Al Mohamed and Al Mohamed
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Application of fuzzy group decision-making selecting green supplier: a case study of the manufacture of natural laurel soap

Alaa Alden Al Mohamed[1*] and Sobhi Al Mohamed[1]

Abstract

The selection of suppliers alone is one of the most important competitive challenges facing organizations today. With today's increasing awareness and facing many significant environmental pressures, the process of selecting the right suppliers for green supply chain management is even more difficult for decision-makers. The process of developing and implementing decision-making tools seek to face these challenges is rapidly evolving, especially in a fuzzy environment whose data are incomplete. The purpose of this article is to investigate prospective green chain suppliers for a laurel soap producing company based on a framework using MCDA fuzzy technologies such as Fuzzy GRA, Fuzzy TOPSIS, and Fuzzy VIKOR. During this paper, a discussion of fuzzy set was discussed with Fuzzy MCDM. Within a realistic case study, where a comparison was made between the tools, and it was noted that the results were consistent between the two tools Fuzzy TOPSIS and Fuzzy GRA, and the arrival of similar results and a slight difference with results was observed in Fuzzy VIKOR interpreted. The most detailed analyses were conducted on distance measurements, linguistic variables, assembly functions, and confusion processing. This study introduces the Fuzzy MCDM method to help researchers choose a more effective approach for green supplier selection and the conclusions and other study directions are offered toward the conclusion of the paper.

Keywords Fuzzy TOPSIS, Fuzzy VILKOR, Fuzzy GRA, Fuzzy MCDM, Environmental sustainability, Green supplier selection

Introduction

Considering the local and globally competitive market and the rapid changes in the market due to changes in the products and services provided by institutions, many organizations focus on the supply chain to gain a competitive advantage in global business environments. Recently, supplier selection (SS) process has been considered one of the basic determinants of the supply chain and one of the most significant issues for organizations to maintain their strategic competitive position and what this reflects on the companies' budget in terms of profits and costs. The process of evaluating suppliers is somewhat complex because it varies from company to company and from organization to organization because of the diversity of the mix of products and quantitative and qualitative services provided by them, different organizational goals, and conflicting supply chains, in addition to the stringent governmental, regional economic, and political standards that are used to evaluate suppliers [1]. Its imposition on companies has made the decision-making process of selecting suppliers a complex matter, especially in an uncertain environment [2].

One of the most significant issues that organizations and supply chains must deal with recently is their focus on economic growth separate from the environment and the deterioration that afflicts it, which in the long run can

*Correspondence:
Alaa Alden Al Mohamed
aldeenalaa53@gmail.com
[1] Department of Business Administration, Ebla Privat University, Aleppo, Syria

affect business and marketing issues. With the increase in consumer awareness and the attendant transformation in the purchasing decisions that he takes to purchase environmentally friendly products and services, companies must consider environmental aspects as a basic approach in their production and service operations as well as in their choices of suppliers, as they have become a competitive advantage in the business world [3]. For companies to handle responsibilities, the supply chain environment can not only focus on greening the organization's supply chain processes by greening its internal production processes, transportation and warehousing, but it also needs to focus on the external aspects of the organization and inter-organization that go beyond looking at its organizational limits and supplier performance, and orientation to establish collaborative relationships and synchronize multiple organizations to run common goals to meet customer requirements effectively and efficiently [4].

The decision-making process, on the other hand, is a scientific method for evaluating the chances of overcoming difficulties that develop in any institution's operation and choosing the best alternative among these options. The modern approach to running a firm requires the adoption of scientific approaches that are updated and suitable for current circumstances when making judgments. To make appropriate decisions, one must have a solid grasp of the system in which problems arise, and develop a dependable mathematical model (algorithm) that accurately represents the problems. Today, it is believed that the secret to successful company operations is the variety of scientific approaches used in decision-making procedures. Furthermore, quick changes and competitive conditions make it necessary to work together to solve difficulties and employ current technical procedures [5], Fig. 1 illustrates the green supplier selection process path through which the research gap in decision support can be illustrated.

In the multi-criteria decision-making methodology, decision-makers may have difficulty predicting the future, especially in fuzzy environments, because the data obtained are incomplete or in the absence of confirmation. Many researchers have interpreted the term "uncertainty" including (Galbraith) considering the variation between the amount of information needed and the amount of information available and pre-owned. [6] indicated that uncertainty is due to three reasons: (1) cases of conceptual or cognitive uncertainty, such as lack of knowledge of the prevailing processes that drive the typical phenomenon; (2) measurement uncertainty due to the limited accuracy of the instruments; and (3) uncertainties due to scarcity or measurements in space and time. However, there are some methods for addressing uncertainty, such as employing methods based ion interval analysis or methods based on fuzzy arithmetic [7–9]. The input data are represented as intervals when using interval methods, which allow statistical tools to evaluate the uncertainty [10]. On the other side, fuzzy numbers are used in fuzzy logic to express uncertain facts [11].

TOPSIS "Technique for Order of Preference by Similarity to Ideal Solution" method is one of the MCDM methods that were evolved by Hong and Yoon in 1981 [12]. It is based on a method where a ranking of alternatives is created by measuring the distance between the ideal positive and ideal negative solutions. In addition, the TOPSIS technique includes an extension that deals with data that are insufficient or ambiguous

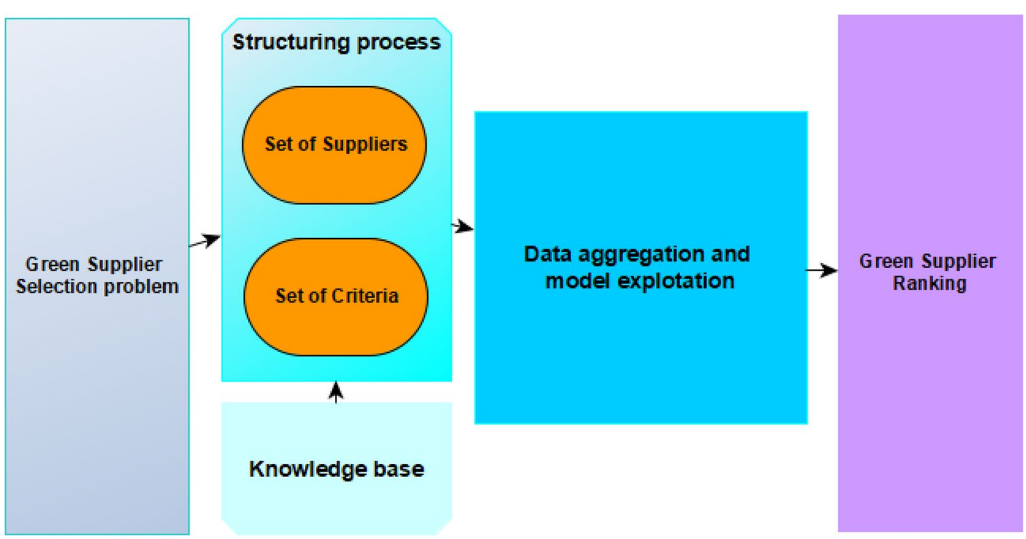

Fig. 1 Illustrative framework for selecting a green supplier

and is represented as fuzzy numbers. Fuzzy TOPSIS method has gained considerable importance in many studies owing to its ability to express preferences using fuzzy numbers and its ease of application. Fuzzy TOPSIS method was used to address issues related to decision-making under uncertainty. Many studies have used Fuzzy TOPSIS method to select suppliers [13] which suggests using Fuzzy TOPSIS-AHP methods to rank suppliers and use the ISM model to evaluate the criteria for choosing agile suppliers.

VIKOR "Vlsekriterijumska Optimizacija I Kompromisno Resenje" method was suggested as a method to address decision-making (DM) problems. Opricovic first suggested this method in 1998, and he did so based on a compromise with opposing criteria [14]. This technique, similar to TOPSIS method, presents a compromise closest to the ideal solution. To solve uncertainty issues, Opricovic (2007) suggested a new version of VIKOR that uses fuzzy logic to express options [15]. Fuzzy VIKOR has grown in popularity and has been used in many studies addressing uncertainty-based decision-making problems. Fuzzy VIKOR technique was applied to address the third-party logistics problem in Vietnam [16] using Fuzzy VIKOR and Fuzzy AHP methods to solve problems related to uncertainty.

GRA ("gray relational analysis") was developed by Deng and is used to address MCDM issues. GRA method is based on translating the performance of all available alternatives into comparability sequence. According to Fuzzy GRA method that has been used in many studies, the first one was [17], which applied this technique to the Taiwanese container lines, and [18] suggested the fuzzy set theory in using GRA in evaluating software performance.

This study discusses the application of MCDM methods based on fuzzy logic to select the optimal green supplier. The best green suppliers were chosen using three Fuzzy MCDM approaches, represented as triangular fuzzy numbers. This study extracted the results for each of the proposed fuzzy methods and compared them to reach the best sequence for each method to choose the best green resource.

The remainder of this study is divided into four categories. The next section introduces fuzzy set theory and explains each Fuzzy MCDM technique used in this study. Section "Methodology" provides the similarity coefficients between the methods. Section "Results and discussion" presents the case study. In Sect. "Conclusion," an analytical comparison between the arrangements provided by the three methods is presented. This paper concludes with a conclusion.

Literature review

The literature review consists of three subsections—"Supplier Selection", "Research gap and study contribution," and "supplier selection methods."

