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Supplier Selection in Downstream Oil and Gas and Petrochemicals with the Fuzzy BWM and Gray COCOSO Methods Considering Sustainability Criteria and Uncertainty Conditions

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Abstract: A project always needs the participation of suppliers to provide the goods and services needed by the project. As the size of the project increases, the need to use suppliers also increases. Choosing the appropriate suppliers for the project is always a difficult task, and considering different criteria along with the existence of multiple alternatives always increases the difficulty and complexity of the supplier selection problem. This study deals with the supplier selection problem, which is one of the important issues in projects and organizations in the downstream field of oil, gas, and petrochemicals. The purpose of this paper was to investigate and improve the supplier selection procedure in this field by considering real-world uncertain conditions. To this end, the fuzzy set theory and gray numbers were taken into account. In the present study, the criteria were first determined by expert judgment; then, the fuzzy best–worst method (FBWM) was exploited to rank the criteria; finally, the suppliers were prioritized and ranked by using the gray COCOSO method The results showed that the highest and the lowest weights were obtained for the "price" and "attention to environmental issues" criteria, respectively. Also, the selected supplier was a supplier with a high score in all criteria. One of the practical benefits of this research is to provide a solution to speed up, facilitate, and improve the process of selecting suppliers for companies in the downstream field of oil, gas, and petrochemicals.

Keywords: project management; supplier selection; fuzzy best–worst method (FBWM); COCOSO-G; oil and gas industry; petrochemical downstream

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1. Introduction

Projects need resources for the implementation and achievement of their predefined goals. In many cases, these required resources are provided by suppliers. The need for suppliers in large and complex projects is reasonably more than in other projects. In fact, suppliers should provide quality goods or services at a competitive price to survive in the globally competitive market. Supplier selection is one of the problems of project employers. It might be thought that outsourcing is very simple and facilitates project implementation. However, it may cause new issues and problems that did not exist in the inherent characteristics and implementation processes of the project. For example, one of the problems that organizations and project managers face is that suppliers should provide the required equipment, machinery, and materials for the project [1]. Also, the performance of the suppliers is another important issue in project management. In other words, it is a matter of how accurately, speedily, and efficiently the supplier accomplishes the tasks. It should be noted that choosing suppliers has its own problems, hardships, and difficulties to the extent that the selection of unknown suppliers or suppliers that are less known can be considered as major risks of a project [2]. On the other hand, the environmental issues and destructive effects of various activities on the environment have been receiving more attention from governments and organizations to the point that regulatory orders on environmental issues have been raised so that these issues are taken into consideration in the selection of suppliers [3]. Therefore, it has been attempted to consider the aspects of sustainability in order to achieve a sustainable supply chain by examining and selecting sustainable suppliers. Various organizations are seeking to achieve sustainable goals according to the awareness of customers, beneficiaries, and stakeholders in order to exploit these achievements as a competitive advantage and strengthen their reputation [4,5], because selecting a sustainable and reliable supplier can reduce costs and improve the performance of the entire supply chain network [6,7].

In general, the selection of suppliers is one of the substantial and key activities of a project. There are several traditional methods for selecting suppliers in projects, but the multitude of suppliers as well as their different characteristics have caused the inefficiency of these traditional supplier selection methods [2]. Various methods have been introduced to help decision-makers in selecting suppliers based on different criteria. However, an appropriate supplier selection method should consider all the necessary aspects and include important and influential factors as well as uncertainty conditions [8,9]. On the other hand, due to the fact that the field of oil, gas, and petrochemicals is vast and plays a critical role in many countries, the projects in this field are also of extreme importance and have large dimensions as well as a high complexity [10]. In addition, the main part of the economy of any country active in this field relies on these projects. As a result, the selection of suppliers is of extreme importance and sensitivity, and any mistake in the selection process may lead to detrimental time, cost, and credit consequences for the project and its stakeholders [11]. In other words, it can be said that the larger the size and complexity of a project, the more requirements for suppliers. This magnitude and complexity can be seen in the field of oil, gas, and petrochemicals, and decision-making in this field, particularly for selecting suppliers, has always been associated with numerous difficulties.

Furthermore, to the authors' knowledge, very limited studies have addressed various data-gathering techniques together with uncertainty and sustainability features. Also, the sustainable supplier selection problem has rarely been investigated in the oil, gas, and petrochemicals sectors.

In this study, the best–worst method (BWM) is used to weight the criteria. This method is based on pairwise comparisons, provides a clear understanding of the evaluation scope of the paired comparisons and also provides more reliable comparisons. In other words, a smaller number of pairwise comparisons as well as a higher consistency rate can be mentioned as the prominent advantages and distinctions of the BWM compared to other weighting techniques [12]. In addition, if there are more than three criteria in nonlinear models, they usually produce multiple solutions, but this problem has been solved in this linear model. Since experts use linguistic expressions to compare the criteria, the weighting method can be improved by incorporating fuzzy logic and utilizing the fuzzy best–worst method (FBWM) as an extension of the BWM method.

Subsequently, the COCOSO (combined compromise solution) method, as a novel multicriteria decision-making method introduced in 2019, is exploited to rank the suppliers. One of the advantages of this method and a reason for employing it is its compensability feature. Another reason for using this method is that the COCOSO contains a combination of methods such as the weighted aggregated sum product assessment (WASPAS), simple additive weighting (SAW), and exponentially weighted product (EWP), which enables the formation of a more robust model and a more accurate decision-making [13,14]. In the present research, the COCOSO-G method is employed by incorporating gray numbers into the COCOSO method to deal with uncertainty conditions. In the COCOSO-G method, a number of suppliers are evaluated and ranked based on the final criteria. In order to improve the ranking, uncertainty conditions are considered by using gray numbers instead of crisp numbers so that the errors of the linguistic variables that are expressed by the experts are lessened and the obtained results are more reliable [15].

