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Green Supplier Selection Based on the Combination of Fuzzy SWARA (SWARA-F) and Fuzzy MARCOS (MARCOS-F) Methods

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Highlights

- Proposes MCDM methodology that includes the combination of SWARA-F and MARCOS-F methods.
- Implements the novel hybrid MCDM methodology for green supplier selection.
- Presents real case study for the solution based on prioritizing and selecting the green suppliers.

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Abstract

The green supply chain operations try to minimize environmental impact over the product's lifetime including product recycling or use, reduction of harmful substances, resource saving, green design, etc. Supplier selection is the vital issue in green purchasing. This paper aims to develop applicable and efficient methodology for green supplier selection. The proposed methodology includes the combination of Fuzzy Stepwise Weight Assessment Ratio Analysis (SWARA-F) and Fuzzy Measurement Alternatives and Ranking according to the COmpromise Solution (MARCOS-F) methods. Fuzzy extensions of these methods are preferred because of the complexity of the green supplier selection problem and inclusion of both quantitative and qualitative criteria. Also, these criteria may be uncertain and conflict with each other. It is the first time that SWARA-F is combined with MARCOS-F for the green supplier assessment and selection of the best one among them. The effectiveness of the proposed methodology is demonstrated by solving the real selection problem of a company from textile industry. In the problem both classic and green criteria including main and sub-criteria are considered. SWARA-F is used for weighting the evaluation criteria and the rank of each green supplier alternatives is obtained from incomplete information by assessment score calculated from MARCOS-F. The effectiveness of the combination of two methods is verified by sensitivity and comparative analyses. The proposed methodology provides acceptable and satisfactory results in determining the best green supplier namely improving the environmental and cost efficiency evaluation process.

1. INTRODUCTION

The supply chain includes operations related with getting materials, producing intermediate and final products and distributing them to customers which provide relationships with suppliers and customers [1]. The management of these -upstream and downstream- relationships is called Supply Chain Management (SCM) [2]. It includes not only flows of money, processes, information and material but also planning of production and distribution scheduling [3, 4]. The main goal of SCM is adding customer value to the supply chain at less cost [2]. To achieve this goal, matching the right products with the right customers is vital. In the short run, effective SCM provides a reduction in inventory cycle time and an increase in productivity whereas in the long run, it provides an augmentation in the customer satisfaction and market share [5].

Suppliers are main and vital players of SCM. The supplier selection and their performance evaluations are strategic and critical decisions for the companies [6]. There are many scientific approaches in the literature that are suggested to make these decisions effectively. This study focuses on the suppliers selection decision process in which companies identify initial set of supplier alternatives, evaluate them, choose the bests and

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make contract with suppliers. Actually, reduction the alternatives to the final choices is the main aim of this process [7]. While evaluating the suppliers who have potential for fulfilling the companies' needs consistently and at an acceptable cost, multiple factors or criteria (qualitative or quantitative) are examined [5]. When the supplier selection literature has been reviewed, some common criteria such as quality, performance and delivery on time are encountered by the researchers [8]. However due to environmental awareness, environmental protection, governmental legislation and sustainable development issues, companies cannot survive in the global market considering only these criteria [6]. By adding the environmental thinking to the SCM, Green Supply Chain Management (GSCM) has arisen [9]. GSCM is the combination of environmental and SCM operations including material selection, product design, manufacturing, distribution and recycling [10]. Throughout the green supply chain, the green suppliers play a critical role and help the company to produce products with the right quality at a reasonable price as well as totally remove the environmental impact of operations in the supply chain.

As mentioned earlier, supplier selection and also green supplier selection are complex processes that consider multiple factors or criteria. Therefore, it is considered as a Multi Criteria Decision Making (MCDM) problem and solved with different MCDM analyzes. However, fuzzy structure in different parts of life makes such MCDM analyzes even more difficult. Decision makers' preferences and evaluations on a specific subject are often fuzzy and complex. The evaluations or opinions of decision makers cannot be expressed completely. Even the problem may involve uncertain and conflicting factors that cannot be foreseen and controlled [8]. Fuzzy set theory proposed by Zadeh [11] can enable to cope with ambiguity and complexity in the problem. Thanks to fuzzy set theory, precise evaluations are processed with linguistic variables and evaluations. In this study, an evaluation methodology is proposed to judge wide variety of green suppliers for a company which has environmental considerations. The objectives of current study can be summarized as: (i) to determine the selection criteria taken into account in evaluating green suppliers, (ii) to compute the relative importance weights of green supplier selection criteria, (iii) to rank green suppliers and select the best one by using a real case study in Turkey and (iv) to propose a practical and effective fuzzy decision making evaluation methodology to the decision makers for green supplier selection by achieving the first three objectives.

Fuzzy extensions of SWARA and MARCOS shortly named as SWARA-F and MARCOS-F are performed to measure validity of the methodology. In the application part, traditional and green criteria are integrated and weighted by SWARA-F. SWARA-F is one of the subjective weighting methods which is important in terms of reflecting decision makers' professional knowledge and experience. SWARA-F has several advantages when compared to other weighting methods. There is no need for large number of pairwise comparison matrices to determine relationships between criteria [12]. On the other hand, ranking and selection of potential green suppliers are performed with MARCOS-F. MARCOS method proposed by Stević et al. [13] was used to select sustainable suppliers. They also compared this method with other MCDM methods. As a result of the comparison, MARCOS method yielded good results and provided certain advantages over other MCDM methods in terms of processing ideal and anti-ideal solutions. To the best of our knowledge, combining SWARA-F and MARCOS-F is used for the first time in solving green supplier selection problem. To fill the gap in fuzzy MCDM literature, a real case study from Turkey has been presented. In this paper, sensitivity analysis is conducted to reveal the changes in rank order of green supplier alternatives due to variations of decision makers' weights in MARCOS method. Also, a comparative analysis is conducted between the rank orders of green supplier alternatives from MARCOS-F, CODAS-F, TOPSIS-F, and EDAS-F methods. A researcher may notice that complex decision making processes can be dealt more smoothly and efficiently by the proposed integrated evaluation methodology. Moreover, sensible and logical solutions for the problems and situations are provided by strengthening with multi-faceted decision analyses. The study also provides extensive literature review of these methods.

The organization of study is as follows. Literature related with green supplier selection criteria and selection methods are reviewed at the second section. In the third section, firstly main concepts of fuzzy set theory and basic fuzzy operations are presented. After that, core methods of this study are explained in detail. In the fourth section, a real case study from textile industry is solved. In the fifth section, sensitivity and comparative analyses are performed. In the sixth section, discussion and managerial implications are conducted. Finally, the conclusion and future research are given.

