

Green Supplier Evaluation by Using an Integrated Fuzzy AHP- VIKOR Approach

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Abstract

In recent years, depletion of fossil fuel reserves and environmental challenges such as air and water pollution, global warming, and greenhouse-gas emissions have increased environmental concerns considerably. Subsequently, one of the most practical and useful solutions to decrease environmental pollutants is to deploy green purchasing and use of clean energies by organizations or even governments. Thus, construction of renewable-energy power plants and, consequently, green supplier selection for equipment of these plants have become increasingly more important. In this respect, this article presents a novel approach to assess and select green suppliers of a solar power plant. The proposed approach integrates Fuzzy Analytic Hierarchy Process and VIKOR methodologies. The results demonstrate the efficiency of the suggested approach as a practical tool to assist managers and CEOs of electric power industry in assessing suppliers for their required equipment.

Keywords: Green supplier evaluation and selection; Solar power plant; Fuzzy AHP; VIKOR.

1. Introduction

Increased awareness of environmental issues, heightened concerns about hazards of environmental pollution and pressing worries due to depletion of fossil fuel reserves force organizations and governments to seek alternative sources of energy. As a result, renewable energy and sustainable

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development have been steadily established worldwide as some of the most environmentally justifiable alternatives. Solar energy is one of the critical sources of renewable energies that pervasively serves as a viable energy supply alternative in most parts of the world (D. Al Katsaprakakis, 2012). Some of the significant advantages of using solar energy cited in the literature include (<http://www.sun.org.ir>), (M. S. Jame et al., 2013):

- Serving as a clean and renewable energy source
- Causing no pollution
- Producing solar energy free of charge once a solar panel is installed
- Being noise free while the giant machines utilized for pumping oil are extremely noisy and impractical
- Requiring very little maintenance to keep solar cells running as there are no moving parts in a solar cell
- Providing high return on investment in the long term due to the amount of free energy a solar panel can produce (it is estimated that the average household will see 50% of their energy coming from solar panels)

Renewable Energy Organization of Iran (SUNA) indicated that as Iran is located on the global Sunbelt, it enjoys an annual total of 2800 sunshine hours (M. Bahrami and P. Abbaszadeh, 2013). Iran, with 300 sunny days in more than two third of its area, and a daily average radiation of 4.5-5.5 kwh/m² is one of the countries with huge potential in terms of solar energy (<http://www.sun.org.ir>).

One of the best solutions to decrease the level of environmental pollutants is using green supply chain concepts (M. H. Zavvar Sabegh et al., 2016). For this reason, the Green Supply Chain Management (GSCM) approach has attracted much attention in recent years (M. Nazam et al., 2015). For example, Rostamzadeh *et al.* (R. Rostamzadeh et al., 2015) evaluated GSCM practices by using fuzzy VIKOR technique. GSCM includes several components such as green packaging, green production, and green supplier evaluation

Supplier selection plays a key role in the field of GSCM. In today's global competitive environment, many critical issues such as success or failure of the chosen supply chain, reduction of procurement costs, and improvement of the quality of final products are strongly dependent on the selected supplier (J. Roshandel et al., 2013). Therefore, companies have paid great attention to choose the most appropriate supplier (H. Mohamadi and A. Sadeghi, 2014). Many researchers have addressed the issues related to green supplier selection. For example, Kuo *et al.* (T. C. Kuo et al., 2015) evaluated the green suppliers of an electronics company by means of a novel hybrid multi-criteria decision-making method. First, they deployed a hybrid method of DEMATEL¹ and ANP to determine the weights for the evaluation criteria of the suppliers. Then, they evaluated the environmental performance of the company's suppliers by applying VIKOR² Method. Similarly, Awasthi *et al.* (A. Awasthi et al. 2010) presented a fuzzy multi-criteria approach in order to evaluate

¹ Decision Making Trial and Evaluation Laboratory Model (DEMATEL)

² Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

the environmental performance of suppliers. In addition, Freeman and Chen (D. Gary Graham, 2015) evaluated green suppliers using an AHP–Entropy–TOPSIS framework. Chaghooshi *et al.* (A. J. Chaghooshi, 2015) used an integrated method based on AHP-VIKOR methodology to select the best green supplier. In this regard, they obtained the weights of each criterion by using AHP method. Then, VIKOR methodology was employed for ranking green suppliers. Chen *et al.* (H. M. Wang Chen *et al.* 2016) used hybrid FAHP- FTOPSIS technique in order to evaluate suppliers from the economic and environmental aspects.

The present study attempts to offer an integrated approach for evaluating green suppliers of solar power plant's equipment. It does so while considering environmental factors within the bounds of Iran's potential implementation of solar energy and some aspects related to the problem of green supplier selection.

2. Multi-Attribute Evaluation Techniques: Fuzzy AHP- VIKOR Method

Zadeh (L. Zadeh, 1965) introduced the basic concept of fuzzy sets to consider the vagueness, ambiguity, and subjectivity of human judgment. A major contribution of Fuzzy set theory is its ability of representing ambiguous data in decision-making process. Fuzzy logic theory provides a mathematical platform from which the uncertainties associated with human cognitive procedures such as thinking and reasoning is obtained. Fuzzy multi-criteria decision making (FMCDM) has provoked high interest in different fields such as: decision science, management science and etc. Fuzzy multi-attribute decision making is one of the significant components of the FMCDM. Therefore, in this research, Fuzzy AHP-VIKOR approach is employed to tackle imprecision and uncertainty in decision makers' judgments for evaluating green suppliers (C. Cruz, 2006).