The remainder of this paper is structured as follows: Section 2 provides a review of the relevant studies on supplier selection. Subsequently, Section 3 explains the research methodology. In Section 4, the computational results are presented. Finally, Section 5 concludes the paper.

2. Literature Review

Increasing the efficiency of project execution and reducing waste is one of the important issues in project management. Suppliers play a very important role in this matter, and their selection has always been a crucial management issue. Therefore, a systematic review of the literature was carried out to identify the research gaps in this field and how to select suppliers in the future. In addition to the cost criterion, other criteria should be considered for the selection of a supplier [16]. For this purpose, Thevenin et al. [17] proposed a robust optimization approach for supplier selection considering uncertainty conditions and declared that a supplier that did not offer the lowest price may be selected. Project activities need resources to be executed and accomplished. Hence, the selection of suppliers that provide these required resources becomes more important since the time it takes to provide the resources can affect the project schedule. To this end, project managers must pay special attention to the integrity of the entire supply chain to control its effect on the project schedule. Therefore, Abdzadeh et al. [18] presented a tabu search (TS) algorithm for supplier selection to increase customer satisfaction and reduce the total cost.

There are several mathematical models considering various evaluation criteria. For example, Feng et al. [19] considered different supplier evaluation criteria such as carbon emissions, quality, order cost, and service level. Despite considering various evaluation criteria in different models, they had some shortcomings; for example, they did not consider the conditions of uncertainty. There are several types of uncertainty associated with the supplier selection problem such as failure in on-time delivery and an uncertain price. Therefore, Mohammadivojdan et al. [20] dealt with uncertainty in this problem using a Monte Carlo simulation. Numerous research works have been conducted to identify and find the criteria for selecting suppliers using the opinions of experts in this field. Sonar et al. [21] suggested that emerging paradigms such as lean, agile, green, sustainability, etc., can be incorporated to find the key criteria for supplier selection more appropriately. Moreover, Zaretalab et al. [22] developed a multiobjective model for the supplier selection problem and solved it using a nondominated sorting genetic algorithm (NGSA-II) to obtain more reliable and favorable results.

In order to consider uncertainty in the suppler selection problem in the oil and gas industry, Yazdi et al. [23] used the BWM-G method and ranked a number of supplier selection criteria. Saputro et al. [24] reviewed a large number of published articles in the last 20 years on the supplier selection problem as a key lever for the success of companies. Hosseini et al. [25] tried to balance the aspects of sustainability by presenting a biobjective mathematical model for the supplier selection problem and solved the problem by presenting an integrated approach based on stochastic and dynamic programming. Shang et al. [26] utilized the fuzzy Shannon entropy with BWM and MULTIMOORA methods to select a sustainable supplier. Finger and Lima-Junior [27] developed the HFLTS-QFD model for sustainable supplier selection and used fuzzy logic to deal with linguistic expressions. Ahmad et al. [28] presented a mixed-integer nonlinear model for the supplier selection problem. Zhou et al. [29] introduced a stochastic programming model to develop suppliers' performance and implemented the model on a small manufacturing company. They concluded that the evaluation as well as the correct selection and management of suppliers could greatly reduce the impact and probability of risks related to suppliers. Masoomi et al. [30] also investigated the green supply chain problem and selected a strategic green supplier by using FBWM methods for weighting and WASPAS and COPRAS for evaluating and ranking the alternatives. Bonnedahl et al. [31] stated that many factors had caused increasing concerns about environmental issues. Also, sustainable development has been one of the goals of the international community for more than three decades; for this purpose, sustainable development was included in the UN 2030 agenda. Sarrakh et al. [32] adopted a qualitative approach to collect and analyze the data of eight organizations based on 24 interviewees and concluded that despite the implementation of the 2030 vision, there were many key challenges such as resistance to changes, price fluctuations, and initial costs that hindered the implementation of sustainability strategies. Many organizations are paying more attention to the issue of sustainability, particularly in the field of oil and gas and petrochemicals [33].

Table 1 presents a summary of the review of past related studies along with research gaps.

Table 1. A summary of the relevant studies.

Oil, Gas, and Petrochemical Industry	Sustainability	Uncertainty Conditions	Data Gathering Method			Method		Year	Resources
			Interview with Experts	Organizational Data	Systematic Review	Nonfuzzy	Fuzzy		
					✔			2019	[8]
✔	✔				✔			2022	[9]
					✔			2022	[14]
		✔						2022	[15]
					✔			2022	[16]
		✔			✔			2022	[17]
		✔						2022	[18]
	✔		✔		✔			2022	[19]
					✔			2022	[20]
	✔		✔		✔			2022	[21]
	✔				✔			2022	[22]
✔		✔	✔					2022	[23]
	✔	✔					✔	2022	[24]
	✔	✔					✔	2022	[25]
				✔			✔	2022	[26]
		✔						2022	[27]
	✔	✔					✔	2022	[28]
	✔							2022	[29]
✔	✔		✔					2022	[32]
✔	✔		✔	✔			✔	2022	[33]
	✔		✔		✔			2022	[34]
✔				✔				2021	[35]
✔								2022	[36]
✔	✔	✔		✔				2022	[37]
	✔	✔		✔			✔	2022	[38]
✔				✔				2022	[39]
✔	✔	✔	✔	✔	✔	✔	✔	-	This study

According to Table 1, the proposed supplier selection method in this research, which includes different data-gathering methods and sustainability aspects and deals with uncertainty conditions, can be mentioned as the main contribution of the present study. In addition, the sustainable supplier selection problem has rarely been addressed in the oil, gas, and petrochemical industry. Also, in order to take the uncertainty in the weights of criteria and ranking into account, the FBWM method is utilized to obtain the weights of the criteria, and the COCOSO-G method is employed to rank the suppliers.

