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Bipolar q-ROF Hybrid Decision Making Model With Golden Cut for Analyzing the Levelized Cost of Renewable Energy Alternatives

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ABSTRACT Energy costs are the key factors regarding the selection of appropriate renewable energy (RWG) alternatives. All costs of a power plant, such as investment, operation, maintenance, and repair are considered in the scope of levelized costs. Therefore, for the effective determination of the selling price of the energy, levelized cost has a guiding role. Because the levelized costs of RWG alternatives develop the sustainable production and energy consumption for the long term, the leading indicators of these costs should be analyzed significantly. Accordingly, in this study, it is aimed to investigate the levelized cost of RWG alternatives by using bipolar q-rung orthopair fuzzy (q-ROF) hybrid decision-making approach. The novelty of this study is to recommend an integrated decision-making model based on bipolar and q-ROFSs with golden cut. At the first stage, bipolar q-ROF multi stepwise weight assessment ratio analysis (M-SWARA) is employed for weighting the selected criteria of levelized costs of RWG alternatives. At the following stage, bipolar q-ROF technique for order preference by similarity to ideal solution (TOPSIS) is considered to rank the alternatives in terms of the levelized cost performance. On the other side, vise kriterijumska optimizacija i kompromisno resenje (VIKOR) model is also considered to rank the alternatives. In addition to this issue, the sensitivity analysis is also performed with four cases comparatively. Hence, consistency, reliability and coherency of the proposed model can be measured. It is identified that capacity loss has the greatest importance regarding the levelized cost of RWG projects. Solar is found as the best clean energy type with respect to the levelized cost management performance. In this context, it would be appropriate for investors to design projects close to the center. This will contribute to increasing the efficiency and productivity of these projects.

INDEX TERMS Renewable energy, bipolar fuzzy sets, q-ROFSs, golden cut.

I. INTRODUCTION

RWG alternatives provide many different benefits for the economies. Because carbon emission is minimized, these alternatives are accepted as environment-friendly energy types. Additionally, energy dependency problem of the countries can be decreased with the help of RWG alternatives. Hence, the performance of these projects should be increased. For this purpose, the price of the energy should be identified effectively. Otherwise, the profitability of these investments is decreased. Hence, cost effectiveness of these projects should be provided. In this context, the levelized costs play a critical role regarding the sustainable production and energy consumption for the long term. It is mainly considered for the calculation of the unit energy cost of power generation plants. All costs of a power plant, such as investment, operation, maintenance, and repair are considered in the scope of levelized costs. Hence, this cost has a guiding role to determine the selling price of the energy effectively [1]. Thus, for the implementing an effective price policy, this cost should be

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analyzed in a detailed manner. This situation has a powerful impact for the sustainability of the green energy projects.

Some issues should be considered for the effective management of the levelized energy costs. Regarding the establishment costs, total amount of initial investment costs is taken into consideration. Moreover, repair, routine service and controlling of the energy equipment is also used with respect to the operations and maintenance costs. On the other side, potential loss of capacity for generated electricity plays a significant role as for the capacity loss. Additionally, energy loss also leads to higher levelized energy costs [2]. Deviation of expected service life of the energy plants is quite important for the management of the levelized energy costs. Hence, for the aim of managing the levelized energy costs more effectively, these factors should be analyzed in a detailed manner so that optimal clean energy alternative can be selected.

Hence, the influencing items of the levelized cost should be evaluated. With the help of this situation, appropriate investment decisions can be made by energy investment companies. Within this framework, making a priority analysis among these factors helps these companies to determine the right strategies quickly. For this purpose, decision-making techniques can be taken into consideration [3]. These approaches are used to determine the most important ones by performing a priority analysis among different alternatives [4]. These methods are also considered with the fuzzy logic since uncertainties in this process can be managed more effectively. This situation has a positive contribution to achieve more appropriate results. In summary, these methods can be considered in determining the most important factors affecting the levelized costs in clean energy investments.

In this study, a novel model is constructed to evaluate the levelized costs of RWG alternatives by using bipolar and q-ROFSs with golden cut. At the first stage of this proposed model, bipolar q-ROF M-SWARA is considered to weight the selected criteria of levelized costs. In the following stage, bipolar q-ROF TOPSIS is applied to rank the alternatives in terms of the levelized cost performance. Additionally, VIKOR model is also considered to rank the alternatives. Hence, the reliability of the analysis results can be measured. On the other side, the sensitivity analysis is also performed with 4 cases comparatively so that coherency and consistency of the findings can be evaluated. The novelty of this study is to recommend an original integrated decision-making model based on bipolar and q-ROFSs with golden cut.

