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Green supplier selection of a textile manufacturer: a hybrid approach based on AHP and VIKOR

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ABSTRACT

Because of the increasing popularity on protecting the environment, consumers prefer environmentally friendly products in recent years. Due to the trend among consumers, companies have changed their production processes. The first necessity for production of an environmentally friendly product is to supply less harmless raw materials. Therefore, companies have to supply production inputs from green suppliers in order to produce environmentally friendly products. Since the wide use range of textile products make them products that are desired to be green products, green supplier selection of a textile manufacturer was examined in this study. The main aim in this study is to propose a decision model for determination of the best green suppliers. In the proposed model, Analytic Hierarchy Process (AHP) and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods were integrated. AHP was used to determine criteria weights and VIKOR was used to evaluate alternative suppliers. Seven alternative green suppliers were evaluated by taking 5 main criteria and 17 sub-criteria into account according to the opinions of planning department experts of the company. Alternative green suppliers were ranked by using the proposed methodology and the study was concluded with suggestions for further studies and by giving some managerial implications.

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1. Introduction

In the past, companies have been choosing suppliers by considering some features such as price, speed, quality, references, flexibility, size of supplier, and cultural compatibility between manufacturer and supplier. Now, in addition to the given features, they also consider the working places of the producers, characteristics of the products they produce, production conditions and legal arrangements.

The addition of new features into the supplier selection is a result of increasing environmental awareness. Now, consumers tend to choose more environmentally friendly products. This trend among consumers led companies to change their production processes to produce green products. Environmentally friendly raw materials usage is the first necessity in order to produce environmentally friendly products. In short, companies should prefer green suppliers who supply environmentally friendly production inputs.
Environmentally friendly clothing is made by using environmentally friendly and sustainable resources to manage green clothing production effectively, companies have to consider all stages of production, including design, purchasing of raw materials, production processes, distribution to market and also reverse logistics and waste. Textile industry is one of the largest polluters in the world. Therefore, it should be said that making textile and clothing production more environmentally friendly could be possible by environmentally friendly management. That is why determination of suitable and green suppliers and logistics structures along the textile supply chain have become a key strategic consideration during recent years.

Selection of green suppliers was confronted in the literature within the last 20 years. Some of these studies can be summarized as follows: Green supplier selection was made by Lu et al. [1] by using AHP in electronic industry. Lee et al. [2] proposed a Delphi and fuzzy extended AHP approach for green supplier selection in high tech electronics industry. Fuzzy ANP (Analytic Network Process) and PROMETHEE techniques were integrated as a hybrid decision-making approach for green supplier selection in manufacturing industry [3]. Hashemi et al. [4] proposed a green supplier selection approach, which integrates ANP and Grey Relational Analysis techniques for automobile manufacturing. Kuo et al. [5] developed a green supplier selection model for electronics industry based on DEMATEL, ANP and VIKOR techniques. Luthra et al. [6] used an AHP – VIKOR integrated decision-making approach for green supplier selection in automobile manufacturing. Song et al. [7] considered decision maker's psychology to be changing over time for green supplier decision, so, they proposed a green supplier selection framework in a dynamic environment. They used Third Generation Prospect Theory for supplier evaluation. Haeri and Rezaei [8] used grey cognitive maps to determine the best green supplier by considering economic and environmental factors. Six sigma quality indices were included in green supplier selection under fuzzy uncertainty by Chen et al. [9].

In this study, the selection of the green suppliers of a textile company was discussed. In the green supplier selection process, there are different criteria to consider and different alternative companies to evaluate as a supplier. Multi-criteria decision-making approaches are used in such kind of decision problems to find a compromise solution. In order to find the most appropriate supplier company, a hybrid multi-criteria decision-making approach was proposed in this study. Within the proposed approach, criteria weights were calculated with the Analytical Hierarchy Process (AHP) and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was used to select the most suitable green supplier.

The rest of the paper was organized as follows: in the 2nd part, a brief explanation of methodology of the proposed approach was introduced. A case study of green supplier selection in a textile company was presented in detail in the 3rd part. The paper was concluded in the 4th part with conclusions and suggestions for further studies.

