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Fuzzy Multi-Criteria Analyses on Green Supplier Selection in an Agri-Food Company

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Abstract: The way agri-food companies conduct business has changed as a result of changes in the market. These companies must start working in a more environmentally friendly manner. This study aims to examine, assess, and compare how various fuzzy methodologies are applied in green supplier selection (GSS), using an agri-food industry as an example. The company Biljana Brko, which engages in GSS, was observed in this study. The selection aids in the acquisition of raw materials and materials whose environmental impact will be minimized. Ecological and economic factors were taken into consideration when choosing green suppliers. Experts who assessed the weight of the criteria and the suppliers with linguistic values were chosen to carry out this selection. In order to do this, a fuzzy set that effectively applies these linguistic values was employed. The fuzzy SWARA (FSWARA) approach was utilized to calculate the weights of the criteria, revealing that the criterion of Environmental Management System has the highest weight. Drawing on the opinions of experts, suppliers were ranked using the fuzzy MABAC, MARCOS, and CRADIS techniques. The results show that supplier S2 receives the highest ratings. Along with this provider, supplier S3 is noteworthy because it excelled in the sensitivity analysis across a variety of scenarios. In light of this, Biljana Brko should give preference to these suppliers. Further, the results of the three adopted techniques were compared. The comparison reveals that the ranking order produced by all three techniques is remarkably similar. This supplier order differed slightly from the FMABAC method just in one scenario. Hence, this work demonstrates that the three fuzzy techniques can solve the GSS problem and other problems by ranking alternatives.

Keywords: Multicriteria analysis; Fuzzy set; Agri-food; Green supplier selection (GSS)

1. Introduction

The manner that agri-food companies conduct business is changing as a result of all the significant market shifts [1]. They need to adjust to the brand-new market standards. According to Shi et al. [2], these standards are mainly concerned with increasing public knowledge of environmental preservation and with meeting consumer demands for safe food products [3]. Consumers now care more about their health and are better informed. As a result, producers need to focus more on raising product quality, and lessen the detrimental effects of production on the environment.

To meet the above requirements, agri-food companies must have trustworthy suppliers who can provide them with raw materials that are safe for the environment and people's health. The company's environmental objectives depend heavily on its suppliers [4]. Moreover, a significant portion of product quality is determined by the supplier's raw material quality. The poor supplier selection can lead to a needless waste of resources and an increase in production costs [5].

Therefore, while choosing suppliers, agri-food companies must take environmental factors into consideration [6]. This promotes a green supply chain, which is essential for the current production management of modern companies [2]. A combination of economic and environmental criteria should be applied to complete green supplier selection (GSS). The GSS entails a number of difficulties, starting with the supplier search and continuing through supplier evaluation and selection [7]. Suppliers should assist the company in adjusting to market demands so that the GSS will benefit the company.

In order to conduct GSS, suppliers must be evaluated using two basic criteria (economic and ecological), as well as extra sub-criteria for each of these main criteria. As a result, the GSS can be transformed into a multi-criteria decision-making (MCDM) problem. Additionally, collective decision-making is needed to overcome this challenge of decision-making [8]. The decision maker has access to a variety of quantitative and qualitative factors during the GSS [9]. Numerical values make up quantitative criteria, eliminating the need for any additional processing. Most often, linguistic values are utilized to assess qualitative standards. These values are more descriptive and in line with human thinking.

Fuzzy set theory, a particularly effective approach for solving complicated issues [10], including the GSS problem, is used to apply linguistic values. Following to this idea, linguistic values are converted into fuzzy numbers before being applied to fuzzy methods for multi-criteria decision analysis (MCDA). In practice, various techniques have been applied to solve the problem. Each of these techniques has benefits and drawbacks. The decision-maker may find it challenging to select the best technique out of them for GSS.

This study seeks to help the decision-maker choose a suitable GSS technique, providing a reference for any selection problem, where the outcomes are displayed as a ranking of alternatives. Thus, the primary objective is to explore, analyze, and compare the use of various fuzzy techniques in GSS using an agri-food company as an example. Firstly, it is important to decide on which technique is the best for GSS. Fuzzy MABAC (Multi-Attributive Border Approximation Area Comparison), fuzzy MARCOS (Measurement Alternatives and Ranking according to the Compromise Solution), and fuzzy CRADIS (Compromise Ranking of Alternatives from Distance to Ideal Solution) were compared in details. The weights of the criteria were determined before using these techniques. The criteria were weighted via fuzzy SWARA (Stepwise Weight Assessment Ratio Analysis).

Overall, this study intends to achieve the following goals:

- Complete GSS of the target agri-food company.
- Compare the results of different GSS techniques.
- Determine the influence of weights on ranking of different alternatives.

By pursuing these goals, this work contributes significantly to the application of different fuzzy methods in GSS for the needs of decision-makers.

2. Literature Review

Many earlier studies used fuzzy techniques to solve the GSS problem. Only a select few are covered in this part because it would be impossible to present all of them. Taking agri-food companies as examples, Banaeian et al. [6] compared TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR (Multi-Criteria Compromise Ranking), and GRA (Grey relational analysis) techniques in GSS. They found that applying the GRA technique necessitates fewer intricate calculations.

In a green supply chain, Qu et al. [11] solved the GSS of an online retailer, using the fuzzy TOPSIS and ELECTRE (ELimination and Choice Expressing REALITY) techniques. The fuzzy MABAC, WASPAS (Weighted Aggregated Sum Product Assessment), and TOPSIS methods were utilized to conduct GSS by a car company, and the fuzzy AHP (Analytic Hierarchy Process) approach was used to calculate the weights of the criteria.

Wang Chen et al. [12] solved the GSS by a light-enhancing film manufacturer using AHP and TOPSIS. The fuzzy TOPSIS approach was adopted to rank the alternatives, and the fuzzy AHP was utilized to calculate the weights of the criteria. Rouyendegh et al. [13] performed GSS for a company in Ankara using an intuitionistic fuzzy set, with the aid of TOPSIS. To optimize order quantity, Bakeshlow et al. [14] applied hybrid fuzzy multi-objective decision-making (MODM) and ANP (Analytic Network Process). Six sigma indicators were utilized by Chen et al. [15] to complete GSS in the case of a Taiwanese electronics company.

Çalık [16] tried to solve GSS via collaborative decision-making based on Industry 4.0 principles. The TOPSIS was utilized for ranking alternatives and the Pythagorean fuzzy approach with AHP for criteria weighting. Oroojeni Mohammad Javad et al. [17] identified key factors for the GSS by the Khouzestan Steel Company, using TOPSIS. Focusing on a producer of home appliances, Ecer [18] performed GSS using the interval type-2 fuzzy methodology based on the AHP. Yucesan et al. [19] applied a comparable interval type-2 fuzzy methodology for GSS, along with the BWM (Best-Worst method) and TOPSIS. The BWM was used to weigh the criteria, while the TOPSIS to rank the alternatives.