The recommended model has essential superiorities over previous decision-making models. Firstly, in this model, some improvements are made to SWARA methodology so that a new technique is created with the name of M-SWARA. Owing to these new improvements, causal relationship can be identified between the criteria. It is obvious that this situation helps to solve the problems more precisely in comparison with the models that used classical SWARA [5], [6]. Another important benefit of this model is integrating bipolar fuzzy sets and golden cut to the q-ROFSs. While using bipolar fuzzy sets, positive and negative aspects can be examined [7]. Additionally, degrees of q-ROFSs are computed with golden cut in this study. With the help of these new implementations, uncertainty in decision-making process can be handled more effectively. Also, this situation has a powerful impact on the originality of the proposed model [8].

Furthermore, q-ROFs are generated as an integration of IFSs and PFSs so that a wider space can be taken into consideration in the analysis process. Therefore, by using this technique, more appropriate evaluations can be performed [9]. In addition, in this model, the reliability of the findings can be controlled by making additional calculations with IFSs and PFSs. However, the previous models that used only one fuzzy set do not have the opportunity to test the coherency of the findings [10], [11].

Preferring SWARA and TOPSIS also provides some benefits. For example, the priorities of the decision makers are considered in SWARA approach [6]. Furthermore, negative and positive solutions are considered in TOPSIS unlike other methods [12]. Owing to this situation, ranking process can be performed more effectively. On the other side, VIKOR model is also considered to rank the alternatives. In addition to this issue, the sensitivity analysis is also performed with four cases comparatively. With the help of these evaluations, the coherency and the reliability of the findings can be measured.

Section 2 gives information about the review of the literature. The following section focuses on the explanations of the methodology. Section 4 demonstrates the results of the analysis. In the next section, concluding remarks are presented.

II. LITERATURE REVIEW

Establishment cost is an important type of the levelized energy costs. It includes the total amount of initial investment cost. Establishment cost of the green energy projects is quite higher than fossil fuels. This situation can be accepted as a crucial weakness of RWG projects [13]. For the effective management of the levelized energy costs, establishment cost should be minimized. For this purpose, technological development plays a significant role. New improvements have a powerful contribution to the cost minimization [14]. In addition to the technological development, government supports to the RWG investors have also positive influence on this situation [15]. Owing to these subsidies, such as tax reduction, RWG investors can get the opportunity to decrease establishment costs [16]. Carvalho *et al.* [17] focused on the energy investments in Brazil. They reached a conclusion that for the effective management of the levelized energy costs, high establishment cost problem can be handled. Additionally, Al-Najjar *et al.* [18] also identified that there should be technological improvements to minimize establishment costs of energy investments.

Operations and maintenance costs are also important regarding the levelized energy cost management. Repair, routine service and controlling of the energy equipment can be categorized in these costs. In this framework, the design of the RWG projects is important [19]. Hence, a comprehensive evaluation should be performed to understand the cost of the equipment used in the projects [20]. This situation has a significant impact on the identifying the levelized costs more appropriately [21]. With the help of this issue, the price of the energy can be identified accurately so that efficiency in the RWG investment projects can be provided [22]. Basu *et al.* [15] made feasibility analysis regarding the hydrogen-based hybrid energy system. They claimed that maintenance costs should be prioritized to become successful for levelized energy costs. Moreover, Kumar and Saini [23] also focused on the performance indicators of hydropower plants. It is identified that operational costs should be evaluated carefully for this condition.

Capacity loss should also be considered for the effectiveness in levelized energy cost management. It defines potential loss of capacity for generated electricity [20]. One of the weaknesses of RWG projects is that the amount of energy produced varies at certain times of the day. Therefore, to increase the efficiency of these projects, energy loss should be minimized [24]. In this context, when choosing RWG projects, the one suitable for each region may be preferred. Energy projects that are effective only in certain regions may have low efficiency [25]. Additionally, if these projects are far from the center, energy losses may occur. This may adversely affect the profitability of energy investments. Naveenkumar *et al.* [26] evaluated the effectiveness of the energy investment projects. They defined that energy loss should be reduced to increase the performance of levelized cost management. Sulaiman [27] studied energy investments in tropical countries. They stated that investors should mainly focused on the capacity loss problem to increase the efficiency.