Supplier selection

Supplier performance has become a very important contributor to the success of companies, and with the increasing dependence on suppliers, the need has increased to rely on a systematic method for selecting suppliers, as the selection of suppliers is a significant DM issue in the field of supply chain management. Companies also need to pay more attention to how they manage their suppliers, as a management system can support professional procurement processes, and well-designed suppliers can increase matching and systematic procurement. It also has an important impact on risk because risk management is in close contact with supplier management, as suppliers are also a source of risk.

Selection process is critical for enhancing the competitiveness of the company and requires the evaluation of different alternative suppliers based on different criteria [19]. According to Tookey [20], one of the significant components of SCM is the selection of suppliers; it is a multi-criteria decision-making (MCDM) problem that includes both qualitative and quantitative criteria [21]. Selecting the right suppliers can reduce procurement costs, improve profits, reduce product lead time, increase customer satisfaction, and strengthen competitiveness. With today's increasing awareness and many significant environmental pressures, the process of selecting the right suppliers for green supply chain management is more difficult for decision-makers. The process of developing and implementing decision-making tools capable of facing these challenges is developing rapidly, particularly in fuzzy environments with incomplete data. For this reason, it has become the primary focus of every organization [20]; however, there is no standard for selecting green suppliers, and it must be applied based on the situation. While the wrong choice can lead to losses in the supply chain, it would directly affect the company's performance [22].

Process of selecting the most suitable supplier is one of the most difficult things that purchasing managers can face, especially today, when the need for supplier selection criteria is witnessing rapid change. There are three important steps. First, it sets criteria that are most related to quality, delivery performance, cost, and capacity, but price is no longer the primary factor. The selection of appropriate criteria depends on the purchase situation. Second, the survey comes with a questionnaire that separates the analysis of the results from the determination of the weights of the criteria. It is organized with all major criteria and sub-criteria, and one question to investigate additional supplier selection criteria. Then, the third step is to implement the MCDM method which consists of selecting the method to use to select the best supplier.

According to A.E. Cengiza, the goal of good supplier selection is to find the correct supplier who can provide the customer with the right quality goods or services at the right price, in the right quantities, and at the right time [21]. It can be difficult to maintain the same approach when dealing with various financial situations and client reputations, even when creating goods of the same specifications and quality. Because of this, many organizations prefer to invest more resources—money, time, and effort—to streamline the purchasing process before screening suppliers and potential risks. However, the actual supplier selection procedure may function differently, depending on the firm.

Research gap and study contribution

A decade after the outbreak of the Syrian crisis in 2011, the industrial sector in the country faced many challenges and obstacles, as the performance of suppliers has decreased to a large extent, as most suppliers are supplying raw materials of very low quality owing to the low purchasing power of factories and consumers, in addition to supplying most of the materials. Primary products were sent abroad, which had a negative impact on the operations of local factories and lack of resources [23]. The Syrian crisis led to an increase in production weakness and the spread of low-quality products, in addition to a decline in some factories at the level of services provided (such as transportation and delays in delivery times).

Due to the increasing environmental risks accompanying the deterioration of infrastructure and after the spread of the coronavirus, environmental standards have become very important and supportive, especially with regard to learning about waste management and the use of green energy in manufacturing and other environmental matters from one point of view; from another point of view, the demand for detergent products (such as laurel soap) has increased. Being made of natural (non-chemical) products, and with the increase in consumer awareness of the quality of the detergents provided, this has increased the pressure on manufacturers of soap and cleaning materials to focus on the quality of raw materials and the level of service provided by suppliers. At the same time, they are within the prices planned by the companies, so they have become criteria of service level. Quality and price are among the basic criteria that must be considered first and be within a green environment. This promotes a sustainableI supply chain. Low-order quantities minimize emissions during transportation and processing, maximize resource utilization, and reduce the environmental impacts associated with various logistics operations [24].

Some scholars have focused on the industrial sectori, according to Table 1. However, most previous studies relied on one technique and supported the results with sensitivity analysis or relied on the integration of two techniques to reach the required results. Nevertheless, the goal of this study is to compare the effectiveness of three widely used MCDM approaches, including the Order Preference Technique by Perfect

Table 1 A summary of the decision-making processes in relation to DM strategies

Source	Focused area	Core DM techniques
[25]	Manufacturing industry	AHP
[26]	Pharmaceutical industry	AHP
[27]	Wafer fabricating industry	AHP and ANP
[28]	Postal industry	AHP
[29]	Airline industry	AHP
[30]	Textile industry	AHP
[31]	Clothing industry	AHP
[32]	Mining industry	AHP and DEA
[33]	Mobile phone industry	TOPSIS and AHP
[34]	Airline industry	AHP
[35]	Tourism industry	AHP
[36]	Textile industries	TOPSIS and AHP
[37]	Real-estate industry	AHP
[38]	Tourism industry	AHP
[39]	Retail industry	DEA and AHP
[40]	Banking industry	DEA
[41]	Computer industry	DEA
[42]	Auto component industry	DEA
[43]	Insurance industry	DEA
[44]	Banking industry	DEA and TOPSIS
[45]	ICT industry	DEA and AHP
[46]	Petrochemical industry	DEA
[47]	Banking industry	DEA
[48]	Hotel industry	DEA and AHP
[49]	Hotel industry	DEA
[50]	Airline industry	DEA
[51]	Construction industry	DEA
[52]	Petroleum industry	ANP and TOPSIS
[53]	Hospitality industry	ANP
[54]	Maritime industry	ANP
[55]	Manufacturing industry	ANP
[56]	Brazilian industry	ANP and AHP

Solution Similarity (TOPSIS), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and Gray Relationship Analysis (GRA), when combined with fuzzy groups to address concerns about decision uncertainty. Model applications were completed in the actual case where real data were used to select green suppliers of raw materials for the case of the company under study from the soap industry sector. Stakeholders are urging detergent material producers to increase the environmental performance of their supply chains and maintain their focus on the sustainability performance of their suppliers now more than ever due to the escalating environmental concerns in the industry and detergent processing industries over the past 10 years.

Thus, this research gap is filled by defining the basic criteria for health-care testing facilities and selecting the most appropriate supplier based on the weights of these selection criteria. Hence, this study makes the following contributions to the literature:

- Create an integrated decision-making framework by applying three popular methods: Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA.
- Comparing the findings with some other well-known MCDM methods to demonstrate the viability of the proposed framework.
- Highlighting the implications of the proposed research in terms of theory, practice, and sustainability
- Investigate how the suggested integrated models may be used in a sector that has a significant impact on global warming and climate change.

Supplier selection methods

Many previous studies have examined supplier selection procedures in various industrial or service industries. Since several supplier selection techniques, from basic single-objective techniques to sophisticated multi-objective techniques, have been created, the methods chosen are extremely important to the overall selection process and can have a significant impact on the selection outcome. It is important to understand why a company chooses one method (or a combination of different methods) over another. Several well-known selection methods have been developed and classified by scientists over the years. Some methods have been popular for years; over 80% of published models are based on single methods [57] because of (1) the integration of methods' relatively recent development and (2) the complexity of modeling integrated approaches. In addition, when a business sets out to create or choose a supplier selection methodology, the outcome frequently entails the blending of a number of diverse approaches with varying strengths that are suitable for the company's particular selection requirements. However, with the fuzzy environment surrounding the application place and with uncertain data, the review of methods made the traditional decision to choose suppliers does not address the problem of the study, and decision-making criteria with a qualitative component are those that are difficult to quantify numerically. They might consist of immaterial elements, such as danger, harm to one's reputation, and specific sustainability problems. [58] evaluated supplier performance using a fuzzy logic technique. This strategy can assist the decision-maker (DM) in determining the proper demand from each provider. Our evaluation and analysis concentrates on qualitative descriptive approaches, and we also try to analyze the most popular MCDM techniques used in prior research for choosing green resources, combining them with fuzzy logic to enable us to situate our work within this body of the literature.

By reviewing previous studies, a development was observed in the structure of the purchasing function during the nineties, and it was accompanied by the problem of selecting suppliers, which gradually became one of the important issues in our current era to establish an effective system for the supply chain. With the great and continuous dependence on suppliers in supplying the raw materials necessary for the production process, it makes the selection process; suppliers are a strategic process for the company, and with the passage of time, the criteria that are relied upon have become different according to time, product, and variety [59], in addition to the diversity and change of the company's options in choosing suppliers.

With the change in the criteria that are relied upon, there is also a gradual and evolving change in the methods followed by companies and research in the process of selecting suppliers because of their impact on the results. Thus, it is very important to know the appropriate methods that can be used, and they differ according to the situation or the problem facing the researcher or company.

By reviewing previous studies, it was found that there are many available supplier selection methods, and most of them rely on a specific number of techniques, such as the Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) methods, as shown in Table 1. Both methods require continuous user participation and consistency of judgment in order to complete many pairwise comparisons with a sufficient level of accuracy [60, 61]

According to [62], the number of alternatives used in DEA must be three times greater than the total number of inputs and outputs (criteria); as a result, there are restrictions on the range of criteria and options. Since

PROMETHEE demands excellent user engagement and is akin to AHP and ANP.

In the context of decision-making issues, many fuzzy model applications are examined [63]. To choose resource issues utilizing a trapezoidal fuzzy number, [64] introduced the simultaneous Fuzzy MCGP and TOPSIS techniques. [65] mentioned (Fuzzy TOPSIS) in an aluminum manufacturing unit in Turkey to evaluate and select suppliers. [26] reported an AHP approach to assess and select suppliers in a pharmaceutical manufacturing unit in Ghana. [36] Integration of the Fuzzy AHP method in analyzing the weight evaluation ratio with the Fuzzy TOPSIS method for resource selection. Linguistic terms or ambiguous concepts are also represented by obvious values for modeling real-life situations. [66] also presented the integration of the WASPAS method in analyzing the percentage of weight assessment using the WASPAS method for assessing weighted total production.