3. Materials and Methods

In the current research, first, the related studies were reviewed. Then, the organizational data of one of the companies in the downstream field of the oil, gas, and petrochemical industry were examined. Subsequently, using semistructured interviews with experts and the Delphi method, the procedure of selecting suppliers was investigated. By integrating the factors obtained from the literature review as well as the opinions of experts and organizational data, a complete summary of the important factors for the selection of suppliers in this field was obtained. Afterward, the FBWM method was exploited to weight the final criteria. Finally, the criteria were ranked using the COCOSO-G method. This method is a multicriteria decision-making technique to choose the best alternative among several alternatives. In this method, a number of alternatives are measured with a set of factors and criteria and finally the best alternative is selected.

3.1. Fuzzy Sets Theory

In 1965, Lotfizadeh introduced the fuzzy set theory for a better evaluation of experts' opinions in the decision-making process. This theory is used as a powerful tool to solve problems under conditions of uncertainty [40]. A triangular fuzzy number $\tilde{A} = (l, m, u)$ consists of three values, an upper limit (u), a middle limit (m), and a lower limit (l). The mathematical calculations of two fuzzy numbers are defined as follows. In Equation (1), $\tilde{A}_1$ and $\tilde{A}_2$ are two given triangular fuzzy numbers. Also, k is a given positive crisp number.

$$\begin{aligned} \tilde{A}_1 + \tilde{A}_2 &= (l_1 + l_2, m_1 + m_2, u_1 + u_2) \\ \tilde{A}_1 - \tilde{A}_2 &= (l_1 - u_2, m_1 - m_2, u_1 - l_2) \\ \tilde{A}_1 * \tilde{A}_2 &= (l_1 * l_2, m_1 * m_2, u_1 * u_2) \\ k * \tilde{A}_1 &= (k * l_1, k * m_1, k * u_1), (k > 0) \\ \frac{\tilde{A}_1}{k} &= \left(\frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k}\right), (k > 0) \end{aligned} \tag{1}$$

The following equation is used to obtain the average of fuzzy numbers [41]:

$$R\left(\tilde{A}_i\right) = \frac{l_i + 4m_i + u_i}{6} \tag{2}$$

3.2. The Fuzzy Best–Worst Method (FBWM)

In this section, the steps of the fuzzy BWM method as an extension of the conventional BWM method [42] are explained:

First step: Specify the criteria set: in this step a set of decision criteria is formed.

Second step: Determine the best and worst (most important and least important) criteria: In this step, the decision-makers are asked to determine the most important (best) and the least important (worst) criteria.

Third step: Comparing the best criterion with other criteria: in this step, the best-to-other vector $\tilde{A}_B = \left\{\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn}\right\}$ is formed, where $\tilde{a}_{Bj}$ denotes the fuzzy comparison of the best criterion B with other criteria j.

Fourth step: Comparing other criteria with the worst criterion: in this step, the other-to-worst vector $\widetilde{A}_W = \left\{\widetilde{a}_{1W}, \widetilde{a}_{2W}, \ldots, \widetilde{a}_{nW}\right\}$ is formed, where $\widetilde{a}_{jW}$ denotes the fuzzy comparison of the worst criterion W with other criteria.

In order to make comparisons in step 3 and 4, it is necessary to convert the linguistic expressions into fuzzy numbers by using the rules of transformation of the linguistic variables of the decision-makers presented in Table 2.

Table 2. Transformation rules of the linguistic variables associated with the decision-makers' verbal judgments.

Linguistic Terms	Abbreviated Phrase	Membership Function
Equally importance	(EI)	$(1, 1, 1)$
Weakly important	(WI)	$(2/3, 1, 3/2)$
Fairly important	(FI)	$(3/2, 2, 5/2)$
Very important	(VI)	$(5/2, 3, 7/2)$
Absolutely important	(AI)	$(7/2, 4, 9/2)$

Fifth step: Creating the fuzzy BWM model: In this step, the weights of the defined criteria are computed using the below nonlinear model. It is recommended to convert the model into a linear model when the number of criteria is greater than 3 to achieve better results [41].

$$\min \widetilde{\xi}^*$$
$$\text{s.t.}\begin{cases} \left|\dfrac{\left(l_B^W,\, m_B^W,\, u_B^W\right)}{\left(l_j^W,\, m_j^W,\, u_j^W\right)} - \left(l_{Bj},\, m_{Bj},\, u_{Bj}\right)\right| \leq (k^*,\, k^*,\, k^*) \\ \left|\dfrac{\left(l_j^W,\, m_j^W,\, u_j^W\right)}{\left(l_W^W,\, m_W^W,\, u_W^W\right)} - \left(l_{jW},\, m_{jW},\, u_{jW}\right)\right| \leq (k^*,\, k^*,\, k^*) \\ \sum\limits_{j=1}^{n} R\left(\widetilde{W}_j\right) = 1 \\ l_j^W \leq m_j^W \leq u_j^W \\ l_j^W \geq 0 \\ j = 1, 2, \ldots, n \end{cases} \tag{3}$$

where $\widetilde{w}_B = \left(l_B^w, m_B^w, u_B^w\right)$, $\widetilde{w}_j = \left(l_j^w, m_j^w, u_j^w\right)$, $\widetilde{w}_w = \left(l_W^w, m_W^w, u_W^w\right)$, $\widetilde{a}_{Bj} = \left(l_{Bj}, m_{Bj}, u_{Bj}\right)$, $\widetilde{a}_{jW} = \left(l_{jW}, m_{jW}, u_{jw}\right)$ and $\widetilde{\xi} = \left(l^{\xi}, m^{\xi}, u^{\xi}\right)$. For more information, we refer to [41].