Another essential factor that affects the performance of the levelized energy cost management of the green energy investments is changes in project lifetime. This situation gives information about the deviation of expected service life of the energy plants [28]. There are serious costs at the beginning of RWG investments. Due to this situation, a certain amount of time may have to pass to make a profit in these projects [29]. Therefore, how long this project will take is a very important issue [30]. In other words, ending these projects before the expected time will lead to a decrease in profitability [31]. Hence, to increase the efficiency of green energy projects, significant changes should not occur in the lifetime of the projects [32].

Levelized energy costs play a vital role for the performance of the RWG projects. Thus, energy investors should make effective management regarding these costs. For this purpose, leading indicators of these costs should be identified. Within this context, a new study is required that makes a prioritization analysis about these items. A novel model is constructed to examine the levelized cost of RWG alternatives by using bipolar and q-ROFSs with golden cut.

III. METHODOLOGY

Bipolar q-ROFs with golden cut, M-SWARA, TOPSIS and VIKOR are explained in this section.

A. BIPOLAR Q-ROFs WITH GOLDEN CUT

Atanassov [33] generated IFSs by membership (M) and non-membership (N) degrees (μ_I, n_I). Equation (1) gives information about these sets.

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta)\rangle / \vartheta \epsilon U\} \tag{1}$$

Necessary condition of IFSs is demonstrated in Equation (2).

$$0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1 \tag{2}$$

Yager [34] introduced PFSs by considering new degrees (μ_p, n_p). These sets are shown in Equation (3).

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta)\rangle / \vartheta \epsilon U\} \tag{3}$$

Equation (4) indicates the required condition of them.

$$0 \leq (\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{4}$$

Yager [35] developed q-ROFSs by extending IFSs and PFSs. The details are demonstrated in Equation (5).

$$Q = \left\{\langle \vartheta, \mu_Q(\vartheta), n_Q(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{5}$$

The condition of these sets is shown in Equation (6).

$$0 \leq (\mu_Q(\vartheta))^q + (n_Q(\vartheta))^q \leq 1, q \geq 1 \tag{6}$$

Zhang [36] generated bipolar fuzzy sets with the interval [0,1] and [−1,0]. With these sets, it is aimed to have more effective evaluation with the help of this wide range. Equation (7) indicates these sets.

$$B = \left\{\langle \vartheta, \mu_B^+(\vartheta), \mu_B^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{7}$$

Within this framework, μ_B^+ and μ_B^- state satisfaction degree and satisfaction of the same element. Equation (8)-(13) represent bipolar IFSs, PFSs and q-ROFSs.

$$B_I = \left\{\langle \vartheta, \mu_{B_I}^+(\vartheta), n_{B_I}^+(\vartheta), \mu_{B_I}^-(\vartheta), n_{B_I}^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{8}$$

$$B_P = \left\{\langle \vartheta, \mu_{B_P}^+(\vartheta), n_{B_P}^+(\vartheta), \mu_{B_P}^-(\vartheta), n_{B_P}^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{9}$$

$$B_Q = \left\{\langle \vartheta, \mu_{B_Q}^+(\vartheta), n_{B_Q}^+(\vartheta), \mu_{B_Q}^-(\vartheta), n_{B_Q}^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{10}$$

$$0 \leq \left(\mu_{B_I}^+(\vartheta)\right) + \left(n_{B_I}^+(\vartheta)\right) \leq 1, -1 \leq \left(\mu_{B_I}^-(\vartheta)\right) + \left(n_{B_I}^-(\vartheta)\right) \leq 0 \tag{11}$$

$$0 \leq \left(\mu_{B_P}^+(\vartheta)\right)^2 + \left(n_{B_P}^+(\vartheta)\right)^2 \leq 1, 0 \leq \left(\mu_{B_P}^-(\vartheta)\right)^2 + \left(n_{B_P}^-(\vartheta)\right)^2 \leq 1 \tag{12}$$

$$0 \leq \left(\mu_{B_Q}^+(\vartheta)\right)^q + \left(n_{B_Q}^+(\vartheta)\right)^q \leq 1, -1 \leq \left(\mu_{B_Q}^-(\vartheta)\right)^q + \left(n_{B_Q}^-(\vartheta)\right)^q \leq 0 \tag{13}$$

Equations (14)-(16) show the calculational process of bipolar q-ROFSs.

$$B_{Q1} = \left\{\langle \vartheta, \mu_{B_{Q1}}^+(\vartheta), n_{B_{Q1}}^+(\vartheta), \mu_{B_{Q1}}^-(\vartheta), n_{B_{Q1}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \text{ and}$$

