SCIENTIFIC OASIS

Spectrum of Operational Research

Journal homepage: www.sor-journal.org
ISSN: 3042-1470

Sustainable Supplier Selection Based on a Comparative Decision-Making Approach Under Uncertainty

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ARTICLE INFO

Article history:
Received 11 March 2025
Received in revised form 19 April 2025
Accepted 25 May 2025
Available online 1 June 2025

Keywords:
Supplier selection; Fuzzy Delphi; Multi-criteria decision-making; MCDM; Comparative analysis; Fuzzy numbers; Sustainable development.

ABSTRACT

Nowadays, due to the increasing awareness of sustainability and green issues worldwide, companies are forced to implement sustainable projects in their Supply Chain (SC) to maintain and increase their competitive advantage. To enhance business performance and gain a competitive edge, it is crucial to select green and sustainable suppliers in the supply chain, as they play a vital role in executing sustainable projects. Therefore, the research was conducted to select sustainable suppliers in the SC. Initially, a list of indicators for selecting sustainable suppliers was extracted, and these indicators were adjusted and finalized using the fuzzy Delphi technique. Also, the Step-wise Weight Assessment Ratio Analysis (SWARA) technique was used for weighting, and the Fuzzy Weighted Aggregates Sum-Product Assessment (F-WASPAS) technique was used for prioritizing suppliers. In addition, the robustness of the findings was examined using a comparative analysis of different decision methods in a fuzzy environment. The weighting results showed that the product price, transportation cost, and green design and purchasing indicators were of the highest importance, respectively. Moreover, the results of the supplier ranking revealed that the first supplier had the highest priority.

1. Introduction

Businesses can no longer afford to ignore sustainability issues as a result of increased public knowledge of environmental and sustainability challenges, stronger government restrictions, and a more informed populace [1]. To improve Supply Chain (SC) performance, industrial companies now need to include green and sustainable practices in their current planning process [2]. In recent years, commercial organizations have made focusing on environmental, economic, and social considerations to achieve sustainable development a key strategic objective [3]. Sustainable strategies must be implemented and carried out in the SC in a methodical manner [4]. To accomplish social, environmental, and financial objectives and carry out sustainable SC efforts, suppliers are crucial [5]. A strategic choice for sustainable SC management is selecting a sustainable supplier [6].

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https://doi.org/10.31181/sor31202644

The SC must select sustainable and green suppliers to improve business performance and competitive advantage [7]. Choosing a sustainable supplier in the SC is essential, as it reduces environmental and social risks, improves brand reputation, increases productivity, and ensures sustainability in crises [8]. By adhering to the principles of social and environmental responsibility, such suppliers reduce long-term costs, improve overall SC performance, and comply with international standards, which ultimately creates a sustainable competitive advantage for the organization [5]. Therefore, to achieve sustainability, the SC's supplier selection is crucial.

Therefore, considering sustainable projects in the SC and the necessity of selecting sustainable suppliers to achieve this, this research, in addition to identifying the criteria for selecting sustainable suppliers, also deals with their evaluation and selection. Since the selection of suppliers is a decision-making problem, there is a need to use Multi-Criteria Decision-Making (MCDM) methods. On the other hand, fuzzy numbers must be used in the evaluations due to the uncertainty in expert evaluations. In this sense, a list of indicators is first created by analyzing the research done in this area, and the fuzzy Delphi technique is used to confirm and finalize the discovered indicators. In the next step, the Step-wise Weight Assessment Ratio Analysis (SWARA) technique is used to weigh the indicators, and the Fuzzy Weighted Aggregates Sum-Product Assessment (F-WASPAS) technique is used to rank suppliers. The combined use of the SWARA and F-WASPAS methods, which are innovative combinations among MCDM techniques, increases the accuracy and precision of the results. Also, to examine the robustness of the results, a comparative analysis of the findings with different decision-making approaches is performed.

In the next section, the research literature is examined. Then, the research method and the SWARA and F-WASPAS methods are explained. Next, data analysis is discussed, and finally, some practical suggestions are presented based on the results.