2.1. Fuzzy Analytical Hierarchical Process (FAHP)

Analytical hierarchy process (AHP) method is one of the MADM methods, which has been used successfully in several practical decision-making problems (D. Choudhary and R. Shankar, 2012). Though the goal of AHP is to capture an expert's knowledge, the conventional AHP cannot still reflect the human thought. Thus, fuzzy AHP, a fuzzy extension of AHP, was developed for solving the hierarchical fuzzy problems (S. Mahmoodzadeh, 2007).

2.2. VIKOR

The VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) is one of the most popular and widely applied Multi Attribute Decision Making (MADM) methods, which was developed for multi criteria optimization of complex systems (C.-L. Hwang and K. Yoon, 1981). It specifies the compromise ranking list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution acquired with the initial (given) weights. This method concentrates on ranking and selecting from a set of alternatives in the presence of different criteria. It introduces the multi criteria ranking index with respect to the particular measure of "closeness" to the "ideal" solution (S. Opricovic, 1998).

Assume that each alternative is evaluated based on each criteria function, the compromise ranking could be done by comparing the measure of closeness to the ideal alternative. The multiple criteria measure for compromise ranking is extended from the L_p -metric that is used as an aggregating function in a compromise programming technique (P.-L. Yu, 1973), (M. Zeleny and J. L. Cochrane, 1973). The various k alternatives ($k = 1, 2, \dots, n$) are shown as a_1, a_2, \dots, a_n . For k th alternative, the rating of the j th criteria is shown by f_{kj} , in other words, f_{kj} is the value of the j th criteria function for the alternative a_k ; m is the number of criteria ($j = 1, 2, \dots, m$). Development of the VIKOR method started with the following form of L_p -metric:

$$L_{p,k} = \left\{ \sum_{j=1}^n [w_j (f_j^* - f_{kj}) / (f_j^* - f_j^-)]^p \right\}^{1/p}, \quad 1 \leq p \leq \infty; k = 1, 2, \dots, n. \quad (1)$$

Within the VIKOR method, $L_{1,k}$ and $L_{\infty,k}$ are used to formulate ranking measure. The solution calculated by $\min_k S_k$ is with a maximum group utility (“majority” rule, demonstrated as average gap, when $p = 1$) and the solution calculated by $\min_k R_k$ is with a minimum individual regret of the “opponent”. The compromise solution F^c is a feasible solution that is the “closest” to the ideal F^* and compromise means an agreement established by mutual concessions, by these equations $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$.

3. Problem Definition

Mazandaran Province is an Iranian province, which is located along the southern coast of the Caspian Sea in the north of Iran (M. S. Khavarinejad, 2014). The province of Mazandaran covers an area of 23701 km² in northern Iran. It constitutes the northern slopes of the Alborz Mountain Range and coastal lowland along the Caspian Sea. It is dominated by the green belt of the Hyrcanian vegetation zone, which stretches over the northern slopes of the Alborz mountain range and covers the southern coast of the Caspian Sea (G. Ghobadi et al. 2013). According to dramatic growth of electricity consumption in Mazandaran Province, the Regional Electric Company attempts to build a solar power plant in the province (<http://www.suna.org.ir>). Since, construction of this solar power plant needs purchasing solar panels, this article presents an integrated approach to evaluate and rank solar panels’ suppliers for establishing the solar power plant. As a result, eight authentic firms (GS01-08) in terms of supplying solar panels are to be evaluated.

4. Proposed Design

In this section, the steps of the integrated FAHP-VIKOR approach for purchasing solar panels used in the solar power plant are described. Figure 1 outlines the proposed approach.