2. LITERATURE REVIEW

Different evaluation models are proposed for the green supply selection in the literature. These models handle both qualitative and quantitative criteria including traditional and green criteria. The most commonly used traditional criteria are cost, service and product quality, on time delivery, and flexibility [8]. The green criteria are mentioned with different names in different studies. While some authors have taken the green criteria generally, some authors have discussed these criteria in more detail. But in general, green criteria include green production process activities [14]. On the other hand, some researchers have considered only environmental sustainability issues and they have handled only environmental criteria for supplier selection [5]. Table 1 summarizes the results of the literature review in terms of the criteria used for green supply selection.

Table 1. *Summary of green supplier selection criteria*

Criteria	Authors	Definitions
Service or Service Level	Banaeian et al. [15], Sarwar et al. [16], Sun and Chai [17]	Performance in terms of reliability, responsiveness, assurance, warranty, on time delivery, after sale service, satisfaction
Enviromental Management System or Environment Management	Banaeian et al. [15], Sarwar et al. [16], Tuzkaya et al. [18], Gao et al. [19], Kannan et al. [20], Mohammed et al. [21], Qin et al. [22], Xu et al. [23], Javad et al. [24], Akcan ve Tas [25], Yazdani et al. [26]	Environmental quality assurance certificates, environmental policies, green process management
Cost	Zafar et al. [5], Galankashi et al. [7], Banaeian et al. [15], Sarwar et al. [16], Sun and Chai [17], Tuzkaya et al. [18], Gao et al. [19], Xu et al. [23], Javad et al. [24], Duan et al [27]	Purchasing, production, transportation, inspection, security, inventory, warranty, environmental costs
Quality	Zafar et al. [5], Galankashi et al. [7], Bali et al. [14], Banaeian et al. [15], Sarwar et al. [16], Sun and Chai [17], Gao et al. [19], Mohammed et al. [21], Xu et al. [23], Yazdani et al. [26], Duan et al. [27]	Material quality, operation excellence including percentage of defective products and percentage of rejected products, quality assurance and quality related certificates
Green Product	Buyukozkan and Cifci [4], Zafar et al. [5], Kannan et al. [6], Galankashi et al. [7], Bali et al. [14], Sarwar et al. [16], Tuzkaya et al. [18], Gao et al. [19], Qin et al. [22], Duan et al [27]	Green processes including green packaging, recycling, remanufacturing, reusing
Green Image	Kannan et al. [6], Bali et al. [14], Tuzkaya et al. [18], Qin et al. [22], Akcan ve Tas [25]	Social responsibility activities, trainings and programs for green consciousness
Pollution Control	Kannan et al. [6], Bali et al. [14], Sarwar et al. [16], Tuzkaya et al. [18], Gao et al. [19], Kannan et al. [20], Qin et al. [22], Duan et al [27]	Air emission pollutant, wastes of water and solid and harmful materials releases
Green Design or R&D	Galankashi et al. [7], Bali et al. [14], Kannan et al. [20], Javad et al. [24]	R&D activities for green design and green products

When the literature has been reviewed for solution methods of green supply selection problems, it is seen that different single and integrated methods have been proposed. These methods are summarized as MCDM methods, weighted linear model approaches, mathematical programming models, clustering methods, models based on human judgment, statistical analysis, and heuristic approaches [8]. In this study, we focused only on studies based on fuzzy set theory and MCDM methods. Table 2 summarizes existing single and integrated fuzzy MCDM methods for such problems.

Table 2. *Existing fuzzy MCDM methods for green supplier selection problems*

	Single methods	Integrated methods	
Fuzzy TOPSIS	Sarwar et al. [16], Mohammed et al. [21], Dogan et al. [28], Mousakhani et al. [29], Yucesan et al. [30], Rouyendegh et al. [31]	Fuzzy ANP and Fuzzy PROMETHEE	Tuzkaya et al. [18]
Fuzzy GRA	Vishnu et al. [32]	Fuzzy AHP and Fuzzy MOLP	Shaw et al. [44]
Fuzzy AHP	Zafar et al. [5], Ecer [33]	Fuzzy ANP, Fuzzy DEMATEL and Fuzzy TOPSIS	Buyukozkan and Cifci [4]
Fuzzy ANP	Galankashi et al. [7], Mina et al. [34]	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy MOLP	Kannan et al. [20]
Intuitionistic Fuzzy ELECTRE	Ustunyer et al. [35]	Intuitionistic Fuzzy Set and GRA	Bali et al. [14]
Fuzzy DEA	Yu and Su [36]	Fuzzy TOPSIS and TODIM	Arshadi Khamseh and Mahmoodi [10]
Fuzzy MULTIMOORA	Sen et al. [37]	Fuzzy AHP and Fuzzy ARAS	Mavi [45]
Fuzzy AD	Kannan et al. [6], Beng and Badrul [38], Guo et al. [39]	Interpretive Structural Modeling, Fuzzy MICMAC, Fuzzy AHP and Fuzzy VIKOR	Gavareshki et al. [46]
Fuzzy TODIM	Qin et al. [22], Sang and Liu [40]	Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy GRA	Banaeian et al. [15]
Fuzzy WASPAS	Keshavarz Ghorabaee et al. [41], Mishra et al. [42]	BWM, Modified fuzzy TOPSIS and Fuzzy MOLP	Lo et al. [47]
Intuitionistic Fuzzy COPRAS	Kumari and Mishra [43]	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy WASPAS and Fuzzy MABAC	Gupta et al. [48]
		Fuzzy PIPRECIA and Interval Rough SAW	Đalić et al. [49]
		Fuzzy TOPSIS and Fuzzy ELECTRE	Qu et al. [50]
		BWM and fuzzy TOPSIS	Javad et al. [24]
		Hesitant Fuzzy Linguistic SWARA and DNMA	Liao et al. [51]

3. SWARA-F AND MARCOS-F METHODS FOR GREEN SUPPLIER SELECTION

3.1. Fuzzy Set Theory

Fuzzy set theory was firstly introduced by Zadeh [12]. The main aim of the theory is modelling the uncertainty and vagueness mathematically. Also, it provides methods for analyzing the uncertainty in the structure of most decision problems [5]. A fuzzy set is defined as an extension of a crisp set. $\mu_{\tilde{A}}(x)$ presents membership function of a fuzzy set $\tilde{A}$ and it can take any real number value in the range [0,1]. Uncertain information in a problem or uncertain judgments of decision-makers are represented by a fuzzy number. A fuzzy number $\tilde{A}$ can be defined as a convex normalized fuzzy set $\tilde{A}$ belonging to the real line R. It has two features: (1) It exists such that $x_0 \in R$ with $\mu_{\tilde{A}}(x_0) = 1$ and (2) $\mu_{\tilde{A}}(x)$ is piecewise continuous [52].