From the foregoing, we note the reliance on one method in the selection process such as [25], [26], [28], and there are other studies that relied on the integration of two methods of selecting suppliers such as [44], [48], [52] as shown in Table 1, but these studies simply cannot confirm the validity of the results that the company can rely on in the process addressing the problem of suppliers, due to the existence of a group of problems or gaps that it did not address, such as relying on the results of one method only and the lack of consistency between the experts in the judgment on the other hand, relying on integration between two methods, although it is better than the previous method, but the results it produces it results from integration and not from a comparison between the two methods. However, we cannot judge the quality of the results obtained from these studies.

The majority of supplier selection techniques include gathering vast amounts of data via surveys, investigations, and sampling. Owing to the infrequent availability of such information, many practical judgments depend on qualitative data, which are frequently skewed by the decision-maker's own preferences when it comes to weighing supplier and criteria preferences [67]. In any case, DM process is somewhat unpredictable due to the subjective assessment of qualitative or quantitative criteria (i.e., bounded rationality of multiple decision-makers relying on limited historical data). Dealing with problems involving the selection of green suppliers, where sustainability criteria are frequently expressed qualitatively, may make these uncertainties even more pronounced. Additionally, a model built on a decision-maker's subjective preferences is not always reliable because it requires a lot of information, skill, and experience [68]. In MCDM difficulties, "fuzzy" techniques are utilized in this situation.

The process of incorporating fuzzy groups into decision-making models can lead to more realistic results because it aims to transform uncertain human knowledge into a mathematical formula that supports decision-makers in the selection process. The purpose of this study was to offer a unified framework for choosing environmentally friendly resources in hazy situations. When inadequate quantitative data are available, this study compares three MCDM techniques in a real study to enable efficient qualitative evaluation and decision-making. In this study, Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA methods were developed and implemented to evaluate and select the suppliers of oils involved in the production and manufacture of laurel soap with various products (traditional laurel soap, perfumed laurel soap, and olive oil soap (cosmetic)). The normalization functions, distance metrics, supported collection functions, agility, and temporal complexity of each approach were examined in a comparative study of numerical findings.

Methodology

The main purpose of this research is to build an evaluation model for the ranking and selection of the best green suppliers in the field of laurel soap industry. The F-TOPSIS, F-VIKOR, and F-GRA methods are used in a two-stage process. In the first stage, the weights of aggregated criteria weights were calculated. The decision factors for this study were based on the supplier evaluation structure of the laurel soap manufacturing companies in Aleppo. The study company adopted four main dimensions (service level, quality, price, and environmental management systems) to arrange green suppliers of primary resources for three basic products (traditional laurel soap, perfumed laurel soap, and olive oil soap (cosmetic)). The questions have been reviewed and qualified by experts. In the second stage, three fuzzy multi-criteria decision-making methods (F-TOPSIS, F-VIKOR, F-GRA) were applied to select four laurel soap manufacturing establishments for ranking. To make the research results reliable, the selected experts must have professional knowledge in this research field and have long-term academic research or more than 5 years of practical experience. The search process is shown in Fig. 2.

Fuzzy set theory (FST)

Fuzzy logic depends on the extended fuzzy group theory from the classical set theory known as binary logic, where the fuzzy set came to extend the binary membership in the classical set that takes the value one in the case of belonging and the value zero if they do not belong to the set, where the fuzzy set differs from the classic set, which allows the element to belong partially to the set. The membership functions are used to

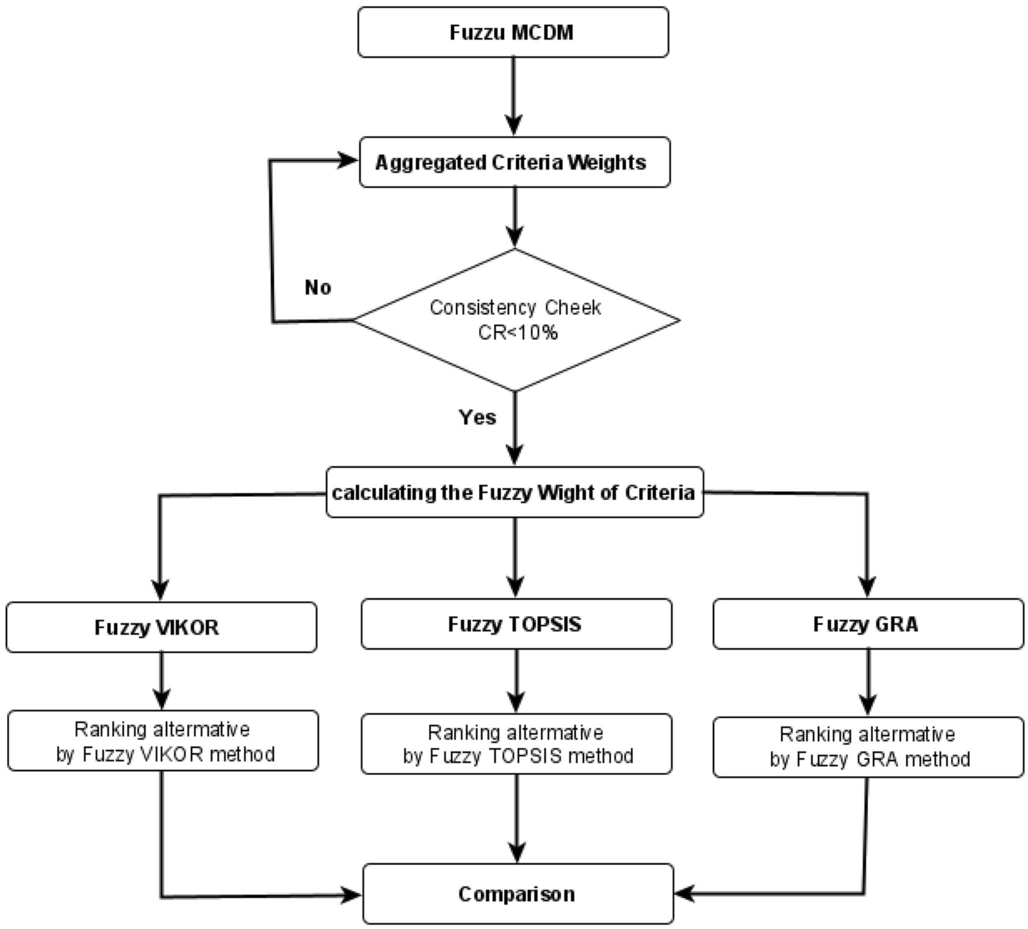

Fig. 2 The research framework

determine the degree of affiliation of the element (the degree of membership) in the fuzzy set, and the fuzzy numbers are used to denote the partial fuzzy set. The membership function can take the degree of membership value 1 in the case of complete affiliation and the value 0 in the case of non-affiliation and values between 0 and 1 in the case of partial affiliation. Triangular fuzzy number is taking three values as illustrated in Fig. 3, and it is expressed mathematically as follows[69]:

$$\mu_A(x) = \begin{cases} 0 : x < a \\ \frac{x-a}{b-a} : a \le x \le b \\ \frac{c-x}{c-b} : b \le x \le c \\ 0 : x > c \end{cases} \quad (1)$$

We can perform arithmetic operations using two positive triangular fuzzy numbers, $A = (a_1, b_1, c_1)$ and $B = (a_2, b_2, c_2)$ as follows:

1. Combining positive triangular fuzzy numbers:

$$A \oplus B = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (2)$$

2. Subtract positive triangular fuzzy numbers:

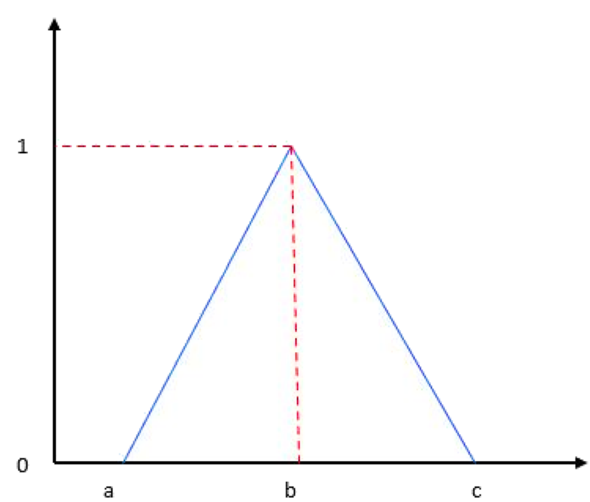

Fig. 3 Illustration of triangular fuzzy number $\widetilde{x} = (a, b, c)$

Table 2 Linguistic variables for rating each supplier

Number	Linguistic variables	TFNs
1	Very poor (VP)	(0, 1, 2)
2	Poor (P)	(1, 2, 3)
3	Mid poor (MP)	(2, 3.5, 5)
4	Fair (F)	(4, 5, 6)
5	Mid good (MG)	(5, 6.5, 8)
6	Good (G)	(7, 8, 9)
7	Very good (VG)	(8, 9, 10)

Table 3 Linguistic variables for rating each weight of criteria

Number	Linguistic variables	Membership function
1	Very low (VL)	(0, 0.1, 0.2)
2	Low (L)	(0.1, 0.2, 0.3)
3	Mid low (ML)	(0.2, 0.35, 0.5)
4	Medium (M)	(0.4, 0.5, 0.6)
5	Mid high (MH)	(0.5, 0.65, 0.8)
6	High (H)	(0.7, 0.8, 0.9)
7	Very high (VH)	(0.8, 0.9, 1)

$$A \ominus B = (a_1 - a_2, b_1 - b_2, c_1 - c_2) \tag{3}$$

3. Multiply positive triangular fuzzy numbers:

$$A \otimes B = (a_1 * a_2, b_1 * b_2, c_1 * c_2) \tag{4}$$

4. Divide positive triangular fuzzy numbers:

$$A \oslash B = (a_1/a_2, b_1/b_2, c_1/c_2) \tag{5}$$

The linguistic variables

Linguistic variables can be defined as words from natural language, which were proposed by scientist Lotfi Zadeh between 1973 and 1975. Natural language words are used to describe the variables [70], and, as indicated in Tables 2 and 3, positive TFNs are capable of transmitting these linguistic characteristics. For visualization purposes, comparable membership functions are shown in Figs. 4 and 5. It should be stressed that the values of the membership function can be obtained from both comprehensive expert judgments and historical data.