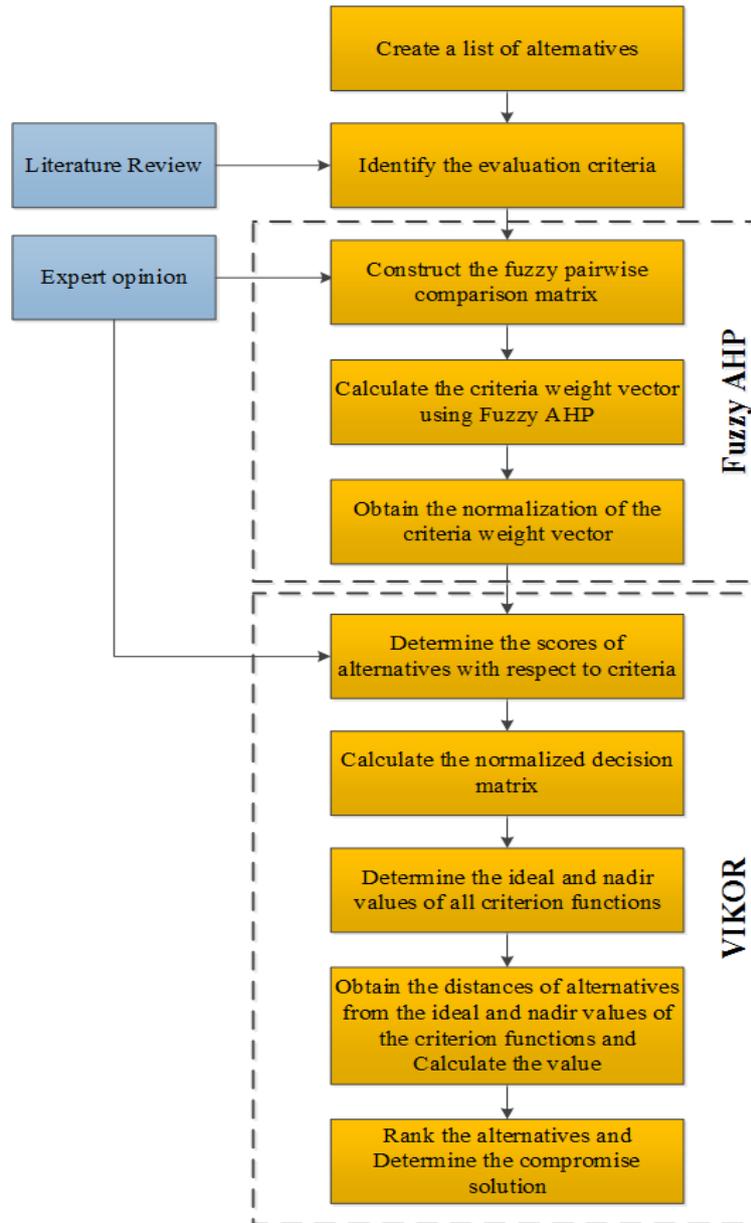


Figure 1. The Proposed approach

Step 1: Preparing a list of green suppliers

As mentioned before, in this article, eight authentic firms (GS01-08) will be evaluated in terms of supplying solar panels.

Step 2: Identify the evaluation criteria

Since this article aims to evaluate the green supplier of solar power plant’s equipment, at first by reviewing scientific texts in this field and interviewing the experts of SUNA, ten criteria for suppliers’ evaluation were derived, which are shown in Table 1.

Step 3: Obtain the criteria weights

In this step, the weight of each criterion is obtained by applying FAHP method as follows (D.-Y.

Chang, 1996):

A: Create pairwise comparison matrix

In this part, the experts are asked to determine the importance of each criterion in pairwise comparison matrix, regarding to Table 2, presented by Kahraman et al. (C. Kahraman, 2006). In the proposed model, (l, m, u) shows three elements of a triangular fuzzy number which always $l \leq m \leq u$. The questionnaires are filled by the experts in the way that each criterion in each row will be compared with the criteria in the columns.

B: Calculate S_i for each row of the pairwise comparison matrix

For each row of the pairwise comparison matrix, S_i is computed by Equation 2:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \tag{2}$$

where i shows the row's number; and j , the column's. In this equation M_{gi}^j and S_i are triangular fuzzy numbers.

$\sum_{j=1}^m M_{gi}^j$, $\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j$, and $\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1}$ can be calculated by Equations 2 to 4 respectively:

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right) \tag{3}$$

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left(\sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i \right) \tag{4}$$

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i} \right) \tag{5}$$

C: Calculate the degree of possibility of S_i to each other

In general, if $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of \tilde{M}_2 to \tilde{M}_1 ($V(\tilde{M}_2 \geq \tilde{M}_1)$) is computed as Equation 6:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \text{hgt}(\tilde{M}_1 \cap \tilde{M}_2) = \left\{ \begin{array}{ll} 0 & \text{if } m_2 \geq m_1 \\ 1 & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{o.w} \end{array} \right\} \tag{6}$$

In this step, the degree of possibility for a convex fuzzy number to be greater than n convex fuzzy

numbers $\tilde{M}_j (j = 1, 2, \dots, n)$ can be calculated by Equation 6.

$$V(\tilde{M}_N \geq \tilde{M}_1, \tilde{M}_2, \dots, \tilde{M}_{N-1}, \tilde{M}_n) = V(\tilde{M}_N \geq \tilde{M}_1), \dots, V(\tilde{M}_N \geq \tilde{M}_n) = \text{Min } V(\tilde{M}_N \geq \tilde{M}_j) = d'(c_j) \quad (7)$$