It is preferred to use triangular fuzzy numbers (TFNs) in this study. TFNs are characterized as a triplet (a_1, a_2, a_3) and its membership function is described in Equation (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a_1 \\ (x - a_1) / (a_2 - a_1), & a_1 < x < a_2 \\ (a_3 - x) / (a_3 - a_2), & a_2 < x < a_3. \\ 0, & x > a_3 \end{cases} \quad (1)$$

By considering any two positive TFNs, $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ and a positive real number *r*, some main algebraic operations of two TFNs are expressed in the following [53]:

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (2)$$
$$\tilde{A} - \tilde{B} = (a_1 - b_3, a_2 - b_2, a_3 - b_1) \quad (3)$$
$$\tilde{A} \text{ x } r = (a_1 r, a_2 r, a_3 r) \quad (4)$$
$$\tilde{A} \text{ x } \tilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3) \quad (5)$$
$$\tilde{A} \div \tilde{B} = (a_1 \div b_3, a_2 \div b_2, a_3 \div b_1) . \quad (6)$$

Defuzzification process is required when a researcher wants to use a crisp number as output from a fuzzy system [54]. In this study, graded mean integration method [55] is adopted in terms of simplicity. This method defuzzifies a TFN $\tilde{A} = (a_1, a_2, a_3)$ as in Equation (7). $R(\tilde{A})$ is deffuzified value of $\tilde{A}$ [56]

$$R(\tilde{A}) = \frac{a_1 + 4a_2 + a_3}{6} . \quad (7)$$

3.2. Determining Selection Criteria and Alternatives

The companies have realized importance of the supplier selection issue for their operations due to increased environmental awareness and pressures. Green supplier selection process in GSCM requires several decision making steps. After defining company’s problem exactly, the next step is determination of green supplier selection criteria by considering needs of a company or structure of a problem. The decision makers, experts or decision committee identify the criteria by reviewing existing literature, considering industry’s specifications or examining on-site [39]. Both traditional and green criteria may be considered. After determining the criteria, a set of potential green supplier alternatives that meet these criteria is identified. In order to compare the alternatives with each other, it is necessary to clearly specify their performances under each criterion. The selection problem becomes more complex as number of alternatives and criteria in a problem increases.

3.3. Finding Selection Criteria Weights

The weights or importance degrees of criteria may be derived from different objective and subjective methods. In this paper, one of the subjective methods which is called SWARA (***S****tep-wise* ***W****eight* ***A****ssessment* ***R****atio* ***A****nalysis*) is performed for getting criteria weights. This method was firstly introduced by Keršuliene et al. [57] for the rational dispute resolution method selection. The main difference of

SWARA method from other similar methods is that decision makers choose their priorities according to the existing state of the environment. If the priorities of criteria are known former, the decisions about criteria and their priorities are made directly by SWARA method. The prime role on determining the criteria weights in this method belongs to a decision maker or an expert. Therefore, it is named as an expert oriented method [58-60].

Although many decision problems in the literature have been solved by performing SWARA method successfully, the development of SWARA-F method has been needed because of the nature of uncertainty in decision making. SWARA-F method is used to calculate the criteria weights in a fuzzy environment. It is also applicable for the problems including the group decision making [61]. SWARA-F method has been used for many problems in different areas due to be more appropriate to real case studies. These are outlined in Table 3.

Table 3. *Existing SWARA-F studies*

Methods	Authors	Application Areas
Fuzzy SWARA and Fuzzy MOORA	Mavi et al. [62]	Sustainable third-party reverse logistics provider selection
Fuzzy SWARA and Fuzzy WASPAS	Mardani et al. [12], Ulutas [63], Agarwal et al. [64]	Systematic review and meta-analysis, university website performance evaluation, solutions evaluation to overcome humanitarian supply chain management barriers
Fuzzy SWARA and Fuzzy COPRAS	Zarbakhshnia et al. [65], Ansari et al. [66]	Sustainable third-party reverse logistics provider selection, sustainable remanufacturing supply chain
Fuzzy SWARA and Fuzzy AD	Percin [61]	Outsourcing provider selection
Fuzzy SWARA and WASPAS	Ren et al. [67]	Electric vehicle charging station site selection
Fuzzy SWARA, Fuzzy TOPSIS, Fuzzy ARAS	Petrović et al. [68]	Supplier selection
Fuzzy SWARA and Fuzzy ARAS	Ulutas [69]	Supplier selection
Fuzzy SWARA and COPRAS	Rani et al. [70], Mishra et al. [71]	Sustainable supplier selection, sustainability evaluation of the bioenergy production process
Fuzzy SWARA and CoCoSo	Ulutas et al. [72]	Location selection
Fuzzy SWARA and PROMETHEE	Ghasemi et al. [73]	Sustainable medical tourism destinations ranking

SWARA-F method requires same application steps as SWARA method. Researchers who need more information about SWARA method can refer to the article of Keršulienė et al. [57]. The main difference between SWARA and SWARA-F methods is employment of fuzzy numbers. The application steps of SWARA-F method are summarized as follows by assuming that there is a set of *n* criteria C_j (j = 1,2,…,n) in the problem [62, 65]:

Step 1. The decision maker is asked to rank the criteria from the best (ideal) to the worst (anti-ideal) by considering his/her expertise. Starting from the second criterion, the comparative importance levels are determined for each criterion by using fuzzy scale presented in Table 4. This ratio represents the comparative importance of average value ($\tilde{s}_j$).

Table 4. *Linguistic variables for comparative importance levels [74]*

Linguistic variable	Corresponding triangular fuzzy number
Much less important	(0.222, 0.250, 0.286)
Very less important	(0.286, 0.333, 0.400)
Less important	(0.400, 0.500, 0.667)
Moderately less important	(0.667, 1.000, 1.500)
Equally important	(1.000, 1.000, 1.000)

Step 2. The fuzzy coefficient ($\tilde{k}_j$) is calculated by considering each criterion as follows:

$$\tilde{k}_j = \begin{cases} 1 & \text{if} \quad j = 1 \\ \tilde{s}_j + 1 & \text{if} \quad j > 1. \end{cases} \tag{8}$$

Step 3. The fuzzy weight ($\tilde{q}_j$) is calculated by considering each criterion as follows:

$$\tilde{q}_j = \begin{cases} 1 & \text{if} \quad j = 1 \\ \dfrac{\tilde{q}_{j-1}}{\tilde{k}_j} & \text{if} \quad j > 1. \end{cases} \tag{9}$$

Step 4. The final fuzzy weight of each criterion ($\tilde{w}_j$) is calculated by dividing fuzzy weights ($\tilde{q}_j$) found in Step 3 by their sum

$$\widetilde{w}_j = \frac{\tilde{q}_j}{\sum \tilde{q}_j}. \tag{10}$$

The four steps mentioned above for SWARA-F are applied separately for each decision maker in the selection process. Thus, it can be said that number of criteria weight set is equal to number of decision makers. To continue the selection process, these different criteria weights sets need to be aggregated. The aggregation can be performed with different ways. In this study, weights of decision makers are performed during aggregation process. The weights of decision makers are also chosen to reflect decision maker's professional knowledge and experience. In this study, they are taken as crisp numbers and following formula is applied for aggregation purposes by assuming that there is a set of K decision makers (k = 1,2,…,K) in the problem:

$$\widetilde{w}_j = \sum_{k=1}^{K} w_k \, \widetilde{w}_j^k = \left(\sum_{k=1}^{K} w_k \, a_j^k, \sum_{k=1}^{K} w_k \, b_j^k, \sum_{k=1}^{K} w_k \, c_j^k\right), \quad (j = 1,2,...,n;\ k=1,2,...,K). \tag{11}$$

In Equation (11), $\widetilde{w}_j$ is the aggregated fuzzy weight of jth criterion. $\widetilde{w}_j^k$ presents fuzzy weight of jth criterion which is determined by kth decision maker and it is described by TFNs, $\widetilde{w}_j^k=(a_j^k, b_j^k, c_j^k)$. Finally, w_k presents weight of kth decision maker.