Sixth step: Solve the above model with optimization software such as GAMS 44.4.0 or LINGO 17.0 to find the criteria's weights $\left(\widetilde{w}_1^*, \widetilde{w}_2^*, \ldots, \widetilde{w}_N^*\right)$. In addition, the Consistency Index (CI) (shown in Table 3) and the optimal value k^* are applied to compute the Consistency Ratio (CR) as follows:

$$\text{Consistency Ratio (CR)} = \frac{k^*}{Consistency} \tag{4}$$

Table 3. Consistency Index (CI) for the fuzzy BWM.

Linguistic Terms	$\tilde{a}_{BW}$	CI
Equally importance (EI)	$(1, 1, 1)$	3.00
Weakly important (WI)	$(2/3, 1, 3/2)$	3.80
Fairly Important (FI)	$(3/2, 2, 5/2)$	5.29
Very important (VI)	$(5/2, 3, 7/2)$	6.69
Absolutely important (AI)	$(7/2, 4, 9/2)$	8.04

It should be mentioned that the best and worst criteria are identified using each expert's opinion separately. Then, the fuzzy BWM model is created for each expert and solved in order to calculate the criteria's weights. Finally, the obtained weights based on each expert' opinion are merged [42].

3.3. The COCOSO-G Method

After calculating the weights of the criteria, the suppliers are ranked using the COCOSO-G method [43]. In this section, the steps of the COCOSO-G method are presented [44].

Step 1: Forming the decision matrix: in this step, the following decision matrix is created:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{nm} \end{bmatrix} i = 1,\ 2, \dots,\ m; j = 1,\ 2, \dots,\ n$$

Step 2: Normalizing the decision matrix: in this step, the decision matrix is normalized by using the following equations:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \qquad (\text{forpositivecriteria}) \tag{5}$$

$$r_{ij} = \frac{\min_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \qquad (\text{fornegativecriteria}) \tag{6}$$

Step 3: Calculating the values of the weighted multiplication and weighted sum: In this step, the values of the weighted multiplication and weighted sum are calculated, which are called P and S. To implement this step, the decision matrix elements that have been normalized in the previous step are multiplied once by the weights of the criteria and once again are raised to the power of those weights.

$$S_i = \sum_{j=1}^{n} (w_i r_{ij}) \tag{7}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{8}$$

Step 4: Calculating factor evaluation scores based on three strategies: in this step, the three following equations are used to implement three strategies:

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \tag{9}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{10}$$

$$k_{ic} = \frac{(S_i) + (1-\lambda)(P_i)}{\min_i S_i + (1-\lambda) \min_i P_i}; \qquad 0 \leq \lambda \leq 1 \tag{11}$$

Step 5: Determining the final scores and rankings of the alternatives: In this step, according to the following equation, the final score is obtained. In other words, the alternative that achieves the highest score is determined as the most important alternative.

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} k_{ib} k_{ic}) \tag{12}$$

3.4. Gray Logic

Gray logic is similar to fuzzy logic, but there are some differences that distinguish them from each other [45]. The main difference between gray numbers and fuzzy numbers is that in gray numbers, the interval in which the number is placed is known, but the value of the number itself is not known; in other words, there is doubt and uncertainty about its exact value [46,47]. Gray numbers are applied to cases where research is conducted based on uncertain and unreliable information. Therefore, in the current research where the criteria are ranked by using the linguistic variables, gray numbers can be easily used. In general, a gray number is defined as follows [47]:

$$\tilde{\mathrm{z}} = [\mathrm{a}, \mathrm{b}] \tag{13}$$

A number of operations on two gray numbers are defined as follows:

$$\tilde{Z}_1 = [a, b] \qquad \tilde{Z}_2 = [c, d] \tag{14}$$

$$\tilde{Z}_1 + \tilde{Z}_2 = [a + c,\ b + d] \tag{15}$$

$$\tilde{Z}_1 - \tilde{Z}_2 = [a - c,\ b - d] \tag{16}$$

$$-\tilde{Z}_1 = [-b, -a] \tag{17}$$

$$\lambda \tilde{Z}_1 = [\lambda a, \lambda b] \tag{18}$$

3.5. The COCOSO-G Method

The COCOSO-G method as an extension of the COCOSO method is efficient and includes the general advantages of both the COCOSO method and gray logic. The steps of the COCOSO-G method are as follows [48]:

Step 1: Identifying the criteria and alternatives: in this step, the criteria and alternatives are defined.

Step 2: In this step, as in the COCOSO method, the following decision matrix is formed

$$X = \begin{bmatrix} \bigcup[a_{11},\ b_{11}] & \bigcup[a_{12},\ b_{12}] & \cdots & \bigcup[a_{1m},\ b_{1m}] \\ \bigcup[a_{21},\ b_{21}] & \bigcup[a_{22},\ b_{22}] & \cdots & \bigcup[a_{2m},\ b_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ \bigcup[a_{n1},\ b_{n1}] & \bigcup[a_{n2},\ b_{n2}] & \cdots & \bigcup[a_{nm},\ b_{nm}] \end{bmatrix}$$

where a_{ij} denotes the upper limit of the gray number, and b_{ij} indicates the lower limit of the gray number.

