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Green-based supplier selection using BWM and VIKOR methods in the Indonesian manufacturing sector

Yudam Alkolid[1], V. Reza Bayu Kurniawan[1*], Syamsul Ma'arif[1], Nerda Zura Zaibidi[2], Norfaridatul Akmaliah Othman[3]

[1] Department of Industrial Engineering, Universitas Sarjanawiyata Tamansiswa, Indonesia
[2] School of Quantitative Sciences, Universiti Utara Malaysia, Malaysia
[2] Department of Technology Management, Universiti Teknikal Malaysia Melaka, Malaysia

E-mail: reza.kurniawan@ustjogja.ac.id*
* Corresponding Author

ABSTRACT

The selection of green-based suppliers remains a challenge for manufacturing firms in Indonesia. In today's business landscape, it is crucial to consider green aspects as part of sustainability practices when choosing suppliers. However, there is a limited number of studies providing frameworks for selecting suppliers based on green factors, particularly in developing countries. This study aimed to propose a framework for selecting suppliers using multicriteria decision-making (MCDM) techniques. A case study was conducted in an Indonesian metal manufacturing company that considers carbon reduction and incorporates traditional supplier selection factors such as quality, cost, and capacity. The study integrated two MCDM techniques, namely the best-worst method (BWM) and *Višekriterijumsko Kompromisno Rangiranje* (VIKOR), to evaluate and select green-based suppliers. BWM was employed to determine the weights of the criteria, while VIKOR ranked the suppliers. Seven criteria were identified, including cost (C_1), quality (C_2), delivery time (C_3), technology application (C_4), compliance with environmental regulations (C_5), green practice certification (C_6), and green efforts (C_7). Nine suppliers were screened and ranked accordingly. The results indicate that quality, delivery time, and cost are the top three ranked criteria based on their importance. Further, this study includes nine suppliers in which supplier S_7 demonstrates the best performance compared to the others. This study highlights that in Indonesia, most organizations tend to prioritize traditional criteria, while green factors are still overlooked. However, the company examined in this study has taken the initiative to include environmental factors in its decision-making process. The findings of this study contribute to the development of a framework for selecting green suppliers in a developing country context.

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1. Introduction

The process of selecting the optimal supplier presents a significant challenge for numerous organizations in Indonesia. In order to effectively choose their suppliers, organizations must take into consideration various tangible and intangible factors, as well as employ different selection techniques [1]. As the business environment becomes increasingly intricate, a multitude of criteria must be considered [2]. However, the limited expertise and research available regarding this decision-making process exacerbates the difficulties associated with supplier selection, particularly in developing countries [3]. Therefore, it is crucial to propose a comprehensive framework for supplier selection, as it ultimately enhances product quality and customer satisfaction within today's fiercely competitive business landscape [4][5].

In Indonesia, numerous companies are currently adopting green-based carbon reduction practices for diverse reasons, including improving their corporate image [6], complying with regulations [7], and striving for greater sustainability [8]. Additionally, green innovations have yielded competitive advantages and significantly influenced the entire supply chain system [9]. The growing emphasis on green aspects in supplier selection decision-making has spurred a rise in related studies. Many previous studies have addressed the supplier selection problem using Multicriteria Decision-Making (MCDM) techniques. These methods are favoured due to the complexity of supplier selection, which involves multiple factors and alternatives.