3.4. Finding The Rank Order of the Alternatives

MARCOS (**M**easurement **A**lternatives and **R**anking according to the **CO**mpromise Solution) is relatively new MCDM method. It was developed by Stević et al. [13]. This method determines preferability of alternatives by considering the relationship between alternatives and reference values. Defining decision making preferences is performed through utility functions. They show the position of an alternative relative to ideal and anti-ideal solutions [75]. The alternative closest to the ideal alternative and furthest from the anti-ideal alternative is the best [76]. Since it is a new method, there are few studies in the literature. These are outlined in Table 5.

Table 5. *Existing MARCOS-F studies*

Methods	Authors	Application Areas
MARCOS	Stević et al. [13]	Sustainable supplier selection for the healthcare industry
	Stević and Brković [76]	Personnel selection in logistic
	Puška et al. [77]	Project management software evaluation
	Ulutaş et al. [78]	Stackers selection in a logistics system
	Biswas [79]	Performance measurement of healthcare supply chains
Fuzzy MARCOS	Stanković et al. [75]	Traffic risk assessment problem
	Ilieva et al. [80]	Cloud service selection
	Mitrović Simić et al. [81]	Safety evaluation of road sections
	Simić et al. [82]	Risk assessment of railway infrastructure
	Taş and Çakır [83]	Road risk analysis
	Pamucar et al. [84]	Prioritization of alternatives for hydrogen bus development
	Bakır and Atalık [85]	E-service quality evaluation in the airline industry
	Puška et al. [86]	Sustainable supplier selection
	Tuş and Aytaç Adalı [87]	Internet service provider selection problem
	Ecer and Pamucar [88]	Insurance companies assessment
	Celik and Gul [89]	Hazard identification, risk assessment and control for dam construction
	Gong et al. [90]	Renewable energy accommodation potential evaluation of distribution network
	Ali [91]	Smartphone selection problem
	Pamucar et al. [92]	Assessment of alternative fuel vehicles for sustainable road transportation
	Deveci et al. [93]	Offshore wind farm site selection
Grey MARCOS	Badi and Pamucar [94]	Supplier selection for the steelmaking company
	Torkayesh et al. [95]	Landfill location selection for healthcare waste of urban areas
D-MARCOS	Chakraborty et al. [96]	Supplier selection in an iron and steel industry

MARCOS-F, developed by Stanković et al. [75], defines fuzzy ideal and fuzzy anti-ideal reference values instead of crisp reference values differently from MARCOS method. It determines the relationships between alternatives and these fuzzy reference values and also defines the utility degrees of alternatives related with the fuzzy ideal and fuzzy anti-ideal solutions for ranking purpose. The steps of this method are as follows:

Step 1*:* The fuzzy decision matrix $\tilde{X}^k$ which includes fuzzy performances of different alternatives according to various criteria is formed by kth decision maker by assuming that problem includes m alternatives, A_i (i = 1,2,…,m), n criteria C_j (j = 1,2,…,n) and K decision makers DM_k (k = 1,2,…,K). The decision makers use linguistic variables which are shown in Table 6 while evaluating the alternatives according to criteria.

$$\tilde{X}^k = \left[\tilde{x}_{ij}^k\right]_{mxn} = \begin{bmatrix} \tilde{x}_{11}^k & \cdots & \tilde{x}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^k & \cdots & \tilde{x}_{mm}^k \end{bmatrix} \quad , \quad (i = 1,2...,m;\ j = 1,2,...,n;\ k=1,2, K), \tag{12}$$

$\tilde{x}_{ij}^k$ is the fuzzy performance value of *i*th alternative on *j*th criterion of the *k*th decision maker and it is described by TFNs, $\tilde{x}_{ij}^k$ =(a_{ij}^k , b_{ij}^k , c_{ij}^k). To continue MARCOS-F method, different decision matrices need to be aggregated. In this study, weights of decision makers are taken into consideration during aggregation process as in previous section. The decision makers' weights in this section are still crisp numbers. Equation (14) is applied for finding the elements of group decision matrix ($\tilde{X}$). It is formed as:

$$\tilde{X} = \left[\tilde{x}_{ij}\right]_{mxn} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \qquad (i = 1,2...,m;\ j = 1,2,...,n)\ , \tag{13}$$

$$\tilde{x}_{ij} = \sum_{k=1}^{K} w_k\, \tilde{x}_{ij}^k = \left(\sum_{k=1}^{K} w_k\, a_{ij}^k\, ,\ \sum_{k=1}^{K} w_k\, b_{ij}^k\, ,\ \sum_{k=1}^{K} w_k\, c_{ij}^k\right) (i=1,2,...,m;\ j=1,2,...,n;\ k=1,2,...,K), \tag{14}$$

$\tilde{x}_{ij}$ is aggregated fuzzy performance value of *i*th alternative on *j*th criterion, $\tilde{x}_{ij}$ =(a_{ij} , b_{ij} , c_{ij}) and w_k is weight of *k*th decision maker.

Table 6. *Linguistic variables for alternatives' performances evaluations [97]*

Rank	Corresponding triangular fuzzy number
Very Low (VL)	(0, 0, 0.25)
Low (L)	(0, 0.25, 0.5)
Medium (M)	(0.25, 0.5, 0.75)
High (H)	(0.5, 0.75, 1)
Very High (VH)	(0.75, 1, 1)

Step 2: An extended fuzzy group decision matrix is formed by adding ideal $\tilde{A}(ID)$ and anti-ideal $\tilde{A}(AID)$ solutions. The alternative with the best and worst characteristics is called ideal solution and anti-ideal solution, respectively

$$\tilde{X} = \left[\tilde{x}_{ij}\right]_{(m+1)x(n+1)} = \begin{bmatrix} \tilde{x}_{AID1} & \cdots & \tilde{x}_{AIDn} \\ \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ . & \ddots & . \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \\ \tilde{x}_{ID1} & \cdots & \tilde{x}_{IDn} \end{bmatrix} \quad , \quad (i = 1,2...,m;\ j = 1,2,...,n). \tag{15}$$

Types of the criteria, maximization or minimization, are considered while determining $\tilde{A}(ID)$ and $\tilde{A}(AID)$ solutions. The necessary procedure is as follows:

for maximization criteria $\quad \tilde{A}(ID) = \max_i \tilde{x}_{ij}$ (16a)

$\tilde{A}(AID) = \min_i \tilde{x}_{ij}$

for minimization criteria $\quad \tilde{A}(ID) = \min_i \tilde{x}_{ij}$ (16b)

$\tilde{A}(AID) = \max_i \tilde{x}_{ij}$.