Table 1. Supplier selection criteria

Criteria	References
C01: Price/Cost	(J. Roshandel et al., 2013), (D. Golmohammadi and M. Mellat-Parast, 2012), (D. Simić et al., 2014), (S. Talluri and R. C. Baker, 2002), (S. H. Hashemi, 2015), (K. Govindan et al., 2013), (G. Kannan et al., 2009), (R. Florez-Lopez, 2007)
C02: Quality	(D. Simić et al., 2014), (S. H. Hashemi et al., 2015), (F. T. S. Chan and N. Kumar, 2007), (C. Gencer and D. Gürpınar, 2007), (S. H. Huang and H. Keskar, 2007)
C03: Delivery	(M. Nazam et al., 2015), (J. Roshandel et al., 2013), (K. Govindan et al., 2013), (R. Florez-Lopez, 2007), (Y. M. Chen et al., 2007)
C04: Financial performance	(G. Büyüközkan and G. Çifçi, 2011), (F. T. S. Chan, 2003)
C05: Production Flexibility	(M. Nazam et al., 2015), (S. H. Hashemi et al., 2015), (S. H. Huang and H. Keskar, 2007), (C. Bai and J. Sarkis, 2010)
C06: Innovation Capability	(M. Nazam et al., 2015), (C. Bai and J. Sarkis, 2010), (F. T. S. Chan et al., 2007), (A. Amindoust et al., 2012)
C07: Organizational culture	(J. Roshandel et al., 2013), (R. Florez-Lopez, 2007), (S. H. Huang and H. Keskar, 2007)
C08: Environmental Management System	(M.-L. Tseng and A. S. F. Chiu, 2013), (A. S. Darjazi, 2014), (L. C. Harris and A. Crane, 2002), (L. Shen, L. Olfat, and K. Govindan, 2013), (C. Ninlawan et al., 2010), (R. O. Large et al., 2011)
C09 Green procurement	(L. Shen, L. Olfat, and K. Govindan, 2013), (C. Ninlawan et al., 2010), (A. Webb, 2010), (H. Shekari et al., 2011), (Q. Zhu et al., 2005)
C10: Pollution	(K. Govindan et al., 2013), (S. H. Huang and H. Keskar, 2007), (A. Amindoust et al., 2012), (P. Rao, 2004)

Table 2. Linguistic scales for difficulty and importance

Linguistic scales for difficulty	Linguistic scales for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal (JI)	Just equal (JI)	(1, 1, 1)	(1, 1, 1)
Equally difficult (ED)	Equally importance (EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more difficult (WMD)	Weakly more importance (WMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more difficult (SMD)	Strongly more importance (SMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more difficult (VSMD)	Very Strongly more importance (VSMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more difficult (AMD)	Absolutely more importance (AMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

D: Calculate the criteria weight vector

The criteria's weight vector will be as Equation 8:

$$W' = (d'(C_1), d'(C_2), \dots, d'(C_n))^T \quad (8)$$

E: Obtain the final weight vector

To calculate the final criteria weights, it is enough to normalize the obtained weight vector of the previous step according to Equation 9:

$$W = \left(\frac{d'(C_1)}{\sum_{j=1}^m d'(C_j)}, \frac{d'(C_2)}{\sum_{j=1}^m d'(C_j)}, \dots, \frac{d'(C_n)}{\sum_{j=1}^m d'(C_j)} \right) \quad (9)$$

Step 4: Ranking the suppliers

In this step, the VIKOR method is used to evaluate the different green suppliers, as follows (C.-L. Hwang and K. Yoon, 1981), (S. Opricovic and G.-H. Tzeng, 2004):

A- Construct the decision matrix

In this step, considering experts' opinion, the score of each supplier is determined on each criterion. Accordingly, the Fuzzy Logic Theory was employed to determine each supplier's score (L. Zadeh, 1965). The fuzzy linguistic variables are transformed into crisp values (defuzzification) by applying Chen and Hwang approach. The crisp value, corresponding to the Fuzzy number M can be obtained as follows: The presented minimizing and maximizing sets, are like Equations 10 and 11 (S.-J. J. Chen et al. 1992).

$$\mu_{max}(x) = \begin{cases} x & 0 \leq x \leq 1 \\ 0 & otherwise \end{cases} \quad (10)$$

$$\mu_{min}(x) = \begin{cases} 1 - x & 0 \leq x \leq 1 \\ 0 & otherwise \end{cases} \quad (11)$$

The left utility score of each Fuzzy number (M_i) is introduced as $\mu_L(M_i) = Sup_x [\mu_{min}(x) \wedge \mu_{M_i}(x)]$.

The $\mu_L(M_i)$ is a unique real number, within [0, 1]. This score is the maximum membership amount from the intersection of M_i and Fuzzy min. The right utility value is similarly calculated as $\mu_R(M_i) = Sup_x [\mu_{max}(x) \wedge \mu_{M_i}(x)]$. As $\mu_L(M_i)$, $\mu_R(M_i)$ is a unique real number within [0, 1]. By

Calculating the left- and right scores, the total score of M_i is obtained as follows.

$$\mu_{Total}(M_i) = [\mu_R(M_i) + 1 - \mu_L(M_i)]/2 \quad (12)$$

According to this approach, crisp score for linguistic terms (M_i) can be computed as shown in Fig. 2. (A. Baykasoglu, 2012).

B- Calculate the normalized decision matrix

In this part, the normalized value r_{ij} is calculated by means of Equation 13:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^J f_{ij}^2}}, j = 1, \dots, J; i = 1, \dots, n \tag{13}$$

C- Determine the best f_j^* and the worst f_j^- values

In this step, the best f_j^* and the worst f_j^- values of all criterion functions, ($j = 1, 2, \dots, m$) are determined. If the j th function represents a benefit, then $f_j^* = \max_k f_{kj}$ or is set as the aspired/desired level, $f_j^- = \min_k f_{kj}$ or is set as the worst level.