For GSS, Qin et al. [20] additionally used the TODIM (Tomada de Deciso Iterativa Multicritério) approach and interval type-2 fuzzy methodology. The TOPSIS approach was implemented to conduct the sensitivity analysis. Wu et al. [21] combined interval type-2 fuzzy methodology with BWM and VIKOR. Specifically, they calculated the weights of the criteria using the BWM and the ranking order of the alternatives using the VIKOR. Puška et al.

[1] used the LMAW (Logarithm Methodology of Additive Weights) and CRADIS methodologies to perform GSS on the case of agricultural pharmacies, with the help of fuzzy Z-numbers. They calculated the weights of the criteria using the LMAW approach and ranked the alternatives using the CRADIS.

All of these studies are unique in that different techniques are utilized to weigh the criteria and different techniques to rank the alternatives. This allows for the use of an alternative strategy based on a fuzzy environment. The analysis of these studies demonstrates that a variety of methods can be utilized, including classical fuzzy, interval fuzzy numbers, Z-numbers, intuitionistic fuzzy numbers, hesitant fuzzy numbers, q-rung orthopair fuzzy numbers, Pythagorean fuzzy numbers, spherical fuzzy numbers, and neuro-fuzzy models. The traditional fuzzy methodology was employed in this study to facilitate decision-makers to comprehend how certain GSS strategies could be applied.

3. Methodology

This study was carried out in five phases:

- Phase 1. Initial phase
- Phase 2. Data collection
- Phase 3. Data processing and analysis
- Phase 4. Sensitivity analysis
- Phase 5. Result comparison

The initial phase intends to identify the objectives and subjects. This study was conducted using Biljana Brko, a company that manufactures food goods, as an example. This company owns plantations where it grows the raw components for its products. Due to the low level of raw material manufacturing, the company must purchase the majority of its raw materials from suppliers. Three experts were chosen to participate in this study along with the management of this company, aiming to meet the increasingly stringent criteria surrounding the safety of food products.

The head of the procurement department is the first expert, followed by a sales specialist and the deputy director. It was initially decided how the suppliers will be assessed in conjunction with the experts. The GSS is a must b ecause the products of Biljana Brko are unique. Following that, the new possible sources who could provide the raw material were identified. Four suppliers in total were chosen after ten assessment criteria were established. The criteria equally split between economic and ecological categories. All these criteria were assessed collectively (Table 1).

Table 1. GSS criteria

ID	Criteria	Description	Reference
C1	Costs/price	Total cost and purchase price	Banaeian et al. [6]; Matić et al. [22]
C2	Quality	Degree to which products meet customer requirements	Matić et al. [22]; Lo et al. [23]
C3	Innovation	Ability to improve products and services in the company	Jafarzadeh Ghoushchi et al. [24]; Sen et al. [25]
C4	Partner relation	Level of connection between suppliers and their customers	Jafarzadeh Ghoushchi et al. [24]; Vasiljević et al. [26]
C5	Organization and management	Organization of the company in terms of the division of work and processes	Bakeshlou et al. [14]; Amindoust [27]
C6	Environmental management system	Application of ISO 14001 standard in the company	Banaeian et al. [6]; Amindoust [27]
C7	Recycling	Reuse of materials and waste during production	Sen et al. [25]; Đalić et al. [28]
C8	Pollution control	Reducing the impact on the environment during production	Matić et al. [22]; Sen et al. [25]
C9	Green products	Production of environmentally friendly products	Matić et al. [22]; Jafarzadeh Ghoushchi et al. [24]
C10	Environmental competencies	The company's efforts to improve production and reduce pollution	Sen et al. [25]; Amindoust [27]

The second phase is about data collection. A survey questionnaire was designed once the suppliers (alternatives) and the evaluation criteria were determined. The questionnaire has two sections. The first section intends to assess the significance of the criteria based on expert opinions. The second section of the questionnaire was to rate suppliers against a set of criteria. Linguistic values in the form of descriptive values were utilized to assess the criteria and alternatives (Table 2). These values were determined by a 7-point Likert scale, ranging from very low (VL) to very high (VH). VL and VH represent the least and most importance as seen by the experts. The alternatives were rated from very bad (VB) to very good (VG). VB and VG represent the lowest and highest ratings indicating how much a supplier meets a criterion.

Table 2. Linguistic values for evaluation of criteria and alternatives

Linguistic values	Fuzzy numbers	Linguistic values	Fuzzy numbers
Very low (VL)	(0, 0, 0.1)	Very bad (VB)	(0,0,1)
Low (L)	(0, 0.1, 0.3)	Bad (B)	(0,1,3)
Medium-low (ML)	(0.1, 0.3, 0.5)	Medium bad (MB)	(1,3,5)
Medium (M)	(0.3, 0.5, 0.7)	Medium (M)	(3,5,7)
Medium-High (MH)	(0.5, 0.7, 0.9)	Medium good (MG)	(5,7,9)
High (H)	(0.7, 0.9, 1)	Good (G)	(7,9,10)
Very High (VH)	(0.9, 0.9, 1)	Very Good (VG)	(9,10,10)

The third phase concentrated on data processing and analysis. Based on the first section of the questionnaire, the fuzzy SWARA approach was used to determine the weights of the criteria. The linguistic values were first converted into fuzzy numbers numbers by the membership function based on the evaluation of the criteria by experts. Then, the mean fuzzy numbers for the criteria were determined, and used to solve the relative importance of each criterion, producing the weight of each criterion. Based on the observed criteria, the alternatives (suppliers) were ranked, using the second section of the questionnaire. Firstly, an initial decision matrix was created out of the linguistic values of supplier ratings. The alternatives were then ranked using the aforementioned techniques after those linguistic values were converted into fuzzy numbers. The suppliers were ranked using the three said fuzzy techniques.

In the fourth phase, a sensitivity analysis was carried out to examine how the criteria weights affect the alternative ranking obtained by the three fuzzy methods. Out of the multiple approaches of sensitivity analysis, this study weighs the criteria without using the SWARA technique, because the ranking orders are not formed in the light of the subjective evaluations of the criteria. Following Puska et al.'s method [29], scenarios were created from the number of criteria. The zero scenarios were taken, which represents the weights obtained from the research. The first scenario prioritizes each criterion equally, whereas the other scenarios prioritize one criterion and gave it an 11 times greater weight than the other scenarios.

The fifth phase compares the results obtained by different fuzzy techniques. The results obtained using subjective weights were compared first, before contrasting the results obtained through sensitivity analysis. The differences in these results were investigated, as well as their causes.