Fuzzy TOPSIS (F-TOPSIS)

It was proposed by Huang and Yoon as a mathematical technique for addressing MCDM. The basic idea of this technique is to order the available alternatives depending on how close they are to positive and negative ideal solutions. The following six steps represent this method, based on [71, 72]:

Step 1: Forming a decision matrix made up of triangular fuzzy numbers, where the fuzzy set is as follows:

$$A = \{x, \mu_A(x) : x \in X, \mu_A(x) \in (0, 1)\} \tag{6}$$

Each of the three values for each unique criterion for the alternatives will be represented by the following formula:

$$\widehat{X}_{ij} = (I_{ij}, m_{ij}, u_{ij}) \tag{7}$$

Step 2: Normalized decision matrix can be made by using Eq. (9) with the fuzzy decision matrix ($\widetilde{R}$):

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{m*n}, , i = (1, 2, .., m), j = (1, 2, ..n) \tag{8}$$

where:

$$\widetilde{r}_{ij} = \left(\frac{I_{ij}}{\sqrt{\sum_i u_{ij}^2}}, \frac{m_{ij}}{\sqrt{\sum_i u_{ij}^2}}, \frac{u_{ij}}{\sqrt{\sum_i u_{ij}^2}}\right) \tag{9}$$

Step 3: We could insert the weights ($\widetilde{w}_j$) into the normalized decisions matrix ($\widetilde{R}$) using Eq. (11) to form the weighted decisions matrix ($\widetilde{v}$):

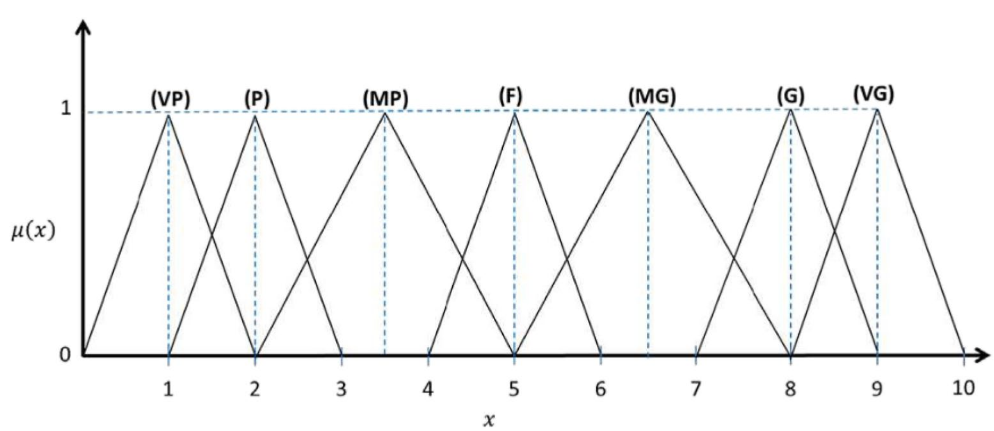

Fig. 4 Membership functions for rating each supplier

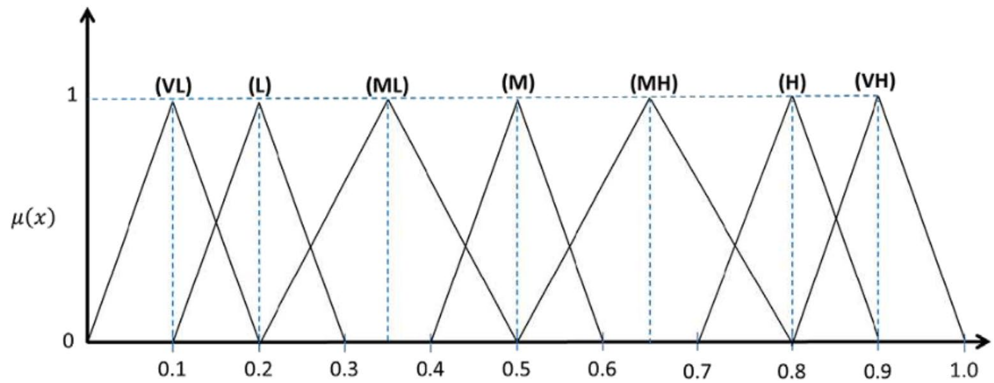

Fig. 5 Membership functions for rating each weight of criteria

$$\widetilde{v} = \left[\widetilde{v}_{ij}\right]_{m*n}, , i = (1, 2, .., m), j = (1, 2, ..n) \quad (10)$$

where:

$$\widetilde{v}_{ij} = \widetilde{r}_{ij} * \widetilde{w}_j \quad (11)$$

Step 4: The positive ideal answer $(\widetilde{A}^{+})$ is obtained by choosing the highest normalized and weighted score for each criterion (Eq. 12). Similarly, the least normalized and weighted score for each criterion $(\widetilde{A}^{-})$ (Eq.) is chosen to represent the negative optimal option (Eq. 13).

$$\widetilde{A}^{+} = \left\{\widetilde{v}_1^{+}, \widetilde{v}_2^{+}, \widetilde{v}_3^{+} \ldots .., \widetilde{v}_n^{+}\right\} \quad (12)$$

$$\widetilde{A}^{-} = \left\{\widetilde{v}_1^{-}, \widetilde{v}_2^{-}, \widetilde{v}_3^{-} \ldots .., \widetilde{v}_n^{-}\right\} \quad (13)$$

Step 5: Calculating how far the alternative is from the ideal and anti-ideal solution:

$$d_i^{+} = \sqrt{\frac{1}{3}\left(\left(I_1 - I_2^{+}\right)^2 + \left(m_1 - m_2^{+}\right)^2 + \left(u_1 - u_2^{+}\right)^2\right)} \quad (14)$$

$$d_i^{-} = \sqrt{\frac{1}{3}\left(\left(I_1 - I_2^{-}\right)^2 + \left(m_1 - m_2^{-}\right)^2 + \left(u_1 - u_2^{-}\right)^2\right)} \quad (15)$$

Step 6: The closeness index (CI) is calculated for each alternative to the proximity index using distance values:

$$\text{closeness index(CI)} = \frac{d_i^{-}}{d_i^{-} + d_i^{+}}, i = (1, 2, .., m) \quad (16)$$

Fuzzy VIKOR (F-VIKOR)

VIKOR "Vlsekriterijumska Optimizacija I Kompromisno Resenje" method was suggested by Opricovic and Tzeng (Opricovic and Tzeng, 2002). VIKOR offers a compromise solution closest to the optimal solution with some concessions. The VIKOR technique with fuzzy logic is applied as an extension of VIKOR to address problems related to uncertainty. Fuzzy VIKOR method can be expressed through the following steps:

Step 1: Establishing a decision matrix with triangular fuzzy numbers.

$$X = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} \ldots . & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} \ldots . & \widetilde{x}_{2n} \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \widetilde{x}_{mn} \end{bmatrix}$$

Step 2: For each of the criterion values, positive optimal values and negative optimal values are calculated:

$$\textit{The best value} \widetilde{f}_j^{*} = (I_j^{*}, m_j^{*}, u_j^{*}), \widetilde{f}_j^{*} = Max_i \widetilde{x}_{ij} \quad (17)$$

$$\textit{The worst value} \widetilde{f}_j^{o} = (I_j^{o}, m_j^{o}, u_j^{o}), \widetilde{f}_j^{o} = Min_i \widetilde{x}_{ij} \quad (18)$$

Step 3: The normalized fuzzy difference $(\widetilde{d}_{ij})$ can be calculated from the following equation:

$$\widetilde{d}_{ij} = \left(\widetilde{f}_j^{*} - \widetilde{x}_{ij}\right) / \left(u_j^{*} - I_j^{o}\right) \quad (19)$$

Step 4: Determine the fuzzy weighted sum $(\widetilde{S})$ and the fuzzy weighted operator max $(\widetilde{R})$.

$$\widetilde{S}_j = \sum_{i=1}^{n} \left(\widetilde{w}_i * \widetilde{d}_{ij}\right) \quad (20)$$

$$\widetilde{R}_j = MAX_i\left(\widetilde{w}_i * \widetilde{d}_{ij}\right) \quad (21)$$

Step 5: Calculation of values $\widetilde{Q}_j$ ($\widetilde{Q}_j = (I_i, m_i, u_i)$

$$\widetilde{Q}_j = \frac{\nu\left(\widetilde{S}_j - \widetilde{S}^*\right)}{\widetilde{S}^{Ou} - \widetilde{S}^{OI}} + (1-\nu)\left[\frac{\widetilde{R}_i - \widetilde{R}^*}{R^{ou} - R^{*I}}\right] \quad (22)$$

Step 6: Rank the alternatives in three ranking list in ascending order of S, R, and Q.