D- Calculate the S_k and R_k values

In this part, the S_k values ($k = 1, 2, \dots, n$), are obtained by using equation (14), which are shown as in the average gap. Also, R_k values are obtained by using equation (15), which are shown as maximal gap for improvement priority, where w_j are the weights of criteria, expressing their relative importance.

$$S_k = \sum_{j=1}^m w_j |f_j^* - f_{kj}| / |f_j^* - f_j^-| \tag{14}$$

$$R_k = \max_j \{|f_j^* - f_{kj}| / |f_j^* - f_j^-| \quad j = 1, 2, \dots, m\} \tag{15}$$

E- Calculate the value Q_k

The Q_k ($k = 1, 2, \dots, n$) values are obtained by equation (16):

$$Q_k = v \frac{(S_k - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_k - R^*)}{(R^- - R^*)}, \quad k = 1, 2, \dots, m \tag{16}$$

Where

$S^* = \min_k S_k$ or let $S^* = 0$ be zero gap, i.e., achieve the aspired level,

$S^- = \max_k S_k$ or let $S^- = 1$ be the worst level,

$R^* = \min_j R_j$ or let $R^* = 0$ be zero gap, i.e., achieve the aspired level,

$R^- = \max_j R_j$ or let $R^- = 1$ be the worst level

Thus, we also can re-write $Q_k = vS_k + (1 - v)R_k$, when $S^* = 0, S^- = 1, R^* = 0$, and $R^- = 1$. v is

defined as the weight of the strategy of “the majority of criteria” (or “the maximum group utility”) and here $v = 0.5$.

F- Rank the alternatives

In this step, the alternatives are ranked based on the values of S , R , and Q . The results are three ranking lists.

G-Determine the compromise solution

The best alternative is selected (a'') based on the minimum value of Q . if the following two conditions are satisfied:

C1. “Acceptable advantage”:

$$Q(a'') - Q(a') \geq DQ,$$

Where a'' is the alternative with second position in the ranking list by Q ; $DQ = 1/(J - 1)$; and J is the number of alternatives.

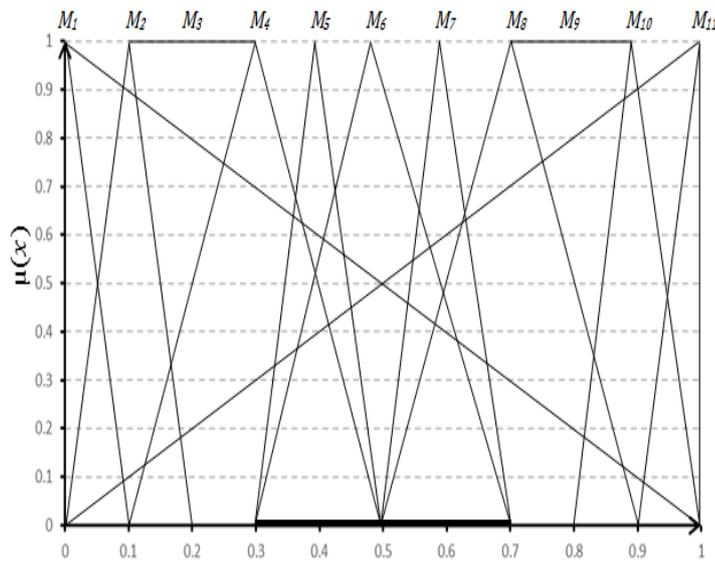
C2. “Acceptable stability in decision making”:

Alternative a' must also be the best ranked by S or/and R . This compromise solution is stable within a decision-making process, which could be: “voting by majority rule” (when $v > 0.5$ is required), “by consensus” ($v \approx 0.5$), or “with vote” ($v < 0.5$). At this point, v is the weight of the decision-making strategy “the majority of criteria” (or “the maximum group utility”).

If one of the conditions is not satisfied, then a set of compromise solutions is suggested, which includes:

- Alternative a' and a'' if only condition C2 is not satisfied, or
- Alternative $a', a'', \dots, a^{(n)}$ if condition C1 is not satisfied; and $a^{(n)}$ is determined by the relation $Q(a^{(n)} - Q(a')) < DQ$ for maximum n (the positions of these alternatives are “in closeness”).

As mentioned before, the best alternative, which is ranked by Q , is the one with the minimum value of Q . The main ranking result is the compromise ranking list of alternatives and the compromise solution with the “advantage rate.”



Linguistic term	Crisp score
Exceptionally low (M_1)	0.045
Extremely low (M_2)	0.135
Very low (M_3)	0.255
Low (M_4)	0.335
Below average (M_5)	0.420
Average (M_6)	0.500
Above average (M_7)	0.590
High (M_8)	0.665
Very high (M_9)	0.745
Extremely high (M_{10})	0.865
Exceptionally high (M_{11})	0.955

Figure 2. Linguistic terms to fuzzy number conversion to evaluate criteria values for each alternative

(A. Baykasoglu, 2012)

5. Results and Discussions

Initially, the weights of the ten criteria were determined by deploying FAHP method. Table 3 shows part of the pairwise comparison matrix as completed by the experts. The FAHP results show that the criteria weight vector consists of 0.113, 0.111, 0.110, 0.104, 0.098, 0.095, 0.099, 0.093, 0.091 and 0.086, respectively. The results show that the price criteria and pollution criteria have the highest and lowest weights respectively in determining the most appropriate supplier for solar power plant’s equipment.