Step 3: Normalizing the decision matrix: in this step, the decision matrix is normalized using the following two equations for positive and negative criteria:

$$r = \bigcup[c_{ij},\ d_{ij}] = \frac{\bigcup[a_{ij},\ b_{ij}] - \min_i \bigcup[a_{ij},\ b_{ij}]}{\max_i \bigcup[a_{ij},\ b_{ij}] - \min_i \bigcup[a_{ij},\ b_{ij}]} \quad (\mathrm{forpositivenumbers}) \tag{19}$$

$$r = \bigcup[c_{ij},\ d_{ij}] = \frac{\max_i \bigcup[a_{ij},\ b_{ij}] - \bigcup[a_{ij},\ b_{ij}]}{\max_i \bigcup[a_{ij},\ b_{ij}] - \min_i \bigcup[a_{ij},\ b_{ij}]} \quad (\mathrm{fornegativenumbers}) \tag{20}$$

Step 4: Calculating the values of the weighted multiplication and weighted sum: In this step, the values of the weighted multiplication and weighted sum are normalized and calculated as follows. The weights obtained by the FBWM are used in this step.

$$S_i = \sum_{j=1}^{n} \left(w_i \bigcup[c_{ij},\ d_{ij}] \right) \tag{21}$$

$$P_i = \sum_{j=1}^{n}\left(\bigcup\left[c_{ij},\ d_{ij}\right]^{w_j}\right) \tag{22}$$

Step 5: Calculating factor evaluation scores based on three strategies: in this step, the relative weights of the alternatives are used by applying three strategies, where λ is between 0 and 1, but usually, it is considered to be 0.5.

$$H_{ia} = \left[h_{1ij},\ h_{2ij}\right] = \frac{P_i + S_i}{\sum_{i=1}^{m}(P_i + S_i)} \tag{23}$$

$$L_{ia} = \left[l_{1ij},\ l_{2ij}\right] = \frac{S_i}{\min\limits_i S_i} + \frac{P_i}{\min\limits_i P_i} \tag{24}$$

$$M_{ia} = \left[m_{1ij},\ m_{2ij}\right] = \frac{(\lambda S_i) + (1-\lambda)(P_i)}{\lambda \max\limits_i S_i + (1-\lambda)\max\limits_i P_i} \tag{25}$$

$$0 \le \lambda \le 1$$

Step 6: Calculating the sum of the geometric mean and the arithmetic mean of the three strategies of the previous step: in this step, the sum of the geometric mean and the arithmetic mean of the three numbers (obtained from the strategy of the previous step) are calculated by using the following equation:

$$K_i = (H_{ia} * L_{ia} * M_{ia})^{\frac{1}{3}} + \frac{1}{3}(H_{ia} + L_{ia} + M_{ia}) \tag{26}$$

Step 7: Calculating the final scores: in this step, the obtained K's are compared with each other to be ranked. The gray vector $K_i = [s_i,\ t_i]$ is converted into the final score using the following equation:

$$K = (t_i - s_i)/t_i \tag{27}$$

where s and t are greater than zero.

4. Results

First, according to the literature studies, the most important criteria for selecting suppliers are presented in the following table to be investigated further.

Then, after examining the organizational data of the company under study as well as several meetings with experts, a further investigation of the information provided in Table 4 was carried out, and several discussions were held about these criteria to determine if a criterion was not of high importance and should be removed. Also, in these meetings, it was determined that if an important criterion was not on this list, it would be added to this list.

Table 4. Supplier selection criteria.

Criteria	Resources
Quality, geographical location, and project expectations	[8]
Cost, quality, and delivery method	[49]
Delivery time, price, health and safety of employees, and environmental management system	[50]
Price and quality	[51]
Reputation and position in the industry, reliability of delivery, attention to environmental issues, waste management, and safety and health of employees	[52]
Cost, quality, and capability	[53,54]

Table 4. *Cont.*

Criteria	Resources
Payment method and price	[53]
Research and development	[55]
Experts' expertise, technical capability, and organization size	[56]
Cost, quality, service, and capacity	[57]
Geographical location and political stability	[58]
Environmental and economic criteria	[59]
Strategy and communication	[60]
Market and desire	[61]
Response rate, capability for unexpected disruptions, capability for reverse logistics, sustainable product design, and long-term relationship	[62]
Cybersecurity, digital collaboration, and the internet of things integration	[63]
Additional discount on quantity, certification of the product, price, quality, warranty period, method of payment, reputations, delivery time, and reliability	[64]
Reputation and financial aspect	[65]
Environmental management system, green products, green finance, pollution control, reuse and recycle, vulnerability and reaction, risk taking, the capacity to return to the initial state, and adaptation	[66]
Business, customer relations, technology and logistics	[67]
Ecological, social, and economic	[68–70]

The information about the experts is given in Table 5.

Table 5. Expert information and interviews.

Expert	Gender	Qualification	Experience	Number of Interviews	Duration of Each Interview	Total (Hour)
1	Male	Masters	More than 30 years	4	2	8
2	Male	Masters	Between 20 and 30 years	3	3	9
3	Male	Ph.D.	Between 20 and 30 years	2	2	4
4	Male	Ph.D.	Between 15 and 20 years	2	2	4
5	Female	Masters	Between 15 and 20 years	2	3	6
			Total interview hours			31

In these meetings, by using organizational data and reviewing relevant studies as well as experts' opinions, all the important criteria in the field of oil, gas, and petrochemical industry were categorized and finalized. The result of these meetings, which were conducted using the Delphi method, are presented in the Table 6:

Table 6. Finalized criteria for sustainable supplier selection in the oil, gas, and petrochemical industry.

Category	Abbreviated Phrase	Finalized Criteria	Abbreviated Phrase
Sustainability	C1	Health and safety of employees	C11
		Attention to environmental issues	C12
		Waste management	C13
Financial	C2	Price	C21
		Settling an account method	C22
Expertise and experience	C3	Reputation and position in the industry	C31
		Familiarity with the conditions, culture, language and environmental conditions at the project site	C32
		Experience in similar projects	C33
Technical	C4	Optimal and applicable schedule	C41
		The suitability of the company's expertise with the technical characteristics of the project	C42
		Providing a complete and accurate proposal	C43
		Quality	C44
		Delivery method	C45

In order to perform better and easier calculations for weighting the criteria, first, the FBWM method was implemented on the categories (C1, C2, C3, C4), and then, the FBWM method was implemented for each category of criteria. This process was performed once for each expert. As an instance, the information related to one expert is presented as follows.