As evident, the utilization of Multicriteria Decision-Making (MCDM) methods in supplier selection decision-making involves two stages: Stage 1 is determining the criteria weights, while Stage 2 involves ranking the suppliers. Previous research has employed various methods, such as AHP, BWM, CBA, WSM, and DEMATEL, to establish the weights of supplier selection criteria [10]–[12]. AHP and BWM have gained popularity due to their ability to simplify complex problems into a hierarchical structure [13]. Furthermore, these methods offer straightforward mathematical computations that yield reliable results. On the other hand, while the DEMATEL method can determine criteria weights, past studies have primarily utilized it to examine the interrelationships among criteria [12], [14]. In the second stage, ranking methods often employed include VIKOR, ELECTRE, PROMETHEE, and TOPSIS. Among these, TOPSIS and VIKOR, as distance-based MCDM techniques, are preferred for calculating the rank of alternatives due to their simple procedures that incorporate the obtained criteria weights. Moreover, these methods are applicable when implemented in industrial practice. While previous studies have developed decision-making frameworks, the application of such frameworks, to the best of our knowledge, remains limited. Prior studies have primarily applied hybrid MCDM methods in the context of the food and beverages industry, pharmacy, chemical, paper and printing, machinery and heavy equipment, textile, and automotive [15]–[17]. Hence, this study aims to bridge this gap by selecting suppliers based on green factors using the BWM and VIKOR methods, as demonstrated in an Indonesian metal manufacturer.

The present study focuses on a local metal manufacturer in Indonesia, serving as a case study due to the company's carbon reduction goal. Consequently, when selecting suppliers, the company considers not only traditional supplier selection criteria but also environmental factors. This approach ensures that the chosen suppliers align with the company's sustainability practices [18]. The study incorporates two MCDM methods, namely BWM for determining the weight of decision criteria and VIKOR for ranking the suppliers. Ultimately, this research holds two implications. For academics, the proposed case study expands the literature on MCDM's supplier selection studies within the metal industry, specifically in developing nations. For practitioners, the decision-making framework presented is highly applicable to decision-makers (DMs).

2. Method

This study consists of two main stages as illustrated in Fig. 1. Stage 1 involves determining the weights of decision criteria using the BWM method, while Stage 2 focuses on ranking the suppliers using VIKOR. Initially, the decision criteria were identified through a literature review and interviews with three key decision-makers (DMs) from the company. These DMs possess significant knowledge of green factors and the procurement process. Expert group discussions were conducted to obtain pairwise comparison matrices for the decision criteria, which serve as the foundation for BWM calculations.

The selection of BWM in this study is based on three reasons. Firstly, the BWM method facilitates more consistent comparisons between criteria through group decision-making involving multiple experts [19]. Secondly, it yields more reliable results by quantifying criteria using qualitative judgments.

Thirdly, it is compatible with other MCDM methods, as it is integrated with VIKOR. Following the BWM steps outlined, the decision criteria are initially ranked to determine the best and worst criteria [20]. Preference assessments provided by the decision-makers are then used to calculate the best-to-others (BO) vector and the others-to-worst (OW) vector. Finally, the optimal weights are determined using the Solver Add-in based on the min-max optimization model, as shown in formulas 1 to 4.

$$min\ \xi \quad (1)$$

Subject to:

$$|\frac{w_B}{w_j} - \alpha_{Bj}| \leq \xi, for\ all\ j \quad (2)$$

$$|\frac{w_j}{w_w} - \alpha_{jw}| \leq \xi, for\ all\ j \quad (3)$$

$$\sum_j w_j = 1 \quad (4)$$

$$w_j \geq 0, for\ all\ j$$

In the second phase, the VIKOR technique is utilized to arrange suppliers according to evaluations given by participants, taking into account predefined criteria and weights determined through the BWM approach [21]. VIKOR is chosen to address this case due to its ability to generate rankings for suppliers [22]. The steps involved in VIKOR are described in formulas 5 to 7.

a. Normalize the data using the formula 5.

$$R_{ij=}\left(\frac{X_{j+}\ _{-}\ X_{ij}}{X_{j+}\ _{-}\ X_{j-}}\right) \quad (5)$$

Where R_{ij} and X_{ij} (i=1,2,3,...,m and j=1,2,3,...,n) represent the elements of the decision matrix for alternative i with respect to criterion j, X+j denotes the best element of criterion j, and X-j represents the worst element of criterion j.

b. Calculate the values of S and R using the formula 6.

$$S_i = \sum_{j=1}^{n} w_j \left(\frac{x_{j+} - x_{ij}}{x_{j+} - x_{j-}}\right) and\ \ R_i = Max\ j\left[w_j\left(\frac{x_{j+} - x_{ij}}{x_{j+} - x_{j-}}\right)\right] \quad (6)$$