Table.4 shows part of the suppliers’ scores on each criterion. The suppliers’ score with respect to each criterion was determined by using the experts’ opinion.. For example, in Table 4 the score of supplier 1 on criteria 1 is M5. It means, the decision maker believes that performance of supplier 1 with respect to criterion 1 is “Below average” where, according to the linguistic terms as shown in Figure 2, “Below average” is equal to 0.420. Eventually, after constructing Table 4, the final rank of each supplier was determined by using VIKOR method. As shown in Table 5, the eighth supplier (GS08) is the most appropriate firm for supplying panels used in Mazandaran solar power plant.

Table 3. Part of the pairwise comparisons matrix of criteria

	C01	C02	C03	C04	C05
C01	1	JI	WMI	SMI	EI
C02	JD	1	WMD	VSMI	JI
C03	WMD	WMI	1	SMI	SMD
C04	SMD	VSMI	SMD	1	VSMI
C05	ED	ED	SMI	VSMI	1

Table 4. Part of the scores of suppliers with respect to each criterion

	C01	C02	C03	C04	C05	...	C10
GS01	M5	M5	M5	M5	M5	...	M8
GS02	M6	M6	M6	M7	M6	...	M10
GS03	M4	M4	M4	M4	M4	...	M8
GS04	M2	M2	M2	M3	M3	...	M5
GS05	M3	M3	M3	M2	M2	...	M6

6. Conclusion

The worldwide awareness of ecological protection is dramatically increasing. This is due to the ever-worsening ecological pollution. For organizations in need of attaining competitive advantage, the significance of green purchasing has become more prominent. The environmental performance of organizations interacts with two sets of factors namely: the inner environmental efforts and the suppliers' environmental performances. Hence, in order to choose an appropriate supplier, a company needs to carry out a performance evaluation on potential green suppliers.

In this study, an integrated approach to select green suppliers of solar power plant was presented. Initially a list of suppliers meeting the minimum required conditions, was prepared. Then, based on the scientific texts and opinions of solar power industry experts, ten assessment criteria, including both economic and environmental factors were identified. Then, the weights of criteria were calculated with FAHP. The obtained results show that the price criterion is the most significant factor in selecting the best supplier for solar power plant's equipment. Afterwards, based on experts' opinion, on each criterion, the score of each supplier was determined and eventually, the rank of each supplier was acquired using VIKOR technique. Accordingly, supplier number 8 (GS08) was selected as the best firm for purchasing solar panels of Mazandaran solar power plant.

It is noteworthy that our proposed approach has the ability to evaluate green suppliers of solar power plant's equipment without quantitative information and by using linguistic terms to overcome the uncertainty due to human qualitative judgment. Senior and mid-level managers can use this method to select the most appropriate green suppliers for solar power plant's equipment.

For future research, the results can be compared with other fuzzy MCDM techniques such as fuzzy ANP- VIKOR. It can also be helpful to analyze the interdependencies among the decision criteria and their relative intensities. The impact of inter-relationship between criteria on decision making results need to be examined.

Table 5. Final Rank of Suppliers

Final Rank	Supplier's code
1	GS8
2	GS2
3	GS7
4	GS1
5	GS3
6	GS5
7	GS4
8	GS6

References

- A. Amindoust, S. Ahmed, A. Saghafinia, and A. Bahreininejad, "Sustainable supplier selection: A ranking model based on fuzzy inference system," *Appl. Soft Comput.*, vol. 12, no. 6, pp. 1668–1677, Jun. 2012.
- A. Awasthi, S. S. Chauhan, and S. K. Goyal, "A fuzzy multicriteria approach for evaluating environmental performance of suppliers," *Int. J. Prod. Econ.*, vol. 126, no. 2, pp. 370–378, Aug. 2010.
- A. Baykasoglu, "A review and analysis of 'graph theoretical-matrix permanent' approach to decision making with example applications," *Artif. Intell. Rev.*, vol. 42, no. 4, pp. 573–605, Sep. 2012.
- A. J. Chaghooshi, A. karim Pahlevani, and E. S. Zarchi, "Integration of MCDM Methods for Green Supplier Selection," *Glob. J. Manag. Stud. Res.*, vol. 2, no. 1, pp. 32–37, 2015.
- A. S. Darjazi, "A Goal Programming Approach for Multiple Objective Green Supply Chain Management," *Glob. J. Human-Social Sci. Res.*, vol. 14, no. 1, 2014.
- A. Webb, "How green is my supply chain," *Dev. Learn. Organ. An Int. J.*, vol. 24, no. 3, 2010.
- C. Bai and J. Sarkis, "Integrating sustainability into supplier selection with grey system and rough set methodologies," *Int. J. Prod. Econ.*, vol. 124, no. 1, pp. 252–264, Mar. 2010.
- C. Cruz, A. Sancho-Royo, D. Pelta, and J. L. Verdegay, "Fuzzy sets based cooperative heuristics for solving optimization problems," in *Fuzzy applications in industrial engineering*, no. November 2015, 2006, pp. 505–519.
- C. Gencer and D. Gürpınar, "Analytic network process in supplier selection: A case study in an