Step 3: Fuzzy normalized decision matrix ($\tilde{N}$) is determined. Maximization and minimization criteria are normalized by Equations (18a)-(18b), respectively. In this study, it is preferred to use linear scale normalization formulas used in fuzzy TOPSIS method. The reason for performing this formula is the comparative analysis performed in the later section of the study. One of the methods in the comparative analysis section is fuzzy TOPSIS. It is thought that it would be correct to use the same normalization method in order to make the meaningful comparisons with the results of the fuzzy MARCOS method

$$\tilde{N} = \left[\tilde{n}_{ij}\right]_{mxn}\ , \tag{17}$$

$$\tilde{n}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad , \qquad (i = 1,2\ldots,m;\ j = 1,2,\ldots,n)\ , \tag{18a}$$

$$\tilde{n}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \qquad (i = 1,2...,m;\ j = 1,2,...,n)\ , \tag{18b}$$

$$a_j^- = \min_i a_{ij}\ , \tag{19}$$

$$c_j^* = \max_i c_{ij}\ , \tag{20}$$

$\tilde{n}_{ij}$ is the normalized fuzzy performance values. The normalization formulas in Equations (18a) and (18b) provide the ranges of normalized TFNs are between [0,1].

Step 4: The fuzzy weighted normalized decision matrix $\tilde{R}$ is calculated. $\tilde{r}_{ij}$ values are calculated by Equation (22):

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn} \tag{21}$$

$$\tilde{r}_{ij} = \widetilde{w}_j \tilde{n}_{\mathrm{ij}} \tag{22}$$

where $\widetilde{w}_{\mathrm{j}}$ ($0 < \widetilde{w}_{\mathrm{j}} < 1$) is the weight of *j*th criterion.

***Step 5**:* The utility degree of each alternative ($\widetilde{K}_i$) is computed by Equations (23a)-(23b)

$$\widetilde{\mathrm{K}}_{\mathrm{i}}^- = \frac{\tilde{S}_i}{\tilde{S}_{AID}} \tag{23a}$$

$$\widetilde{\mathrm{K}}_{\mathrm{i}}^+ = \frac{\tilde{S}_i}{\tilde{S}_{ID}} \tag{23b}$$

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{r}_{ij}. \tag{24}$$

Step 6: The total utility degree including both ideal and anti-ideal solutions of each alternative ($\tilde{T}_i$) is computed by Equation (25):

$$\tilde{T}_i = \widetilde{\mathrm{K}}_{\mathrm{i}}^- + \widetilde{\mathrm{K}}_{\mathrm{i}}^+ . \tag{25}$$

To continue the operations, a new fuzzy representative value of total utility degrees is found as:

$$\tilde{R}_i = \max_i \tilde{T}_i. \tag{26}$$

Then $\tilde{R}_i$ is defuzzified with Equation (7) and the crisp result is R_i.

Step 7: Utility functions for the ideal and anti-ideal solutions are computed by Equations (27a)-(27b), respectively

$$f\left(\widetilde{K}_i^+\right) = \frac{\widetilde{\mathrm{K}}_{\mathrm{i}}^-}{R_i}, \tag{27a}$$

$$f\left(\widetilde{K}_i^-\right) = \frac{\widetilde{\mathrm{K}}_{\mathrm{i}}^+}{R_i}. \tag{27b}$$

Step 8: The total utility of each alternative *f(K$_i$)* is computed as follows:

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

K_i^+, K_i^-, $f(K_i^+)$ and $f(K_i^-)$ are defuzzified values of $\widetilde{K}_i^+$, $\widetilde{K}_i^-$, $f\left(\widetilde{K}_i^+\right)$ and $f\left(\widetilde{K}_i^-\right)$ respectively in Equation (28). The total utility of each alternative, *f(K$_i$)*, is used as the final assessment score of each alternative for ranking purposes. The one with the highest total utility value is the best alternative.

4. APPLICATION

In this part, real case study is considered for applicability of SWARA-F and MARCOS-F in solving green supplier selection problems. A textile company operated in Denizli, Turkey is chosen as a real case study. The case company produces its own woven and knitted fabrics, converts them to the towel and bathrobe, and then exports them to European market. The company supplies many raw materials from its suppliers. The textile dyes, one of the main raw materials, are the subject of this study. Many foreign customers prefer to purchase green and environmental friendly textile products. The company searches the best green supplier for purchasing the textile dyes of its products. The main aim of this search is surviving in the competitive market and protecting the environment. An expert group of three people, managers from purchasing (DM_1), production (DM_2) and quality control (DM_3) departments, are responsible from identifying the green supplier alternatives and selecting the best supplier. Purchasing managers procure goods and services for resale or company use. Production managers provide technical management, supervision and control of production process. Quality control managers ensure products meet quality, reliability and performance standards. As mentioned before, weight values are assigned to each decision maker during the selection process to get more rational results. In this way, each decision maker can be part of the selection process as much as his/her own weight. In this study, their weights are considered as: $w_{DM1}=0.3$, $w_{DM2}=0.3$ and $w_{DM3}=0.4$. Then, they determine the criteria by taking into account of the company's needs and existing green supplier management literature. There are four main criteria and their sub-criteria in the evaluation process:

- Cost (C_1): Product price (C_{11}), Logistic cost (C_{12})
- Service (C_2): Delivery on time (C_{21}), Flexibility and responsiveness (C_{22})
- Quality of the ingredient (C_3): Conformance to specification (C_{31}), Product reliability (C_{32}), Packaging facilities (C_{33})
- Green criteria (C_4): Environmental management system (C_{41}), Recycle rate (C_{42}), Green technology (C_{43}), Waste management system (C_{44})

The first three main criteria and related the sub-criteria are classical criteria as mentioned in Section 2. The fourth main criterion and related sub-criteria are the green criteria. Since the main purpose of this study is the selection of green suppliers, only the explanations of the fourth criterion and related sub-criteria are given in this section. In fact, general descriptions of these criteria are provided in Table 1. Green criteria (C_4) address the evaluation of environmental impact. Environmental management system (C_{41}) involves environmental certificates, environmental policies, planning, checking, and control of environmental activities. Recycle rate (C_{42}) is the percentage of product unit to be collected and recycled by the service provider. Green technology (C_{43}) is the type of technology that is considered environmentally friendly based on its production process or its supply chain. Finally, waste management system (C_{44}) is the strategy that an organization uses to dispose, reduce, reuse, and prevent waste. On the other hand, C_{11}, C_{12} and C_{21} are minimization criteria while the others are maximization criteria. After investigating all potential suppliers, they determine five green supplier alternatives (A_1, A_2,…,A_5) for further analysis. The relative weights of main criteria given by DM_1 with SWARA-F method are shown in Table 7. Tables 8-11 show local weights of sub-criteria given by DM_1. These weights are obtained by using Equations (8)-(10). This process is same for the other decision makers, DM_2 and DM_3. Final weights of sub-criteria for all decision makers are presented in Table 12. These weights are aggregated by using Equation (11) and the results are shown in the last three column of Table 12.