2. Research Background

One of the critical and intricate choices in SC management that directly affects product quality, pricing, delivery time, and customer satisfaction is the supplier selection issue. This problem usually involves evaluating and comparing multiple suppliers based on various factors. Due to the presence of several sometimes conflicting factors, decision-making in this field is challenging and cannot be based solely on subjective judgment. Hence, the use of MCDM approaches helps organizations to have a more accurate, coherent, and data-driven assessment [6]. These techniques allow for analyzing the relative weight of criteria, quantitatively comparing options, and choosing the best supplier in complex and risky situations [9]. As a result, the use of these methods improves decision-making, reduces human errors, and increases SC effectiveness. Numerous studies have been carried out to choose green and sustainable suppliers because of the significance of these concerns in SCs and the critical role that suppliers play in accomplishing this:

Kannan et al. [10] investigated green supplier selection indicators for environmental performance. For this purpose, ISM and AHP were used, and the effectiveness of these models was demonstrated with a case in an automobile in India. The ANP technique was put out by Hsu and Hu [11] as a way to integrate Hazardous Substance Management (HSM) into the supplier selection procedure. This study proposes the MCDM approach and divides the HSM competency criteria into four aspects. By taking into account the internal dependencies among the decision structure's components, ANP is used to choose the best provider. To choose sustainable suppliers, Bai and Sarkis [12] employed the rough set and the gray system. In this study, explicit consideration of sustainability characteristics and sensitivity analysis was investigated to examine the accuracy of the model. The paper also discusses the limitations of existing methods and provides future research directions to expand the applications of this method.

Amindoust et al. [13] presented a method for assessing and ranking suppliers by identifying factors related to sustainability. In this process, the decision-makers' perspective on the importance of criteria and supplier performance is examined based on linguistic terms. To manage the subjectivity present in the evaluations, fuzzy logic and fuzzy inference systems (FIS) are used. An integrated method for choosing suppliers that take greenhouse gas emissions into account is presented by Shaw et al. [14]. It combines fuzzy multi-objective linear programming with fuzzy AHP. Additionally, a case study illustrates how well the suggested approach works in practical settings and when faced with ambiguous information. Models based on the triple sustainability approach were studied by Govindan et al. [15], who concentrated on sustainable supplier selection. The fuzzy TOPSIS methodology was used to rate providers in the suggested method. To show how applicable this method is, a case study is also provided. By determining the important criteria for carbon management in a green SC, Hsu et al. [16] employed the DEMATEL technique to enhance suppliers' overall carbon management performance. A literature review and conversations with three specialists in an electronics firm led to the identification of thirteen criteria in three distinct aspects. The findings showed that training pertaining to carbon management and carbon information management systems had the biggest effects.

Based on the principles of green supply chain management, Kannan et al. [17] presented a framework for choosing green suppliers for a Brazilian electronics company. Twelve vendors' worth of data were gathered, and the fuzzy TOPSIS algorithm was used to rank the suppliers. To find green supplier development programs that successfully raise supplier performance, Dou et al. [18] developed a model based on the gray ANP. This methodology took into account suppliers' desire to engage to thoroughly assess green supplier development initiatives. Supplier selection based on technical, environmental, and economic efficiency considerations was covered by Mahdiloo et al. [19]. Rather than employing three distinct models, technical, environmental, and ecological efficiency goals were combined into a computationally simpler multi-objective DEA model using linear goal programming. A thorough methodology for choosing green suppliers based on both economic and environmental factors was presented by Hashemi et al. [20]. To further account for the uncertainties in supplier selection decisions, the dependencies between criteria were examined using the ANP and grey relationship analysis. A thorough fuzzy MCDM method for choosing and assessing green suppliers was presented by Wang Chen et al. [21]. It combined environmental and economic factors. This approach uses fuzzy TOPSIS to rank and assess possible providers and fuzzy AHP to establish the relevance weights of criteria in an unclear setting.

In an integrated approach to green supplier selection, Yazdani et al. [22] mapped the relationship structure of their customers' criteria using the DEMATEL method. A core relationship matrix was then created using the QFD approach, and the degree of relationship between each supplier selection criterion and customer wants was ascertained. Lastly, the COPRAS approach was applied to rank and prioritize other providers. An easy-to-use fuzzy TOPSIS-based decision-making technique for an automotive manufacturer's sustainable supplier selection was provided by Memari et al. [23]. The approach offered a trustworthy solution for sustainable sourcing decision-making as well as an accurate rating of sustainable suppliers. Additionally, a real-world case study was provided to support the methodology. Using the TODIM technique, a hybrid model for choosing the best green suppliers. First, a thorough assessment system is created using green indicators and the features of cloud manufacturing environments. The fuzzy BWM approach is combined with entropy to establish the weight of the criterion, and the TODIM method is then used to prioritize green suppliers by taking decision-makers risk attitudes into account. Menon and Ravi [24] proposed a hybrid AHP-TOPSIS method for supplier choice that evaluated both quantitative and qualitative data under uncertainty.

The model was implemented in a real electronics industry company, and the results showed that economic factors still had the most influence.