2. Methodology

Complex decision problems require considering different criteria simultaneously. Multiple criteria decision-making (MCDM) approaches are useful in such problems to obtain a compromise solution. Green supplier decision is one of such kind of decisions that needs to take various criteria into consideration for selection between alternatives. In this study, green supplier selection was made by using a hybrid MCDM methodology based on AHP and VIKOR methods. AHP was used to calculate main and sub criteria weights and alternative suppliers were evaluated via VIKOR. A flowchart of the proposed decision model is given in Figure 1 as follows:

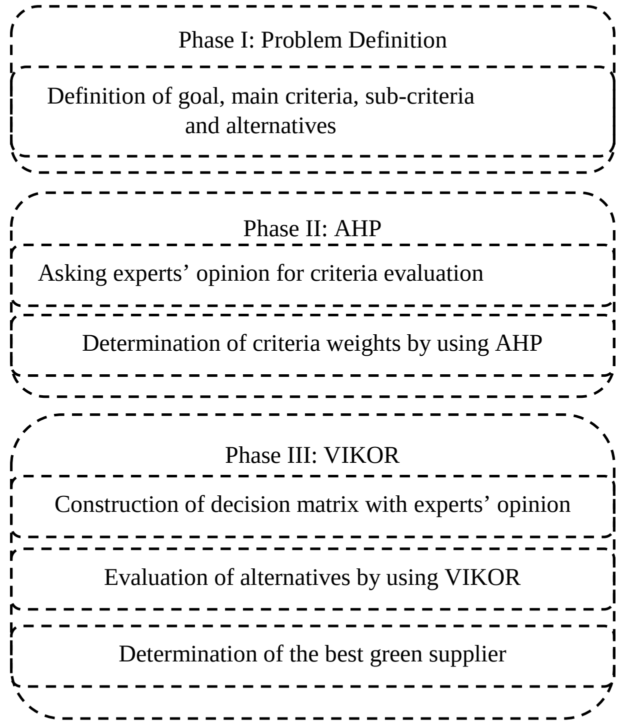

Figure 1. *Flowchart for the proposed decision model*

2.1. Problem Definition

First action in this step is to define the aim of the decision precisely. Then, decision criteria and sub-criteria to take into account must be identified and a set of alternatives should be formed.

2.2. AHP

AHP was used for calculation of criteria weights. The AHP is a widely used MCDM method for solving complex decision problems and it is introduced by Thomas L. Saaty [10]. The Analytical Hierarchy Process method has a wide range of applications, including marketing [11], human resources [12], economics [13], information technology selection [14], planning [15], production [16], purchasing [17], health [18], environmental sciences [19] and many other applications. The procedure of AHP consists of five steps. These steps of AHP are explained as follows:

Step 1. Determination of decision criteria and alternatives

Decision criteria and alternatives can be determined by conducting a literature review for the studies related to the decision problem or by asking experts of the field.
In the problem description step of the AHP method, a one-way hierarchical structure from the goal to decision criteria and to alternatives is constructed. An example hierarchical structure, which represents a decision problem with n criteria and m alternatives, is shown in Figure 2.

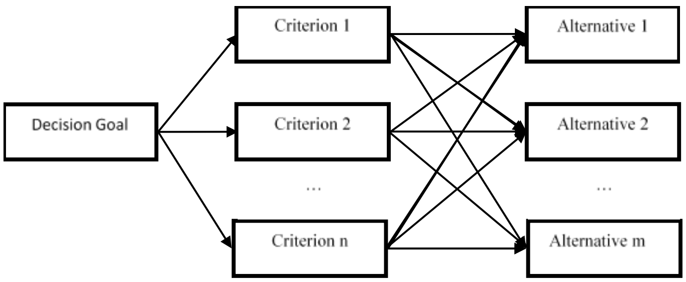

Figure 2. *Hierarchical structure of a MCDM problem with n criteria and m alternatives*

Step 2. Construction of pair wise comparison matrices

Pairwise comparison matrices are formed by using the 1 – 9 scale of Saaty. Elements of 1 – 9 scale are given in Table 1 with their definitions.

Row element of the matrix is compared with the column element and the relative importance score is written into the cell. If the column element has importance over the row element, multiplicative inverse of the corresponding importance score is written into the cell. In addition, symmetrical elements of the pairwise comparison matrix are multiplicative inverse of each other. Elements on the main diagonal are equal to one, which means the comparison of element with itself.

