A Hybrid Fuzzy Decision-making Method for the Supplier Selection Problem Based on the Digitalization, Agility, and Sustainability Dimensions for the Energy Industry

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Abstract
In today's competitive business environment, the crucial role of supply chain management is undeniable. In this field, one of the critically important branches is the supplier selection problem which plays a key role in improving the efficiency of the companies. In this study, due to the importance of the mentioned points, a hybrid fuzzy decision-making method is proposed to investigate the supplier selection problem with three important and crucial dimensions namely digitalization, agility, and sustainability. To do this, at the outset, the main aspects and indicators of the research problem are determined based on the literature and experts. Then, the Fuzzy Best-Worst Method (FBWM) is used to calculate the weight of indicators. In the next step, the suppliers are ranked by applying the Fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje (FVIKOR) method. Finally, the validity and robustness of the applied approaches have been checked by comparing them with other methods.

Keywords: Supplier selection problem, Digitalization; Agility, Sustainability, Decision-making

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Introduction

With the significant increase in competition in today's marketplace, the importance of supply chain (SC) management has been drastically highlighted. In this way, researchers and managers have paid considerable attention to this critically important concept [1]. In this area, one of the crucial subsections is the supplier selection problem (SSP) which aims to evaluate the performance of the potential suppliers based on the considered indicators [2]. Since a significant part of the budget of each company is assigned to the purchasing of raw materials, setting an appropriate plan to evaluate the suppliers' performance is a crucial task for managers [3]. Although researchers only considered general indicators like price and delivery time in the traditional approach, their attention has been dramatically attracted towards some other indicators such as digitalization, agility, and sustainability in recent years due to different reasons such as technology growth, uncertainties, and environmental concerns [4].

One of the industries that plays a significant role in other industries and also society, is the energy industry. Energy supply is done through various carriers such as oil, gas and their products, coal, nuclear and renewable energy and there are many challenges in this regard to be continuously taken into consideration. Hence, the efficacious role of energy in economic development and prosperity, increase in energy consumption in parallel with the growth and development of countries, and limited resources are the main factors that create a necessity for proper management of energy production and consumption in order to prevent crises in the future. Hence, investigating the supply chain of the energy industry is an important problem in both theoretical and practical aspects.

In the field of supplier selection or the energy industry, Kaviani et al., [5] focused on evaluating the performance of the suppliers in an oil and gas company in an uncertain environment. In this regard, the authors used the grey-Delphi approach to evaluate and refine a number of available criteria to attain the most relevant and significant criteria for the oil and gas industry. Then, by employing an integrated Grey-Shannon entropy and grey-evaluation based on distance from the average solution, they evaluate the performance of the feasible suppliers. Habibah and Kusumastuti [6] evaluated the suppliers of the energy industry sector using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. In this regard, first of all, the author determined ten indicators and then dispatched the questionnaire among 57 interviewees to identify the importance of indicators. Li et al. [7] focused on the sustainable supplier selection problem for the oil and gas industry by employing the decision-making approach. To this end, they developed this TOPSIS procedure for selecting sustainable suppliers, which combined the advantages of cloud model theory in manipulating randomness uncertainty and coarse set theory in dealing with interpersonal uncertainty flexibly without additional information. Gidiagba et al. [8] suggested a decision-making framework for the evaluation of the potential suppliers for the energy industry. The authors used the Delphi method for filtering and ranking unnecessary factors to find the most appropriate criteria. In the next step, the authors combined the best-worst method (BWM) and TOPSIS approach to assess the suppliers' performance. [9] addressed the oil and gas supplier selection by considering environmental factors. In this regard, the authors used the group best-worst method to determine the most desirable indicators and employed the PROMETHEE method to rank the suppliers. As can be seen in the reviewed literature, although there are several papers that have focused on the supplier selection problem for the energy industry, the simultaneous consideration of the digitalization, agility, and sustainability dimensions in this field has been ignored by the previous works. However, as aforementioned, all of these dimensions play a critically important role in improving the efficiency and productivity of a company. Hence, motivated by the importance of the supplier selection problem and also the key role of the mentioned dimensions (i.e., digitalization, agility, and sustainability), this study aims to develop a hybrid fuzzy decision-making approach based on the fuzzy BWM (FBWM) and Fuzzy VIKOR (FVIKOR) to investigate the digital-agile-sustainable supplier selection problem for the energy industry. Overall, the main contribution of this work is the simultaneous consideration of the digitalization, agility, and sustainability dimensions in the supplier evaluation process for the energy industry.

Determining the indicators and alternatives

In this section, the main aspects and indicators of the research problem are determined based on the literature and experts. For this purpose, we first extract the potential indicators based on the related studies (for example [10] [8] [11][4][12]), and then the experts chosen the most related indicators. Table 1 shows the selected aspects and indicators for the current study. Also, in this work, we consider five suppliers for evaluation.