For sustainable supplier selection in the oil and gas sector, Gidiagba et al. [25] offered a thorough MCDM strategy. After identifying and eliminating superfluous criteria using the Delphi technique, 15 important criteria were identified, taking into account typical issues including delays in resource extraction and refining. The weight of the criteria was then established using the BWM. Lastly, suppliers were ranked using the TOPSIS approach. Štreimikienė et al. [26] examined the importance of sustainable SC in the Iranian automotive and assessed the sustainability performance of suppliers in light of increasing global environmental concerns and regulatory requirements. The study used the TOPSIS technique to evaluate five major suppliers. Phan Ha et al. [27] identified and categorized the critical criteria affecting supplier selection in the apparel industry that focused on sustainable development. In this study, suppliers were ranked using the AHP-TOPSIS approach. Ulutaş et al. [28] presented a strategic approach to supplier selection focusing on resilience characteristics to reduce risks in the SC. In this study, a grey MCDM method was developed considering resilience indicators. The weights of the criteria were established using the grey PSI and BWM methodologies, and resilient providers were assessed and ranked using the grey MCRAT and COBRA methods.

Sithi et al. [29] evaluated sustainable suppliers in the textile industry and developed a comprehensive framework combining the three sustainability principles and the SWARA and TOPSIS methods. For buying managers, this study offered insightful information, particularly in developing nations like Bangladesh. Şişman et al. [30] investigated the monitoring and evaluation of supplier sustainability performance in the automotive industry. Using intuitive fuzzy AHP, EDAS, CODAS, and MOORA, suppliers were ranked. The results showed that more general criteria can be used in initial selection, and more precise internal and external criteria can be used in continuous assessment to guide suppliers towards real sustainability. An enhanced AHP-FMEA approach that integrated the FMEA, the entropy method, and the AHP for green supplier selection was presented by Chen and Wang [31]. By evaluating risk and detecting possible supplier failures, the FMEA further enhanced the evaluation. The AHP established the subjective weights of the criteria, and the entropy approach objectively corrected them to minimize bias. The case study demonstrated that taking risk into account improved the accuracy and dependability of the selection process and had a significant effect on supplier ranking.

2.1 Research gap

A survey of the study literature reveals that the majority of studies in this area are based on broad, unspecific criteria that don't apply to choosing suppliers for particular industries. On the other hand, methods have been used in selecting suppliers that have a high inconsistency rate due to the large number of pairwise comparisons and do not have sufficient accuracy and validity. Therefore, to address the shortcomings in this research, a list of indicators for selecting sustainable suppliers is extracted by reviewing the research in this field, and these indicators are adjusted and finalized using the fuzzy Delphi method. Also, to increase the accuracy and precision of the assessment, a combined SWARA and F-WASPAS approach is used. The reasons for using these techniques include the need for less comparative data and more reliable answers than other decision-making methods due to a more robust comparison. Validation is also carried out by comparative analysis of different decision-making approaches.

3. Methodology

The goal and data collection of this study make it a descriptive survey. In this research, a library method was used to identify the indicators for selecting suppliers. In contrast, a questionnaire was distributed to experts and professionals as part of a field study to assess and ascertain the relative significance of each of these factors and choose a sustainable supplier. Using a case study in the cable and peripheral equipment SC, the efficacy of the suggested model was illustrated. Since the electricity sector is a mother industry and a vital component of the nation's infrastructure, the SC of this sector faces numerous difficulties. One of the challenges that this industry faces is sustainable development and sustainability issues. Due to the importance of the role of suppliers in the SC, a study was conducted to identify and select sustainable suppliers in the SC of cables and peripheral equipment. A decision-making team consisting of 3 experts (from the company's logistics and SC members) was formed under the supervision of the company's logistics manager to select sustainable suppliers.

3.1 Fuzzy Delphi technique

The Delphi approach, which was first introduced in 1963, was used to gather expert opinions with characteristics such as anonymity of responses, repetition with controlled feedback, and statistical analysis of opinions. This method faced issues such as high costs, low convergence of opinions, and the likelihood of excluding specific viewpoints. To address these problems, the fuzzy Delphi method was proposed in 1985, which utilizes triangular fuzzy numbers to reduce ambiguity and inconsistency in opinions [32]. Unlike the traditional method that requires multiple assessments, the fuzzy Delphi method only needs to be assessed once and covers more opinions. In this research, instead of the usual ten-point scale, a five-point scale has been used due to its greater suitability for the conditions in Iran. The steps for using the fuzzy Delphi approach are as follows [33].