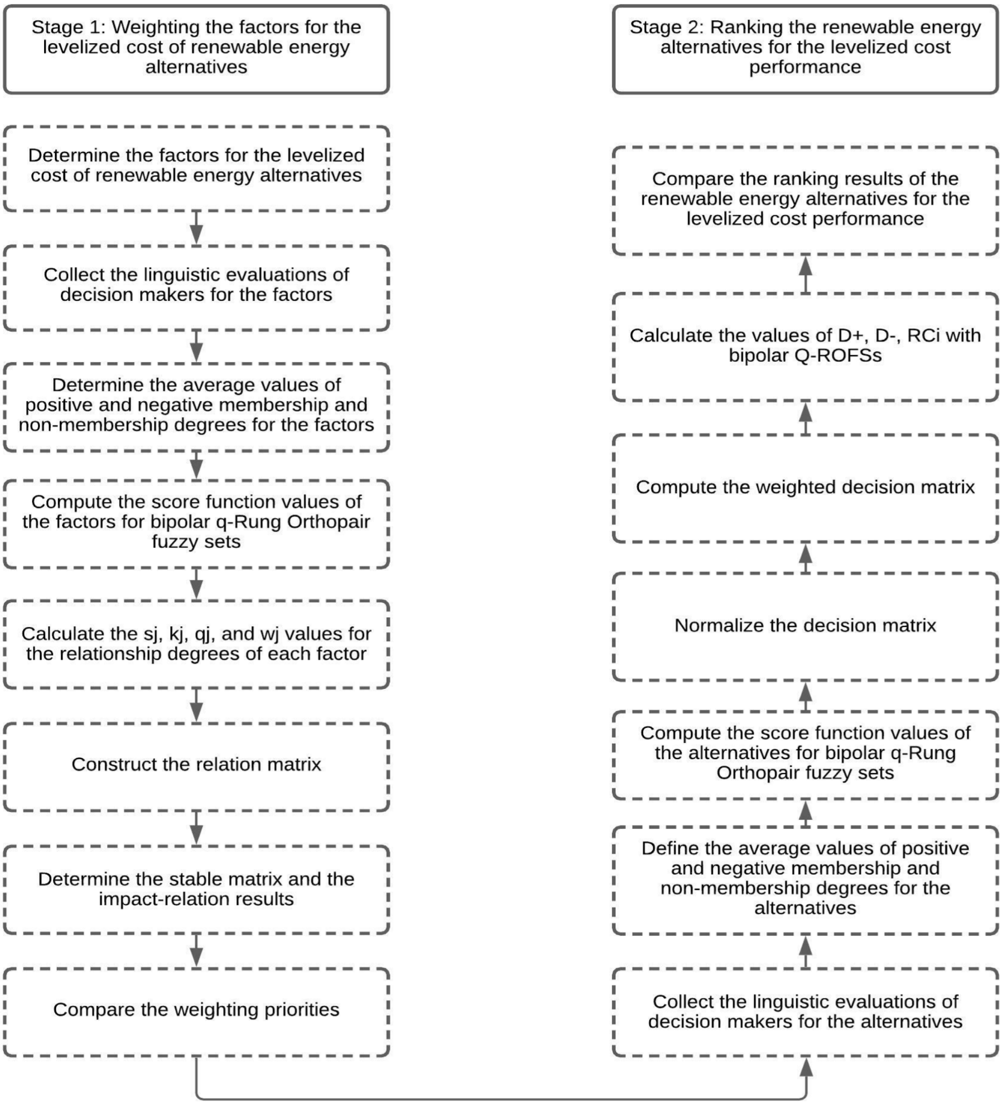

FIGURE 1. The model.

$$B_{Q2} = \left\{ \langle \vartheta, \mu^{+}_{B_{Q2}}(\vartheta), n^{+}_{B_{Q2}}(\vartheta), \mu^{-}_{B_{Q2}}(\vartheta), n^{-}_{B_{Q2}}(\vartheta) \rangle / \vartheta \epsilon U \right\}$$