4. Preliminaries

4.1 Fuzzy Logic

Fuzzy logic was founded in 1965 by Zadeh [30]. The membership function must be determined before applying fuzzy logic. The membership function adopted in the present study is displayed in Table 2. The conversion of linguistic values into fuzzy numbers is necessary in order to perform operations on such values. The following operations need to be carried out when we have two fuzzy sets $\widetilde{A_1} = (m_1, m_2, m_3)$ and $\widetilde{A_2} = (n_1, n_2, n_3)$:

Addition:

$$\widetilde{A_1}+\widetilde{A_2}=(m_1,m_2,m_3) + (n_1,n_2,n_3)=(m_1 + n_1\,, m_2 + n_2, m_3 + n_3) \tag{1}$$

Subtraction:

$$\widetilde{A_1} - \widetilde{A_2}=(m_1,m_2,m_3) - (n_1,n_2,n_3)=(m_1 - n_1\,, m_2 - n_2, m_3 - n_3) \tag{2}$$

Multiplication:

$$\widetilde{A_1}\times\widetilde{A_2}=(m_1,m_2,m_3) \times (n_1,n_2,n_3)=(m_1 \times n_1\,, m_2 \times n_2, m_3 \times n_3) \tag{3}$$

Division:

$$\widetilde{A_1}\div\widetilde{A_2}=(m_1,m_2,m_3) \div (n_1,n_2,n_3)=(m_1 \div n_1, m_2 \div n_2, m_3 \div n_3) \tag{4}$$

Linguistic values are ideal to deal with situations that are too complex or poorly defined to be represented in quantitative terms. This study utilizes these values to represent ratings.

4.2 Fuzzy SWARA

The fuzzy SWARA was used to determine the weights of the criteria. This is a subjective technique to weigh criteria. Created by Keršuliene et al. [31], fuzzy SWARA can be implemented in the following steps:

Step 1. Criteria identification and selection.

Experts evaluate the criteria using linguistic standards. The mean criterion value is determined after these values have been converted into fuzzy numbers.

Step 2. Importance ranking of criteria.

The criteria are sorted in descending order of importance, i.e., the mean value.

Step 3. Determining relative importance.

The top-ranking criterion has the highest mean, and is assigned the value of 1. The value of any other criterion is determined according to its deviation from the mean.

Step 4. Calculating coefficient k_j.

This coefficient is calculated by overwriting the value of the most significant criterion, while adding a unit to the relevant importance of any other criterion:

$$k_j = \begin{cases} 1 & if\ j = 1 \\ s_j + 1 & if\ j > 1 \end{cases} \tag{5}$$

Step 5. Calculating significance q_j.

The significance is calculated by overwriting the value of the most significant criterion, while dividing the value q_j of the previous criterion with value k_j of any other criterion:

$$q_j = \begin{cases} 1 & if\ j = 1 \\ \frac{q_j - 1}{\bar{k}_j} & if\ j > 1 \end{cases} \tag{6}$$

Step 6. Criteria weighting.

The value q_j of an individual criterion is divided by the total value q_j for all criteria:

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_k} \tag{7}$$

4.3 Fuzzy MABAC

Pamučar and Ćirović created the MABAC method [32], which is used to rank alternatives. This method assumes that the geometric mean of a criterion is reflected by the border approximate area (BAA), and that the alternative is positive if the alternative value is above that area. The inverse is also true. The MABAC can be implemented in the following steps:

Step 1. Initializing fuzzy decision matrix.

The alternatives are assessed using the predetermined criteria, forming the initial matrix. Then, the matrix is transformed into the initial fuzzy decision matrix.

Step 2. Normalizing matrix elements.

The matrix elements are equalized and unified through normalization.

For positive criteria:

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{ij}^{l} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}, \frac{x_{ij}^{m} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}, \frac{x_{ij}^{u} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}\right)\ if\ j \in B \tag{8}$$

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(1 - \frac{x_{ij}^{l} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}, 1 - \frac{x_{ij}^{m} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}, 1 - \frac{x_{ij}^{u} - x_{aid}^{u}}{x_{id}^{u} - x_{aid}^{l}}\right)\ if\ j \in C \tag{9}$$

where, *l*, *m* and *u* are the first, second, and third fuzzy numbers, respectively; x_{id}^{u} is the maximum (best value) of *u*; x_{aid}^{l} is the minimum (worst value) of *l*.

Step 3. Element weighting.

The matrix elements can be weighed by:

$$\tilde{v}_{ij} = w_i \cdot \tilde{t}_{ij} + w_i \tag{10}$$

where, w_i is the weighting coefficient of a criterion.

Step 4. Building the approximate border area matrix (G).

The geometric mean of a criterion in matrix G can be solved by:

$$g = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{11}$$

where, *m* is the total number of alternatives.

Step 5. Calculating distance of each alternative from BAA.

Each alternative value for a particular criterion can be subtracted from the value G.

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{12}$$

where, V is the weighted matrix elements.

Step 6. Calculating MABAC results.

The alternatives are ranked according to the matrix $\tilde{Q}$ elements per rows. If the mean of the alternatives is greater than the value G, the MABAC results would be positive. The inverse is also true.

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij}\ , j = 1,2, \dots, n, i = 1,2, \dots, m \tag{13}$$

Step 7. Determining the final values.

The final value of each alternative can be solved by defuzzification of the obtained values $\tilde{S}_i$.

$$S = \frac{t_1 + 4t_2 + t_3}{6} \tag{14}$$

The best alternative is the one with the highest MABAC values.

4.4 Fuzzy MARCOS

The MARCOS method, developed by the Stević et al. [33], is a technique of multi-criteria analysis for alternative ranking. Drawing on the relationship between alternatives and ideal and anti-ideal points, MARCO uses utility functions. The best alternative is the one the closest to the ideal point, and furthest away from the anti-ideal point. This method can be implemented in the following steps:

Step 1. Initializing the fuzzy decision matrix.

Step 2. Expanding the matrix.

This step finds an anti-ideal (AAI) and an ideal solution (AI). The former represents the worst value of an alternative in relation to the observed criterion, and the latter represents the best value of one of the alternatives according to the observed criteria. The AAI and AI can be respectively expressed as:

$$AAI = \min_j x_{ij}\ \ if\ \ j \in\ \ B\ and\ \max_j x_{ij}\ if\ \ j \in C \tag{15}$$

$$AAI = \max_j x_{ij}\ \ if\ \ j \in\ \ B\ and\ \min_j x_{ij}\ if\ \ j \in C \tag{16}$$

Step 3. Matrix normalization.