First, the factors extracted in the previous stages of the thesis, which were suggested by the experts, were used as the basis and basis for designing the questionnaire. Additionally, the questionnaire ended with a free-form question asking participants to list any significant influences they felt were crucial to the study's goal.

Second, to determine the relative relevance of the influential elements and their ranking, the questionnaire was utilized to gather the opinions of specialists in the group that made the decisions.

Third, the expert questionnaire and the following formulas can be used to determine the fuzzy trigonometric function associated with each influential factor:

$$\tilde{A} = (L_A, M_A, U_A) \tag{1}$$

$$L_A = \min(X_{A_i}), i = 1,2,3, \dots, n \tag{2}$$

$$M_A = \left(X_{A_1} \times X_{A_2} \times \dots \times X_{A_n}\right)^{\frac{1}{n}} \tag{3}$$

$$U_A = \max\left(X_{A_i}\right), i = 1,2,3, \dots, n \tag{4}$$

where L_A, M_A, and U_A are the lower bound, geometric mean, and upper bound of the decision group values for the influencing factor A, respectively; X_{A_i} is the value of the ith decision maker for the influencing factor A; and $\tilde{A}$ is the fuzzy value of the importance of the influencing factor A.

Fourth: Assume that the membership function M_A is formed by the geometric mean of the fuzzy trigonometric function for each influencing factor. This reflects the consensus of the decision committee about this factor.

Fifth: Selecting a threshold value S to eliminate unsuitable elements.

(a) If $M_A \geq S$, accept the influential factor A.

(b) If $M_A < S$, remove the effective factor A.

In essence, the decision maker's subjective assessment determines the threshold value, which has a direct impact on the number of elements that need to be eliminated.

3.2 SWARA technique

The SWARA approach, developed in 2010 by Keršuliene et al. [34], allows decision-makers to select, evaluate, and weigh indicators. This method's capacity to evaluate the precision of expert judgments in the indicator weighting process is its greatest benefit over other comparable approaches [35]. In contrast to other MCDM techniques, experts can also confer with one another, which improves the accuracy of the outcomes [36]. The following are the primary steps for weighting using the SWARA approach:

The indications are sorted in step one; each indicator's relative relevance (S_j) is determined in step two; and the coefficient (K_j) is calculated in step three. Equation (5) is used to get the coefficient (K_j), which depends on the proportional importance of each indication.

$$K_j = S_j + 1 \tag{5}$$

Each indicator's starting weight is computed in step four. Using Equation (6), the indicators' starting weight can be determined.

$$q_j = \frac{q_{j-1}}{K_j} \tag{6}$$

Step 5: Calculating the final weight;

Equation (7) is used in the final phase of the SWARA method to get the indicators' final weight, also known as the normalized weight.

$$w_j = \frac{q_j}{\sum q_j} \tag{7}$$

3.3 F-WASPAS technique

One alternate ranking technique that assesses options using a combination of the two WSM and WPM models is the WASPAS approach [37]. This approach is helpful for difficult decision-making situations since it employs fewer comparable data and yields flexible, robust, and trustworthy outcomes [38]. The F-WASPAS approach was created to address the ambiguity in expert evaluation, and this method is as follows [39]:

It is necessary to first create a matrix of expert perspectives. The following is the expert opinion matrix:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \dots & \tilde{x}_{1j} & \dots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \dots & \tilde{x}_{ij} & \dots & \tilde{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \dots & \tilde{x}_{mj} & \dots & \tilde{x}_{mn} \end{bmatrix} ; i = \overline{1,m};\ \ j = \overline{1,n} \tag{8}$$

Next, the data must be normalized, and the following relations are used to normalize the data:

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}} \tag{9}$$

$$\tilde{\bar{x}}_{ij} = \frac{\min_i \tilde{x}_{ij}}{\tilde{x}_{ij}} \tag{10}$$

Next, the matrix $\tilde{\hat{X}}_q$ and $\tilde{\hat{X}}_p$ are calculated according to the following equation:

$$\tilde{\hat{X}}_q = \begin{bmatrix} \tilde{\hat{x}}_{11} & \dots & \tilde{\hat{x}}_{1j} & \dots & \tilde{\hat{x}}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\hat{x}}_{i1} & \dots & \tilde{\hat{x}}_{ij} & \dots & \tilde{\hat{x}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\hat{x}}_{m1} & \dots & \tilde{\hat{x}}_{mj} & \dots & \tilde{\hat{x}}_{mn} \end{bmatrix} ; \tilde{\hat{x}}_{ij} = \tilde{\bar{x}}_{ij} . \tilde{w}_j \quad , i = \overline{1,m};\ \ j = \overline{1,n} \tag{11}$$