Table 1. *The selected aspects and indicators*

Aspect	Indictor
General	Quality
	Cost
	Delivery
	Service
	Turnover
Sustainability	Greenhouse gas emission
	Waste management
	Pollution control
	Job safety and labor health
	Job opportunities
Agility	Manufacturing flexibility
	Lead time flexibility
	Resource flexibility
	Responsiveness
	Reliability
Digitalization	Information sharing
	Smart factory
	Security and privacy
	Technical capability
	Digital engagement

Methodology

As aforementioned, this study employed a hybrid fuzzy decision-making to evaluate the performance of the suppliers based on the agility, digitalization and sustainability dimensions for the energy industry. In this regard, the FBWM is used to calculate the weight of indicators and FVIKOR is employed to assess the suppliers. In the following, we have briefly described these approaches.

3.3.1. FBWM

One of the approaches that drastically attracted the attention of researchers in recent years due to its advantages is the Best-Worst Method (BWM). This approach has dramatically reduced the number of pairwise comparisons resulting in decreasing the computing burden and enhancing reliability [13]. Since the traditional BWM couldn't deal with the uncertain environment, researchers developed its fuzzy version [14]. In the present article, we employ the FBWM to compute the weight of the indicators due to its advantages. In this method, first of all, the best and worst indicators have been specified. In the next step, the pairwise comparison vectors have been formed. To do this, let$\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \dots, \tilde{a}_{Bn})$ and $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \dots, \tilde{a}_{nW})$ respectively denote the comparison vector between the best indicator with other indicators, and the worst indicators with other indicators. Then, Table 2 can be utilized to make a comparison. Afterwards, using Model (1), the weight of indicators is obtained. In this model, $\widetilde{w}_j = (l_j^w, m_j^w, u_j^w)$ denotes the fuzzy weights of the indicators, $\widetilde{a}_{Bj} = (l_{Bj}, m_{Bj}, u_{Bj})$ is the best-to-other vector, $\tilde{a}_{jW} = (l_{jW}, m_{jW}, u_{jW})$ shows the other-to-worst vector, and $\tilde{\xi}^* = (k^*, k^*, k^*)$. Also, $R(\tilde{a}) = \frac{l+4m+u}{6}$. In the last step, the CR (Consistency Ratio) should be checked. To this end, CR is calculated according to $CR = {\xi^*}/{CI}$ where CI is the consistency index and can be extracted based on Table 3.

Table 2. Linguistic variables and their membership functions [14]

Linguistic terms	Very Important (VI)	Very Important (VI)	Fairly Important (FI)	Weakly Important (WI)	Equally Important (EI)
Membership function	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(0.6667, 1, 1.5)	(1, 1, 1)

$$
\begin{aligned}
&\text{Min } \tilde{\xi}^* \\
&\text{S.t:} \\
&\left|\frac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj})\right| \le (k^*, k^*, k^*) && \forall j, \\
&\left|\frac{(l_j^w, m_j^w, u_j^w)}{(l_W^w, m_W^w, u_W^w)} - (l_{jW}, m_{jW}, u_{jW})\right| \le (k^*, k^*, k^*) && \forall j, \qquad (1)\\
&\sum_{j=1}^{n} R(\widetilde{w}_j) = 1, \\
&l_j^w \le m_j^w \le u_j^w && \forall j, \\
&l_j^w \ge 0 && \forall j.
\end{aligned}
$$

Table 3. Consistency Index values [14]

	(EI)	**(WI)**	**(FI)**	**(VI)**	**(AI)**
$\tilde{a}_{BW}$	(1, 1, 1)	(0.667, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
CI	3.00	3.80	5.29	6.69	8.04

3.3.2. FVIKOR

VIKOR is one of the widely-used decision-making methods that offer compromising solutions and can create stable decision-making performance by replacing the adaptive solution with the primary weight [15]. Adaptive solution theory is a practical solution that is close to the ideal solution, and adaptation means the agreement made by scores. VIKOR method provides the maximum productivity of the "majority" group and the minimum individual regret of the "opposite" group and the agreed solution can be easily achieved by decision-makers. As the VIKOR method is not able to model uncertainty, researchers developed the fuzzy VIKOR method that consisting of the following steps:

Step 1: Creating a group of decision-makers (experts).

Step 2: Determine the appropriate linguistic variables for scoring alternatives according to the criteria. For this step, Table 4 can be applied.