Step 7: Making a fuzzy ranking. If $min_{k \in j}\widetilde{Q}^k = \widetilde{Q}^j$, where $J^j = j, j+1, ..., J$ and $\widetilde{Q}^k$ is a fuzzy metric for the alternative $A^{(k)}$ located at the k-th position in the set A_{Qm} then the J-th ranked A_{Qm} alternative $A^{(j)}$, $j = 1, ..., J$ is confirmed. Although, the set $A_{\widetilde{Q}}$ may not be a complete ranking (it may be a partial ranking), the validated ordering provides an "exact fuzzy ranking of $A_{\widetilde{Q}}$."

Step 8: Defuzzification $\widetilde{S}_j, \widetilde{R}_j, \widetilde{Q}_j, j = 1, 2, \ldots, j$ as follows:

$$\text{crisp}\left(\widetilde{A}\right) = \frac{2m + I + u}{4} \quad (23)$$

The triangular fuzzy number is transformed into a crisp number as part of second weighted mean decomposition techniques.

Step 9: To organize the choices in decreasing order, we used the Q values. In addition to this ranking, ratings can also be generated by emphasizing the sharpness of the S and R values and selecting a compromise ranking. Yet this paper opts to order the options according to the Crips Q value.

Fuzzy GRA (F-GRA)

Dong first suggested GRA, which attempts to demonstrate how closely or how dissimilar the development trends are between the reference (ideal) alternative and alternative. An alternative and an ideal alternative have a greater link if the pattern of change between them is consistent; otherwise, the relational grade is lower. GRA technique can be used to evaluate the relationship between the reference and comparative series. The steps listed below can be used to express Fuzzy GRA technique:

Step 1: Convert the matrix of decisions to the matrix of normalized decisions R. Geven $\widetilde{r}_{ij} = (I_i, m_i, u_i)$ The rink of normalized performance can be calculated as follows:

$$\widetilde{r}_{ij} = \left(\frac{I_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right) \quad (24)$$

where:

$$u_j^+ = MAX_i\left(u_{ij}\right) \quad (25)$$

Step 2: Determine the reference series from the following:

$$\widetilde{R}_o = \left[\widetilde{r}_{01}, \widetilde{r}_{02}, \ldots, \widetilde{r}_{on} = MAX_i\left(\widetilde{r}_{ij}\right)\right] j = 1, 2, \ldots, n \quad (26)$$

Step 3: Then, a distance matrix is created where the distance δ_{ij} is computed from the following between each comparison value and the reference value:

$$\delta_{ij} = \sqrt{\frac{1}{3}\left(\left(I_1 - I_2^+\right)^2 + \left(m_1 - m_2^+\right)^2 + \left(u_1 - u_2^+\right)^2\right)} \quad (27)$$

Step 4: Fuzzy GRA coefficient (ξ_{ij}) is defined as follows:

$$\xi_{ij} = \frac{\delta_{min} + \rho\delta_{max}}{\delta_{ij} + \rho\delta_{max}} \quad (28)$$

$\xi_{min} = \max\xi_{ij}$ and ρ resolving coefficient $\rho \in [0, 1]$.

Step 5: Estimate the fuzzy gray relational grade by the relation:

$$\gamma_i = \sum\nolimits_{j=1}^{n} \widetilde{w}_j \xi_{ij}, i = 1, 2, \ldots, m \quad (29)$$

where $\widetilde{w}_i$ is the weight of the jth criterion, and $\sum_{j=1}^{n} \widetilde{w}_j = 1$.

Results and discussion

This section shows and evaluates the results of the approach for choosing green suppliers that have been suggested.

Case study

Chemical product makers in the chemical industry are under pressure to measure, control, and decrease the environmental burden in their supply chains, particularly with regard to water, waste, and energy management, as these are key contributors to climate change and global warming. [73] The selection of suppliers in our paper in this section relates to a company Leading manufacturer of Aleppo laurel soap in the chemicals and detergents sector. The case company is one of the leading Syrian companies in the production and supply of Aleppo laurel soap, which is one of the historical

Table 4 Supplier evaluations based on several decision-makers' criteria

Type of supplier	Decision-makers	Suppliers	C1	C2	C3	C4
Traditional laurel soap	DM1	*T*1	VG	F	VG	F
		*T*2	MG	MG	MG	MG
		*T*3	P	VG	F	F
		*T*4	G	MP	G	F
	DM2	*T*1	MP	F	MP	F
		*T*2	P	MP	MP	F
		*T*3	G	G	MG	MG
		*T*4	MG	MP	VP	VP
	DM3	*T*1	G	P	MG	MG
		*T*2	VG	G	VG	G
		*T*3	G	MP	MG	F
		*T*4	P	MP	MG	F
Perfumed laurel soap	DM1	*P*1	F	MP	MP	VG
		*P*2	G	F	F	MG
		*P*3	MP	VG	MG	G
		*P*4	P	VP	P	MP
	DM2	*P*1	P	G	MP	F
		*P*2	F	G	MG	F
		*P*3	VG	MP	VG	VG
		*P*4	MP	MG	F	MG
	DM3	*P*1	MP	F	G	MG
		*P*2	VG	P	G	G
		*P*3	P	G	G	G
		*P*4	F	P	G	G
Olive oil soap (cosmetic)	DM1	*O*1	G	MG	MG	G
		*O*2	P	MP	MP	P
		*O*3	MG	F	F	MG
		*O*4	G	MG	MG	MG
	DM2	*O*1	P	P	P	P
		*O*2	F	F	G	F
		*O*3	VG	VG	G	G
		*O*4	MG	F	MP	MP
	DM3	*O*1	MG	F	G	MP
		*O*2	MG	MG	MG	MG
		*O*3	G	G	VG	VG
		*O*4	MG	P	P	MG

and ancient products in Aleppo and has many subtypes (perfumed laurel soap, hair laurel soap, skin care laurel soap, perfumed soap for clothes and air, etc.), where the products of laurel soap range from 14 types of laurel soap. The company is one of the economically contributing companies to the manufacture of laurel soap in Aleppo. The company, which has ISO 14000 certification, manages its environmental duties using pertinent criteria, including pushing suppliers to consistently improve their environmental performance and methods. Traditional laurel soap, perfumed laurel soap, and olive oil soap (cosmetic) are the main products. Olive oil and laurel are considered basic materials in the manufacture of laurel soap, and olive oil constitutes 60–90% of the total purchase costs. The goal is to evaluate and analyze suppliers in order to select the best oils from olive oil and laurel. Through a preliminary screening procedure, available vendors were

Table 5 Rankings of the criteria used by various decision-makers

Decision-makers	C1	C2	C3	C4
DM1	H	VH	MH	MH
DM2	VH	MH	H	M
DM3	VH	MH	H	ML

Table 6 Fuzzy TOPSIS analysis result

Suppliers	Traditional laurel soap				Perfumed laurel soap				Olive oil soap			
	*T*1	*T*2	*T*3	*T*4	*P*1	*P*2	*P*3	*P*4	*O*1	*O*2	*O*3	*O*4
d_i^+	0.01	0.37	0.45	0.34	0.54	0.23	0.18	0.70	0.51	0.51	0.00	0.46
d_i^-	0.57	0.21	0.13	0.23	0.17	0.47	0.53	0.01	0.14	0.14	0.65	0.19

found. Four were olive oil vendors. During our evaluation of supplier selection criteria, we discovered a set of traditional and green supplier selection criteria. Service level, quality, and price have been set as the basic traditional standards and environmental management systems as the green standards. C1–C4 are referred to as the four decision criteria, in this order. The various criteria are given below:

	Criteria	name	Description
Supplier selection criteria [65, 74–76]:	*C*1	Service level	Supply capacity, on time delivery, and after sales service
	*C*2	Quality	Operation excellence, quality of material and labor expertise and
	*C*3	Price	financial power, product/service price, and capital
Green supplier selection criteria: [77, 78]	*C*4	EMS	Environmental prerequisite, planning, and certificates

The relative weight of each selection criterion was discussed by a panel of four industry professionals and (2) each potential supplier's performance in relation to each criterion to gather data for our research. All industry experts who replied to the surveys provided their thoughts, which were then converted into triangular fuzzy numbers using linguistic factors (see Tables 2 and 3 for linguistic variables utilized for the comparative evaluation of criteria and supplier evaluations). Tables 4 and 5 present the outcomes of the linguistic experts' views. Tables 2 and 3 can be used to transform the data into triangular fuzzy numbers.

