using a novel integrated grey LOPCOW-PSI-MACONT model. Expert Syst. Appl. 241, 122680.
Undavalli, V., Olatunde, O.B.G., Boylu, R., Wei, C., Haeker, J., Hamilton, J., Khandelwal, B., 2023. Recent advancements in sustainable aviation fuels. Prog. Aero. Sci. 136, 100876.
Vahidi, F., Torabi, S.A., Ramezankhani, M.J., 2018. Sustainable supplier selection and order allocation under operational and disruption risks. J. Clean. Prod. 174, 1351–1365.
Van Hemel, C., Cramer, J., 2002. Barriers and stimuli for ecodesign in SMEs. J. Clean. Prod. 10 (5), 439–453.
Wang, J., Wei, G., Lu, M., 2018. An extended VIKOR method for multiple criteria group decision making with triangular fuzzy neutrosophic numbers. Symmetry 10 (10), 497.
Watson, M.J., Machado, P.G., da Silva, A.V., Saltar, Y., Ribeiro, C.O., Nascimento, C.A.O., Dowling, A.W., 2024. Sustainable aviation fuel technologies, costs, emissions, policies, and markets: a critical review. J. Clean. Prod. 449, 141472.
World Resource Institute, 2023. What does "net-zero emissions" mean? https://www.wri.org/insights/net-zero-ghg-emissions-questions-answered#:~:text=Thelatestsciencesuggeststhat,orexceeding1.5degreesC.
Yang, Z., Zhang, H., Xie, E., 2017. Performance feedback and supplier selection: a perspective from the behavioral theory of the firm. Ind. Market. Manag. 63, 105–115.
Yazdani, M., Torkayesh, A.E., Stević, Ž., Chatterjee, P., Ahari, S.A., Hernandez, V.D., 2021. An interval valued neutrosophic decision-making structure for sustainable supplier selection. Expert Syst. Appl. 183, 115354.
Yiğit, F., 2023. A three-stage fuzzy neutrosophic decision support system for human resources decisions in organizations. Dec. Analyt. J. 7, 100259.
Yilmaz, O., Gülsün, B., Güneri, A.F., Özgürler, Ş., Endüstri, B.Y., Besiktas, M.B., 2011. Supplier selection of a textile company with ANP. Int. Research. Conf. Trends. 15, 257–260.
Yucesan, M., Gul, M., 2021. Failure prioritization and control using the neutrosophic best and worst method. Granular Compu. 6, 435–449.
Yusriza, F.A., Abdul Rahman, N.A., Jraisat, L., Upadhyay, A., 2023. Airline catering supply chain performance during pandemic disruption: a Bayesian network modelling approach. Int. J. Qual. Reliab. Manag. 40 (5), 1119–1146.
Zadeh, L.A., 1965. Fuzzy sets. Inf. Control 8 (3), 338–353.
Zailani, S., Jeyaraman, K., Vengadasan, G., Premkumar, R., 2012. Sustainable supply chain management (SSCM) in Malaysia: a survey. Int. J. Prod. Econ. 140 (1), 330–340.
Zavadskas, E.K., Bausys, R., Lescauskiene, I., Usovaite, A., 2020. MULTIMOORA under interval-valued neutrosophic sets as the basis for the quantitative heuristic evaluation methodology HEBIN. Mathematics 9 (1), 66.
Zkik, K., Sebbar, A., Nejjari, N., Lahlou, S., Fadi, O., Oudani, M., 2023. Secure model for records traceability in airline supply chain based on blockchain and machine learning. In: EAI/Springer Innovations in Communication and Computing, pp. 141–159.