Table 7. *Relative weights of main criteria for DM_1*

	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_1		(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(0.453, 0.460, 0.468)
C_2	(1.000, 1.000, 1.000)	(2.000, 2.000, 2.000)	(0.500, 0.500, 0.500)	(0.227, 0.230, 0.234)
C_3	(0.286, 0.333, 0.400)	(1.286, 1.333, 1.400)	(0.357, 0.375, 0.389)	(0.162, 0.172, 0.182)
C_4	(0.222, 0.250, 0.286)	(1.222, 1.250, 1.286)	(0.278, 0.300, 0.318)	(0.126, 0.138, 0.149)

Table 8. *Local weights of cost for DM_1*

	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_{11}		(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(0.563, 0.571, 0.583)
C_{12}	(0.286, 0.333, 0.400)	(1.286, 1.333, 1.400)	(0.714, 0.750, 0.778)	(0.402, 0.429, 0.454)

Table 9. *Local weights of service for DM_1*

	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_{21}		(1.000 1.000 1.000)	(1.000 1.000 1.000)	(0.583 0.600 0.625)
C_{22}	(0.400 0.500 0.667)	(1.400 1.500 1.667)	(0.600 0.667 0.714)	(0.350 0.400 0.446)

Table 10. *Local weights of* quality of the ingredient *for DM_1*

	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_{31}		(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(0.493, 0.545, 0.610)
C_{32}	(0.667, 1.000, 1.500)	(1.667, 2.000, 2.500)	(0.400, 0.500, 0.600)	(0.197, 0.273, 0.366)
C_{33}	(0.400, 0.500, 0.667)	(1.400, 1.500, 1.667)	(0.240, 0.333, 0.428)	(0.118, 0.182, 0.261)

Table 11. *Local weights of* green criteria *for DM_1*

	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_{41}		(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(0.375, 0.400, 0.438)
C_{42}	(0.400, 0.500, 0.667)	(1.400, 1.500, 1.667)	(0.600, 0.667, 0.714)	(0.225, 0.267, 0.313)
C_{43}	(0.286, 0.333, 0.400)	(1.286, 1.333, 1.400)	(0.428, 0.500, 0.555)	(0.161, 0.200, 0.243)
C_{44}	(0.400, 0.500, 0.667)	(1.400, 1.500, 1.667)	(0.257, 0.333, 0.397)	(0.096, 0.133, 0.174)

Table 12. *Final weights of sub-criteria*

	DM_1	DM_2	DM_3	Aggregated weights
C_{11}	(0.255, 0.263, 0.273)	(0.156, 0.171, 0.192)	(0.106, 0.121, 0.138)	(0.166, 0.179, 0.195)
C_{12}	(0.182, 0.197, 0.212)	(0.094, 0.114, 0.137)	(0.083, 0.097, 0.113)	(0.116, 0.132, 0.150)
C_{21}	(0.132, 0.138, 0.146)	(0.064, 0.082, 0.099)	(0.064, 0.081, 0.098)	(0.085, 0.098, 0.113)
C_{22}	(0.079, 0.092, 0.105)	(0.046, 0.061, 0.077)	(0.050, 0.065, 0.080)	(0.057, 0.072, 0.087)
C_{31}	(0.080, 0.094, 0.111)	(0.151, 0.165, 0.185)	(0.142, 0.151, 0.165)	(0.126, 0.138, 0.155)
C_{32}	(0.032, 0.047, 0.067)	(0.091, 0.110, 0.132)	(0.110, 0.121, 0.135)	(0.081, 0.096, 0.114)
C_{33}	(0.019, 0.031, 0.048)	(0.065, 0.082, 0.103)	(0.079, 0.091, 0.105)	(0.057, 0.070, 0.087)
C_{41}	(0.047, 0.055, 0.065)	(0.068, 0.081, 0.096)	(0.093, 0.109, 0.129)	(0.072, 0.084, 0.100)
C_{42}	(0.028, 0.037, 0.047)	(0.049, 0.061, 0.075)	(0.072, 0.087, 0.106)	(0.052, 0.064, 0.079)
C_{43}	(0.020, 0.028, 0.036)	(0.029, 0.040, 0.054)	(0.029, 0.044, 0.063)	(0.026, 0.038, 0.052)
C_{44}	(0.012, 0.018, 0.026)	(0.023, 0.032, 0.044)	(0.021, 0.033, 0.049)	(0.019, 0.028, 0.041)

Before proceeding implementation steps of MARCOS-F method for ranking purpose, each decision maker is asked to assess the alternatives on the criteria basis. The linguistic variables in Table 6 are utilized while making these evaluations. The linguistic evaluations are presented in Table 13. These linguistic variables are translated into TFNs to be processed. Three different decision matrices belong to each decision maker are aggregated to get only one decision matrix. By using Equation (14), the weights of decision makers are considered during aggregation process. Then, ideal and anti-ideal solutions are determined and placed in the fuzzy group decision matrix. By this way, extended fuzzy decision matrix is formed and this matrix is normalized by using Equation (18a) and (18b) and weighted normalized fuzzy decision matrix is obtained by using Equation (22). Utility degree of each alternative ($\tilde{K}_i$) is computed by Equation (23a)-(23b); the total utility degree in terms of both ideal and anti-ideal solutions of each alternative ($\tilde{T}_i$) is computed by Equation (25); utility functions for ideal and anti-ideal solutions are computed by Equation (27a)-(27b); and lastly, the total utility of each alternative $f(K_i)$ is computed by Equation (28). K_i^+ , K_i^-, $f(K_i^+)$ and $f(K_i^-)$ are defuzzified values of $\tilde{K}_i^+$, $\tilde{K}_i^-$, $f(\tilde{K}_i^+)$ and $f(\tilde{K}_i^-)$ computed with Equation (7). According to $f(K_i)$ values in Table 14, alternatives are ranked and A_1 is seen more appropriate than the other alternatives.