Where W_j denotes the weight of each criterion j.

c. Compute the index value using the formula 7.

$$Q = \left[\frac{S_i - S^+}{S^+ - S^-}\right] v + \left[\frac{R_i - R^+}{R^+ - R^-}\right](1 - v) \quad (7)$$

Where $S^- = min\ S_i, S^+$ and $R^- = min\ R_i, R^+ = max\ R_i$ and $v = 0{,}5$.

d. The arrangement of the *S* value, *R*-value, and *Q* value determines the ranking outcome. The optimal ranking solution is determined by selecting the alternative with the lowest *Q* value, with the following conditions:

1) $Q(A(2)) - Q(A(1)) \geq DQ(4)$ (8)
Where *A*(2) is the alternative ranked second in the *Q* ranking, *A*(1) is the alternative ranked first in the *Q* ranking, and $DQ = 1 - (m - 1)$ where *m* is the number of alternatives.
2) *A*(1) must be ranked highest in the *S*-value and/or *R*-value.

To achieve optimal results in green supplier selection, a combination of the BWM and VIKOR methods can be utilized. Firstly, the relative priority values obtained from the BWM analysis are employed as weights in the VIKOR score calculation for each potential supplier. Subsequently, the potential suppliers are ranked based on the calculated VIKOR scores using the BWM weights. This integration of the two methods enables the BWM method to determine criteria weights based on relative priorities, while VIKOR aids in the selection of potential suppliers by considering ideal solution values.

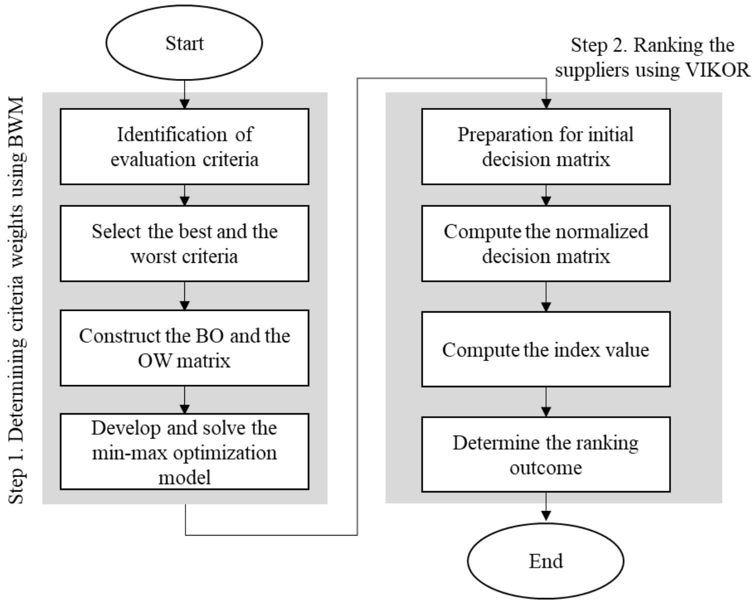

Fig. 1. The conceptual framework

3. Results and Discussion

Initially, seven criteria were identified through a combination of literature review and expert interviews. These criteria include cost (C_1), quality (C_2), delivery time (C_3), technology application (C_4), compliance towards environmental regulations (C_5), green practice certification (C_6), and green efforts (C_7). The company then considered nine alternative suppliers (S_1 to S_9) that prioritize green initiatives.

To calculate the weights of the criteria using the BWM method, the best and worst criteria were determined. The best criteria are those considered to be most important and have a significant impact on the overall evaluation, while the worst criteria are deemed less important. The three decision-makers (DMs) provided their subjective judgments for each factor, as shown in Table 1.

Table 1. The best and worst criteria defined by experts.

