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Research Article

An Application of Fuzzy Integrated Model in Green Supplier Selection

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"Sustainability" term has not only become increasingly important globally for individual companies, but also become important for whole supply chains. The selection of supplier is a significant decision for the sustainability of supply chains. Literature review revealed that supplier selection is made traditionally based on economic attributes which are insufficient for sustainability of supply chains as sustainability requires taking economic, environmental, and social issues into account. For this purpose, this paper proposes determining the green supplier selection attributes and then developing a methodology for assessment and ranking of green suppliers based on determined attributes. The first contribution of this study is to propose a novel method, which is FROV (fuzzy extension of range of value) to literature. The latter is to utilize fuzzy extension of preference selection index (FPSI) to identify the weights of attributes. The third is to develop a novel fuzzy multiattribute decision-making model consisting of FPSI and FROV to determine the best supplier for a Turkish textile company.

1. Introduction

"Sustainable Development" has become increasingly important globally in recent decades. The World Commission on Environment and Development [1] explained "Sustainable Development" as supplying resources for meeting the needs of people currently living without making a significant impact on the resources needed for people living in the future, in Our Common Future report. It is suggested in the report that effective long-term development will be successful if economic, environmental, and social concerns will be taken into consideration.

Numerous studies have shown that, with the entry of sustainability into plans and policies, meeting environmental and social goals together with economic goals has been important not only for government sector but also for private sector such as construction [2–5], fisheries [6–11], mining [12–17], and transportation [18–24].

Despite the studies above discussing sustainability in the scale of individual companies, Vachon and Klassen [51] suggested that the environmental management should not be restricted to the individual companies alone and must go further to the whole supply chain involving all companies throughout the entire life of product. For this purpose, the perception of GSCM (Green Supply Chain Management) appeared in the literature during the 1990s when competition had an increasing trend [52]. GSCM is defined as incorporating environmental or green concerns into the supply chain processes beginning from design of the product to recycling of the goods at the end of its life [53].

Traditionally, supplier selection has a crucial role in supply chains as it contributes to increasing product quality and customer satisfaction [54]. It has become more important and complex with recent trends, sustainability development, and GSCM. Therefore, developing a model for selecting green suppliers is necessary for maintaining sustainability in a supply chain. The process of supplier selection in traditional supply chains has been named as green supplier selection in GSCM and became a central part of GSCM [55].

Table 1: The most common used economic attributes in supplier selection.

Quality	Financial Performance
Delivery (Time)	Management and Organization
Price	Production Facilities and Capacity
Flexibility	Reliability
Technical Capability	Long-term Relationship

Sources: [25–37].

For this purpose, this paper proposes determining the green attributes for the selection of supplier and then developing a model for assessing and ordering of green suppliers based on determined attributes. Three contributions have been made into the literature by this paper. The first is to propose a novel model, which is fuzzy extension of range of value (FROV) to literature. Generally, fuzzy extension of preference selection index (FPSI) has not been applied to acquire attribute weights, so the second is to utilize FPSI to identify the weights of attributes. The third is to develop a novel fuzzy multiattribute decision-making (MADM) model consisting of FPSI and FROV to address supplier selection problem for a Turkish textile company.

The rest of the paper is organized as follows. After the introduction, the attributes used for selecting green supplier in the literature are reviewed in Section 2. Then, the novel model is explained in detail in Section 3. In Section 4, the results are presented and the results of FROV are compared with the results of other fuzzy MADM, which are fuzzy additive ratio assessment (ARAS) [56], fuzzy multiple objective optimization on the basis of ratio analysis plus full multiplicative form (MULTIMOORA) [57], fuzzy complex proportional assessment (COPRAS) [58], and fuzzy grey relational analysis (GRA) [59]. In Section 5, a sensitivity analysis is done in order to observe the changing of the results with respect to the changing of attribute weights. In Section 6, a brief conclusion is presented.

2. Literature Review

In the literature review section, attributes utilized for green supplier selection in the literature have been reviewed to determine which attributes to be used in the model (Section 3). There are three groups of attributes in the literature used for green supplier selection: economic, environmental, and social. Environmental and social attributes are addressed as green attributes in this section.

2.1. Economic Attributes. Economic attributes have been used commonly for a long time in supplier selection before sustainability introduced to supply chain management [25]. The economic attributes mostly used for supplier selection were summarized in Table 1.

Due to the profit maximization objectives of firms, price attribute was once the most popular economic attribute used in supplier selection [26, 27]. However, it was shown that price attribute alone is insufficient for supplier selection problems in the literature review conducted by Ho et al. [28]. The review presented that quality, delivery, management, technology, relationship, and flexibility attributes are also significant in supplier selection besides price attribute. Financial performance attribute is deemed significant by Büyüközkan and Çifçi [29] and Dickson [30] as it shows the stability and thus the continuity of supplier firms. Dickson [30] presented the importance of production capacity in addition to the attributes mentioned above. Kannan et al. [31] indicated that reliability attribute is among most common used traditional attributes in the literature.

As it is seen in the literature, economic attributes are the main focus for traditional supplier selection. However, recent changes in the economy and politics such as increasing competition and foreign trade, consumers, and governments giving more importance to sustainability therefore required environmental and social attributes to be included in supplier selection.

2.2. Green Attributes. Several studies in the literature addressed the green attributes (social and environmental) in supplier selection problems. Table 2 summarizes the green attributes used in the literature.