The tables for the FBWM related to the first expert are as follows (Table 7):

Table 7. Comparison table of the best criterion with other criteria in general categories.

Criteria	C1	C2	C3	C4
Best criterion C2	AI	EI	VI	FI
Worst criterion C1	EI	AI	FI	VI

And the related model is also expressed as follows:

$$
\begin{aligned}
& min\ \xi: \\
& \text{s.t.} \\
& l_2 - 3.5 * u_1 - e * u_1 \le 0;\ \ l_2 - 3.5 * u_1 + e * u_1 \ge 0; \\
& m_2 - 4 * m_1 - e * m_1 \le 0;\ \ m_2 - 4 * m_1 + e * m_1 \ge 0; \\
& u_2 - 4.5 * l_1 - e * l_1 \le 0;\ \ u_2 - 4.5 * l_1 + e * l_1 \ge 0; \\
& l_2 - 2.5 * u_3 - e * u_3 \le 0;\ \ l_2 - 2.5 * u_3 + e * u_3 \ge 0; \\
& m_2 - 3 * m_3 - e * m_3 \le 0;\ \ m_2 - 3 * m_3 + e * m_3 \ge 0; \\
& u_2 - 3.5 * l_3 - e * l_3 \le 0;\ \ u_2 - 3.5 * l_3 + e * l_3 \ge 0; \\
& l_2 - 1.5 * u_4 - e * u_4 \le 0;\ \ l_2 - 1.5 * u_4 + e * u_4 \ge 0; \\
& m_2 - 2 * m_4 - e * m_4 \le 0;\ \ m_2 - 2 * m_4 + e * m_4 \ge 0; \\
& u_2 - 2.5 * l_4 - e * l_4 \le 0;\ \ u_2 - 2.5 * l_4 + e * l_4 \ge 0; \\
& l_3 - 1.5 * u_1 - e * u_1 \le 0;\ \ l_3 - 1.5 * u_1 + e * u_1 \ge 0; \\
& m_3 - 2 * m_1 - e * m_1 \le 0;\ \ m_3 - 2 * m_1 + e * m_1 \ge 0; \\
& u_3 - 2.5 * l_1 - e * l_1 \le 0;\ \ u_3 - 2.5 * l_1 + e * l_1 \ge 0; \\
& l_4 - 2.5 * u_1 - e * u_1 \le 0;\ \ l_4 - 2.5 * u_1 + e * u_1 \ge 0; \\
& m_4 - 3 * m_1 - e * m_1 \le 0;\ \ m_4 - 3 * m_1 + e * m_1 \ge 0; \\
& u_4 - 3.5 * l_1 - e * l_1 \le 0;\ \ u_4 - 2.5 * l_1 + e * l_1 \ge 0; \\
& \tfrac{1}{6}\big(l_1 + 4 * m_1 + u_1\big) + \tfrac{1}{6}\big(l_2 + 4 * m_2 + u_2\big) + \tfrac{1}{6}\big(l_3 + 4 * m_3 + u_3\big) + \tfrac{1}{6}\big(l_4 + 4 * m_4 + u_4\big) = 1; \\
& l_1 \le m_1 \le u_1;\quad l_2 \le m_2 \le u_2;\quad l_3 \le m_3 \le u_3;\quad l_4 \le m_4 \le u_4; \\
& l_1 > 0;\quad l_2 > 0;\quad l_3 > 0;\quad l_4 > 0; \\
& e \ge 0;
\end{aligned}
$$

The following solution was obtained by coding the above model in the LINGO optimization software (shown in Table 8):

Table 8. Fuzzy weights table of the criteria and defuzzified weights (for expert one).

Criteria	Criteria's Weights	Defuzzified Weights
C1	(0.0918, 0.1029, 0.1029)	0.101
C2	(0.4021, 0.4506, 0.4506)	0.443
C3	(0.1457, 0.1738, 0.1921)	0.172
C4	(0.2153, 0.2829, 0.3855)	0.284

Finally, after modeling all categories of criteria and solving them for all five experts, the final weights of the criteria were obtained by calculating the average of the weights obtained from the experts. The final weights of the criteria are presented in Table 9.

Table 9. Finalized criteria and their final weights.

Category	Finalized Criteria	Abbreviated Phrase	Weight (Expert 1)	Weight (Expert 2)	Weight (Expert 3)	Weight (Expert 4)	Weight (Expert 5)	Final Weight
Sustainability	Health and safety of employees	C11	0.029	0.016	0.035	0.071	0.137	0.057
	Attention to environmental issues	C12	0.014	0.027	0.014	0.032	0.043	0.026
	Waste management	C13	0.058	0.058	0.05	0.156	0.078	0.080
Financial	Price	C21	0.332	0.332	0.254	0.240	0.272	0.286
	Settling an account method	C22	0.111	0.111	0.128	0.121	0.091	0.113
Expertise and experience	Reputation and position in the industry	C31	0.057	0.064	0.158	0.055	0.049	0.076
	Familiarity with the conditions, culture, language and environmental conditions at the project site	C32	0.022	0.029	0.045	0.024	0.018	0.027
	Experience in similar projects	C33	0.093	0.079	0.109	0.068	0.079	0.086
Technical	Optimal and applicable schedule	C41	0.055	0.063	0.052	0.025	0.025	0.044
	The suitability of the company's expertise with the technical characteristics of the project	C42	0.032	0.025	0.019	0.034	0.035	0.029
	Providing a complete and accurate proposal	C43	0.025	0.037	0.041	0.020	0.019	0.028
	Quality	C44	0.096	0.065	0.070	0.078	0.078	0.078
	Delivery method	C45	0.076	0. 094	0.025	0.076	0.076	0.070

In order to rank suppliers using the COCOSO-G method, in the first step, each supplier's score was calculated according to the finalized criteria using experts' opinions (as shown in Table 10).