$$\tilde{\tilde{X}}_p = \begin{bmatrix} \tilde{\tilde{x}}_{11} & \dots & \tilde{\tilde{x}}_{1j} & \dots & \tilde{\tilde{x}}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{i1} & \dots & \tilde{\tilde{x}}_{ij} & \dots & \tilde{\tilde{x}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{m1} & \dots & \tilde{\tilde{x}}_{mj} & \dots & \tilde{\tilde{x}}_{mn} \end{bmatrix} ; \tilde{\tilde{x}}_{ij} = (\tilde{\bar{x}}_{ij})^{\widetilde{w}_j} \quad , i = \overline{1,m}; \ j = \overline{1,n} \tag{12}$$

Then, $\tilde{Q}_i$, $\tilde{P}_i$, Q_i, and P_i are computed as follows:

$$\tilde{Q}_i = \sum_{j=1}^{n} \hat{\tilde{x}}_{ij}, i = \overline{1,m} \tag{13}$$

$$\tilde{P}_i = \prod_{j=1}^{n} \tilde{\tilde{x}}_{ij}, i = \overline{1,m} \tag{14}$$

$$Q_i = \frac{1}{3} \left(Q_{ia} + Q_{ib} + Q_{ic} \right) \tag{15}$$

$$P_i = \frac{1}{3} \left(P_{ia} + P_{ib} + P_{ic} \right) \tag{16}$$

Then the value of WPS_i is calculated as follows:

$$WPS_i = \theta \sum_{j=1}^{m} Q_i + (1-\theta) \sum_{j=1}^{m} P_i \tag{17}$$

The θ is determined by experts and the options are ranked based on the values of WPS_i.

4. Findings

4.1 Identification of indicators

The process of identifying indicators for sustainable supplier selection is one of the key steps in the MCDM approach, which aims to comprehensively evaluate suppliers based on sustainability dimensions. This process usually begins with an extensive review of specialized literature and consultation with experts in the field to extract a set of initial criteria. Then, using the fuzzy Delphi technique, the relevant criteria are refined and prioritized. Finally, the final set of criteria is used as the basis for evaluating and ranking suppliers to achieve a sustainable SC. In this regard, first, by reviewing the research, a comprehensive list of indicators for selecting sustainable suppliers is identified, which is listed in Table 2.

Table 2
Indicators for selecting sustainable suppliers

Indicators	Sub-indicators	References
Economic	Product cost	[6, 20]
	Product benefits	[13]
	Product quality	[20]
	Flexibility	[20]
	Technological and financial capability	[31, 40]
	Production facilities and capacity	[40]
	Delivery time	[15, 41]
	Transportation cost	[40]
Environmental	Environmental management system	[31]
	Green design and purchasing	[31]
	Green manufacturing	[31]
	Green packaging	[20]
	Waste and pollution management	[6]
	Green research and development	[42]
Social	Stakeholder rights	[15]
	Employee benefits and rights	[43]
	Occupational health and safety	[6, 42]
	Information transparency	[44]

The final set of indicators is indicated in Table 3. The identified indicators were refined and finalized by sending the fuzzy Delphi questionnaire to the decision specialists.

Table 3
Indicators confirmed by the fuzzy Delphi method

Indicators	Sub-indicators
A-Economic	A11-Product cost A12-Technological and financial capability A13-Transportation cost
B-Environmental	B11-Green design and purchasing B12-Green manufacturing B13-Green packaging B14-Waste and pollution management B15-Green research and development
C-Social	C11-Stakeholder rights C12-Employee benefits and rights C13-Occupational health and safety

4.2 Weighting indicators and ranking sustainable suppliers

Initially, experts ranked the indicators in descending order of priority. Then the relative significance of the indicators is determined. Finally, after completing the normalization process, the final weights are computed, which are given in Table 4.

Table 4
Calculation of indicator weights

Indicators	S_j	K_j	q_j	W_j
A	1.000	1.000	1.000	0.403
B	0.120	1.120	0.893	0.360
C	0.520	1.520	0.587	0.237

Similarly, the weight of the sub-indicators of the economic, environmental, and social is specified. Then, each sub-indicator's final weight is calculated and shown in Table 5.