Noci [38] presented a supplier selection model based on environmental performance of suppliers. It was claimed that increasing concerns about environmental performance of corporates will lead the corporates to choose suppliers based on an environmental viewpoint. Handfield et al. [39] presented an analytic hierarchy process (AHP) based supplier selection model to be used in the selection of suppliers based on environmental responsibility attribute. Humphreys et al. [40] introduced a supplier selection decision-making model by using Knowledge-Based System (KBS) which used qualitative and quantitative environmental attributes.

Lee et al. [32] developed an integrated model including fuzzy AHP and Delphi methods to choose the most appropriate green suppliers for corporations. Kuo et al. [33] created green supplier selection model by integrating the artificial neural network (ANN), the data envelopment analysis (DEA), and analytic network process (ANP).

Büyüközkan and Çifçi [41] conducted a study to evaluate the sustainability of suppliers with ANP. Kannan et al. [42] selected suppliers based on economic and environmental attributes in their model integrating fuzzy AHP, fuzzy technique for order preference by similarity to ideal solution (TOPSIS), multiobjective linear programming, and fuzzy logic. Hashemi et al. [43] suggested a comprehensive green supplier selection model by using ANP, the traditional GRA, and both economic and environmental attributes. Rostamzadeh et al. [44] presented a model for evaluating green suppliers based on quantitative data by using fuzzy sets

Table 2: Green attributes used in supplier selection.

ATTRIBUTES
(i) Using green technologies
(ii) Environmental efficiency
(iii) Supplier's green image
(iv) Reverse logistics (recycling, remanufacturing, reusing)
(v) Reducing activities
(i) Pollution level
(ii) Waste management
(iii) Noise
(iv) Resource consumption (energy, material, water)
(i) Green packaging and labelling
(ii) Green transportation
(iii) Green product design
(iv) Green procurement
(v) Green warehousing
(vi) Green innovation and R&D
(vii) Green stock politics
(i) Occupational health and safety systems,
(ii) Social responsibility
(iii) Employees' interests and rights
(iv) The stakeholders' rights

Sources: [32–34, 38–50].

Table 3: Linguistic and fuzzy performance ratings.

Linguistic Performance Ratings	Fuzzy Performance Ratings
Very Strong	(7,9,10)
Strong	(5,7,9)
Moderate	(3,5,7)
Weak	(1,3,5)
Very Weak	(0,1,3)

theory and the Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method.

Awasthi and Kannan [45] developed an integrated decision approach to analyse and select development programs for green suppliers by using a fuzzy nominal group technique (NGT) and VIKOR. Uygun and Dede [46] provided an integrated fuzzy model including fuzzy decision-making trial and evaluation laboratory (DEMATEL) method, ANP, and fuzzy TOPSIS to analyse green performances of companies in supply chains. Chen et al. [60] proposed fuzzy AHP and fuzzy TOPSIS to solve green supplier selection problem. Pang et al. [61] proposed a fuzzy grey model to address green supplier selection problem. Guo et al. [47] presented a framework including the triple bottom line principle and fuzzy axiomatic design (AD) technique to solve green supplier selection problem in global apparel industry. Luthra et al. [34] provided a framework selecting suppliers in accordance with sustainability by using a model integrating AHP and VIKOR methods. They identified 22 economic, environmental, and social attributes. Wang et al. [48] developed a framework for selecting green suppliers by using the cloud model and qualitative flexible multiple criteria method (QUALIFLEX) with the economic and environmental attributes.

Vahidi et al. [49] developed a novel possibilistic-stochastic model for the selection of sustainable suppliers. It showed that sustainability is significant in terms of reducing supply costs. Yu et al. [50] presented a model for selecting green suppliers based on carbon footprints. Yucesan et al. [62] combined the best-worst method (BWM) and the interval type 2 fuzzy TOPSIS methods to solve green supplier selection problem.

3. Methodology

Maniya and Bhatt [63] introduced preference selection index (PSI) to solve material selection problem. The range of value (ROV) was developed by Yakowitz et al. [64]. The ROV method is one of the scoring methods. The easiest MADM methods are scoring methods [65]. However, there are limited studies related to ROV method in the literature. While most of these studies were using the crisp ROV method, Zavadskas et al. [66] developed the rough ROV method. In this study, FPSI and FROV are used to select the best supplier by considering environmental aspects. FPSI is used to identify the objective weights of attributes and FROV is used to order the suppliers with respect to their performances. Methodology section consists of three subsections including fuzzy arithmetic operations, FPSI, and FROV methods.

3.1. Fuzzy Arithmetic Operations. It can be supposed that the arithmetic operations are used for the fuzzy numbers and crisp numbers. $\widetilde{G} = (g^l, g^m, g^u)$ and $\widetilde{H} = (h^l, h^m, h^u)$ represent the two positive triangular fuzzy numbers. More details are indicated as follows [67].

(i) Addition: $\widetilde{G} + \widetilde{H} = (g^l + h^l, g^m + h^m, g^u + h^u)$

(ii) Subtraction: $\widetilde{G} - \widetilde{H} = (g^l - h^l, g^m - h^m, g^u - h^u)$

(iii) Multiplication: $\widetilde{G} \times \widetilde{H} = (\min(g^l h^l, g^l h^u, g^u h^l, g^u h^u), g^m h^m, \max(g^l h^l, g^l h^u, g^u h^l, g^u h^u))$

(iv) Division: $\widetilde{G}/\widetilde{H} = (\min(g^l/h^l, g^l/h^u, g^u/h^l, g^u/h^u), g^m/h^m, \max(g^l/h^l, g^l/h^u, g^u/h^l, g^u/h^u))$

The e represents a positive crisp number [68].