Fuzzy rating values are combined using Eqs. (30) and (31):

$$\widetilde{x}_{ij} = \frac{1}{k}\left[\widetilde{x}_{ij}^{1}, \widetilde{x}_{ij}^{2}, \ldots, \widetilde{x}_{ij}^{k}\right] \tag{30}$$

$$\widetilde{w}_{ij} = \frac{1}{k}\left[\widetilde{w}_{ij}^{1}, \widetilde{w}_{ij}^{2}, \ldots, \widetilde{w}_{ij}^{k}\right] \tag{31}$$

Equation (10) creates combined criteria weights (W) and a decision matrix (x) for the suppliers of the three different types of products. The combined criteria weights and decision matrix for traditional laurel soap suppliers are presented in Eq. (32). The weights and decision matrices for additional suppliers can be created using a similar method.

$$\begin{aligned}\widetilde{w}_i = &[(0.77, 0.87, 0.97)(0.60, 0.73, 0.87)\\ &(0.63, 0.75, 0.87)(0.37, 0.60, 0.63)]\end{aligned} \tag{32}$$

$$\widetilde{x}_{\text{Traditional}} = \begin{bmatrix} (7.3, 8.3, 9.3) & (4.3, 5.5, 6.7) & (6.7, 7.8, 9.0) & (4.3, 5.5, 6.7) \\ (4.0, 5.5, 7.0) & (3.7, 5.0, 6.3) & (4.0, 5.5, 7.0) & (3.0, 4.2, 5.3) \\ (3.0, 4.0, 5.0) & (3.7, 4.8, 6.0) & (3.7, 5.0, 6.3) & (4.3, 5.5, 6.7) \\ (5.7, 7.0, 8.3) & (3.3, 4.5, 5.7) & (2.7, 4.0, 5.3) & (4.0, 5.5, 7.0) \end{bmatrix}$$

In the following sections, this article will discuss each of the three methods—Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA—for selecting suppliers consciously for the three product categories. For one product type (olive oil), step-by-step calculations are provided to choose the providers; similar methods may be used for other items.

Fuzzy TOPSIS implementation

Normalized decision matrix ($\widetilde{R}$) for traditional laurel soap suppliers was formed using Eq. (9) as following:

$$\widetilde{R} = \begin{bmatrix} (0.19, 0.29, 0.38) & (0.34, 0.43, 0.52) & (0.25, 0.34, 0.43) & (0.35, 0.42, 0.49) \\ (0.52, 0.60, 0.68) & (0.31, 0.39, 0.47) & (0.36, 0.44, 0.52) & (0.33, 0.40, 0.47) \\ (0.30, 0.40, 0.49) & (0.44, 0.53, 0.63) & (0.45, 0.53, 0.61) & (0.45, 0.51, 0.57) \\ (0.19, 0.29, 0.38) & (0.16, 0.25, 0.34) & (0.27, 0.34, 0.41) & (0.29, 0.37, 0.45) \end{bmatrix}$$

After forming the normalized decisions matrix and according to Eq. (11), we can convert this matrix into the weighted normalized matrix ($\widetilde{v}$) by multiplying the weight with each value of the normalized decisions matrix, and the result appears as follows:

$$\widetilde{v} = \begin{bmatrix} (0.37, 0.48, 0.59) & (0.21, 0.33, 0.47) & (0.30, 0.42, 0.55) & (0.12, 0.21, 0.33) \\ (0.20, 0.31, 0.45) & (0.18, 0.30, 0.44) & (0.18, 0.29, 0.43) & (0.09, 0.16, 0.26) \\ (0.15, 0.23, 0.32) & (0.18, 0.29, 0.42) & (0.16, 0.27, 0.39) & (0.12, 0.21, 0.33) \\ (0.29, 0.40, 0.53) & (0.16, 0.27, 0.40) & (0.12, 0.21, 0.33) & (0.11, 0.21, 0.34) \end{bmatrix}$$

After forming the weighted normalized matrix ($\widetilde{v}$), we can get at the positive ideal solution and the negative ideal solution for the suppliers of traditional laurel soap using Eqs. (12) and (13):

$$\widetilde{A}^{+} = \begin{bmatrix} (0.37, 0.48, 0.59) & (0.21, 0.33, 0.47) & (0.30, 0.42, 0.55) & (0.12, 0.21, 0.34) \end{bmatrix}$$

$$\widetilde{A}^{-} = \begin{bmatrix} (0.15, 0.23, 0.32) & (0.16, 0.27, 0.40) & (0.12, 0.21, 0.33) & (0.09, 016, 0.26) \end{bmatrix}$$

After deducing the positive and negative optimum solution, we can now calculate the distance between each alternative and the positive optimum solution ($\widetilde{A}^{+}$) and the negative optimum ($\widetilde{A}^{-}$) solution through Eqs. (14) and (15) as follows (Table 6):

Fuzzy VIKOR implementation

The best value ($\widetilde{f}_j^{*}$) and the worst value $\widetilde{f}_j^{o}$ can be calculated from Eqs. (17) and (18):

$$\widetilde{f}_j^{*} = \begin{bmatrix} (7.3, 8.3, 9.3) & (4.3, 5.5, 6.7) & (6.7, 7.8, 9.0) & (4.3, 5.5, 7.0) \end{bmatrix}$$

$$\widetilde{f}_j^{o} = \begin{bmatrix} (3.0, 4.0, 3.0) & (3.3, 4.5, 5.7) & (2.7, 4.0, 5.3) & (3.0, 4.2, 5.3) \end{bmatrix}$$

From Eq. (19), we can deduce the standard fuzzy differences, and from Eq. (3), we can clarify the subtraction process and reach the following results:

$$\widetilde{d}_{ij} = \begin{bmatrix} (-0.32, 0.00, 0.32) & (-0.70, 0.00, 0.70) & (-0.37, 0.00, 0.37) & (-0.58, 0.00, 0.67) \\ (0.05, 0.45, 0.84) & (-0.60, 0.15, 0.90) & (-0.05, 0.37, 0.79) & (-0.25, 0.33, 1.00) \\ (0.37, 0.68, 1.00) & (-0.50, 0.20, 0.90) & (0.05, 0.45, 0.84) & (-0.58, 0.00, 0.67) \\ (-0.16, 0.21, 0.58) & (-0.40, 0.30, 1.00) & (0.21, 0.61, 1.00) & (-0.67, 0.00, 0.75) \end{bmatrix}$$

From Eqs. (20) and (21) are used to calculate the value of ($\widetilde{S}_i$) and ($\widetilde{R}_i$):

$$\widetilde{w}_i * \widetilde{d}_{ij} = \begin{bmatrix} (-0.23, 0.00, 0.29) & (-0.47, 0.00, 0.63) & (-0.21, 0.00, 0.31) & (-0.21, 0.00, 0.42) \\ (0.04, 0.37, 0.79) & (-0.40, 0.12, 0.81) & (-0.03, 0.26, 0.66) & (-0.09, 0.17, 0.63) \\ (0.27, 0.57, 0.93) & (-0.33, 0.16, 0.81) & (0.03, 0.31, 0.70) & (-0.21, 0.00, 0.42) \\ (-0.12, 0.18, 0.54) & (-0.27, 0.24, 0.90) & (0.12, 0.42, 0.83) & (-0.24, 0.00, 0.48) \end{bmatrix}$$

$$\tilde{S}_i = \begin{bmatrix} (-1.12, 0.00, 1.65) \\ (-0.48, 0.91, 2.89) \\ (-0.25, 1.04, 2.87) \\ (-0.51, 0.83, 2.75) \end{bmatrix}, \tilde{S}^* = (-1.12, 0.00, 1.65), S^{ou} = 2.89$$

$$\tilde{R}_i = \begin{bmatrix} (-0.21, 0.00, 0.63) \\ (0.04, 0.37, 0.81) \\ (0.27, 0.57, 0.93) \\ (0.12, 0.42, 0.90) \end{bmatrix}, \tilde{R}^* = (-0.21, 0.00, 0.63), R^{ou} = 0.93$$

$\widetilde{Q}_i$ is calculated using Eq. (22) and is defuzzied by using Eq. (23). The results of Fuzzy VILKOR analysis are shown in Table 7.

Fuzzy GRA implementation

We can form the normalized decision matrix ($\widetilde{R}$) from the decision matrix ($\widehat{x}_{ij}$) using Eqs. (24) and (25):

$$u_1^+ = MAX_i(2.3, 3.5, 4.7) = 4.7$$

$$\widetilde{r}_{11} = \left(\frac{2.3}{4.7}, \frac{3.5}{4.7}, \frac{4.7}{4.7}\right) = (0.79, 0.89, 1.00)$$

$$\widetilde{R} = \begin{bmatrix} (0.79, 0.89, 1.00) & (0.65, 0.83, 1.00) & (0.74, 0.87, 1.00) & (0.62, 0.79, 0.95) \\ (0.43, 0.59, 0.75) & (0.55, 0.75, 0.95) & (0.44, 0.61, 0.78) & (0.43, 0.60, 0.76) \\ (0.32, 0.43, 0.54) & (0.55, 0.73, 0.90) & (0.41, 0.56, 0.70) & (0.62, 0.79, 0.95) \\ (0.61, 0.75, 0.89) & (0.50, 0.68, 0.85) & (0.30, 0.44, 0.59) & (0.57, 0.79, 1.00) \end{bmatrix}$$

From Eq. (26) can defined reference series for suppliers as following:

$$\widetilde{R} = \begin{bmatrix} (0.79, 0.89, 1.00) & (0.65, 0.83, 1.00) & (0.74, 0.87, 1.00) & (0.62, 0.79, 1.00) \end{bmatrix}$$

According to Eq. (27), we can calculate the distance between each comparison value and the reference value:

$$\delta_{ij} = \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.02 \\ 0.31 & 0.07 & 0.26 & 0.20 \\ 0.46 & 0.10 & 0.31 & 0.02 \\ 0.15 & 0.15 & 0.42 & 0.02 \end{bmatrix}, \delta_{max} = (0.46), \delta_{min} = (0.00)$$

Equation (28) calculates the gray relational coefficient:

$$\xi_{ij} = \begin{bmatrix} 1.00 & 1.00 & 0.00 & 0.89 \\ 0.43 & 0.75 & 0.47 & 0.53 \\ 0.33 & 0.70 & 0.42 & 0.89 \\ 0.61 & 0.61 & 0.35 & 0.89 \end{bmatrix}$$

From Eq. (30), we can calculate the criteria weights ($\widetilde{w}_i$) and from Eq. (23) can be defuzzified. The largest weight (0.305) was given to financial value, followed by the level of quality (0.263) and the level of service (0.257). The EMS was the lowest among the four groups (0.175). Using Eq. (29), the gray relational grade was calculated as the product of the criteria weights multiplied by the gray relational coefficient (ξ_{ij}). The results of the Fuzzy GRA and other Fuzzy MCDM methods are shown in Table 8.