Table 4. Linguistic variables of FVIKOR [16]

Linguistic terms	Very poor (VP)	Poor (P))	Medium Poor (MP)	Fair (F)	Medium good (MG)	Good (G)	Very good (VG)
Fuzzy numbers	(0.0, 0.0, 1.0)	(0.6667, 1, 1.5)	(1.0, 3.0, 5.0)	(3.0, 5.0, 7.0)	(5.0, 7.0, 9.0)	(7.0, 9.0, 10.0)	(9.0, 10.0, 10.0)

Step 3: Creating the normal fuzzy decision matrix where $\tilde{x}_{ij}$ is the score of alternative A_i based on the criteria of C_j.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & . & . & . & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & . & . & . & \tilde{x}_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & . & . & . & \tilde{x}_{mn} \end{bmatrix} \tag{9}$$

Step 4: Defuzzification of the decision matrix employing equation (11):

$$x_{ij} = \frac{[(Ux_{ij} - Lx_{ij}) + (Mx_{ij} - Lx_{ij})]}{3} + Lx_{ij} \tag{10}$$

Step 5: determine the Best Value (BV) and the Worst Value (WV).

$$f_i^- = \min_i x_{ij}\ , \qquad f_i^* = \max_i x_{ij} \tag{11}$$

Step 6: calculate the value of s_i and R_i.

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - x_{ij})/(f_j^* - f_j^-) \tag{12}$$

$$R_i = \max_j [w_j (f_j^* - x_{ij})/(f_j^* - f_j^-)] \tag{13}$$

Step 7: determine s^-, s^*, R^-, R^*, and Q_i.

$$S^* = \min_i S_i\ , \qquad S^- = \max_i S_i \tag{14}$$

$$\tilde{R}^- = \max_i \tilde{R}_i\ , \qquad R^* = \min_i R_i \tag{15}$$

$$Q_j = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*) \tag{16}$$

Where v means the weight of the group's maximum productivity strategy.

Step 8: Prioritizing the alternatives based on Q_i.

It should be noted that there are some conditions for the final ranking of the FVIKOR that interested readers can see [16] and [17].

Numerical results

In this section, the results obtained by implementing the utilized decision-making framework are presented. In this regard, Table 5 shows the results of the FBWM that presents the weights of the indicators. Based on this table, responsiveness, cost, quality, reliability, security and privacy, technical capability, and waste management are the most important indicators. Finally, Table 6 is the ranking of the suppliers based on the considered indicators using the FVIKOR method. According to Table 6, the ranking of the suppliers is as follows: 1) A1, 2) A5, 3) A2, 4) A4, 5) A3.

Table 5. The results of the FBWM

Aspect	**Aspect's weight**	**Indictor**	**Indicator's initial weight**	**Indicator's final weight**
General	0.2512	Quality	0.2115	0.05333
		Cost	0.2123	0.05313
		Delivery	0.1965	0.04936
		Service	0.1944	0.04883
		Turnover	0.1853	0.04655
Sustainability	0.2502	Greenhouse gas emission	0.2025	0.05067
		Waste management	0.2101	0.05257
		Pollution control	0.1924	0.04814
		Job safety and labor health	0.1906	0.04769
		Job opportunities	0.2044	0.05114
Agility	0.251	Manufacturing flexibility	0.1944	0.04879
		Lead time flexibility	0.1921	0.04822
		Resource flexibility	0.1899	0.04766
		Responsiveness	0.2128	0.05341
		Reliability	0.2108	0.05291
Digitalization	0.2476	Information sharing	0.1932	0.04784

		Smart factory	0.1931	0.04781
		Security and privacy	0.2138	0.05294
		Technical capability	0.2125	0.05262
		Digital engagement	0.1874	0.04640

Table 6. The ranking of the suppliers

	Qj	Rank
A1	0	1
A2	0.18158	3
A3	0.29271	5
A4	0.26279	4
A5	0.00612	2

Performance of the employed methods

In this section, we examine the performance of the employed approach. To this end, at the outset, we compare the performance of the utilized FBWM by comparing it with the FAHP method based on the CR metric. In this regard, Figure 1 compares the mentioned methods based the CR metric. As shown in this figure, the performance of the employed FBWM is significantly better than the FAHP, which confirms its robustness and efficiency. On the other side, to examine the performance of the FVIKOR, we implement this approach using different defuzzification methods such as Bisector of Area (BOA), Center of Area (COA), Smallest of Maximum (SOM), Mean of Maximum (MOM), and Largest of Maximum (LOM) (see to [18,19] more study). The outputs that are shown in Table 7 indicate that changing the defuzzification method has no significant effect on the results, and the rankings of the suppliers are relatively similar. In this regard, supplier A1 is the best in all of the defuzzification methods, which indicates that the model is robust and valid.