(v) Scalar division: $\widetilde{G}/e = (g^l/e, g^m/e, g^u/e)$.

3.2. Fuzzy Preference Selection Index. FPSI method consists of five steps which are explained as follows.

Step 1-1. Decision-makers used Table 3 to assign linguistic performance rating. Fuzzy performance rating of decision-makers is aggregated by using (1) to structure aggregated fuzzy decision matrix ($\widetilde{\text{D}}$):

$$\widetilde{d}_{ij} = \frac{1}{K}\sum_{k=1}^{K}\widetilde{d}_{ijk} \tag{1}$$

In (1), $\widetilde{d}_{ijk}$ denotes kth decision-maker's fuzzy performance rating ($\widetilde{d}_{ij}$) and $\widetilde{d}_{ij}$ is fuzzy performance rating of

ith alternative on jth attribute and it is an element of $\widetilde{D} = [\widetilde{d}_{ij}]_{m\times n}$.

Step 1-2. After structuring aggregated fuzzy decision matrix, the normalized fuzzy performance rating ($\widetilde{t}_{ij}$), which is an element of normalized fuzzy decision matrix ($\widetilde{T} = [\widetilde{t}_{ij}]_{m\times n}$), is calculated by using (2) (beneficial attributes) and (3) (nonbeneficial attributes) indicated as follows.

$$\widetilde{t}_{ij} = \frac{\widetilde{d}_{ij}}{\max\left(\widetilde{d}_{ij}\right)} \quad (2)$$

$$\widetilde{t}_{ij} = \frac{\min\left(\widetilde{d}_{ij}\right)}{\widetilde{d}_{ij}} \quad (3)$$

Step 1-3. The averaged fuzzy normalized value ($\bar{\widetilde{t}}_{ij}$) of each attribute is computed by

$$\bar{\widetilde{t}}_{ij} = \frac{1}{m}\sum_{i=1}^{m}\widetilde{t}_{ij} \quad (4)$$

Step 1-4. The fuzzy preference value ($\widetilde{PV}_j = (PV_j^l, PV_j^m, PV_j^u)$) of each attribute is calculated as follows.

$$\widetilde{PV}_j = \sum_{i=1}^{m}\left(\widetilde{t}_{ij} - \bar{\widetilde{t}}_{ij}\right)^2 \quad (5)$$

Step 1-5. The fuzzy deviation value ($\widetilde{\sigma}_j$) of each attribute is computed by (6). Then, fuzzy weight ($\widetilde{w}_j$) of each attribute is calculated by (7) and fuzzy normalized weight ($\widetilde{w}_j^*$) is computed by (8).

$$\begin{aligned}\widetilde{\sigma}_j &= \left(\sigma_j^l, \sigma_j^m, \sigma_j^u\right) = \left|1 - \widetilde{PV}_j\right| \\ &= \left(\left|1 - PV_j^u\right|, \left|1 - PV_j^m\right|, \left|1 - PV_j^l\right|\right)\end{aligned} \quad (6)$$

$$\widetilde{w}_j = \frac{\widetilde{\sigma}_j}{\sum_{j=1}^{n}\widetilde{\sigma}_j} \quad (7)$$

$$\widetilde{w}_j^* = \frac{3\times\widetilde{w}_j}{\sum_{j=1}^{n} w_j^l + \sum_{j=1}^{n} w_j^m + \sum_{j=1}^{n} w_j^u} \quad (8)$$

After obtaining the fuzzy normalized weight of each attribute, these weights are transferred into FROV method.

3.3. Fuzzy Range of Value. FROV method contains four steps indicated as follows.

Step 2-1. The range of fuzzy values placed in the aggregated fuzzy decision matrix ($\widetilde{D}$), which is structured in (1), is obtained by (9) (beneficial attributes) and (10) (nonbeneficial attributes).

$$\begin{aligned}\widetilde{s}_{ij} &= \frac{\widetilde{d}_{ij} - \min\left(\widetilde{d}_{ij}\right)}{\max\left(\widetilde{d}_{ij}\right) - \min\left(\widetilde{d}_{ij}\right)} \\ &= \left(\frac{d_{ij}^l - \min\left(d_{ij}^u\right)}{\max\left(d_{ij}^l\right) - \min\left(d_{ij}^l\right)}, \right. \\ &\left. \frac{d_{ij}^m - \min\left(d_{ij}^m\right)}{\max\left(d_{ij}^m\right) - \min\left(d_{ij}^m\right)}, \frac{d_{ij}^u - \min\left(d_{ij}^l\right)}{\max\left(d_{ij}^u\right) - \min\left(d_{ij}^l\right)}\right)\end{aligned} \quad (9)$$

$$\begin{aligned}\widetilde{s}_{ij} &= \frac{\max\left(\widetilde{d}_{ij}\right) - \widetilde{d}_{ij}}{\max\left(\widetilde{d}_{ij}\right) - \min\left(\widetilde{d}_{ij}\right)} \\ &= \left(\frac{\max\left(d_{ij}^l\right) - d_{ij}^u}{\max\left(d_{ij}^l\right) - \min\left(d_{ij}^l\right)}, \right. \\ &\left. \frac{\max\left(d_{ij}^m\right) - d_{ij}^m}{\max\left(d_{ij}^m\right) - \min\left(d_{ij}^m\right)}, \frac{\max\left(d_{ij}^u\right) - d_{ij}^l}{\max\left(d_{ij}^u\right) - \min\left(d_{ij}^l\right)}\right)\end{aligned} \quad (10)$$

In (9) and (10), $\widetilde{s}_{ij}$, which is an element of the fuzzy range decision matrix ($\widetilde{S} = [\widetilde{s}_{ij}]_{m\times n}$), indicates the range of fuzzy values.