Table 1. *1 – 9 scale for pairwise comparisons*

Importance Score	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

Step 3. Calculation of priorities of decision criteria and alternatives

Criteria weights can be obtained by using different approaches. Some of these approaches can be listed as follows:

- Logarithmic least squares method
- Least squares method
- Eigenvector/eigenvalue method
- Matrix operations method

In this study, Eigenvector/eigenvalue method is used to obtain criteria weights (priority values). Steps of Eigenvector/eigenvalue method to obtain priorities are as follows:

- Step 3.1: Sum of elements in each column of the pairwise comparison matrix is calculated.
- Step 3.2: Each column is normalized by dividing each element with the corresponding column sum.
- Step 3.3: Arithmetic mean of each row gives the priority value of the row element.

Sum of priority values must be equal to 1. Correction of the obtained priorities can be made by checking sum of priorities.

Step 4. Determination of the consistency index of the matrix

Consistency index is an important issue to consider in AHP applications. If pairwise comparison matrix is inconsistent, the matrix should be formed again. Consistency index is calculated by following the five steps:

- Step 4.1: Each element of pairwise comparison matrix is multiplied by the weight of the corresponding column element. Then, weighted sums vector is obtained by adding elements in each row.
- Step 4.2: Elements of weighted sums vector is divided by the corresponding weight values.
- Step 4.3: The arithmetic mean of the obtained values in Step 4.2 is calculated. This value is called as λ_{max}. λ_{max} is defined as the maximum equivalent of the pairwise comparison matrix. The closer value of λ_{max} to n means the pairwise comparison matrix is more consistent.
- Step 4.4: Consistency index (CI) is calculated according to the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

- Step 5.5: Consistency ratio (CR) is determined by the following formula. If the consistency ratio is less than 0.1, the pairwise comparison matrix is consistent. Otherwise, the pairwise comparison matrix is inconsistent and a new pairwise comparison matrix must be constructed as follows:

$$CR = \frac{CI}{RI}$$

Where the RI (Random Index) values are presented in the Table 2 as follows:

Table 2. *Random Index (RI) values*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.48

Step 5. Making the decision

In the AHP method, decision is made according to the relative weights of alternatives vector. Relative weights of alternatives vector is calculated by the matrix product of alternative weights based on each criterion matrix and criteria weights vector. The best alternative is the alternative with the highest priority value. The AHP method was used for obtaining criteria weights in this study and pairwise comparison matrices for alternative evaluation were not constructed. For this reason, this step is not a part of our application.

2.3. VIKOR

Alternative evaluations were made by using VIKOR. VIKOR is a MCDM methodology, which is firstly proposed by Opricovic and Tzeng [20]. Translation of its name from Serbian to English is multi-criteria optimization and compromise solution. In the literature, VIKOR was used for evaluation of alternative buses for public transport [21], bank performance evaluation [22] and water resources planning [23], supplier selection [24], mobile services evaluation [25], industrial robots selection [26] etc. VIKOR is a method of determining a compromise order and achieving compromise resolution under specified weights. The compromise solution statement indicates the most appropriate result that the decision makers will achieve in complex decision problems by considering different criteria. VIKOR is applied on decision problems by following six steps:

Step 1: Construction of the decision matrix

Decision matrix of the problem (F) consists of alternative scores in views of each criteria. Score of alternative i with respect to criterion j is defined as f_{ij}. Scores can be written as the numerical values of alternatives or as a result of evaluation of experts. In this study, alternatives are evaluated by using a 2 – 10 scale, which is proposed by Tayyar and Arslan [27]. 2 – 10 scale is presented in Table 3 as follows:

Table 3. *Alternative evaluation scale*

Number	2	4	6	8	10
Linguistic Equivalent	Very poor	Poor	Moderate	Good	Very Good

An example decision matrix can be shown as follows:

$$F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{bmatrix}$$

Step 2: Normalization of the decision matrix

Normalization of the decision matrix is made for obtaining normalized decision matrix (R). Elements of R are shown as r_{ij}. To calculate r_{ij} values, the following formula is used:

$$r_{ij} = \frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-}$$

Where $f_j^+ = \max_i f_{ij}$ and $f_j^- = \min_i f_{ij}$.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

Step 3: Weighted normalized decision matrix

In this step, weighted normalized decision matrix (V) is obtained by multiplication of r_{ij} values with the weight of corresponding criteria (w_j). In this study, criteria weights are calculated by using AHP. AHP and VIKOR are integrated in this step.