Table 5
Calculation of the final weight of each sub-indicator

Indicators	Weight	Sub-indicators	Local weight	Final weight
A-Economic	0.403	A11-Product cost	0.417	0.168
		A12-Technological and financial capability	0.249	0.100
		A13-Transportation cost	0.334	0.135
B-Environmental	0.360	B11-Green design and purchasing	0.326	0.117
		B12-Green manufacturing	0.190	0.068
		B13-Green packaging	0.110	0.040
		B14-Waste and pollution management	0.243	0.087
		B15-Green research and development	0.130	0.047
C-Social	0.237	C11-Stakeholder rights	0.429	0.102
		C12-Employee benefits and rights	0.320	0.076
		C13-Occupational health and safety	0.250	0.059

The results of weighting indicated that the product cost, transportation cost, and green design and purchasing indices are of the highest importance, with weights of 0.168, 0.135, and 0.117, respectively. Next, the initial decision matrix is formed using the linguistic expressions specified in Table 6. The assessment of options based on the experts' opinions is shown in Figure 1.

Table 6
Fuzzy linguistic expressions for evaluating options [45]

Linguistic expressions	Very Low (VL)	Low (L)	Medium-Low (ML)	Medium (M)	Medium-High (MH)	High (H)	Very High (VH)
Fuzzy value	$(0, 0, 1)$	$(0, 1, 3)$	$(1, 3, 5)$	$(3, 5, 7)$	$(5, 7, 9)$	$(7, 9, 10)$	$(9, 10, 10)$

	Suppliers	A1	A2	A3	B1	B2	B3	B4	B5	C1	C2	C3
Expert 1	S1	ML	ML	ML	M	M	M	M	ML	MH	M	M
	S2	MH	MH	MH	M	ML	MH	M	M	ML	ML	M
	S3	M	ML	M	M	M	ML	M	ML	MH	M	M
	S4	ML	ML	ML	M	M	M	M	ML	MH	M	M
	S5	MH	MH	L	ML	L	H	MH	MH	ML	ML	L
	S6	MH	MH	M	ML	ML	MH	M	MH	ML	M	ML
	S7	ML	L	ML	H	MH	L	ML	L	MH	H	MH
	S8	M	ML	ML	M	MH	M	ML	M	M	MH	MH
Expert 2	S1	ML	VL	VL	H	VH	VL	L	VL	VH	H	VH
	S2	MH	MH	L	ML	L	H	MH	MH	ML	ML	L
	S3	M	ML	M	M	MH	M	M	ML	M	MH	M
	S4	ML	ML	ML	M	M	M	M	ML	MH	M	M
	S5	MH	MH	M	ML	ML	MH	M	MH	ML	M	ML
	S6	MH	M	MH	M	M	ML	M	ML	M	ML	M
	S7	ML	M	ML	MH	M	ML	M	M	MH	M	MH
	S8	M	M	ML	M	ML	M	M	ML	M	M	ML
Expert 3	S1	VL	L	VL	VH	H	VL	VL	VL	H	VH	VH
	S2	MH	M	MH	M	M	ML	M	ML	M	ML	M
	S3	ML	M	M	MH	M	M	MH	M	M	M	M
	S4	VL	L	VL	H	H	L	L	L	VH	H	H
	S5	MH	M	M	M	ML	MH	MH	MH	M	M	ML
	S6	L	ML	ML	H	MH	ML	L	ML	H	MH	MH
	S7	ML	ML	ML	M	M	M	M	ML	MH	M	M
	S8	M	M	M	ML	ML	M	M	ML	M	M	ML

Fig. 1. Sustainable supplier evaluation decision matrix

Next, the values of $\tilde{Q}_i$ and $\tilde{P}_i$ are appointed. Then, the values of Q_i, P_i and the supplier score are measured, and the alternatives are ranked. The final results of ranking sustainable suppliers in the F-WASPAS technique are illustrated in Table 7.

Table 7
Findings of the sustainable supplier ranking

Suppliers	$\tilde{Q}_i$			$\tilde{P}_i$			Q_i	P_i	Score	Rank
S1	1.520	3.014	8.292	1.005	1.667	3.195	4.275	1.956	3.116	1
S2	0.529	0.775	1.182	0.321	0.527	0.797	0.829	0.548	0.689	8
S3	0.693	1.028	1.824	0.500	0.748	1.210	1.182	0.819	1.000	5
S4	0.993	1.676	4.402	0.724	1.165	2.309	2.357	1.399	1.878	2
S5	0.522	0.785	1.253	0.296	0.513	0.796	0.853	0.535	0.694	7
S6	0.678	1.006	1.661	0.478	0.716	1.090	1.115	0.761	0.938	6
S7	0.862	1.366	2.978	0.630	0.977	1.859	1.735	1.155	1.445	3
S8	0.683	1.048	1.961	0.450	0.710	1.189	1.230	0.783	1.007	4

Also, Figure 2 presents a comparison between the score and rank of each sustainable supplier.