Step 2-2. After this, fuzzy worst utility values ($\widetilde{u}_i^-$) and fuzzy best utility values ($\widetilde{u}_i^+$) for each alternative are computed as follows.

$$\widetilde{u}_i^- = \sum_{i=1}^{f}\widetilde{s}_{ij}\widetilde{w}_j \quad (11)$$

$$\widetilde{u}_i^+ = \sum_{i=f+1}^{m}\widetilde{s}_{ij}\widetilde{w}_j \quad (12)$$

Step 2-3. Fuzzy overall score ($\widetilde{u}_i = (u_i^l, u_i^m, u_i^u)$) for each alternative is calculated by

$$\widetilde{u}_i = \frac{\widetilde{u}_i^- + \widetilde{u}_i^+}{2} \quad (13)$$

Step 2-4. Fuzzy overall scores ($\widetilde{u}_i$) are converted into crisp overall score (u_i) by using

$$u_i = \frac{u_i^l + u_i^m + u_i^u}{3} \quad (14)$$

Then, alternatives are ordered from the highest crisp overall score to the lowest crisp overall score. The alternative having the highest crisp overall score is identified as the most appropriate alternative.

4. Application

The hybrid fuzzy model is applied into a textile company, which has more than 10 years of experience in the

Table 4: The aggregated fuzzy decision matrix.

Suppliers	Attributes A1	Attributes A2	Attributes A3
Supplier 1	(2.5,3,3.2)	(0.020,0.022,0.024)	(0.012,0.013,0.014)
Supplier 2	(3.2,3.3,3.4)	(0.017,0.021,0.023)	(0.011,0.012,0.015)
Supplier 3	(2.8,3,3.1)	(0.019,0.024,0.025)	(0.009,0.010,0.017)
Supplier 4	(2.9,3.1,3.4)	(0.018,0.023,0.024)	(0.010,0.011,0.012)
Supplier 5	(3.2,3.3,3.5)	(0.016,0.019,0.021)	(0.008,0.010,0.015)
Supplier 6	(3.1,3.2,3.4)	(0.018,0.021,0.022)	(0.010,0.014,0.016)
Supplier 7	(3.1,3.3,3.5)	(0.019,0.022,0.023)	(0.010,0.011,0.013)
Supplier 8	(3.2,3.4,3.5)	(0.017,0.021,0.024)	(0.010,0.012,0.014)

Suppliers	Attributes A4	Attributes A5	Attributes A6
Supplier 1	(3.8,5.8,7.8)	(4.6,6.6,8.6)	(3,5,7)
Supplier 2	(3,5,7)	(4.2,6.2,8.2)	(3.4,5.4,7.4)
Supplier 3	(4.2,6.2,8.2)	(4.6,6.6,8.6)	(3.4,5.4,7.4)
Supplier 4	(4.6,6.6,8.6)	(3,5,7)	(3.8,5.8,7.8)
Supplier 5	(5,7,9)	(3.4,5.4,7.4)	(5,7,9)
Supplier 6	(3.8,5.8,7.8)	(7,9,10)	(3,5,7)
Supplier 7	(5,7,9)	(4.6,6.6,8.6)	(3,5,7)
Supplier 8	(7,9,10)	(5.4,7.4,9.2)	(2.2,4.2,6.2)

Suppliers	Attributes A7	Attributes A8	Attributes A9
Supplier 1	(2.2,4.2,6.2)	(1,3,5)	(1.8,3.8,5.8)
Supplier 2	(1,3,5)	(0,1,3)	(0,1,3)
Supplier 3	(2.2,4.2,6.2)	(1.4,3.4,5.4)	(1.4,3.4,5.4)
Supplier 4	(3,5,7)	(2.6,4.6,6.6)	(1,3,5)
Supplier 5	(4.6,6.6,8.6)	(3,5,7)	(2.2,4.2,6.2)
Supplier 6	(2.2,4.2,6.2)	(1.8,3.8,5.8)	(1.8,3.8,5.8)
Supplier 7	(1,3,5)	(2.2,4.2,6.2)	(1,3,5)
Supplier 8	(1,3,5)	(1.4,3.4,5.4)	(1,3,5)

sector manufacturing suits for global market. The buyers of the suits motivate the company to work with green suppliers. Before interviewing with managers of company, attribute list was structured by means of literature. Then, the company managers were asked whether the attributes were appropriate for the company in the supplier selection process. Nine attributes were identified for using in supplier selection. These attributes are Cost (A1), Defective Rate (A2), Late Delivery Rate (A3), Technological Capability (A4), Technical Assistance (A5), Pollution Control (A6), Environmental Management (A7), Green Transportation (A8), and Green Warehousing (A9). The first three attributes are identified as nonbeneficial attributes and the others are identified as beneficial attributes. This company procures yarn (thread spools) from 8 suppliers. The fuzzy data of the first three attributes were obtained from factory manager considering actual data of company. The fuzzy data of other attributes were collected from five managers of company including factory manager, purchasing manager, planning manager, operation manager, and quality manager. The aggregated fuzzy decision matrix is indicated in Table 4.