Table 10. Suppliers' scores based on each criterion using gray numbers (for expert one).

Supplier \ Criteria	C11	C12	C13	C21	C22	C31	C32	C33	C41	C42	C43	C44	C45
S1	[70, 75]	[55, 65]	[60, 65]	[65, 70]	[70, 80]	[70, 75]	[50, 55]	[75, 90]	[85, 90]	[80, 85]	[75, 85]	[80, 85]	[55, 65]
S2	[30, 45]	[40, 50]	[10, 25]	[30, 40]	[50, 60]	[25, 30]	[40, 45]	[25, 35]	[10, 20]	[40, 50]	[15, 20]	[50, 55]	[70, 80]
S3	[65, 70]	[80, 85]	[80, 85]	[5, 15]	[10, 20]	[60, 70]	[30, 35]	[75, 85]	[80, 85]	[80, 90]	[25, 35]	[65, 75]	[80, 90]
S4	[70, 80]	[70, 75]	[50, 60]	[50, 55]	[50, 60]	[50, 60]	[20, 35]	[65, 75]	[60, 70]	[85, 95]	[30, 40]	[80, 85]	[30, 40]
S5	[80, 85]	[70, 75]	[40, 50]	[50, 60]	[30, 40]	[40, 55]	[55, 60]	[60, 65]	[75, 85]	[65, 75]	[80, 90]	[75, 85]	[40, 55]
S6	[80, 85]	[80, 85]	[75, 90]	[20, 30]	[25, 30]	[80, 90]	[70, 75]	[80, 90]	[60, 70]	[90, 95]	[85, 90]	[80, 85]	[45, 55]

This process was performed for each expert and the scores of the suppliers were collected based on the opinions of all five experts. Finally, the average of the scores was calculated in order to rank the suppliers based on the average score (as shown in Table 11).

Table 11. Average scores of suppliers for each criterion using gray numbers (initial decision matrix).

Supplier \ Criteria	C11	C12	C13	C21	C22	C31	C32	C33	C41	C42	C43	C44	C45
S1	[59, 70]	[50, 61]	[47, 57]	[50, 62]	[71, 80]	[50, 66]	[51, 65]	[53, 72]	[82, 91]	[67, 80]	[57, 75]	[75, 85]	[48, 60]
S2	[39, 50]	[40, 49]	[30, 37]	[36, 45]	[47, 57]	[23, 33]	[36, 47]	[23, 36]	[25, 38]	[39, 52]	[30, 39]	[43, 58]	[50, 63]
S3	[43, 58]	[64, 73]	[69, 76]	[14, 28]	[24, 36]	[48, 61]	[41, 49]	[62, 76]	[75, 87]	[72, 85]	[39, 51]	[62, 71]	[64, 79]
S4	[49, 62]	[58, 67]	[48, 62]	[41, 51]	[58, 71]	[46, 55]	[24, 40]	[59, 75]	[58, 75]	[66, 84]	[39, 53]	[62, 74]	[16, 29]
S5	[57, 65]	[60, 70]	[45, 59]	[43, 52]	[35, 49]	[41, 55]	[48, 61]	[49, 62]	[74, 84]	[68, 80]	[69, 75]	[66, 77]	[31, 48]
S6	[60, 72]	[68, 77]	[75, 84]	[34, 48]	[22, 33]	[65, 79]	[55, 67]	[72, 89]	[68, 77]	[83, 94]	[71, 82]	[75, 85]	[20, 33]

After obtaining the average scores of the suppliers, the gray scores were normalized, shown in Table 12:

Table 12. Normalized matrix of the suppliers.

	C11	C12	C13	C21	C22	C31	C32	C33	C41	C42	C43	C44	C45
S1	[0.61, 0.94]	[0.27, 0.57]	[0.31, 0.5]	[0, 0.25]	[0, 0.16]	[0.48, 0.77]	[0.63, 0.95]	[0.45, 0.74]	[0.86, 1]	[0.51, 0.75]	[0.52, 0.87]	[0.76, 1]	[0.51, 0.7]
S2	[0, 0.33]	[0, 0.24]	[0, 0.13]	[0.35, 0.54]	[0.4, 0.57]	[0, 0.18]	[0.28, 0.53]	[0, 0.12]	[0, 0.2]	[0, 0.24]	[0, 0.17]	[0, 0.36]	[0.54, 0.75]
S3	[0.12, 0.58]	[0.65, 0.89]	[0.72, 0.85]	[0.71, 1]	[0.76, 0.97]	[0.45, 0.68]	[0.4, 0.58]	[0.59, 0.8]	[0.76, 0.94]	[0.6, 0.84]	[0.17, 0.4]	[0.45, 0.67]	[0.76, 1]
S4	[0.3, 0.7]	[0.49, 0.73]	[0.33, 0.59]	[0.23, 0.44]	[0.16, 0.38]	[0.41, 0.57]	[0, 0.37]	[0.55, 0.79]	[0.5, 0.76]	[0.49, 0.82]	[0.17, 0.44]	[0.45, 0.74]	[0, 0.21]
S5	[0.55, 0.79]	[0.54, 0.81]	[0.28, 0.54]	[0.21, 0.4]	[0.53, 0.78]	[0.32, 0.57]	[0.56, 0.86]	[0.39, 0.59]	[0.74, 0.89]	[0.53, 0.75]	[0.75, 0.87]	[0.55, 0.81]	[0.24, 0.51]
S6	[0.64, 1]	[0.76, 1]	[0.83, 1]	[0.29, 0.58]	[0.81, 1]	[0.75, 1]	[0.72, 1]	[0.74, 1]	[0.65, 0.79]	[0.8, 1]	[0.79, 1]	[0.76, 1]	[0.06, 0.27]
Wi	0.057	0.026	0.08	0.286	0.113	0.076	0./027	0.086	0.044	0.029	0.028	0.078	0.07

Subsequently, the values of *Si* and *Pi* were obtained, as shown in Table 13:

Table 13. Calculation of *Si* and *Pi* values.