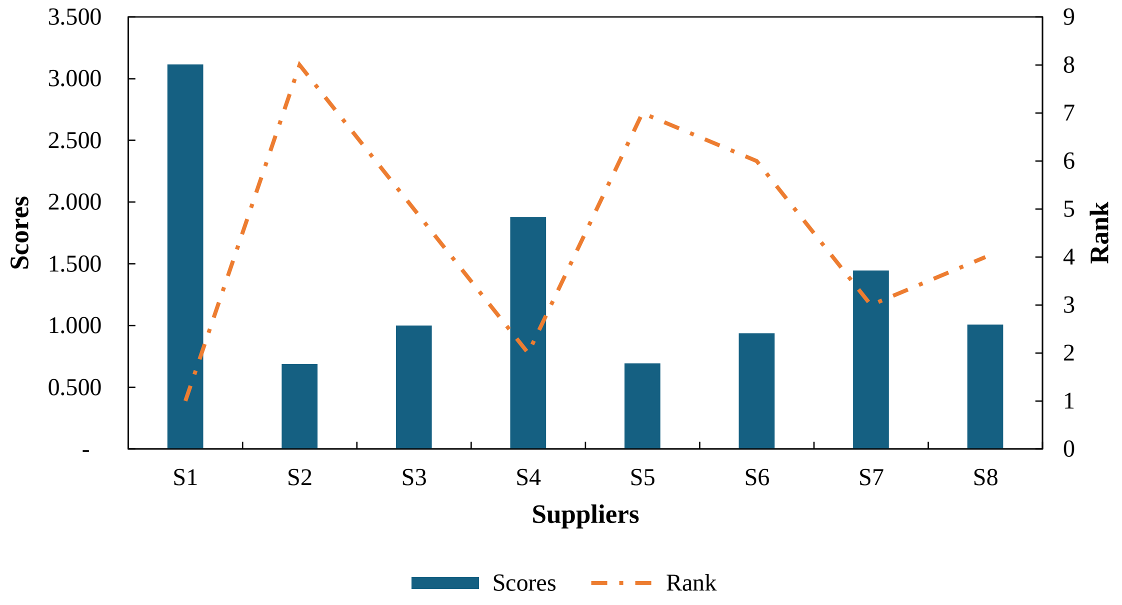

Fig. 2. Comparison between the score and rank of each sustainable supplier

As illustrated in Table 7, the first supplier is the best option with the highest function value. The fourth and seventh suppliers are ranked second and third, respectively.

4.3 Validation of Findings

Next, to verify the validity of the results, supplier rankings are performed using several decision techniques, and the results are compared and analyzed. In this regard, Fuzzy Combined Compromise Solution (F-CoCoSo), Fuzzy Additive Ratio ASsessment (F-ARAS), Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS), and Fuzzy Weighted Sum Model (F-WSM) techniques are used to evaluate sustainable suppliers. The results are indicated in Table 8.

Table 8
Results of comparative analysis of sustainable supplier selection with different approaches

Suppliers	F-CoCoSo		F-ARAS		F-TOPSIS		F-WSM	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
S1	4.354	1	1.000	1	1.000	1	0.773	1
S2	1.608	8	0.299	7	0.020	8	0.236	7
S3	1.920	5	0.446	4	0.114	5	0.357	4
S4	2.956	2	0.713	2	0.461	2	0.552	2
S5	1.694	7	0.288	8	0.029	7	0.230	8
S6	1.792	6	0.426	5	0.094	6	0.340	5
S7	2.394	3	0.601	3	0.272	3	0.473	3
S8	1.937	4	0.410	6	0.130	4	0.324	6

Also in Figure 3, the results of ranking sustainable suppliers based on different methods are compared.

The findings indicate that in all the evaluations conducted, the first, fourth, and seventh suppliers were ranked first to third, respectively. This indicates the robustness and accuracy of the findings in different decision-making situations and using different methods. Even with changing decision-making methods, the change in the rankings is insignificant, and the evaluation conducted is accurate and robust.