Table 13. *Performances of green supplier alternatives on the criteria basis*

		C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}
DM_1	A_1	M	M	M	VH	VH	VH	M	VH	M	VH	M
	A_2	M	M	VH	M	M	M	H	H	VH	M	VH
	A_3	VH	VH	M	M	VH	M	VH	M	M	H	VH
	A_4	H	M	VH	H	M	H	M	VH	VH	VH	H
	A_5	M	H	M	H	M	VH	M	L	H	M	M
DM_2	A_1	H	M	H	VH	H	VH	H	H	H	VH	H
	A_2	VL	H	H	VL	L	H	H	VH	VH	H	VH
	A_3	VH	VH	M	M	VH	M	VH	M	M	H	VH
	A_4	L	H	VH	M	H	L	L	H	H	H	VH
	A_5	H	L	H	H	M	VH	VL	L	VH	VL	H
DM_3	A_1	H	H	M	VH	VH	VH	M	VH	H	H	M
	A_2	L	M	H	H	H	VL	H	H	VH	M	H
	A_3	VH	VH	VL	L	H	L	VH	VL	L	H	VH
	A_4	VH	H	VH	VH	M	H	M	VH	VH	VH	M
	A_5	VL	L	H	H	M	VH	L	L	H	VL	L

Table 14. *Ranking of alternatives*

	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Ranking
A_1	2.821	0.917	0.238	0.733	0.820	1
A_2	2.611	0.830	0.216	0.679	0.673	2
A_3	2.297	0.738	0.192	0.597	0.516	5
A_4	2.380	0.768	0.200	0.619	0.560	3
A_5	2.340	0.745	0.194	0.608	0.531	4

5. SENSITIVITY AND COMPARATIVE ANALYSES

Sensitivity analysis is performed to reveal changes in rank orders of the green supplier alternatives. Since decision makers' weight significantly affects the rank, changes of them should be evaluated. For this purpose, 36 different scenarios including different decision makers' weights are considered and they are shown in Table 15. At the same time, the same green supplier problem is solved also with CODAS-F, TOPSIS-F and EDAS-F methods to show the validity of MARCOS-F method. CODAS, TOPSIS, and EDAS methods are well known MCDM methods. CODAS method was developed by Keshavarz Ghorabaee et al. [98], TOPSIS method was developed by Hwang and Yoon [99] whereas EDAS method was developed by Keshavarz Ghorabaee et al. [100]. In the literature there are lots of successful applications of three methods. The common characteristic of three methods compared to MARCOS method is being distance-based methods. In other words, preferability of an alternative depends on the distance from Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) in TOPSIS method, average solution in EDAS method and NIS in CODAS method [101]. The same normalization procedure is utilized on three methods for the comparison purpose.

Table 15. *36 scenarios generated by different decision makers' weights*

Scenarios				Scenarios				Scenarios			
1	$w_{DM1}=0,1$	$w_{DM2}=0,1$	$w_{DM3}=0,8$	13	$w_{DM1}=0,2$	$w_{DM2}=0,5$	$w_{DM3}=0,3$	25	$w_{DM1}=0,4$	$w_{DM2}=0,4$	$w_{DM3}=0,2$
2	$w_{DM1}=0,1$	$w_{DM2}=0,2$	$w_{DM3}=0,7$	14	$w_{DM1}=0,2$	$w_{DM2}=0,6$	$w_{DM3}=0,2$	26	$w_{DM1}=0,4$	$w_{DM2}=0,5$	$w_{DM3}=0,1$
3	$w_{DM1}=0,1$	$w_{DM2}=0,3$	$w_{DM3}=0,6$	15	$w_{DM1}=0,2$	$w_{DM2}=0,7$	$w_{DM3}=0,1$	27	$w_{DM1}=0,5$	$w_{DM2}=0,1$	$w_{DM3}=0,4$
4	$w_{DM1}=0,1$	$w_{DM2}=0,4$	$w_{DM3}=0,5$	16	$w_{DM1}=0,3$	$w_{DM2}=0,1$	$w_{DM3}=0,6$	28	$w_{DM1}=0,5$	$w_{DM2}=0,2$	$w_{DM3}=0,3$
5	$w_{DM1}=0,1$	$w_{DM2}=0,5$	$w_{DM3}=0,4$	17	$w_{DM1}=0,3$	$w_{DM2}=0,2$	$w_{DM3}=0,5$	29	$w_{DM1}=0,5$	$w_{DM2}=0,3$	$w_{DM3}=0,2$
6	$w_{DM1}=0,1$	$w_{DM2}=0,6$	$w_{DM3}=0,3$	18	$w_{DM1}=0,3$	$w_{DM2}=0,3$	$w_{DM3}=0,4$	30	$w_{DM1}=0,5$	$w_{DM2}=0,4$	$w_{DM3}=0,1$
7	$w_{DM1}=0,1$	$w_{DM2}=0,7$	$w_{DM3}=0,2$	19	$w_{DM1}=0,3$	$w_{DM2}=0,4$	$w_{DM3}=0,3$	31	$w_{DM1}=0,6$	$w_{DM2}=0,1$	$w_{DM3}=0,3$
8	$w_{DM1}=0,1$	$w_{DM2}=0,8$	$w_{DM3}=0,1$	20	$w_{DM1}=0,3$	$w_{DM2}=0,5$	$w_{DM3}=0,2$	32	$w_{DM1}=0,6$	$w_{DM2}=0,2$	$w_{DM3}=0,2$
9	$w_{DM1}=0,2$	$w_{DM2}=0,1$	$w_{DM3}=0,7$	21	$w_{DM1}=0,3$	$w_{DM2}=0,6$	$w_{DM3}=0,1$	33	$w_{DM1}=0,6$	$w_{DM2}=0,3$	$w_{DM3}=0,1$
10	$w_{DM1}=0,2$	$w_{DM2}=0,2$	$w_{DM3}=0,6$	22	$w_{DM1}=0,4$	$w_{DM2}=0,1$	$w_{DM3}=0,5$	34	$w_{DM1}=0,7$	$w_{DM2}=0,1$	$w_{DM3}=0,2$
11	$w_{DM1}=0,2$	$w_{DM2}=0,3$	$w_{DM3}=0,5$	23	$w_{DM1}=0,4$	$w_{DM2}=0,2$	$w_{DM3}=0,4$	35	$w_{DM1}=0,7$	$w_{DM2}=0,2$	$w_{DM3}=0,1$
12	$w_{DM1}=0,2$	$w_{DM2}=0,4$	$w_{DM3}=0,4$	24	$w_{DM1}=0,4$	$w_{DM2}=0,3$	$w_{DM3}=0,3$	36	$w_{DM1}=0,8$	$w_{DM2}=0,1$	$w_{DM3}=0,1$

TOPSIS-F method proposed by Chen [102], EDAS-F method proposed by Keshavarz Ghorabaee et al. [103] and finally CODAS-F method proposed by Keshavarz Ghorabaee et al. [104] have been applied. In CODAS-F method, threshold parameter value is taken as 0.02. The ranking results of proposed method and other methods are presented in Figures 1-4, separately. Figure 5 also presents the comparative analysis of the Scenario 18 in a simpler way. This scenario consists of decision-making weights, which are given in the application section of the study. As it can be seen in Figures 1-4, the ranks of green supplier alternatives change in different methods depending on decision makers' weights. The rankings of A_1 and A_2 do not change in almost all of the alternative rankings that occurred under different methods and different decision-makers' weights. A_1 is the best alternative in 36 scenarios. A_3, A_4 and A_5 take the last place in some rankings. On the other hand, MARCOS-F method also produces a ranking compatible with other distance based-methods. The solution of MARCOS-F gives the first and second orders to A_1 and A_2 regardless of the change in weight of decision makers.