$$v_{ij} = r_{ij} w_j$$

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}$$

Step 4: Calculation of S_i and R_i values

To define the rank between alternatives, VIKOR uses S_i and R_i values. S_i is defined as the utility value and R_i is defined as the regret value. These values are used in the next step for calculation of Q_i values. The formulas for S_i and R_i values are given as follows:

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-} = \sum_{j=1}^{n} v_{ij}$$

$$R_i = \max_j \left(w_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-} \right) = \max_j v_{ij}$$

Step 5: Calculation of Q_i values

Q_i values are calculated in order to be able to make decision by aggregating S_i and R_i values. Alternative ranks may change according to S_i and R_i values, so an aggregated measure would help decision makers. The alternative with the minimum value of Q_i is the best alternative. Alternatives are ranked according to this information. Formula of Q_i integrates normalized S_i and R_i values with a weighting multiplier (v) and is given as follows, Where $S_i^+ = \min_i S_i$, $S_i^- = \max_i S_i$ $R_i^+ = \min_i R_i$ and $R_i^- = \max_i R_i$:

$$Q_i = v \times \frac{S_i - S^+}{S^- - S^+} + (1 - v) \times \frac{R_i - R^+}{R^- - R^+}$$

Step 6: Checking the results

Obtained rank is checked in the last step of VIKOR. To check the rank, we should control whether the results satisfy the following two conditions:

- Condition 1: Acceptable advantage

Let us define Q (a') is the Q_i value of the best alternative and Q (a'') is the Q_i value of the second best alternative, respectively. Also, let us define DQ is equal to 1 / (m – 1). If $Q(a'') - Q(a') \geq DQ$, acceptable advantage condition is met.

- Condition 2: Acceptable stability in decision making

Alternative a' must also be the best ranked by S or/and R.

If both of these conditions are satisfied, alternative rank according to the Q_i values is said to be true.

3. Case study of green supplier selection in a textile company

Green supplier selection of a textile manufacturer was made in this study by using the proposed AHP - VIKOR approach. Steps of application are explained in this part in detail as follows:

3.1. Definition of the Problem

Goal of the problem is determination of the most appropriate green supplier. 5 main criteria and 17 sub criteria were taken into account. Determination of green supplier selection criteria, assessments about criteria and alternatives were made collecting opinions of a decision making group of four planning experts of the company. Decision criteria of the problem can be listed as follows:

- Green Image (C1)
    - Social Responsibility (C11)
    - Protection of Current Customers (C12)
    - Perception of Environment (C13)
    - Market Share (C14)
- Environmental Management System (C2)
    - Quality Certificates (C21)
    - Adaptation to Regulations (C22)
    - Existence of Environmental Policy (C23)
- Green Production (C3)
    - Less Usage of Harmful Material (C31)
    - Energy Saving (C32)
    - Waste Disposal (C33)
- Green Design (C4)
    - Long Life Product (C41)
    - Recoverable Product (C42)
    - Quality Product (C43)
    - Recycling (C44)
- Green Packaging (C5)
    - Green Pack (C51)
    - Less Usage of Package (C52)
    - Transportation Costs (C53)

Hierarchical structure of decision problem was given in Figure 3. According to the hierarchy, criteria and sub-criteria weights were determined with AHP and seven alternative suppliers were evaluated by using VIKOR.

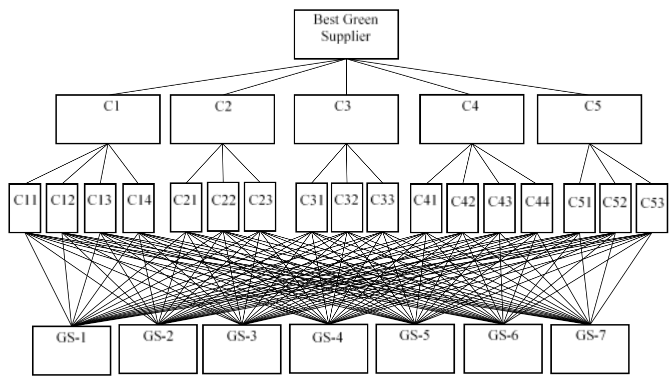

Figure 3. *Hierarchical structure of decision problem*

3.2. Calculation of Criteria Weights with AHP

In this step, criteria and sub-criteria weights were calculated by using pairwise comparison matrices. Pairwise comparison matrices were formed according to opinion of planning experts, and then weights were determined by applying AHP calculations on Microsoft Excel software. Pairwise comparison of main criteria was given in Table 4 with calculated weights and consistency ratio as follows:

Table 4. *Pairwise comparison of main criteria with respect to goal*

	C1	C2	C3	C4	C5	Weights
C1	1	3	1/3	1/5	3	0.146
C2	1/3	1	1/3	1/5	2	0.085
C3	3	3	1	1/3	3	0.227
C4	5	5	3	1	5	0.478
C5	1/3	1/2	1/3	1/5	1	0.063
				CR Value		0.069

As it is seen from Table 4, the most important criterion for green supplier selection was determined as Green Design (C4) since it has the highest weight value. Green Production (C3), Green Image (C1), Environmental Management System (C2) and Green Package (C5) followed Green Design criterion, respectively. Consistency ratio was calculated as 0.069 and it is less than 0.1. Therefore, the pairwise comparison matrix is consistent. Similar to the Table 4, pairwise comparison matrices for sub-criteria were presented in Table 5 – 9 as follows:

Table 5. *Pairwise comparison of Green Image sub-criteria with respect to Green Image criterion*

	C11	C12	C13	C14	Weights
C11	1	1/4	1/3	1/2	0.095
C12	4	1	2	2	0.424
C13	3	1/2	1	3	0.314
C14	2	1/2	1/3	1	0.167
				CR Value	0.044

Table 6. *Pairwise comparison of sub-criteria of C2 with respect to C2*

	C21	C22	C23	Weights
C21	1	1	2	0.411
C22	1	1	1	0.328
C23	1/2	1	1	0.261
			CR Value	0.046

Table 7. *Pairwise comparison of sub-criteria of C3 with respect to C3*

	C31	C32	C33	Weights
C31	1	1/2	3	0.334
C32	2	1	3	0.525
C33	1/3	1/3	1	0.142
			CR Value	0.046

Table 8. *Pairwise comparison of sub-criteria of C4 with respect to C4*

	C41	C42	C43	C44	Weights
C41	1	1/3	1/2	2	0.169
C42	3	1	1	2	0.350
C43	2	1	1	4	0.367
C44	1/2	1/2	1/4	1	0.114
				CR Value	0.044

Table 9. *Pairwise comparison of sub-criteria of C5 with respect to C5*

	C51	C52	C53	Weights
C51	1	2	1/2	0.312
C52	1/2	1	1/2	0.198
C53	2	2	1	0.490
			CR Value	0.046

According to the Table 5 – 9, all pairwise comparisons are consistent, since CR values were less than 0.1. After determination of criteria and sub-criteria weights, global weights of sub-criteria were calculated by multiplication of sub-criteria weight with the corresponding main criterion weight. Global weights of sub-criteria were presented in Table 10 as follows:

Table 10. *Global weights of sub-criteria*

Criteria	Weight	Sub-criteria	Local Weight	Global Weight
C1	0.1456	C11	0.0947	0.0138
		C12	0.4244	0.0618
		C13	0.3141	0.0457
		C14	0.1667	0.0243
C2	0.0855	C21	0.4111	0.0351
		C22	0.3278	0.0280
		C23	0.2611	0.0223
C3	0.2274	C31	0.3338	0.0759
		C32	0.5247	0.1193
		C33	0.1416	0.0322
C4	0.4783	C41	0.1689	0.0808
		C42	0.3501	0.1675
		C43	0.3672	0.1756
		C44	0.1139	0.0545
C5	0.0632	C51	0.3119	0.0197
		C52	0.1976	0.0125
		C53	0.4905	0.0310

According to the Table 10, Quality Product (C43) was the most important sub-criterion among all 17 sub-criteria. Its global weight was calculated as 0.1756. It was followed by Recoverable Product (C42) with the weight value of 0.1675 and Energy Saving (C32) sub-criterion, respectively. Less usage of Package (C52) sub-criterion was considered the least important since its weight is found as 0.0125.

3.3. Evaluation of Alternatives by using VIKOR

Evaluation of alternatives was made by using VIKOR within the proposed algorithm. In this part of the study, we presented steps of VIKOR application. Expert group was asked to evaluate alternative green suppliers in views of sub-criteria by using 2-10 scale given in Table 3.