The matrix elements can be normalized by:

$$\tilde{t} = \left(t_{ij}^{l}, t_{ij}^{m}, t_{ij}^{u}\right) = \left(\frac{x_{id}^{l}}{x_{ij}^{u}}, \frac{x_{id}^{l}}{x_{ij}^{m}}, \frac{x_{id}^{l}}{x_{ij}^{l}}\right)\ if\ j \in C \tag{17}$$

$$\tilde{t} = \left(t_{ij}^{l}, t_{ij}^{m}, t_{ij}^{u}\right) = \left(\frac{x_{ij}^{l}}{x_{id}^{u}}, \frac{x_{ij}^{m}}{x_{id}^{u}}, \frac{x_{ij}^{u}}{x_{id}^{u}}\right)\ if\ j \in B \tag{18}$$

where, *l*, *m* and *u* are the first, second, and third fuzzy numbers, respectively;

Step 4. Aggregation of normalized decision matrix.

The normalized matrix can be aggregated by:

$$\tilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) = \tilde{n}_j \times \widetilde{w}_j \tag{19}$$

Step 5. Calculating matrix *Si*.
The fuzzy numbers for the alternatives, including the anti-ideal and the ideal, are added by:

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{20}$$

Step 6. Calculating degree of utility.
The utility of *Ki* in relation to the anti-ideal and ideal solutions can be calculated by:

$$\widetilde{K}_i^- = \left(\frac{\tilde{S}_i}{\tilde{S}_{ai}}\right) = \left(\frac{s_i^l}{s_{ai}^u}, \frac{s_i^m}{s_{ai}^u}, \frac{s_i^u}{s_{ai}^u}\right) \tag{21}$$

$$\widetilde{K}_i^+ = \left(\frac{\tilde{S}_i}{\tilde{S}_{id}}\right) = \left(\frac{s_i^l}{s_{id}^u}, \frac{s_i^m}{s_{id}^u}, \frac{s_i^u}{s_{id}^u}\right) \tag{22}$$

Step 7. Calculating fuzzy matrix.
The fuzzy matrix $\tilde{T}_i$ can be calculated by:

$$\tilde{T}_i = \tilde{t}_i = \left(t_i^l, t_i^m, t_i^u\right) = \widetilde{K}_i^- + \widetilde{K}_i^+ = (\tilde{k}_i^{-l} + \tilde{k}_i^{+l}, \tilde{k}_i^{-m} + \tilde{k}_i^{+m}, \tilde{k}_i^{-u} + \tilde{k}_i^{+u}) \tag{23}$$

Fuzzy number $\widetilde{D}$ can be determined by:

$$\widetilde{D} = (d^l, d^m, d^u) = \max_i \tilde{t}_{ij} \tag{24}$$

Step 8. Defuzzification.
Fuzzy numbers can be defuzzied by:

$$df_{def} = \frac{l + 4m + u}{6} \tag{25}$$

Step 9. Determining utility function f(Ki).
The utility function can be obtained by aggregating utility functions according to anti-ideal solution a) and ideal solution b):

a)

$$f(\widetilde{K}_i^+) = \frac{\widetilde{K}_i^-}{df_{def}} \tag{26}$$

b)

$$f(\widetilde{K}_i^-) = \frac{\widetilde{K}_i^+}{df_{def}} \tag{27}$$

Step 10. Calculating the final utility.
The final utility can be calculated by:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \tag{28}$$

Step 11. Alternatives ranking.
The best alternative is the one with the highest value and conversely the worst alternative is the one with the lowest value.

4.5 Fuzzy CRADIS

The CRADIS method was developed by Puška et al. [29]. The basic idea is to rank alternatives in relation to ideal and anti-ideal solutions, and the deviation from optimal solutions. CRADIS can be implemented in the following steps:

Step 1. Normalizing decision matrix.

The decision matrix can be normalized by:

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{ij}^{l}}{x_{id}^{u}}, \frac{x_{ij}^{m}}{x_{id}^{u}}, \frac{x_{ij}^{u}}{x_{id}^{u}}\right) \ if\ j \in B \tag{29}$$

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{id}^{l}}{x_{ij}^{u}}, \frac{x_{id}^{l}}{x_{ij}^{m}}, \frac{x_{id}^{l}}{x_{ij}^{l}}\right) \ if\ j \in C \tag{30}$$

Step 2. Aggregating the decision matrix.

The values of elements in the normalized decision matrix are multiplied by the corresponding weights:

$$\tilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) = \tilde{n}_{j} \times \tilde{w}_{j} \tag{31}$$

Step 3. Determining ideal and anti-ideal solutions.

In the aggregated decision matrix, the ideal and anti-ideal solutions represent the greatest value v_{ij} and the smallest value v_{ij}, respectively:

$$t_{i} = max\ \tilde{v}_{ij},\ where\ \tilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) \tag{32}$$

$$t_{ai} = min\ \tilde{v}_{ij},\ where\ \tilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) \tag{33}$$

Step 4. Calculating deviations from ideal and anti-ideal solutions.

This step calculates the aggregated normalized alternative in relation to the ideal and anti-ideal solutions. For this reason, two decision matrices are formed, where the deviation from the ideal solution and the anti-ideal solution is calculated by:

$$d^{+} = t_{i} - \tilde{v}_{ij} \tag{34}$$

$$d^{-} = \tilde{v}_{ij} - t_{ai} \tag{35}$$

The optimal alternatives are also calculated in this step. These alternatives are represented by the individual values that are minimally distant from the ideal solution, i.e., maximally distant from the anti-ideal solution.

Step 5. Calculating the deviation of individual alternatives from ideal and anti-ideal solutions.

The sum of deviations from ideal and anti-ideal solutions can be respectively calculated by:

$$s_{i}^{+} = \sum_{j=1}^{n} d^{+} \tag{36}$$

$$s_{i}^{-} = \sum_{j=1}^{n} d^{-} \tag{37}$$

This step also computes the sum of the deviation of the optimal alternatives from the ideal and anti-ideal solutions.

Step 6. Defuzzification of deviations of alternatives from ideal and anti-ideal solutions.

Fuzzy numbers can be transformed into craps numbers by:

$$s_{i\ def}^{\pm} = \frac{d_{i}^{l} + 4d_{i}^{m} + d_{i}^{u}}{6} \tag{38}$$

Step 7. Calculating utility function.

The utility of each alternative is computed in relation to the deviations from the optimal alternatives. The optimal alternatives can be calculated by:

$$K_{i}^{+} = \frac{s_{0}^{+}}{s_{i}^{+}} \tag{39}$$

$$K_i^- = \frac{s_i^-}{s_0^-} \quad (40)$$

where, s_0^+ and s_0^- are the optimal alternatives the closest from the ideal solution and the furthest away from the anti-ideal solution.

Step 8. Alterative ranking

The final values of fuzzy CRADIS can be obtained by solving the average deviation of the alternatives from the degree of utility.

$$Q_i = \frac{K_i^+ + K_i^+}{2} \quad (41)$$

The best alternative is the one with the highest value Q_i, while the worst is the one with the lowest value Q_i.

5. Results

Before ranking the alternatives, it is necessary to determine the weights of the criteria. These weights are essential to the operation of MCDM. To do this, ratings were collected from chosen experts who graded how important these criteria are (Table 3).