By using (2) and (3), the aggregated fuzzy decision matrix is normalized. The normalized fuzzy decision matrix is demonstrated in Table 5.

By means of (5), the fuzzy preference value ($\widetilde{\mathrm{PV}}_j$) of each attribute is computed. After obtaining $\widetilde{\mathrm{PV}}_j$, the fuzzy deviation value ($\widetilde{\sigma}_j$) of each attribute is calculated by using (6). Then, fuzzy weight ($\widetilde{w}_j$) and fuzzy normalized weight ($\widetilde{w}_j^*$) of each attribute is computed by using (7) and (8), respectively. These results are indicated in Table 6.

The fuzzy weights of attributes are considered into FROV. By means of (9) and (10), the fuzzy range decision matrix ($\widetilde{S}$), which is indicated in Table 7, is calculated.

In final step, the fuzzy best and worst utility values ($\widetilde{u}_i^+, \widetilde{u}_i^-$) of each supplier are calculated by using (11) and (12), respectively. These values are aggregated by (13) to obtain fuzzy overall score ($\widetilde{u}_i$) for each alternative and these fuzzy scores are converted into crisp overall score (u_i) by using (14). These results are indicated in Table 8.

According to crisp overall score (u_i) indicated in Table 8, the ranking of suppliers are as follows: Supplier 5, Supplier 4, Supplier 6, Supplier 3, Supplier 1, Supplier 8, and Supplier 2.

Table 5: The normalized fuzzy decision matrix (for FPSI).

Suppliers	Attributes A1	Attributes A2	Attributes A3
Supplier 1	(0.781,1,1.24)	(0.667,0.864,1.050)	(0.571,0.769,1)
Supplier 2	(0.735,0.909,0.969)	(0.696,0.905,1.235)	(0.533,0.833,1.091)
Supplier 3	(0.806,1,1.107)	(0.640,0.792,1.105)	(0.471,1,1.333)
Supplier 4	(0.735,0.968,1.069)	(0.667,0.826,1.167)	(0.667,0.909,1.2)
Supplier 5	(0.714,0.909,0.969)	(0.762,1,1.313)	(0.533,1,1.5)
Supplier 6	(0.735,0.938,1)	(0.727,0.905,1.167)	(0.5,0.714,1.2)
Supplier 7	(0.714,0.909,1)	(0.696,0.864,1.105)	(0.615,0.909,1.2)
Supplier 8	(0.714,0.882,0.969)	(0.667,0.905,1.235)	(0.571,0.833,1.2)
Suppliers	**Attributes A4**	**Attributes A5**	**Attributes A6**
Supplier 1	(0.380,0.644,1.114)	(0.460,0.733,1.229)	(0.333,0.714,1.4)
Supplier 2	(0.3,0.556,1)	(0.420,0.689,1.171)	(0.378,0.771,1.48)
Supplier 3	(0.420,0.689,1.171)	(0.460,0.733,1.229)	(0.378,0.771,1.48)
Supplier 4	(0.460,0.733,1.229)	(0.3,0.556,1)	(0.422,0.829,1.56)
Supplier 5	(0.5,0.778,1.286)	(0.340,0.6,1.057)	(0.556,1,1.8)
Supplier 6	(0.380,0.644,1.114)	(0.7,1,1.429)	(0.333,0.714,1.4)
Supplier 7	(0.5,0.778,1.286)	(0.460,0.733,1.229)	(0.333,0.714,1.4)
Supplier 8	(0.7,1,1.429)	(0.540,0.822,1.314)	(0.244,0.6,1.240)
Suppliers	**Attributes A7**	**Attributes A8**	**Attributes A9**
Supplier 1	(0.256,0.636,1.348)	(0.143,0.6,1.667)	(0.290,0.905,2.636)
Supplier 2	(0.116,0.455,1.087)	(0,0.2,1)	(0,0.238,1.364)
Supplier 3	(0.256,0.636,1.348)	(0.2,0.680,1.8)	(0.226,0.810,2.455)
Supplier 4	(0.349,0.758,1.522)	(0.371,0.920,2.2)	(0.161,0.714,2.273)
Supplier 5	(0.535,1,1.870)	(0.429,1,2.333)	(0.355,1,2.818)
Supplier 6	(0.256,0.636,1.348)	(0.257,0.760,1.933)	(0.290,0.905,2.636)
Supplier 7	(0.116,0.455,1.087)	(0.314,0.840,2.067)	(0.161,0.714,2.273)
Supplier 8	(0.116,0.455,1.087)	(0.2,0.680,1.8)	(0.161,0.714,2.273)

Table 6: The results of FPSI.