Suppliers	s_i	p_i
S1	[0.321, 0.563]	[10.605, 12.330]
S2	[0.191, 0.394]	[3.566, 11.969]
S3	[0.610, 0.855]	[12.443, 12.824]
S4	[0.295, 0.538]	[10.025, 12.362]
S5	[0.389, 0.613]	[12.068, 12.505]
S6	[0.575, 0.820]	[12.344, 12.758]

In the next step, using Si and Pi values obtained for each supplier, the H_{ia}, L_{ia}, and M_{ia} values were calculated (as shown in Table 14).

Table 14. Calculation of the H_{ia}, L_{ia}, and M_{ia} values.

Suppliers	H_{ia}	L_{ia}	M_{ia}
S1	[0.139, 0.203]	[4.657, 6.41]	[0.799, 0.943]
S2	[0.048, 0.195]	[2, 5.421]	[0.275, 0.904]
S3	[0.166, 0.216]	[6.688, 8.81]	[0.954, 1]
S4	[0.131, 0.203]	[4.356, 6.288]	[0.754, 0.943]
S5	[0.159, 0.207]	[5.426, 6.723]	[0.911, 0.959]
S6	[0.164, 0.214]	[6.475, 7.876]	[0.944, 0.993]

In the last step, the final score of each supplier was calculated. But considering that the final scores are gray numbers, these scores must be converted to integer numbers. Finally, suppliers were ranked according to the final scores (as shown in Table 15).

Table 15. The final ranking obtained by the COCOSO-G method.

Suppliers	K_i	Obtained Scores	Rankings
S1	[2.037, 2.928]	0.304	3
S2	[0.783, 2.492]	0.686	1
S3	[2.956, 3.976]	0.257	4
S4	[1.89, 2.88]	0.344	2
S5	[2.427, 3.075]	0.211	5
S6	[2.862, 3.586]	0.202	6

Practical Implications

One of the practical benefits of this research is to speed up the process of selecting suppliers in companies active in the downstream field of the oil, gas, and petrochemical industry which generally is time-consuming and difficult, as this process is usually faced with various problems that can cause many delays. Therefore, in order to avoid these problems, using the proposed supplier selection method can be exploited to avoid problems and delays; also, the results will be more reliable.

In addition, the sustainability concept, which has received more attention in recent years, has also become more important in this industry; hence, taking the sustainability aspects into account in this study can assist decision-makers and planners in this industry making the supplier selection closer to real-world conditions, which adds to the necessity and importance of this research.

5. Discussion and Conclusions

There are numerous traditional methods to choose the suppliers of the project, but the multiplicity of suppliers as well as the distinctiveness of their characteristics, advantages, and disadvantages make the traditional selection methods ineffective. Hence, various methods have been proposed to help decision-makers and managers select suitable suppliers. However, these methods usually consider few criteria and rarely take uncertainty and sustainability into account. This research can help many managers and decision-makers of oil, gas, and petrochemical projects with the selection of appropriate suppliers by taking into account various criteria together with uncertainty and sustainability. The application of the method presented in this paper in other projects can increase their probability of success since choosing the right suppliers can play a crucial role in reducing project delays and costs and preventing several problems.

In this research, for selecting the best supplier, various criteria and subcriteria were determined by reviewing scientific articles and referable sources, using the Delphi method, and interviewing experts in the oil, gas, and petrochemical industry. The interviews were conducted in a semistructured manner to increase efficiency. That way, if needed, any of the experts could change the questions or add new questions. The criteria were weighted by using the FBWM method and Excel software 2016. The results showed that the price and the way of settling an account were given the most weight, and attention to environmental issues was considered as the least important factor for choosing a supplier. Moreover, work experience on similar oil, gas, and petrochemical projects was ranked next, since it is obvious that previous experiences have a significant impact on the performance and efficiency of suppliers, as they avoid secondary problems and can result in project success. Also, waste management was ranked next; considering the high importance of waste management as a global crisis, this relatively high weight was not unexpected, especially in such a field, where the lack of attention to this factor can trigger several problems for the project. In addition, quality in the technical category, reputation and position in the industry in the expertise and experience category, and the delivery method in the technical category were placed in the following ranks. The findings are aligned with past experience and experts' opinions since reviewing the projects that have been carried out in this field demonstrates that paying attention to these factors leads to reduced delays and improved implementation of projects. It can also be concluded that a supplier gets a higher overall score and rank if it obtains a good score in each criterion. In other words, if a supplier obtains a high score in one or more criteria and low scores in other criteria, it will not gain a high final score and cannot be selected as the best supplier. Therefore, suppliers should try to improve their performance based on all of the criteria and not only pay attention to the cost factor.

The weights obtained by solving the BWM method were used as the input data of the COCOSO method. After obtaining the weights of the criteria, the COCOSO-G method was exploited to rank the suppliers. Several steps were performed including forming the decision matrix, normalizing the matrix, calculating the weighted multiplication and weighted sum values, calculating the final scores, and eventually ranking the suppliers.

As the main limitations of this research, it can be said that due to the sensitive nature of the field of oil, gas, and petrochemicals, there was very limited access to the information of the relevant projects, so most of the required information could not be easily acquired and was obtained only through several time-consuming negotiations and communications.

For future studies, it is suggested to conduct this research in a project-based or strong matrix organization whose senior managers support the research and provide full access to the information. It is also suggested to use an electronic questionnaire instead of an interview to increase the speed of data collection. Moreover, the proposed method in this study should be implemented in another field, and its effectiveness and efficiency should be examined. Furthermore, other multicriteria decision-making techniques may be applied, and their findings may be compared.

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