Table 3. Expert ratings of criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
DM1	ML	M	MH	MH	MH	MH	M	ML	M	ML
DM2	M	MH	M	H	M	H	MH	MH	MH	ML
DM3	ML	MH	MH	MH	MH	VH	H	H	MH	L

The linguistic values must be converted into fuzzy numbers in order to be used as weights by fuzzy SWARA. The established fuzzy number membership function (Table 2) was adopted to complete the conversion. The fuzzy SWARA was then used after calculating the mean of the fuzzy numbers. Criterion C6 received the highest mean and was ranked as the first criterion. The other criteria were ranked based on these mean values.

Next, the difference between the mean values was calculated based on the values of s_j. After that, coefficient k_j (Eq. 5) was calculated, and used to determine coefficient q_j (Eq. 6). On this basis, the criteria were weighed by Eq. 7. The weights of the coefficients reflect the ranking based on the mean rating of the experts (Table 4). Criterion C6 has the highest weight, while criterion C10 has the lowest.

Table 4. Criterion weights obtained by fuzzy SWARA

Criteria		s_j			k_j			q_j			w_j	
C6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.13	0.12	0.12
C4	0.13	0.07	0.03	1.13	1.07	1.03	0.88	0.94	0.97	0.11	0.11	0.11
C7	0.07	0.07	0.07	1.07	1.07	1.07	0.83	0.88	0.91	0.11	0.11	0.11
C2	0.07	0.07	0.03	1.07	1.07	1.03	0.78	0.82	0.88	0.10	0.10	0.10
C3	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.82	0.88	0.10	0.10	0.10
C5	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.82	0.88	0.10	0.10	0.10
C9	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.82	0.88	0.10	0.10	0.10
C8	0.00	0.00	0.03	1.00	1.00	1.03	0.78	0.82	0.85	0.10	0.10	0.10
C1	0.27	0.27	0.23	1.27	1.27	1.23	0.61	0.65	0.69	0.08	0.08	0.08
C10	0.10	0.13	0.13	1.10	1.13	1.13	0.56	0.57	0.61	0.07	0.07	0.07
						Total	7.76	8.16	8.53			

The ranking of the alternatives was determined using the chosen fuzzy methods after the weights of the criteria were ascertained. The experts evaluated the criteria by completing the questionnaire's second section and applying linguistic values (Table 5). Following the conversion of these linguistic values into fuzzy numbers, the steps of the fuzzy method should be performed out. Suppliers are labeled with S1 to S4.

Data normalization is the first step of the selected fuzzy methods. While the FMABAC method employs type 3 normalization, the FMARCOS and FCRADIS methods use the same normalization formula, or type 1 normalization. Every criterion belongs to the positive type, meaning that the objective is to achieve the highest rating so that each supplier is given a higher ranking. Following the creation of the normalized matrix, the fuzzy SWARA was used to calculate the criteria weights for this decision matrix. The FMARCOS and FCRADIS methods used the same formula in this step, while the FMABAC method also employed the weights (Eq. 7). The following steps are different for these methods. The suppliers were ranked by executing the steps of the selected methods (Table 6). The top-ranking supplier is S2, while the worst-ranking is S4. The same ranking was obtained by all fuzzy methods.

Table 5. Linguistic evaluations of alternatives by experts

	DM1				DM2				DM3			
	S1	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
C1	MB	M	MB	MG	B	MB	MB	M	MB	B	VB	MB
C2	M	MG	MG	M	M	G	VG	M	M	G	G	G
C3	MG	M	MG	M	M	MG	MG	M	M	MG	G	M
C4	MG	G	MG	VG	M	VG	G	M	M	VG	G	G
C5	MG	M	MG	M	MG	VG	G	M	M	VG	MG	MG
C6	MG	G	VG	M	MB	G	MG	MG	MG	VG	VG	MG
C7	M	MG	G	M	MB	MG	G	MB	MG	G	G	MG
C8	MB	MG	G	M	MB	G	G	M	MG	G	G	MG
C9	M	MG	MG	G	M	G	MG	M	G	G	G	MG
C10	MB	MB	B	M	MG	MB	MB	M	MB	B	MB	M

Table 6. Supplier ranking by different fuzzy methods

Supplier	FMABAC		FMARCOS		FCRADIS	
	Q_i	Rank	K_i	Rank	Q_i	Rank
S1	-0.186	4	0.374	4	0.482	4
S2	0.159	1	0.771	1	0.808	1
S3	0.148	2	0.759	2	0.798	2
S4	-0.065	3	0.514	3	0.596	3

A sensitivity analysis was conducted to examine the impact of the criteria weights on the ranking of the alternatives, i.e., suppliers. Twelve scenarios were employed in this sensitivity analysis, as was already mentioned. The weight values obtained through subjective evaluation and the FSWARA method are represented by the zero scenario. This scenario was treated as the initial scenario, and compared with the other scenarios. compare with the rankings of other scenarios to the one we started with. The first scenario presupposed that all criteria were given equal weights and importance.