Results	Attributes A1	Attributes A2	Attributes A3
$\widetilde{\mathrm{PV}}_{\mathrm{j}}$	(0.009,0.015,0.064)	(0.012,0.025,0.051)	(0.028,0.073,0.158)
$\tilde{\sigma}_{\mathrm{j}}$	(0.936,0.985,0.991)	(0.949,0.975,0.988)	(0.842,0.927,0.972)
$\widetilde{\mathrm{w}}_{\mathrm{j}}$	(0.112,0.132,0.156)	(0.114,0.130,0.156)	(0.101,0.124,0.153)
$\widetilde{w}_j^*$	(0.109, 0.129, 0.152)	(0.111, 0.127, 0.152)	(0.099, 0.121, 0.149)
Results	**Attributes A4**	**Attributes A5**	**Attributes A6**
$\widetilde{\mathrm{PV}}_{\mathrm{j}}$	(0.101,0.125,0.126)	(0.106,0.127,0.130)	(0.059,0.096,0.185)
$\tilde{\sigma}_{\mathrm{j}}$	(0.874,0.875,0.899)	(0.870,0.873,0.894)	(0.815,0.904,0.941)
$\widetilde{\mathrm{w}}_{\mathrm{j}}$	(0.105,0.117,0.142)	(0.105,0.116,0.141)	(0.098,0.121,0.148)
$\widetilde{w}_j^*$	(0.102, 0.114, 0.139)	(0.102, 0.113, 0.138)	(0.096, 0.118, 0.144)
Results	**Attributes A7**	**Attributes A8**	**Attributes A9**
$\widetilde{\mathrm{PV}}_{\mathrm{j}}$	(0.145,0.245,0.507)	(0.129,0.422,1.172)	(0.084,0.380,1.385)
$\tilde{\sigma}_{\mathrm{j}}$	(0.493,0.755,0.855)	(0.172,0.578,0.871)	(0.385,0.620,0.916)
$\widetilde{\mathrm{w}}_{\mathrm{j}}$	(0.059,0.101,0.135)	(0.021,0.077,0.137)	(0.046,0.083,0.144)
$\widetilde{w}_j^*$	(0.058, 0.099, 0.132)	(0.020, 0.075, 0.134)	(0.045, 0.081, 0.141)

Table 7: The fuzzy range decision matrix.

Suppliers	Attributes		
	A1	A2	A3
Supplier 1	(0, 1, 1.429)	(-1, 0.400, 1.250)	(-0.500, 0.250, 1.250)
Supplier 2	(-0.286, 0.250, 0.429)	(-0.750, 0.600, 2)	(-0.750, 0.500, 1.500)
Supplier 3	(0.100, 1, 1)	(-1.250, 0, 1.500)	(-1.250, 1, 2)
Supplier 4	(-0.286, 0.750, 0.857)	(-1, 0.200, 1.750)	(0, 0.750, 1.750)
Supplier 5	(-0.429, 0.250, 0.429)	(-0.250, 1, 2.250)	(-0.750, 1, 2.250)
Supplier 6	(-0.286, 0.500, 0.571)	(-0.500, 0.600, 1.750)	(-1, 0, 1.750)
Supplier 7	(-0.429, 0.250, 0.571)	(-0.750, 0.400, 1.500)	(-0.250, 0.750, 1.750)
Supplier 8	(-0.429, 0, 0.429)	(-1, 0.600, 2)	(-0.500, 0.500, 1.750)
Suppliers	Attributes		
	A4	A5	A6
Supplier 1	(-0.800, 0.200, 1.200)	(-0.600, 0.400, 1.400)	(-1.143, 0.286, 1.714)
Supplier 2	(-1, 0, 1)	(-0.700, 0.300, 1.300)	(-1, 0.429, 1.857)
Supplier 3	(-0.700, 0.300, 1.300)	(-0.600, 0.400, 1.400)	(-1, 0.429, 1.857)
Supplier 4	(-0.600, 0.400, 1.400)	(-1, 0, 1)	(-0.857, 0.571, 2)
Supplier 5	(-0.500, 0.500, 1.500)	(-0.900, 0.100, 1.100)	(-0.429, 1, 2.429)
Supplier 6	(-0.800, 0.200, 1.200)	(0, 1, 1.750)	(-1.143, 0.286, 1.714)
Supplier 7	(-0.500, 0.500, 1.500)	(-0.600, 0.400, 1.400)	(-1.143, 0.286, 1.714)
Supplier 8	(0, 1, 1.750)	(-0.400, 0.600, 1.550)	(-1.429, 0, 1.429)
Suppliers	Attributes		
	A7	A8	A9
Supplier 1	(-0.778, 0.333, 1.444)	(-0.667, 0.500, 1.667)	(-0.546, 0.875, 2.636)
Supplier 2	(-1.111, 0, 1.111)	(-1, 0, 1)	(-1.364, 0, 1.364)
Supplier 3	(-0.778, 0.333, 1.444)	(-0.533, 0.600, 1.800)	(-0.727, 0.750, 2.455)
Supplier 4	(-0.556, 0.556, 1.667)	(-0.133, 0.900, 2.200)	(-0.909, 0.625, 2.273)
Supplier 5	(-0.111, 1, 2.111)	(0, 1, 2.333)	(-0.364, 1, 2.818)
Supplier 6	(-0.778, 0.333, 1.444)	(-0.400, 0.700, 1.933)	(-0.546, 0.875, 2.636)
Supplier 7	(-1.111, 0, 1.111)	(-0.267, 0.800, 2.067)	(-0.909, 0.625, 2.273)
Supplier 8	(-1.111, 0, 1.111)	(-0.533, 0.600, 1.800)	(-0.909, 0.625, 2.273)

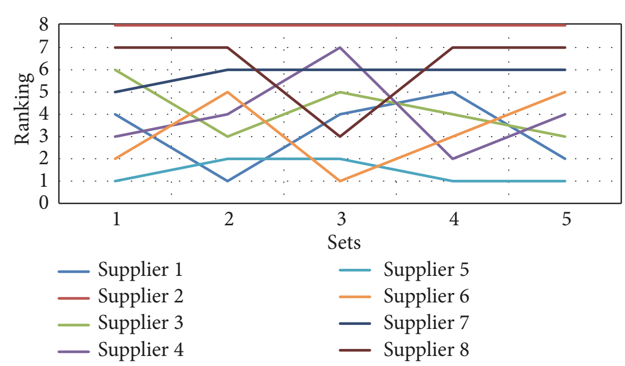

Figure 1: The results of sensitivity analysis.