- electronic firm,” *Appl. Math. Model.*, vol. 31, no. 11, pp. 2475–2486, Nov. 2007.
- C. Kahraman, T. Ertay, and G. Büyüközkan, “A fuzzy optimization model for QFD planning process using analytic network approach,” *Eur. J. Oper. Res.*, vol. 171, no. 2, pp. 390–411, 2006.
- C.-L. Hwang and K. Yoon, *Multiple Attribute Decision Making*, vol. 186. 1981.
- C. Ninlawan, P. Seksan, K. Tossapol, and W. Pilada, “The implementation of green supply chain management practices in electronics industry,” in *Proceedings of the international multiconference of engineers and computer scientists*, 2010, vol. 3, pp. 17–19.
- D. Al Katsaprakakis, “A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete,” *Renew. Sustain. energy Rev.*, vol. 16, no. 5, pp. 2850–2863, 2012.
- D. Choudhary and R. Shankar, “An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India,” *Energy*, vol. 42, no. 1. pp. 510–521, 2012.
- D. Gary Graham, J. Freeman, and T. Chen, “Green supplier selection using an AHP-Entropy-TOPSIS framework,” *Supply Chain Manag. An Int. J.*, vol. 20, no. 3, pp. 327–340, 2015.
- D. Golmohammadi and M. Mellat-Parast, “Developing a grey-based decision-making model for supplier selection,” *Int. J. Prod. Econ.*, vol. 137, no. 2, pp. 191–200, Jun. 2012.
- D. Simić, V. Svirčević, and S. Simić, “An Approach of Fuzzy Models for Supplier Assessment and Selection,” in *International Joint Conference SOCO’14-CISIS’14-ICEUTE’14*, 2014, pp. 175–184.
- D.-Y. Chang, “Applications of the extent analysis method on fuzzy AHP,” *Eur. J. Oper. Res.*, vol. 95, no. 3, pp. 649–655, 1996.
- F. T. S. Chan and N. Kumar, “Global supplier development considering risk factors using fuzzy extended AHP-based approach,” *Omega*, vol. 35, no. 4, pp. 417–431, 2007.
- F. T. S. Chan, “Interactive selection model for supplier selection process: an analytical hierarchy process approach,” *Int. J. Prod. Res.*, vol. 41, no. 15, pp. 3549–3579, 2003.
- F. T. S. Chan, H. K. Chan, R. W. L. Ip, and H. C. W. Lau, “A decision support system for supplier selection in the airline industry,” *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 221, no. 4, pp. 741–758, 2007.
- G. Büyüközkan and G. Çifçi, “A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information,” *Comput. Ind.*, vol. 62, no. 2, pp. 164–174, Feb. 2011.
- G. Ghobadi, B. Gholizadeh, and S. Motavalli, “Estimating global solar radiation from common

meteorological data in sari station, Iran,” *Int. J. Agric. Crop Sci.*, vol. 5, no. 21, p. 2650, 2013.

G. Kannan, S. Pokharel, and P. S. Kumar, “A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider,” *Resour. Conserv. Recycl.*, vol. 54, no. 1, pp. 28–36, 2009.

H. Mohamadi and A. Sadeghi, “Presenting a multi objective model for supplier selection in order to reduce green house gas emission under uncertainty demand,” *Int. J. Supply Oper. Manag.*, vol. 1, no. 2, pp. 228–244, 2014.

H. M. Wang Chen, S.-Y. Chou, Q. D. Luu, and T. H.-K. Yu, “A Fuzzy MCDM Approach for Green Supplier Selection from the Economic and Environmental Aspects,” *Math. Probl. Eng.*, vol. 2016, 2016.

H. Shekari, S. Shirazi, M. A. Afshari, and S. M. Veyseh, “Analyzing the key factors affecting the green supply chain management: A case study of steel industry,” *Manag. Sci. Lett.*, vol. 1, no. 4, pp. 541–550, Oct. 2011.

J. Roshandel, S. S. Miri-Nargesi, and L. Hatami-Shirkouhi, “Evaluating and selecting the supplier in detergent production industry using hierarchical fuzzy TOPSIS,” *Appl. Math. Model.*, vol. 37, no. 24, pp. 10170–10181, Dec. 2013.

K. Govindan, R. Khodaverdi, and A. Jafarian, “A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach,” *J. Clean. Prod.*, vol. 47, pp. 345–354, May 2013.

L. C. Harris and A. Crane, “The greening of organizational culture: Management views on the depth, degree and diffusion of change,” *J. Organ. Chang. Manag.*, vol. 15, no. 3, pp. 214–234, 2002.

L. Shen, L. Olfat, and K. Govindan, “A fuzzy multi criteria approach for evaluating green supplier’s performance in green supply chain with linguistic preferences,” *Resour. Conserv. ...*, vol. 74, pp. 170–179, May 2013.