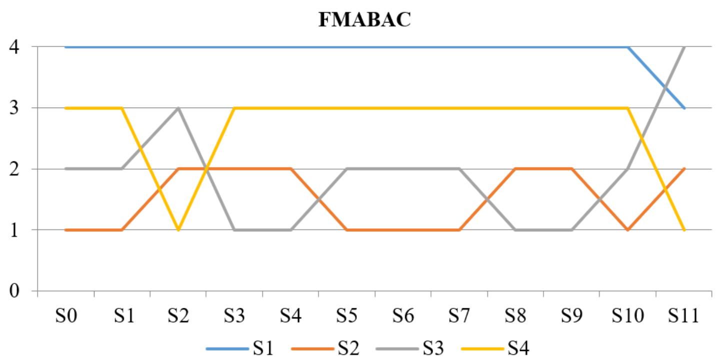

Figure 1. Results of sensitivity analysis by FMABAC method

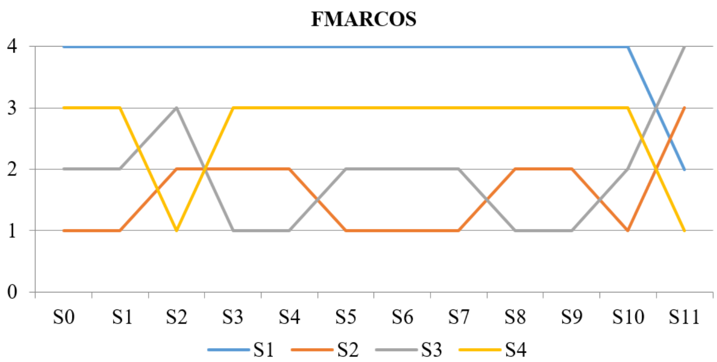

Figure 2. Results of sensitivity analysis by FMARCOS method

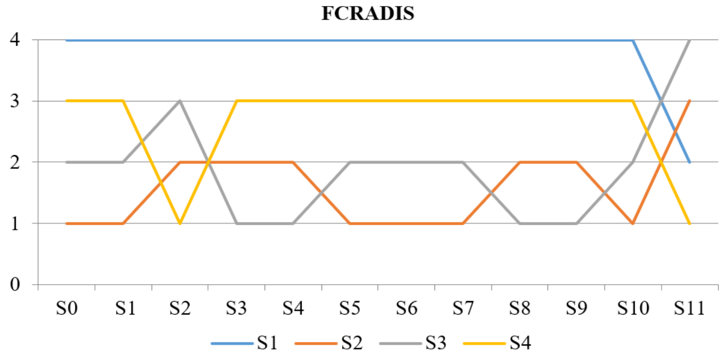

Figure 3. Results of sensitivity analysis by FCRADIS method

Ten additional scenarios were then created, each of which prioritizes one of the criteria. As a result, for the second scenario, criterion C1's weight was assigned so that it is eleven times more significant than other criteria. The other criteria were given a weight of 0.05, while this one was given a weight of w = 0.55. In a similar manner, the other scenarios were also acquired, with the exception that some criteria were given more weight than others.

The results of the sensitivity analysis revealed that almost all scenarios produced the same result, with scenario 11 being the exception, in which supplier S1 was replaced with S2 in the ranking order using the FMABAC method as opposed to the other two methods. Only the supplier S1 did not display the best outcomes in at least one of these scenarios, as shown by all these scenarios (Figures 1-3). The same order as in scenario zero was obtained in scenario S1. According to scenarios S2 and S11, supplier S4 produces the best results.

It was demonstrated that supplier S2 has the best results in five scenarios, while supplier S3 has the best results in four scenarios. This analysis revealed that, despite the FMABAC method using a different normalization and calculating the weighting of the data in a different way, there are no significant differences between the methods used for ranking. The sensitivity analysis showed that when the target company chooses suppliers, S2 and S3 should be prioritized. The supplier S4 has the worst results, so it should not be chosen.

The analyses above revealed that the methods used for the selection of suppliers do not significantly differ from one another. However, those who make decisions should go with the approach they feel works best for them and is the simplest. It is impossible to determine which approach is the best and most convenient for decision-makers based on the results of the obtained analyses. They can all be used for the GSS problem and other problems that try to rank alternatives because they all ended up getting the same results and solved this problem in the same way.

6. Discussion

Agri-food companies must place a high priority on environmental protection in order to comply with the increasingly demanding market conditions. Environmentally friendly components and raw materials must be utilized. They must build relationships with suppliers to obtain these eco-friendly materials. Suppliers should be held accountable for aiding the company in achieving that objective so that they can provide it with high-quality raw materials and components [34]. Only in this way can companies create a product that is both safe for human consumption and not ecologically harmful to the environment. Companies must carry out a GSS and choose a supplier who will assist them in achieving the said objectives. The use of both economic and environmental criteria in the selection process is presumptive for the GSS. Four suppliers were assessed in this study using a mix of economic and environmental criteria. Essentially, the goal of this combination is to choose the supplier who can best meet the objectives [7].

GSS exemplifies one of the fundamental problems with MCDM techniques. Utilizing these techniques is the key to resolving this problem. In fact, MCDM techniques are often employed when a number of alternatives are evaluated against a variety of criteria [35]. It is possible to employ various MCDM techniques at the same time. Each of these techniques has benefits and drawbacks. Additionally, there are numerous ways to apply these techniques, such as u sing a fuzzy set. In this study, fuzzy sets with linguistic values were used to solve the GSS. The goal is to make evaluation more compatible with human thoughts [36, 37]. In this way, the needs of decision-makers are met by this research.

In this study, a hybrid approach made up of various fuzzy methods was used to solve the GSS problem. The fuzzy SWARA method, one of the subjective methods, was used to calculate the weights of the criteria. The criteria were weighed in the light of the opinions of the experts. This approach produced results that indicated C6 (Environmental Management System) is the most critical criterion for experts, followed by C4 and C5 (partnership relations). It is vital to use an environmental management system by suppliers when producing raw materials and components, according to experts from the target company. In this way, they can be certain that the raw materials and components they procure are eco-friendly and will not harm the environment. To lessen the impact on ecology, it is not only crucial that the company does not pollute the environment but also that all processes - from production to consumption - be included. Established partnership ties with the supplier will provide the company with the assurance that the supplier will act as both a good partner and a source of quality raw materials. They will timely deliver the required raw materials and components, as well as assist them with the company's production.

The suppliers are ranked in accordance with the evaluations of the experts after the weights of the criteria have been established. In this study, three fuzzy methods - FMABAC, FMARCOS, and FCRADIS - were employed. These techniques are more recent, with the FCRADIS technique being the newest. The FMARCOS method is newer - it was developed in 2020 - and is very well accepted by scientists. The FMABAC method was developed in 2015 and has since been used in many research projects. The newest of these methods, the FCRADIS method, has not yet gained traction and is not as widely used as the other two. These techniques were used specifically to observe the application of new MCDM techniques at GSS. These methods have similar steps, but each has unique ones of its own.

The FMABAC method adds criterion weights to the traditional weighting and uses type 3 normalization and specific weighting of the normalized decision matrix. This method compares the alternatives based on how far they deviate from the geometric mean. This method is unique in that its values can either be positive or negative. The result will be positive and vice versa if the mean values of the alternatives are higher than this mean. The unique feature of the FMARCOS method is that ideal and anti-ideal solutions are added right away to the initial decision-making matrix. The standard steps of normalization and aggregation are next. Another unique feature is the calculation of the utility function in relation to these solutions. The ranking order is formed based on this function and the degree of utility, which are both determined at the end. The difference between the FCRADIS method and the FMARCOS method is that the utility function is carried out first, followed by the calculation of the deviation from the ideal and anti-ideal solutions. Then comes the calculation of the deviation from the optimal alternatives.

The results of these techniques illustrated that they all produced the same ranking order. S2 is rated as the best supplier, and S1 is rated as the worst. However, the results of these techniques revealed that supplier S3 also has excellent outcomes, though they are marginally inferior to supplier S2's. The sensitivity analysis performed disclosed that in four scenarios, S3 outranked supplier S2 in terms of ranking order. According to the evaluation of the company's experts, it can be said that these two suppliers should be the company's first choice. The sensitivity analysis also indicated that the ranking produced by the employed fuzzy methods is the same, with the exception of scenario S11. In this case, the ranking provided by the FMARCOS and FCRADIS methods differs from that given by the FMABAC method. Only the ranking of suppliers S1 and S4, who switched places in their ranking order, makes a difference. In this way, it was proved that the fuzzy methods used can be applied to MCDM problems where it is necessary to rank multiple alternatives.