Therefore, the best supplier among 8 suppliers is identified as Supplier 5.

The results of FROV are compared with the results of other fuzzy MADM, which are fuzzy ARAS, fuzzy MULTIMOORA, fuzzy COPRAS, and fuzzy GRA. Table 9 presents the coefficient of Spearman's correlation for all other fuzzy MADM.

According to Table 9, the correlation between the results of FROV and the results of other fuzzy MADM methods is very high. Table 9 proves that the FROV method has reached

Table 8: The results of FROV.

Suppliers	Results	
	$\tilde{u}_i^-$	$\tilde{u}_i^+$
Supplier 1	(-0.227, 0.210, 0.593)	(-0.628, 0.244, 1.393)
Supplier 2	(-0.269, 0.169, 0.593)	(-0.853, 0.085, 1.058)
Supplier 3	(-0.365, 0.250, 0.678)	(-0.601, 0.269, 1.419)
Supplier 4	(-0.195, 0.213, 0.657)	(-0.563, 0.287, 1.456)
Supplier 5	(-0.215, 0.280, 0.742)	(-0.322, 0.441, 1.700)
Supplier 6	(-0.268, 0.141, 0.614)	(-0.510, 0.327, 1.478)
Supplier 7	(-0.216, 0.174, 0.576)	(-0.629, 0.247, 1.393)
Supplier 8	(-0.292, 0.137, 0.630)	(-0.607, 0.278, 1.371)
Suppliers	Results	
	$\tilde{u}_i$	u_i
Supplier 1	(-0.428, 0.227, 0.993)	0.264
Supplier 2	(-0.561, 0.127, 0.826)	0.131
Supplier 3	(-0.483, 0.260, 1.049)	0.275
Supplier 4	(-0.379, 0.250, 1.057)	0.309
Supplier 5	(-0.269, 0.361, 1.221)	0.438
Supplier 6	(-0.389, 0.234, 1.046)	0.297
Supplier 7	(-0.423, 0.211, 0.985)	0.258
Supplier 8	(-0.450, 0.208, 1.001)	0.253

Table 9: Spearman correlation coefficient for all fuzzy MADM.

Fuzzy MADM	FROV	Fuzzy ARAS	Fuzzy MULTIMOORA	Fuzzy COPRAS	Fuzzy GRA
FROV	1.000	0.952	0.929	0.881	0.833
Fuzzy ARAS	-	1.000	0.916	0.952	0.952
Fuzzy MULTIMOORA	-	-	1.000	0.952	0.857
Fuzzy COPRAS	-	-	-	1.000	0.952
Fuzzy GRA	-	-	-	-	1.000

the accurate results. Additionally, FROV method includes few and simple steps. It can easily be used to solve MADM problems.

5. Sensitivity Analysis

The sensitivity analysis is done to monitor the changing of the results with respect to the changing of attribute weights. For this purpose, five sets of attribute weights are determined. Table 10 presents the sets of attribute weights.

These attribute weights are used to do the sensitivity analysis. The results of the sensitivity analysis are presented in Figure 1.

As it can be seen that Supplier 5 is determined as the best supplier for Sets 1, 4, and 5, nevertheless, Supplier 1 is identified as the best supplier in Set 2 and Supplier 6 is determined as the best supplier in Set 3. Only one supplier's rank does not change. That supplier is Supplier 2 and this supplier is always 8th rank. The ranking of other suppliers varies at least once with respect to the sets of attribute weights.

6. Conclusion

This study's main objective was to develop a hybrid model to choose suppliers in accordance with sustainability and for this purpose it made three contributions to green supplier selection literature. First contribution is proposing a new method which is FROV to literature, second contribution is utilizing FPSI to identify the weights of attributes, and third contribution is developing a new MADM model consisting of FPSI and FROV to solve supplier selection.

Choosing the most suitable attributes and the method to be used in the decision model is significant for green supplier selection. Therefore, first, a review of attributes used in the selection was conducted and a comprehensive list of suitable attributes for selecting green suppliers was created. Then, an interview was held with the managers of a textile company to shape a final list of applicable attributes for this study. Nine attributes were identified for using in supplier selection. These attributes are Cost (A1), Defective Rate (A2), Late Delivery Rate (A3), Technological Capability (A4), Technical

Table 10: Sensitivity analysis.

Attributes	Sets: Set 1	Set 2	Set 3
Attribute 1	(0.036, 0.043, 0.051)	(0.370, 0.390, 0.450)	(0.200, 0.240, 0.450)
Attribute 2	(0.037, 0.042, 0.051)	(0.012, 0.014, 0.017)	(0.150, 0.180, 0.190)
Attribute 3	(0.033, 0.040, 0.050)	(0.011, 0.013, 0.017)	(0.020, 0.050, 0.070)
Attribute 4	(0.051, 0.057, 0.070)	(0.015, 0.019, 0.023)	(0.210, 0.220, 0.230)
Attribute 5	(0.051, 0.057, 0.069)	(0.017, 0.019, 0.023)	(0.200, 0.220, 0.260)
Attribute 6	(0.048, 0.059, 0.070)	(0.060, 0.080, 0.090)	(0.010, 0.020, 0.030)
Attribute 7	(0.029, 0.050, 0.066)	(0.040, 0.060, 0.070)	(0.020, 0.030, 0.040)
Attribute 8	(0.300, 0.320, 0.330)	(0.140, 0.200, 0.240)	(0.010, 0.020, 0.040)
Attribute 9	(0.290, 0.330, 0.370)	(0.140, 0.190, 0.280)	(0.020, 0.030, 0.040)