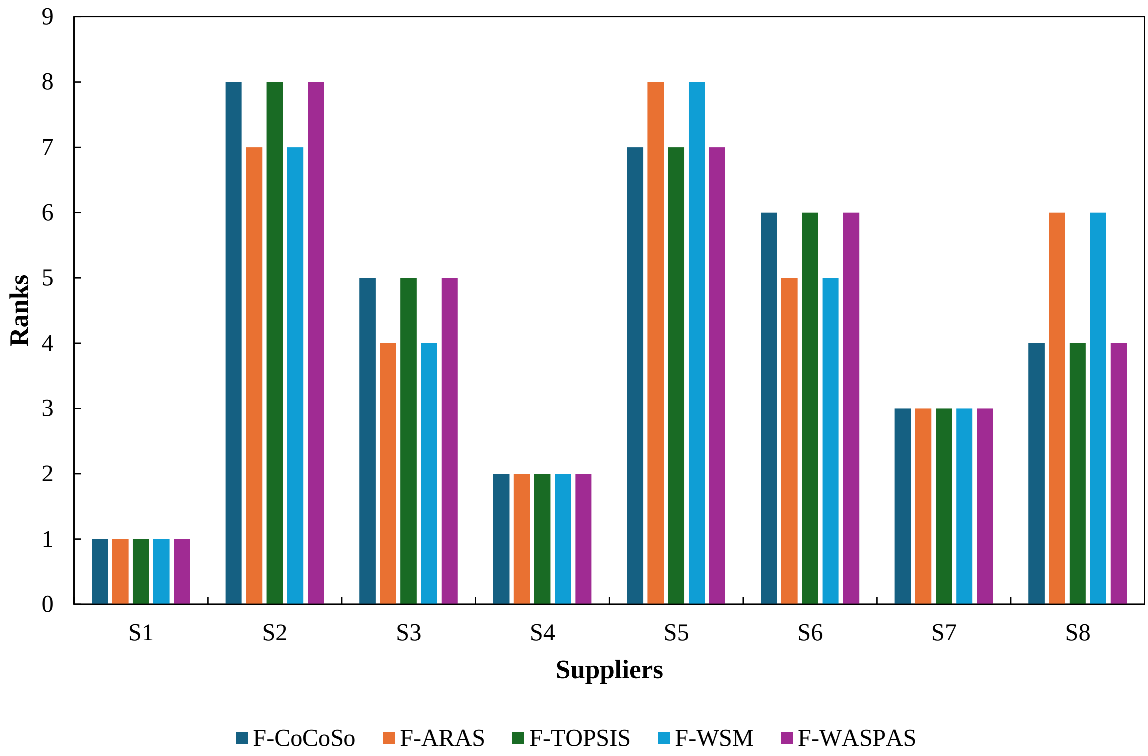

Fig. 3. Comparison of sustainable supplier ranking results based on different methods

5. Conclusions and suggestions

Today, due to the increasing awareness of sustainability and green issues around the world, companies are forced to do sustainable projects in their SCs to maintain and increase their competitive advantage. Choosing green and sustainable suppliers in the SC is crucial to enhancing company efficiency and competitive advantage, as suppliers are crucial to the implementation of sustainable initiatives in the SC. However, a review of the research literature showed that most of the research conducted in this field was based on general and limited indicators and cannot be used for selecting suppliers in specific industries. On the other hand, methods have been used in selecting suppliers that have a high inconsistency rate due to the large number of pairwise comparisons and do not have sufficient accuracy and validity. Therefore, to address the shortcomings in this research, a list of indicators for selecting sustainable suppliers was extracted by reviewing the articles in this field, and these indicators were adjusted and finalized using the fuzzy Delphi method. Additionally, the hybrid SWARA and F-WASPAS technique is employed to enhance the assessment's accuracy and precision. The reasons for using these techniques include the need for less comparative data and more reliable answers than other decision-making methods due to a more robust comparison. Validation is also carried out with several decision-making methods. The results of weighting indicated that the product cost, transportation cost, and green design and purchasing are of the highest preference, respectively. Also, the results of the supplier ranking revealed that the first, fourth, and seventh suppliers had the highest priority in all evaluations. The implementation of sustainable plans for supplier selection should be such that the cost of the product and its transportation costs are considered important indicators. Also, the green design and purchasing index are effective in the selection of suppliers and strengthen the implementation of sustainable plans in the SC. Those interested in this field can follow up on the following as future research:

i. Designing a decision support system using the proposed model of the present study to specify the weights of the indicators;
ii. Considering the uncertainty and using a set of fuzzy numbers of type 2, rough, and Z-numbers in MCDM methods according to the proposed model of the present study;
iii. Selecting suppliers by considering the criteria of agility, resilience, and sustainability in the SC;
iv. Implementing the proposed research model in other SCs and comparing their results with the results of the present study;
v. Prioritizing indications through the use of artificial intelligence techniques like genetic algorithms and artificial neural networks.

Acknowledgments
This research was not funded by any grant.

Conflict of Interest
There is no conflict of interest to disclose.

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