7. Conclusion

One of the main issues with MCDM is supplier selection. Various MCDM techniques are used to solve this problem. The GSS problem was utilized in this study to meet the needs of the Biljana Brko company. While this company manufactures food products for the most part, it also engages in some agriculture activities. To solve the GSS problem, the authors used a fuzzy set to evaluate criteria and alternatives based on linguistic values. Three experts were chosen to assess the alternatives and criteria using linguistic values. These values were selected because, in contrast to traditional ratings, they are better suited to human thoughts.

To determine which supplier is the best, various fuzzy methods were used in conjunction with economic and ecological criteria. The weight of the criteria was established using fuzzy SWARA based on the linguistic evaluations of experts. The results of fuzzy SWARA, the criteria for environmental management system (C6) and partnership relations (C4) were given the highest weights, whereas the criteria for environmental competencies (C10) were given the lowest weights. Since the weights of these criteria did not differ significantly from one another, none of them significantly deviates from the other criteria. The use of three distinct fuzzy methods - FMABAC, FMARCOS, and FCRADIS - makes this study unique.

The results indicated that all of these methods produced the same ranking order and that supplier S2 has the highest expert ratings. The sensitivity analysis demonstrated that these methods do not significantly differ even when other ranking orders are obtained using different techniques. Thus, these approaches can be utilized to address the GSS problem and that decision-makers will obtain results that are nearly identical to each other, allowing them to base their final decisions on these results.

The choice of GSS criteria is the main shortcoming of this study. The experts from the target company assisted in the selection of the criteria and agreed that they were suitable for solving the GSS. The goal of this work, however, was to demonstrate how fuzzy MCDM methods can be used in this problem, not to cover all the criteria that could be used for GSS. The comparison of these approaches was another goal of this work. The comparison showed that all of the techniques used could be applied to future research. Another shortcoming of this study is the inclusion of only three experts. But these experts are the most qualified employees from the target company working in procurement. Other staff members lack sufficient knowledge to evaluate identified suppliers. In future research, it is necessary to include more experts and choose a new approach, whether it is a rough approach or another, and compare the selected methods with that approach.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. Puška, D. Božanić, M. Nedeljković, and M. Janošević, "Green supplier selection in an uncertain environment in agriculture using a hybrid MCDM model: Z-Numbers–Fuzzy LMAW–Fuzzy CRADIS model," *Axioms*, vol. 11, no. 9, pp. 427-427, 2022. https://doi.org/10.3390/axioms11090427.

[2] H. Shi, M. Y. Quan, H. C. Liu, and C. Y. Duan, "A novel integrated approach for green supplier selection with interval-valued intuitionistic uncertain linguistic information: A case study in the agri-food industry," *Sus.*, vol. 10, no. 3, pp. 733-733, 2018. https://doi.org/10.3390/su10030733.

[3] B. Okumus, S. Sönmez, S. Moore, D. P. Auvil, and G. D. Parks, "Exploring safety of food truck products in a developed country," *Int J. Hosp Manag*, vol. 81, pp. 150-158, 2019. https://doi.org/10.1016/j.ijhm.2019.02.011.

[4] M. M. Jenssen and L. de Boer, "Implementing life cycle assessment in green supplier selection: A systematic review and conceptual model," *J. Clean. Prod.*, vol. 229, pp. 1198-1210, 2019. https://doi.org/10.1016/j.jclepro.2019.04.335.

[5] P. Phochanikorn and C. Tan, "An integrated multi-criteria decision-making model based on prospect theory for green supplier selection under uncertain environment: A case study of the Thailand palm oil products industry," *Sus.*, vol. 11, no. 7, pp. 1872-1872, 2019. https://doi.org/10.3390/su11071872.

[6] N. Banaeian, H. Mobli, B. Fahimnia, I. E. Nielsen, and M. Omid, "Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry," *Comput. Oper. Res.*, vol. 89, pp. 337-347, 2018. https://doi.org/10.1016/j.cor.2016.02.015.

[7] S. Gupta, U. Soni, and G. Kumar, "Green supplier selection using multi-criterion decision making under fuzzy environment: A case study in automotive industry," *Comput. Ind. Eng.*, vol. 136, pp. 663-680, 2019. https://doi.org/10.1016/j.cie.2019.07.038.

[8] A. Pınar, R. Babak Daneshvar, and Y. S. Özdemir, "q-Rung ORTHOPAIR fuzzy TOPSIS method for green supplier selection problem," *Sus.*, vol. 13, no. 2, pp. 985-985, 2021. https://doi.org/10.3390/su13020985.

[9] A. Puška, Ž. Stević, and D. Pamučar, "Evaluation and selection of healthcare waste incinerators using extended sustainability criteria and multi-criteria analysis methods," *Environ. Dev. Sus.*, vol. 24, no. 9, pp. 11195-11225, 2022. https://doi.org/10.1007/s10668-021-01902-2.

[10] N. V. Thanh and N. T. K. Lan, "A new hybrid triple bottom line metrics and fuzzy MCDM model: Sustainable supplier selection in the food-processing industry," *Axioms*, vol. 11, no. 2, pp. 57-57, 2022. https://doi.org/10.3390/axioms11020057.

[11] G. Qu, Z. Zhang, W. Qu, and Z. Xu, "Green supplier selection based on green practices evaluated using fuzzy approaches of TOPSIS and ELECTRE with a case study in a Chinese internet company," *Int. J. Env. Res. Pub. He.*, vol. 17, no. 9, Article ID: 3268, 2020. https://doi.org/10.3390/ijerph17093268.

[12] H. M. Wang Chen, S. Y. Chou, Q. D. Luu, and T. H. K. Yu, "A fuzzy MCDM approach for green supplier selection from the economic and environmental aspects," *Math. Probl. Eng.*, vol. 2016, Article ID: 8097386, 2016. https://doi.org/10.1155/2016/8097386.

[13] B. D. Rouyendegh, A. Yildizbasi, and P. Üstünyer, "Intuitionistic fuzzy TOPSIS method for green supplier selection problem," *Soft. Comput.*, vol. 24, no. 3, pp. 2215-2228, 2020. https://doi.org/10.1007/s00500-019-04054-8.

[14] E. A. Bakeshlou, A. A. Khamseh, M. A. G. Asl, J. Sadeghi, and M. Abbaszadeh, "Evaluating a green supplier selection problem using a hybrid MODM algorithm," *J. Intell. Manuf.*, vol. 28, no. 4, pp. 913-927, 2017. https://doi.org/10.1007/s10845-014-1028-y.

[15] K. S. Chen, C. H. Wang, and K. H. Tan, "Developing a fuzzy green supplier selection model using six sigma quality indices," *Int. J. Prod. Econ.*, vol. 212, pp. 1-7, 2019. https://doi.org/10.1016/j.ijpe.2019.02.005.