Attributes	Sets: Set 4	Set 5
Attribute 1	(0.010, 0.030, 0.070)	(0.300, 0.320, 0.350)
Attribute 2	(0.020, 0.030, 0.040)	(0.160, 0.190, 0.200)
Attribute 3	(0.050, 0.060, 0.080)	(0.160, 0.180, 0.190)
Attribute 4	(0.070, 0.080, 0.090)	(0.050, 0.070, 0.090)
Attribute 5	(0.010, 0.020, 0.040)	(0.080, 0.140, 0.150)
Attribute 6	(0.120, 0.140, 0.160)	(0.010, 0.020, 0.040)
Attribute 7	(0.150, 0.170, 0.190)	(0.020, 0.030, 0.040)
Attribute 8	(0.200, 0.220, 0.230)	(0.020, 0.030, 0.040)
Attribute 9	(0.220, 0.249, 0.251)	(0.020, 0.040, 0.060)

Assistance (A5), Pollution Control (A6), Environmental Management (A7), Green Transportation (A8), and Green Warehousing (A9).

In addition, this study provided a novel hybrid MADM model to select green supplier. The proposed model incorporated FPSI which is used to identify the weights of attributes and FROV which is used to order the suppliers with respect to their performances.

Future studies may use this model to solve other MADM problems, such as logistics provider selection, energy sources selection, and warehouse location selection.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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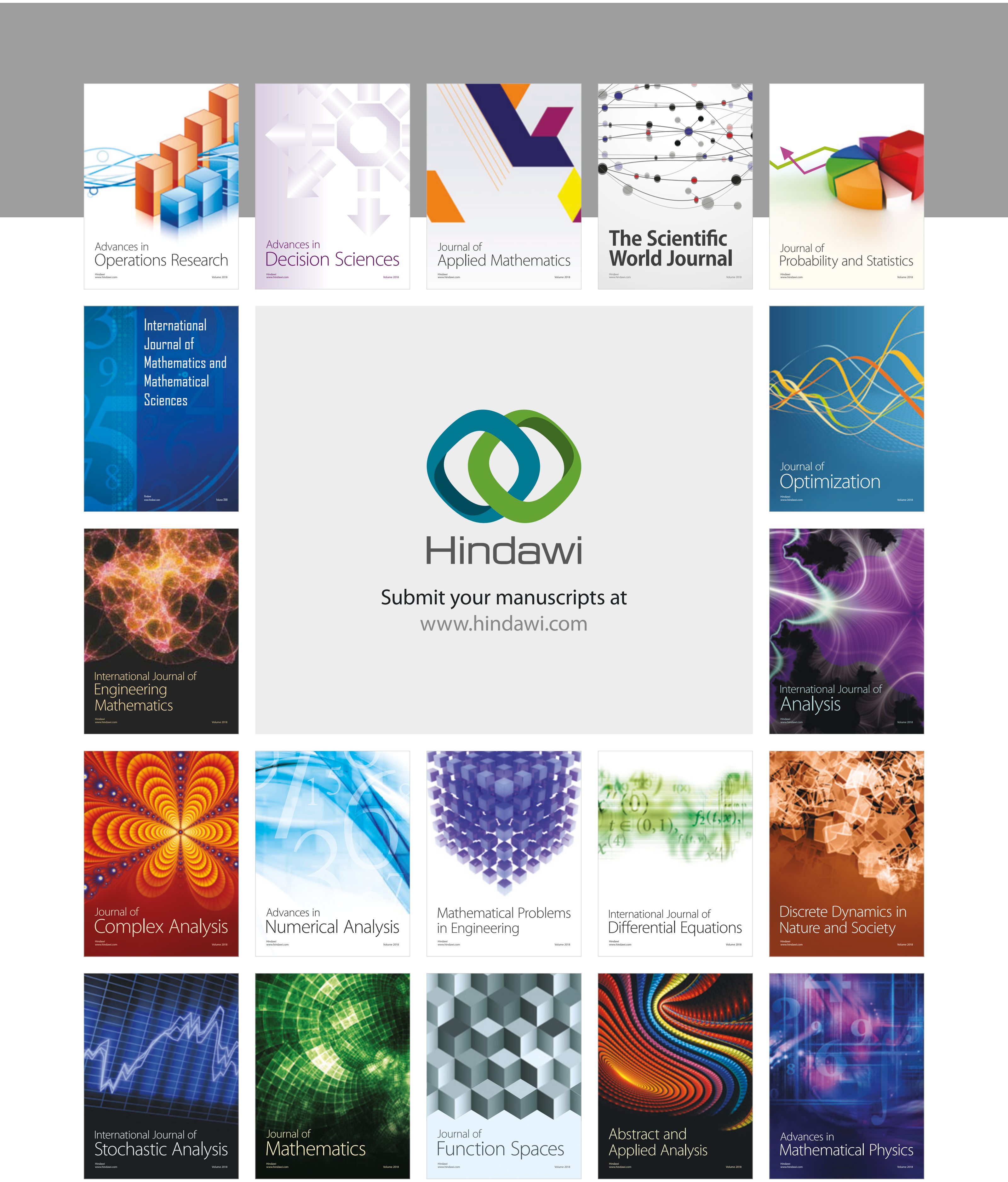

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