Criteria	**Frequency for Best**	**Frequency for Worst**
Cost (C_1)	DM_1; DM_2	
Quality (C_2)	**DM_1; DM_2; DM_3**	
Delivery time (C_3)	DM_2; DM_3	
Technology application (C_4)	DM_1; DM_2	
Compliance towards environmental regulations (C_5)	DM_3	DM_1
Green practice certified (C_6)		**DM_1; DM_2; DM_3**
Green efforts (C_7)		DM_1; DM_3

It can be observed that the three decision-makers (DMs) unanimously agreed that C_2 is the best criterion, while C_6 is considered the worst criterion. Subsequently, the DMs were asked to assign preference scores to the best criterion compared to the other criteria using Saaty's scale, which ranges from 1 to 9. Likewise, they provided preference scores for the other criteria relative to the worst criterion.

These preferences were used to construct the Best-to-Others (BO) vector and Others-to-Worst (OW) vector as presented in Table 2 and Table 3, respectively.

Table 2. The preference comparison of the best criterion

Best to Others	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_2	5	1	3	7	8	9	6

Table 3. The preference comparison of the worst criterion

Others to Worst	C_6
C_1	3
C_2	7
C_3	5
C_4	3
C_5	5
C_6	1
C_7	7

To calculate the weights of the criteria, a mathematical model needs to be constructed using the provided vectors. Once the model is solved, the optimal weights can be derived. The model is represented by formulas 8 to 11.

$$min\ \xi \tag{8}$$

Subject to:

Best constraints (9)

$$w_B - 5w_A \leq \xi$$
$$w_B - 3w_C \leq \xi$$
$$w_B - 7w_D \leq \xi$$
$$w_B - 8w_E \leq \xi$$
$$w_B - 9w_F \leq \xi$$
$$w_B - 6w_G \leq \xi$$

Worst constraints (10)

$$w_A - 3w_F \leq \xi$$
$$w_B - 7w_F \leq \xi$$
$$w_C - 5w_F \leq \xi$$
$$w_D - 3w_F \leq \xi$$
$$w_E - 5w_F \leq \xi$$
$$w_G - 7w_F \leq \xi$$
$$\sum_j w_j = 1 \tag{11}$$
$$w_j \geq 0, for\ all\ j$$

Finally, the BWM model is solved using Solver Add-ins, resulting in the optimal weights for criteria C_1 to C_6 as follows: 0.114 for C_1, 0.412 for C_2, 0.190 for C_3, 0.081 for C_4, 0.071 for C_5, 0.036 for C_6. The criteria are ranked from the best to the worst as C2 > C3 > C1 > C7 > C4 > C5 > C6. The company evaluates that the traditional supplier selection criteria, such as quality, delivery time, and cost, remain prioritized, while the green criteria are considered of secondary importance [23]. This finding aligns with previous research indicating that sustainability, green practices, and environmentally friendly initiatives receive less attention in developing countries [24]. Implementing sustainability disclosure methods can enhance the value and relevance of a company in developing countries [25]. However, the company in this study has already demonstrated commendable initiatives by initiating green practices in alignment with its corporate goals. Moreover, the government has begun enforcing regulations on green practices in the manufacturing industry, indirectly encouraging companies to embark on green initiatives.

In the second stage, the criteria weights obtained using BWM were utilized to rank the suppliers using VIKOR. Firstly, the DMs documented the performance of each supplier for each criterion using a Likert scale ranging from 1 to 5, where 1 indicates the lowest performance and 5 represents the highest. Table 4 presents the initial decision matrix for the nine suppliers. Next, the matrix is calculated using equation (5) to obtain the normalized matrix. Then, the elements in the normalized decision matrix are computed using equation (6) to determine the S and R values, and equation (7) to derive the index value, Q, as shown in table 5.

It is evident from table 5 that the top three suppliers are S_7 with a Q-score of 0.255, S_8 with a Q-score of 0.243, and S_4 with a Q-score of 0.218. Supplier S_7 demonstrates the best performance compared to the others, particularly excelling in the three traditional criteria prioritized by the company. Notably, supplier S_4, despite being ranked third, exhibits higher green performance than both S_7 and S_8. This is evident in several green criteria, where S_4 even achieves the highest scores. It is suggested that if the DMs are committed to enhancing green initiatives in the future, S_4 should be given top priority. On the other hand, supplier S_9 demonstrates the lowest performance with a Q-score of 0.062. While S_9 performs well in traditional criteria, its green initiatives lag behind those of the other suppliers.