[16] A. Çalık, "A novel Pythagorean fuzzy AHP and fuzzy TOPSIS methodology for green supplier selection in the Industry 4.0 era," *Soft Computing*, vol. 25, pp. 2253-2265, 2021. https://doi.org/10.1007/s00500-020-05294-9.

[17] M. Oroojeni Mohammad Javad, M. Darvishi, and A. Oroojeni Mohammad Javad, “Green supplier selection for the steel industry using BWM and fuzzy TOPSIS: A case study of Khouzestan steel company,” *Sus. Futures*, vol. 2, Article ID: 100012, 2020. https://doi.org/10.1016/j.sftr.2020.100012.
[18] F. Ecer, “Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: A case study of a home appliance manufacturer,” *Oper. Res-Ger.*, vol. 22, no. 1, pp. 199-233, 2022. https://doi.org/10.1007/s12351-020-00552-y.
[19] M. Yucesan, S. Mete, F. Serin, E. Celik, and M. Gul, “An integrated best-worst and interval type-2 fuzzy TOPSIS methodology for green supplier selection,” *Math.*, vol. 7, no. 2, pp. 182-182, 2019. https://doi.org/10.3390/math7020182.
[20] J. Qin, X. Liu, and W. Pedrycz, “An extended TODIM multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment,” *Eur. J. Oper. Res*, vol. 258, no. 2, pp. 626-638, 2017. https://doi.org/10.1016/j.ejor.2016.09.059.
[21] Q. Wu, L. Zhou, Y. Chen, and H. Chen, “An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods,” *Inform. Sci.*, vol. 502, pp. 394-417, 2019. https://doi.org/10.1016/j.ins.2019.06.049.
[22] B. Matić, S. Jovanović, D. K. Das, E. K. Zavadskas, Ž. Stević, S. Sremac, and M. Marinković, “A new hybrid MCDM model: Sustainable supplier selection in a construction company,” *Symmetry.*, vol. 11, no. 353, 2019. https://doi.org/10.3390/sym11030353.
[23] H. W. Lo, J. J. H. Liou, H. S. Wang, and Y. S. Tsai, “An integrated model for solving problems in green supplier selection and order allocation,” *J. Clean. Prod.*, vol. 190, pp. 339-352, 2018. https://doi.org/10.1016/j.jclepro.2018.04.105.
[24] S. Jafarzadeh Ghoushchi, M. Dodkanloi Milan, and M. Jahangoshai Rezaee, “Evaluation and selection of sustainable suppliers in supply chain using new GP-DEA model with imprecise data,” *J. Ind. Eng. Int.*, vol. 14, no. 3, pp. 613-625, 2017. https://doi.org/10.1007/s40092-017-0246-2.
[25] D. K. Sen, S. Datta, and S. S. Mahapatra, “Sustainable supplier selection in intuitionistic fuzzy environment: A decision-making perspective,” *Benchmarking: An International Journal*, vol. 25, no. 2, pp. 545-574, 2018. https://doi.org/10.1108/bij-11-2016-0172.
[26] M. Vasiljević, H. Fazlollahtabar, Ž. Stević, and S. Vesković, “A rough multicriteria approach for evaluation of the supplier criteria in automotive industry,” *Decision Making: Applications in Management and Engineering*, vol. 1, no. 1, pp. 82-96, 2018. https://doi.org/10.31181/dmame180182v.
[27] A. Amindoust, “Supplier selection considering sustainability measures: An application of weight restriction fuzzy-DEA approach,” *RAIRO-Oper. Res.*, vol. 52, pp. 981-1001, 2018. https://doi.org/10.1051/ro/2017033.
[28] I. Đalić, Ž. Stević, C. Karamasa, and A. Puška, “A novel integrated fuzzy PIPRECIA – interval rough SAW model: green supplier selection,” *Decision Making: Applications in Management and Engineering*, vol. 3, no. 1, pp. 126-145, 2020. https://doi.org/10.31181/dmame2003114d.
[29] A. Puška, D. Pamucar, I. Stojanović, F. Cavallaro, A. Kaklauskas, and A. Mardani, “Examination of the sustainable rural tourism potential of the Brčko district of Bosnia and Herzegovina using a fuzzy approach based on group decision making,” *Sus.*, vol. 13, no. 2, pp. 583-583, 2021. https://doi.org/10.3390/su13020583.
[30] L. A. Zadeh, “Fuzzy sets,” *Inform. Control*, vol. 8, no. 3, pp. 338-353, 1965. https://doi.org/10.1016/s0019-9958(65)90241-x.
[31] V. Keršuliene, E. K. Zavadskas, and Z. Turskis, “Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (Swara),” *J. Bus. Econ. Manag.*, vol. 11, no. 2, pp. 243-258, 2010. https://doi.org/10.3846/jbem.2010.12.
[32] D. Pamučar and G. Ćirović, “The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC),” *Expert. Syst. Appl.*, vol. 42, no. 6, pp. 3016-3028, 2015. https://doi.org/10.1016/j.eswa.2014.11.057.
[33] Ž. Stević, D. Pamučar, A. Puška, and P. Chatterjee, “Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement Alternatives and Ranking according to Compromise Solution (MARCOS),” *Comput. Ind. Eng.*, vol. 140, Article ID: 106231, 2020. https://doi.org/10.1016/j.cie.2019.106231.
[34] A. Puška, A. Maksimović, and I. Stojanović, “Improving organizational learning by sharing information through innovative supply chain in agro-food companies from Bosnia and Herzegovina,” *Oper. Res-ger. Eng. Sci: Lect. Notes.*, vol. 1, no. 1, pp. 76-90, 2018. https://doi.org/10.31181/oresta19012010175p.
[35] Č. Rozman, Z. Grgić, A. Maksimović, F. Ćejvanović, A. Puška, and B. Š. Bobić, “Multiple-criteria approach of evaluation of milk farm models in Bosnia and Herzegovina,” *Mljekarstvo.*, vol. 66, no. 3, pp. 206-214, 2016. https://doi.org/10.15567/mljekarstvo.2016.0305.
[36] Č. Rozman, A. Maksimović, A. Puška, Z. Grgić, K. Pažek, B. Prevolšek, and F. Ćejvanović, “The use of multi criteria models for decision support system in fruit production,” *Erwerbs-Obstbau.*, vol. 59, no. 3, pp. 235-243, 2017. https://doi.org/10.1007/s10341-017-0320-3.
[37] A. Puška, S. Kozarević, and J. Okičić, “Investigating and analyzing the supply chain practices and

performance in agro-food industry," *Int. J. Manag. Sci. Eng. Manag.*, vol. 15, no. 1, pp. 9-16, 2020. https://doi.org/10.1080/17509653.2019.1582367.