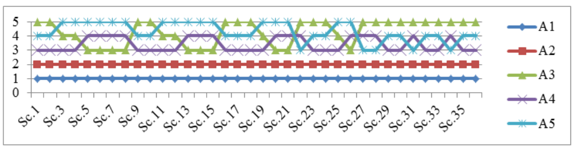

Figure 1. *The ranking results of MARCOS -F method*

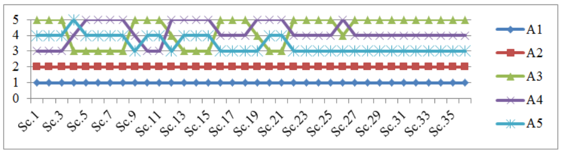

Figure 2. *The ranking results of CODAS -F method*

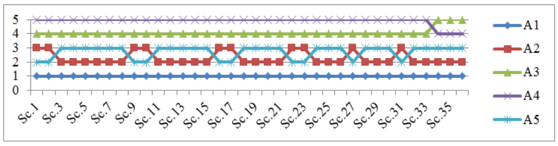

Figure 3. *The ranking results of EDAS -F method*

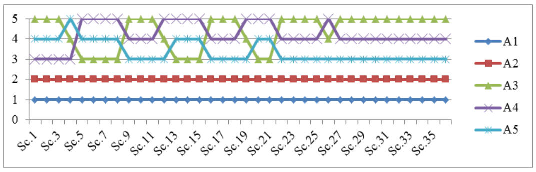

Figure 4. *The ranking results of TOPSIS-F method*

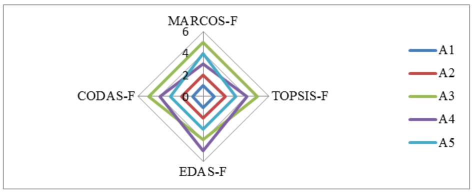

Figure 5. *Radar chart for the ranking in terms of different methods (Scenario 18)*

6. DISCUSSION AND MANAGERIAL IMPLICATIONS

Green supplier selection integrates environmental thinking into traditional supplier selection and it is very important in terms of environmental protection and sustainable development due to increasing consumption levels. The aim of this study is to propose an applicable and combined methodology for green supplier selection and demonstrate a solution of a problem. The data is collected from a textile company in Denizli. Both general and environmental selection criteria are considered. We analyze the criteria affecting the green supplier selection decision by determining the importance levels of these criteria after a detailed literature review. We use SWARA-F method instead of classic SWARA method to determine the criteria weights. The main reason of using SWARA-F method is to consider the expected significance of the criteria decided by the experts. From this point of view, SWARA, decision oriented method, is a suitable research method for this study. In addition, the method is suitable for finding the criteria weights of group decision-making problems in a fuzzy environment. The results show that the cost is the most important main criterion for the textile firm. Service, quality of ingredient and green criteria follow this criterion, respectively. Product price is the most important among the sub-criteria. Environmental management system is the most important sub-criterion when we evaluate the green main criterion in itself. Recycle rate, green technology and waste management system follow this criterion, respectively. Environmental management system sub-criterion is more important than flexibility and responsiveness which is the sub-criterion of service and packaging facilities which is the sub-criterion of quality of ingredient. We consider many criteria and provide richer explanations in terms of examining the impact of significances on green supplier evaluation. On the other hand, green supplier alternatives are ranked with MARCOS-F method according to the total utility degree of each alternative, considering the uncertainty in real life. Also, the supplier that does not meet the requirements of the textile company is determined. This output can also be used to analyze the supplier's shortcomings and identify aspects which are improved for their performance. There are many advantages of the MARCOS-F method over other MCDM methods. This method considers of fuzzy ideal and fuzzy anti-ideal solutions as reference values, determines them at early stage of decision matrix, capture the best alternative with utility functions namely utility degrees by using both reference values. MARCOS-

F method is compared with CODAS-F, TOPSIS-F and EDAS-F methods to check for the validity purpose. In addition, the data are measured consistently with the sensitivity analysis performed with different decision makers' weight sets. The fact that the best green supplier is in the same order with the sensitivity analyzes performed shows the consistency of the results. Small changes in rankings will not make a significant difference in the selection. The empirical results indicate that SWARA-F and MARCOS-F methods have great practical value for green supplier selection in a textile firm with uncertain and complex information and also provide flexibility in decision making. From this point of view, we contribute to the relevant literature by presenting new findings and provide usable suggestions for solving a selection problem on a popular topic. The findings can be used to improve firms' experience with green supplier selection. Therefore, these data allow for a more detailed and meaningful analysis. This study also provides important implications for many companies in different sectors. By considering these methods, managers can successfully solve different types of selection problems that they encounter in real-time production and service environments. It should be noted that we must pay attention while interpreting the findings mentioned above. The limitations of this study can be summarized as follows. Our study is limited a single textile firm. For each firm, the suppliers will be different. The criteria in this study are formed by the expert group consisting of only three department managers of the firm and there are no direct effects of customers or suppliers to this process. So, the results depend on their experiences and observations. Individual differences due to personal preferences and choices may cause different results in group decision making. Different criteria may be considered when evaluating green suppliers. Therefore, criteria should be updated and re-evaluated in each study for future researches. Number of criteria may be increased based on users' needs. The relationships between the criteria are not taken into account.

7. CONCLUSION AND FUTURE RESEARCH

The success of the GSCM mostly depends on suitable green supplier selection. Therefore, the green criteria should also be taken into consideration besides the classical criteria in the evaluation and selection processes. In this study, SWARA-F is combined with MARCOS-F for the evaluation green suppliers' alternatives and selection the best one among them. To demonstrate the proposed methodology, a supplier selection problem of a textile company is solved. The same problem is solved with CODAS-F, TOPSIS-F and EDAS-F methods to perform comparative analyses. Also, sensitivity of the decision makers' weights in the problem is tried to measure. Consequently, proposed methodology is not difficult to apply in spite of the uncertain experts' opinions in the evaluation process. Compared with existing literature, it provides a new way for evaluation and selection of green suppliers. It is thought that combined methodology can be applied to other MCDM problems due to its flexible, simple, and stable characteristics against changes. It is useful for decision makers to rank alternatives by efficiently addressing the problem. Although the proposed methodology is efficient in selecting the most reasonable green supplier and the results obtained from this study are satisfactory for the textile firm, there are aspects of the study that are open to improvement. More complex selection problems including more main and sub criteria may be solved, the solution power of the proposed methodology may be measured. The sensitivity analyses based on changes on criteria weights may be performed by this way, robustness of proposed methodology may be revealed. Different types of both MCDM problems and also problems in different areas such as economy, finance etc. may be solved. Different types of fuzzy memberships, fuzzy numbers, and defuzzification methods may be performed.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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