L. Zadeh, “Fuzzy sets,” *Inf. Control*, vol. 353, pp. 338–353, 1965.

M. Bahrami and P. Abbaszadeh, “An overview of renewable energies in Iran,” *Renew. Sustain. Energy Rev.*, vol. 24, pp. 198–208, Aug. 2013.

M. H. Zavvar Sabegh, Y. OzturkOglu, and T. Kim, “Green Supply Chain Management Practices’ Effect on the Performance of Turkish Business Relationships,” *Int. J. Supply Oper. Manag.*, vol. 2, no. 4, pp. 982–1002, 2016.

M.-L. Tseng and A. S. F. Chiu, “Evaluating firm’s green supply chain management in linguistic preferences,” *J. Clean. Prod.*, vol. 40, pp. 22–31, 2013.

M. Nazam, J. Xu, Z. Tao, J. Ahmad, and M. Hashim, “A fuzzy AHP-TOPSIS framework for the risk assessment of green supply chain implementation in the textile industry,” *Int. J. Supply Oper.*

Manag., vol. 2, no. 1, pp. 548–568, 2015.

M. S. Jamel, A. A. Rahman, and A. H. Shamsuddin, “Advances in the integration of solar thermal energy with conventional and non-conventional power plants,” *Renew. Sustain. Energy Rev.*, vol. 20, pp. 71–81, 2013.

M. S. Khavarinejad, “Determination of genetic distances in spring wheat by cluster analysis in Mazandaran province (North of Iran),” *African J. Agric. Res.*, vol. 9, no. 48, pp. 3488–3493, 2014.

M. Yazdani, “An integrated MCDM approach to green supplier selection,” *Int. J. Ind. Eng. Comput.*, vol. 5, no. 3, pp. 443–458, 2014.

M. Zeleny and J. L. Cochrane, *Multiple criteria decision making*. University of South Carolina Press, 1973.

P.-L. Yu, “A class of solutions for group decision problems,” *Manage. Sci.*, vol. 19, no. 8, pp. 936–946, 1973.

P. Rao, “Greening production: a South-East Asian experience,” *Int. J. Oper. Prod. Manag.*, vol. 24, no. 3, pp. 289–320, Mar. 2004.

Q. Zhu, J. Sarkis, and Y. Geng, “Green supply chain management in China: pressures, practices and performance,” *Int. J. Oper. Prod. Manag.*, vol. 25, no. 5, pp. 449–468, 2005.

R. Florez-Lopez, “Strategic supplier selection in the added-value perspective: A CI approach,” *Inf. Sci. (Ny)*, vol. 177, no. 5, pp. 1169–1179, 2007.

R. O. Large, C. G. Thomsen, and C. Gimenez Thomsen, “Drivers of green supply management performance: Evidence from Germany,” *J. Purch. Supply Manag.*, vol. 17, no. 3, pp. 176–184, Sep. 2011.

R. Rostamzadeh, K. Govindan, A. Esmaili, and M. Sabaghi, “Application of fuzzy VIKOR for evaluation of green supply chain management practices,” *Ecol. Indic.*, vol. 49, pp. 188–203, 2015.

S.-J. J. Chen, C.-L. Hwang, M. J. Beckmann, and W. Krelle, *Fuzzy multiple attribute decision making: methods and applications*. Springer-Verlag New York, Inc., 1992.

S. H. Hashemi, A. Karimi, and M. Tavana, “An integrated green supplier selection approach with analytic network process and improved Grey relational analysis,” *Int. J. Prod. Econ.*, vol. 159, pp. 178–191, Jan. 2015.

S. H. Huang and H. Keskar, “Comprehensive and configurable metrics for supplier selection,” *Int. J. Prod. Econ.*, vol. 105, no. 2, pp. 510–523, Feb. 2007.

S. Mahmoodzadeh, J. Shahrabi, M. Pariazar, and M. S. Zaeri, “Project Selection by Using Fuzzy AHP and TOPSIS Technique.” pp. 333–338, 2007.

S. Opricovic, "Multicriteria optimization of civil engineering systems," *Fac. Civ. Eng. Belgrade*, vol. 2, no. 1, pp. 5–21, 1998.

S. Opricovic and G.-H. Tzeng, "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS," *Eur. J. Oper. Res.*, vol. 156, no. 2, pp. 445–455, 2004.

S. Talluri and R. C. Baker, "A multi-phase mathematical programming approach for effective supply chain design," *Eur. J. Oper. Res.*, vol. 141, no. 3, pp. 544–558, 2002.

T. C. Kuo, C.-W. Hsu, and J.-Y. Li, "Developing a Green Supplier Selection Model by Using the DANP with VIKOR," *Sustainability*, vol. 7, no. 2, pp. 1661–1689, 2015.

Y. M. Chen, P.-N. P. Huang, Y. Ming Chen, and A. Gunasekaran, "Bi-negotiation integrated AHP in suppliers selection," *Int. J. Oper. Prod. Manag.*, vol. 27, no. 11, pp. 1254–1274, Oct. 2007.

"Renewable energy organization of Iran (SUNA)." [Online]. Available: <http://www.suna.org.ir>.