Table 7 The results of Fuzzy VILKOR analysis

Suppliers	S_i	R_i	$\widetilde{Q}_i$
Traditional laurel soap			
T1	0.13	0.11	(−0.70, 0.00, 0.71)
T2	1.06	0.40	(−0.53, 0.27, 0.96)
T3	1.18	0.59	(−0.41, 0.35, 1.00)
T4	0.98	0.47	(−0.50, 0.27, 0.97)
Perfumed laurel soap			
P1	1.34	0.55	(−0.42, 0.26, 0.93)
P2	0.71	0.26	(−0.59, 0.04, 0.67)
P3	0.45	0.37	(−0.60, 0.04, 0.67)
P4	1.73	0.55	(−0.36, 0.32, 1.00)
Olive oil soap			
O1	1.41	0.47	(−0.29, 0.36, 0.98)
O2	1.42	0.51	(−0.28, 0.38, 1.00)
O3	0.09	0.06	(−0.54, 0.00, 0.54)
O4	1.29	0.47	(−0.32, 0.34, 0.97)

Table 8 Numerical results of three Fuzzy MCDM analysis

Suppliers	CI (TOPSIS rank)	Q_i (VILKOR rank)	γ_i(*GRArank*)
Traditional laurel soap			
T1	0.98 (1)	0.00 (4)	0.98 (1)
T2	0.36 (3)	0.24 (3)	0.54 (4)
T3	0.22 (4)	0.32 (1)	0.55 (3)
T4	0.40 (2)	0.25 (2)	0.59 (2)
Perfumed laurel soap			
P1	0.24 (3)	0.26 (2)	0.46 (3)
P2	0.67 (2)	0.040 (4)	0.69 (2)
P3	0.75 (1)	0.042 (3)	0.83 (1)
P4	0.01 (4)	0.32 (1)	0.38 (4)
Olive oil soap			
O1	0.20 (4)	0.35 (2)	0.41 (4)
O2	0.21 (3)	0.37 (1)	0.42 (3)
O3	1.00 (1)	0.00 (4)	1.00 (1)
O4	0.29 (2)	0.34 (3)	0.47 (2)

Table 9 Comparison of different ranking methods of

Ranking methods	Ranking orders of alternatives
Traditional laurel soap	
F-TOPSIS	$T1 > T4 > T2 > T3$
F-GRA	$T1 > T4 > T3 > T2$
F-VILKOR	$T3 > T4 > T2 > T1$
Perfumed laurel soap	
F-TOPSIS	$P3 > P2 > P1 > P4$
F-GRA	$P3 > P2 > P1 > P4$
F-VILKOR	$P4 > P3 > P1 > P2$
Olive oil soap	
F-TOPSIS	$O3 > O4 > O2 > O1$
F-GRA	$O3 > O4 > O2 > O1$
F-VILKOR	$O2 > O1 > O4 > O3$

Comparison

Tables 8 and 9 present a comparison of the ratings of the four analyzed alternatives, which were obtained using the three Fuzzy MCDA methods. For the traditional laurel soap, the leading position is gained by the first supplier (T1) in the resulting ranking of the methods of Fuzzy TOPSIS and Fuzzy GRA. This supplier took the last position in the ranking received using the Fuzzy VIKOR method. As for the rank achieved for the Fuzzy VIKOR method, the third alternative (T3) took the leader of ranking because differs significantly from the rankings. The three methods Fuzzy GRA, Fuzzy TOPSIS, and Fuzzy VIKOR were reconciled with the fourth alternative (T4) as the second optimum supplier for the traditional laurel soap industry. The second alternative occupies the third position according to the Fuzzy VIKOR and Fuzzy TOPSIS methods. For the third alternative (T3), we noticed a discrepancy between the three methods.

For the perfumed laurel soap product, we notice from Fig. 7, the third alternative (P3) ranked first in the resulting classifications for the Fuzzy TOPSIS and Fuzzy GRA methods. The third supplier (p3) is rated almost third because the second supplier (p2) has taken the leading position in this product. Regarding the product of laurel soap with olive oil extract, the third supplier (o3) was ranked first for the Fuzzy TOPSIS and Fuzzy GRA methods, but it ranked fourth for the Fuzzy VIKOR method, whereas the second supplier (O2) ranked first for the Fuzzy VIKOR method.

Complete conformity was observed in Fuzzy TOPSIS and Fuzzy GRA for the arrangement of the four alternatives for suppliers of perfumed laurel soap and laurel soap with olive oil extract. The alternatives that top the rankings on the roads are Fuzzy TOPSIS and Fuzzy GRA. The positions of all analyzed alternatives in the ratings obtained using the three MCDA methods used in this study are depicted in Figs. 6, 7, and 8, using a column chart.

In Figs. 9, 10, and 11, a pie chart displaying the percentages of ranking the alternatives in order of importance is used to highlight the positions of all the studied alternatives in the ratings acquired using the three Fuzzy MCDA methods participating in this study.

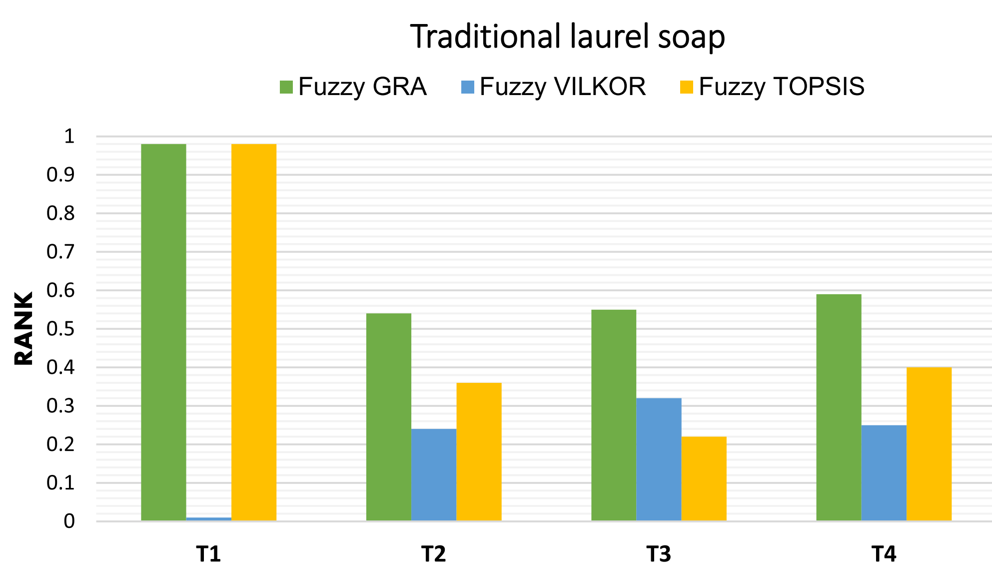

Fig. 6 Rankings for traditional laurel soap using Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA are compared

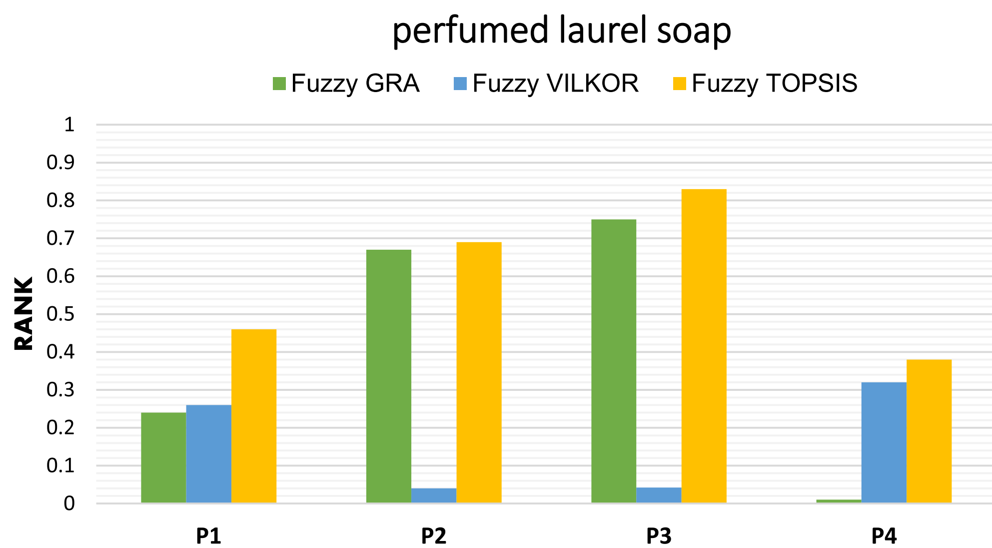

Fig. 7 Rankings for perfumed laurel soap using Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA are compared

Conclusion

Selecting suppliers is one of the most important decisions taken by the organization, and considering the competition that exists between organizations, the green supplier is a milestone in the transition toward designing and managing more environmentally sustainable supply chains. This paper proposes an MCDA-based methodology considering the fuzzy versions of TOPSIS, VIKOR, and GRA to assess the decision problem to choose the best green supplier. The three fuzzy techniques' stages of development are discussed. The supplier evaluation was completed using the three models, and a case firm from the chemical industry sector was selected. The comparison analyses of the outcomes acquired using the three methodologies produced some fascinating findings and insights.