Table 4. Initial decision matrix

Supplier	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	4	5	4	3	3	3	4
S_2	4	4	4	4	2	4	5
S_3	5	4	3	4	3	3	4
S_4	3	5	3	4	5	4	3
S_5	4	4	4	4	3	5	3
S_6	3	5	4	4	4	3	3
S_7	4	4	5	4	4	3	4
S_8	4	5	4	4	3	4	3
S_9	4	4	4	4	3	3	3
Weight	**0.114**	**0.412**	**0.190**	**0.081**	**0.071**	**0.036**	**0.095**
f_i*	5	5	5	4	5	5	5
f_i-	3	4	3	3	2	3	3

Table 5. The normalized matrix and the value of S, R, and Q.

Supplier	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Si	Ri	Q	Rank
S_1	0.50	0.00	0.50	1.00	0.67	1.00	0.50	0.364	0.095	0.185	5
S_2	0.50	1.00	0.50	0.00	1.00	0.50	0.00	0.653	0.412	0.166	6
S_3	0.00	1.00	1.00	0.00	0.67	1.00	0.50	0.733	0.412	0.073	8
S_4	1.00	0.00	1.00	0.00	0.00	0.50	1.00	0.417	0.190	0.218	3
S_5	0.50	1.00	0.50	0.00	0.67	0.00	1.00	0.706	0.412	0.104	7
S_6	1.00	0.00	0.50	0.00	0.33	1.00	1.00	0.364	0.114	0.204	4
S_7	0.50	1.00	0.00	0.00	0.33	1.00	0.50	0.576	0.412	0.255	1
S_8	0.50	0.00	0.50	0.00	0.67	0.50	1.00	0.312	0.095	0.245	2
S_9	0.50	1.00	0.50	0.00	0.67	1.00	1.00	0.742	0.412	0.062	9

This research has ranked the performance of nine suppliers based on the seven identified criteria using a combination of the BWM and VIKOR methods. Based on the criteria' weights, the BWM method used in this study is capable of computing more detailed weights although each supplier has different competitive features. However, the weights calculated using BWM still refer to the expert judgment delivered by the three DMs who place more dominant on the traditional criteria. This interpretation contrasts with [26] and [27] that considered their green criteria more dominantly once companies have started their green initiatives. [26] applied BWM to find the key factors to select green suppliers based on their green innovation abilities, while [27] used the method to weigh the criteria in a supply chain environment with flexibility and greenness. Then, the VIKOR method is employed to rank the nine alternatives in which apart from traditional factors, the three suppliers, namely S_2, S_4, and S_5, have more performance on their green aspects. Sensitivity analysis is clearly encouraged for further evaluation as the analysis may compare and re-rank the suppliers based on a few scenarios allowed [28]. included sensitivity analysis to test the feasibility of the best green chain supplier.

4. Conclusion

The present study introduces an integrated MCDM framework for supplier selection that incorporates green factors. The chosen methods, BWM and VIKOR, offer reliable rankings by considering two groups of criteria, resulting in a total of seven criteria. The case study conducted in this research highlights that while traditional supplier selection criteria like quality, delivery time, and cost remain the primary focus, the company has initiated efforts to incorporate green factors into its goals, thereby encouraging suppliers to align with these objectives. Notably, supplier S_7 emerges as the top performer, excelling in both traditional factors and green initiatives.

Some limitations should be followed up. Sensitivity analysis should be applied to bring the best ranking once the green factors are obviously prioritized. Besides, the green factors discussed in this research warrant further exploration. Future studies should encompass a wider range of industries that face higher environmental risks. Such follow-up studies will shed light on the extent to which sustainability concerns have permeated the entire supply chain network, particularly in developing nations.

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