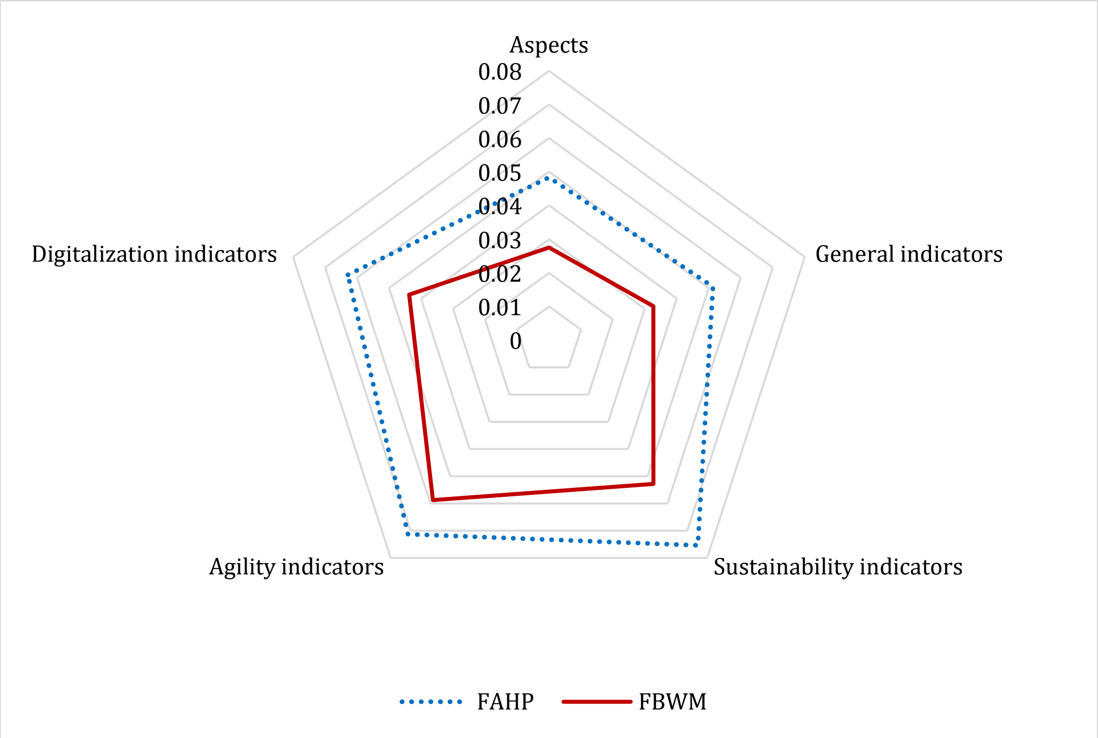

Figure 1. Comparing the performance of the FBWM and FAHP based on the CR metric

Table 7. Results of sensitivity analysis

	BOA	COA	SOM	MOM	LOM
A1	0	0	0	0	0
A2	0.182837	0.170877	0.175788	0.180947	0.173888
A3	0.270513	0.258334	0.267007	0.275681	0.269439
A4	0.262324	0.256348	0.256994	0.254648	0.25783
A5	0.008218	0.00703	0.00704	0.006441	0.007638

Managerial insights

This research has focused on the supplier selection problem by considering three crucial concepts namely digitalization, agility, and sustainability. In this regard, this work developed a hybrid decision-making approach to calculate the indicators' weights and assess the alternatives' performance. This study can give a comprehensive view to managers to be familiar with the main indicators related to the mentioned dimensions (i.e., digitalization, agility, and sustainability) and help them to implement these critically important dimensions in their businesses. Also, this work can help managers to be familiar with the fuzzy uncertainty in the decision-making environment and the way of dealing with it. In general, the main benefit of this work for practical managers is that they should know that only considering the general indicators like cost and quality is not acceptable in today's competitive marketplace and managers should consider other aspects such as agility and digitalization to improve the productivity of their companies.

Conclusions and future suggestions

Owing to the key role of the suppliers in the efficiency and productivity of the energy industry, this study has focused on evaluating the feasible suppliers based on the several critically important dimensions namely sustainability, agility, and digitalization for the energy industry. To do this, the present article has extracted the main indicators of the research problem and then suggested a hybrid fuzzy method based on the FBWM and FVIKOR approaches. The obtained results showed that responsiveness, cost, quality, reliability, security and privacy, technical capability, and waste management are the most important indicators. On the other hand, based on the outputs, the ranking of the suppliers is as follows: 1) A1, 2) A5, 3) A2, 4) A4, 5) A3. Finally, the validity and robustness of the applied approaches have been checked by comparing them with traditional methods. Future studies can consider other dimensions such as resiliency. Also, developing a data-driven approach to evaluate the performance of the suppliers is another direction for future papers.

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