The structure of the problem included the identification of four criteria relevant to the decision-maker's opinions and subject to environmental criteria, according to which alternatives are evaluated. The effect of solving the problem stated in this article is significantly reliant on the MCDA approach employed for this purpose. The range of similarities and variances between the outcomes generated from the methodologies used also vary. The Fuzzy GRA and Fuzzy TOPSIS approaches showed the most similarity in

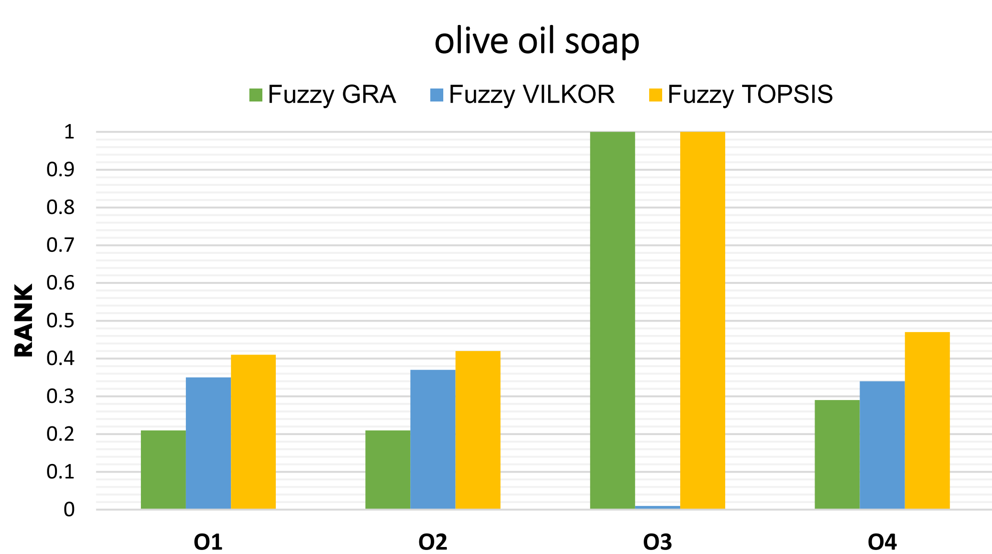

Fig. 8 Rankings for olive oil soap using Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy GRA are compared

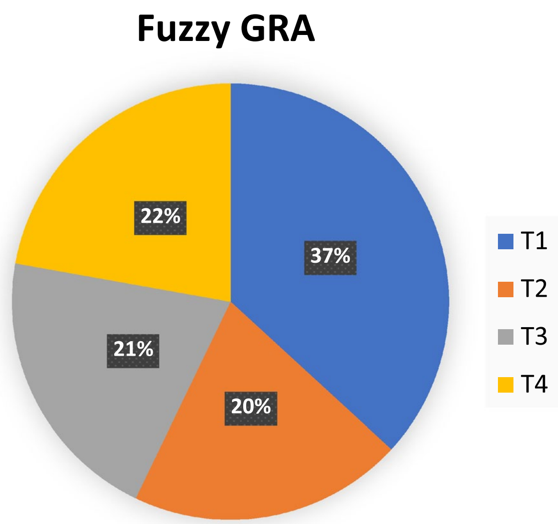

Fig. 9 Comparison of rankings received with Fuzzy GRA for four alternatives

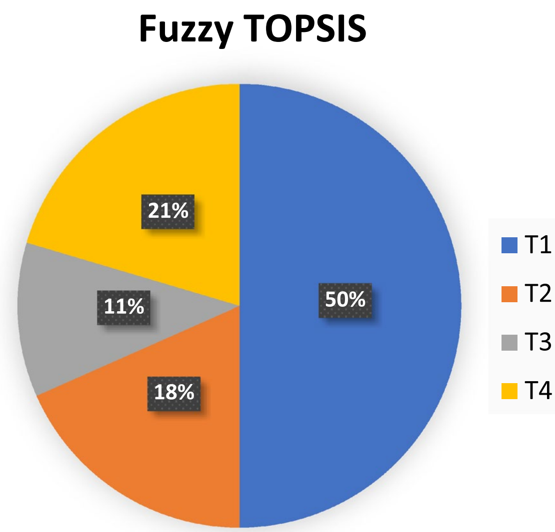

Fig. 11 Comparison of rankings received with Fuzzy TOPSIS for four alternatives

categorization. When contrasting the results obtained using the Fuzzy VIKOR method, the most notable differences were seen. The study that was conducted brought attention to the significance of comparative analysis using various MCDA methods and careful selection of appropriate methods in order to solve the problem of selecting the best green alternative while taking the values of criteria in fuzzy numbers into account. The three MCDA approaches utilized in this study provided ratings, but the results did not clearly identify the best particular choice. If the furthest rank

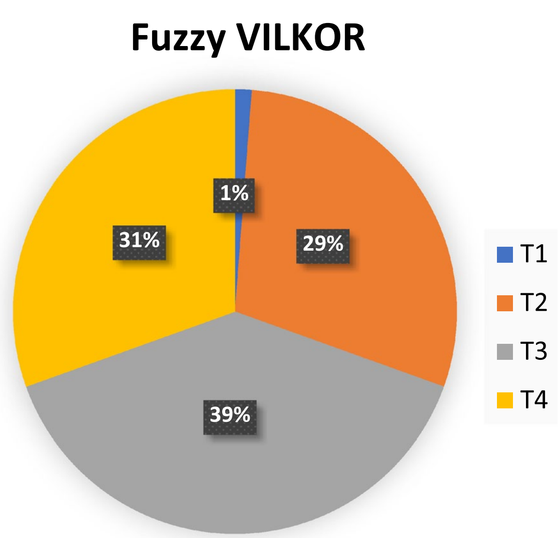

Fig. 10 Comparison of rankings received with Fuzzy VILKOR for four alternatives

given by the Fuzzy VIKOR method is excluded from the analysis, T1 can be identified as the best supplier that received the leading position in two rankings for the first type of supplier and P3 as the best green supplier that received the first position for the second type of supplier for the two rankings Fuzzy GRA and Fuzzy TOPSIS and the position 2nd for the Fuzzy VIKOR rating. Overall, the three methods appear to be comparable in terms of computational complexity, although GRA appears to handle faulty standards and alternate supplier data the most effectively. When dealing with subjective data or insufficient/ambiguous information, it is frequently necessary to integrate fuzzy theory and the gray system (GRA), which can be utilized to handle both problem/system ambiguity and inadequate information. Despite the quantity of criteria and the complexity of the system, GRA is understandable and easy to use. Future research should aim to compare the findings of our study with those obtained from the two new approaches in place of the two MCDM methods that were replaced by two new methods mixed with fuzzy logic.

Environmental regulations need to be considered more and more when choosing suppliers. Many of the problems faced by enterprise management experts can be solved with the development and availability of new analytical tools and supplier selection models. This work opens the path for future research in this significant and expanding area of knowledge by offering a single platform for choosing green providers in a complex context.

The strength of the research lies in its use of three fuzzy multi-criteria decision-making techniques to assess the viability of potential suppliers while working with sparse or inaccurate data. Aleppo city regions can use the suggested method practically to evaluate and choose the best green suppliers among the proposed ones. Decision-makers must be chosen carefully because the decision-making process is sensitive to the number of participants and their level of expertise in the subject, and these methods can also be applied in arranging retail outlets within criteria determined by decision-makers sale.

Future studies should consider new assessment factors with respect to the post-COVID-19 pandemic that can impact the process of evaluation and selection of green suppliers to enhance the robust results. Besides, other multi-criteria decision-making approaches, such as hesitant Fuzzy AHP, were to calculate weights of criteria and compare the results to those found in this study. In addition, the accuracy and reliability of these rankings should be measured using a reference for ranking similarity coefficients (i.e., weighted Spearman's rank correlation coefficient and rank similarity coefficient).

Abbreviations

DM	Decision-making
MCDM	Multi-criteria decision-making
GRA	Gray relationship analysis
TOPSIS	Technique for order of preference by similarity to ideal solution
VIKOR	Vlsekriterijumska optimizacija i kompromisno resenje
SS	Suppliers' selection
AHP	Analytic hierarchy process
WASPAS	Weighted aggregated sum product assessment
ANP	Analytic network process
DEA	Data envelopment analysis

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Author contributions

AAAM contributed to data curation and writing—original draft preparation. SAM contributed to conceptualization, methodology, software, and supervision. Both authors read and approved the final manuscript.

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This is available on request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

I hereby agreed that my submitted manuscript "Application of fuzzy group decision-making Selecting Green Supplier: A case study of the manufacture of natural laurel soap" be published by your firm.

Competing interests

The authors declare no competing interests.

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