By using the given scale, evaluation of alternatives was made and at the end of this evaluation decision matrix of the problem (F) was obtained. In addition to the alternative values, the best (f_i^+) and the worst (f_i^-) values of each column were presented in Table 11 as follows:

Table 11. *Decision matrix of the problem (F)*

Sub-criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C43	C44	C51	C52	C53
GS1	6	8	8	6	6	4	6	8	6	4	6	4	10	4	4	4	2
GS2	8	6	6	4	8	4	8	6	2	8	8	10	6	6	8	4	8
GS3	10	8	8	6	4	8	6	8	10	10	6	8	10	8	6	2	4
GS4	8	4	6	6	8	10	8	10	6	8	8	6	10	8	8	10	8
GS5	6	4	4	8	8	4	6	4	2	6	4	10	8	4	6	6	6
GS6	4	6	8	4	6	10	4	2	4	2	4	6	6	8	6	8	8
GS7	8	10	8	6	10	8	6	6	8	4	10	8	8	6	8	8	6
f_i^+	10	10	8	8	10	10	8	10	10	10	10	10	10	8	8	10	8
f_i^-	4	4	4	4	4	4	4	2	2	2	4	4	6	4	4	2	2

Decision matrix was normalized according to the normalization procedure described in the 2nd part of the paper. An example of normalized value calculation was given for GS1 alternative and C11 sub-criterion (r_{11}) and normalized decision matrix (R) was presented in Table 12 as follows:

$$r_{11} = \frac{f_1^+ - f_{11}}{f_1^+ - f_1^-} = \frac{10-6}{10-4} = \frac{4}{6} = 0.667$$

Table 12. *Normalized decision matrix (R) of the problem*

Sub-criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C43	C44	C51	C52	C53
GS1	0.667	0.333	0.000	0.500	0.667	1.000	0.500	0.250	0.500	0.750	0.667	1.000	0.000	1.000	1.000	0.750	1.000
GS2	0.333	0.667	0.500	1.000	0.333	1.000	0.000	0.500	1.000	0.250	0.333	0.000	1.000	0.500	0.000	0.750	0.000
GS3	0.000	0.333	0.000	0.500	1.000	0.333	0.500	0.250	0.000	0.000	0.667	0.333	0.000	0.000	0.500	1.000	0.667
GS4	0.333	1.000	0.500	0.500	0.333	0.000	0.000	0.000	0.500	0.250	0.333	0.667	0.000	0.000	0.000	0.000	0.000
GS5	0.667	1.000	1.000	0.000	0.333	1.000	0.500	0.750	1.000	0.500	1.000	0.000	0.500	1.000	0.500	0.500	0.333
GS6	1.000	0.667	0.000	1.000	0.667	0.000	1.000	1.000	0.750	1.000	1.000	0.667	1.000	0.000	0.500	0.250	0.000
GS7	0.333	0.000	0.000	0.500	0.000	0.333	0.500	0.500	0.250	0.750	0.000	0.333	0.500	0.500	0.000	0.250	0.333

The next step of VIKOR was weighting the normalized decision matrix. To do so, each value in the normalized decision matrix was multiplied by the global weight value of corresponding sub-criterion calculated via AHP. C11 sub-criterion value of alternative GS1 was calculated below as an example and weighted normalized decision matrix (V) was presented in Table 13 as follows:

$$v_{11} = r_{11} w_1 = 0.667 * 0.0138 = 0.009$$

Table 13. *Weighted normalized decision matrix (V) of the problem*

Sub-criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C43	C44	C51	C52	C53
GS1	0.009	0.021	0.000	0.012	0.023	0.028	0.011	0.019	0.060	0.024	0.054	0.167	0.000	0.054	0.020	0.009	0.031
GS2	0.005	0.041	0.023	0.024	0.012	0.028	0.000	0.038	0.119	0.008	0.027	0.000	0.176	0.027	0.000	0.009	0.000
GS3	0.000	0.021	0.000	0.012	0.035	0.009	0.011	0.019	0.000	0.000	0.054	0.056	0.000	0.000	0.010	0.012	0.021
GS4	0.005	0.062	0.023	0.012	0.012	0.000	0.000	0.000	0.060	0.008	0.027	0.112	0.000	0.000	0.000	0.000	0.000
GS5	0.009	0.062	0.046	0.000	0.012	0.028	0.011	0.057	0.119	0.016	0.081	0.000	0.088	0.054	0.010	0.006	0.010
GS6	0.014	0.041	0.000	0.024	0.023	0.000	0.022	0.076	0.089	0.032	0.081	0.112	0.176	0.000	0.010	0.003	0.000
GS7	0.005	0.000	0.000	0.012	0.000	0.009	0.011	0.038	0.030	0.024	0.000	0.056	0.088	0.027	0.000	0.003	0.010

Weighted normalized decision matrix was used to calculate S_i and R_i values of alternatives. S_i and R_i values are used for calculation of Q_i values, which is an important determinant for alternative ranks. S_i and R_i values of GS1 was given to show the calculation and values for all alternatives were presented in Table 14.

$$S_1 = \sum_{j=1}^{n} w_j \frac{f_j^+ - f_{1j}}{f_j^+ - f_j^-} = \sum_{j=1}^{n} v_{1j} = 0.543$$

$$R_1 = \max_j \left(w_j \frac{f_j^+ - f_{1j}}{f_j^+ - f_j^-} \right) = \max_j v_{1j} = 0.167$$

Table 14. *S_i and R_i values of alternatives*

Alternatives	S_i	R_i
GS1	0.543	0.167
GS2	0.537	0.176
GS3	0.260	0.056
GS4	0.319	0.112
GS5	0.609	0.119
GS6	0.704	0.176
GS7	0.313	0.088

As it is mentioned before, alternative ranks were determined according to the Q_i values. To calculate Qi values, we need S^-, S^+, R^-, and R^+ values. The values were given in Table 15 as follows:

Table 15. *S^-, S^+, R^-, R^+ values*

Measure	S^-	S^+	R^-	R^+,
Value	0.704	0.260	0.176	0.056

By using the formula given in VIKOR explanation part, Q_i values of alternatives were calculated. For v=0.5, Q_i value of alternative GS1 can be calculated as:

$$Q_1 = 0.5 \times \frac{S_1 - S^+}{S^- - S^+} + (1 - 0.5) \times \frac{R_1 - R^+}{R^- - R^+} = 0.5 \times \frac{0.543 - 0.260}{0.704 - 0.260} + 0.5 \times \frac{0.167 - 0.056}{0.176 - 0.056} = 0.7850$$

Q_i values of other alternatives were presented in Table 16 as follows:

Table 16. *Q_i values of alternatives (v=0.5)*

Alternatives	Q_i	Rank
GS1	0.7850	5
GS2	0.8123	6
GS3	0.0000	1
GS4	0.2998	3
GS5	0.6588	4
GS6	1.0000	7
GS7	0.1938	2

At the last step of VIKOR, acceptable advantage and acceptable stability in decision making conditions were investigated.

For the first condition; Q (a') value was determined as 0.0000 and Q (a'') value was 0.1938. DQ was equal to 0.1667, which is calculated as 1 / (7 – 1). Q (a'') – Q (a') = 0.1938 and it was greater than 0.1667. Therefore, acceptable advantage condition was met.

For the second condition; S_i and R_i values of alternative GS3 were the minimum values, which means that the alternative gets the best rank for S_i and R_i values, too. Hence, the second condition to check the obtained rank was met.

Alternative GS3 was determined as the best alternative, after the evaluation with the proposed methodology.

4. Conclusion

In recent years, development of the consumers' environmental awareness and legal obligations have caused the enterprises to produce environmentally friendly products. Raw material selection is the most important stage of production, which directly effects the characteristics of product. The selected raw material has a direct impact on the production process as well as a direct impact on the environmental effects of the product. In this study, the most appropriate green supplier for a textile manufacturer in order to produce an environmentally friendly product was examined. Selection among alternative suppliers was made by using the proposed decision making methodology based on AHP and VIKOR.

AHP evaluation was made for determination of importance degree of supplier selection criteria. Quality product sub-criteria of green design criterion was seen as the most important sub-criterion for selection of a green supplier. VIKOR analysis showed the best alternative supplier as GS3 among the seven alternatives. The alternative rank obtained by VIKOR was corrected by checking both two conditions of VIKOR method are satisfied.

In further studies, this work can be extended by making a comparison study for alternative ranks obtained as a result of different MCDM applications to the problem. Effect of criteria weight changes can be analysed with different experts' opinion or by conducting a sensitivity analysis on current criteria weights.

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