$$B_{Q1} \oplus B_{Q2} = \begin{pmatrix} \left(\left(\mu^{+}_{B_{Q1}}\right)^{q} + \left(\mu^{+}_{B_{Q2}}\right)^{q} - \left(\mu^{+}_{B_{Q1}}\right)^{q} \cdot \left(\mu^{+}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, \\ \left(n^{+}_{B_{Q1}} . n^{+}_{B_{Q2}}\right), -\left(\mu^{-}_{B_{Q1}} . \mu^{-}_{B_{Q2}}\right), \\ -\left(\left(n^{-}_{B_{Q1}}\right)^{q} + \left(n^{-}_{B_{Q2}}\right)^{q} - \left(n^{-}_{B_{Q1}}\right)^{q} \cdot \left(n^{-}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}} \end{pmatrix} \tag{14}$$

$$B_{Q1} \otimes B_{Q2} = \left(\left(\mu^{+}_{B_{Q1}} . \mu^{+}_{B_{Q2}}\right), \left(\left(n^{+}_{B_{Q1}}\right)^{q} + \left(n^{+}_{B_{Q2}}\right)^{q} - \left(n^{+}_{B_{Q1}}\right)^{q} \cdot \left(n^{+}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, -\left(\left(\mu^{-}_{B_{Q1}}\right)^{q} + \left(\mu^{-}_{B_{Q2}}\right)^{q} - \left(\mu^{-}_{B_{Q1}}\right)^{q} \cdot \left(\mu^{-}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, -\left(n^{-}_{B_{Q1}} . n^{-}_{B_{Q2}}\right) \right) \tag{15}$$

$$\lambda B_{Q1} = \begin{pmatrix} \left(1 - \left(1 - \left(\mu^{+}_{B_{Q1}}\right)^{q}\right)^{\lambda}\right)^{\frac{1}{q}}, \left(n^{+}_{B_{Q1}}\right)^{\lambda}, \\ -\left(-\mu^{-}_{B_{Q1}}\right)^{\lambda}, \\ -\left(1 - \left(1 - \left(-n^{-}_{B_{Q1}}\right)^{q}\right)^{\lambda}\right)^{1/q} \end{pmatrix}, \lambda > 0 \tag{16}$$

$$B^{\lambda}_{Q1} = \begin{pmatrix} \left(\mu^{+}_{B_{Q1}}\right)^{\lambda}, \\ \left(1 - \left(1 - \left(n^{+}_{B_{Q1}}\right)^{q}\right)^{\lambda}\right)^{\frac{1}{q}}, \\ -\left(1 - \left(1 - \left(-\mu^{-}_{B_{Q1}}\right)^{q}\right)^{\lambda}\right)^{\frac{1}{q}}, \\ -\left(-n^{-}_{B_{Q1}}\right)^{\lambda} \end{pmatrix}, \lambda > 0 \tag{17}$$

TABLE 1. Criteria.

Factors	References
Establishment cost (EC)	[14]
Operations and maintenance costs (OMC)	[20]
Capacity loss (CL)	[24]
Changes in project lifetime (CPL)	[30]

Equations (18)-(20) give information about the computation of defuzzification.

$$S(\vartheta)_{B_I} = ((\mu^+_{B_I}(\vartheta)) - (n^+_{B_I}(\vartheta))) - ((\mu^-_{B_I}(\vartheta)) - (n^-_{B_I}(\vartheta))) \tag{18}$$

$$S(\vartheta)_{B_P} = ((\mu^+_{B_P}(\vartheta))^2 - (n^+_{B_P}(\vartheta))^2) + ((\mu^-_{B_P}(\vartheta))^2 - (n^-_{B_P}(\vartheta))^2) \tag{19}$$

$$S(\vartheta)_{B_Q} = ((\mu^+_{B_Q}(\vartheta))^q - (n^+_{B_Q}(\vartheta))^q) - ((\mu^-_{B_Q}(\vartheta))^q - (n^-_{B_Q}(\vartheta))^q) \tag{20}$$

In this study, golden ratio (φ) is considered to calculate the degrees. Equations (21)-(23) demonstrate the details. In these equations, the large and small quantities are shown as a and b [8].

$$\varphi = \frac{a}{b} \tag{21}$$

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.618\ldots \tag{22}$$

$$\varphi = \frac{\mu_{G_{B_Q}}}{n_{G_{B_Q}}} \tag{23}$$

Golden cut is integrated to q-ROFSs with Equations (24)-(26).

$$G_{B_Q} = \left\{\langle \vartheta, \mu^+_{G_{B_Q}}(\vartheta), n^+_{G_{B_Q}}(\vartheta), \mu^-_{G_{B_Q}}(\vartheta), n^-_{G_{B_Q}}(\vartheta)\rangle / \vartheta \epsilon U\right\} \tag{24}$$

$$0 \le (\mu^+_{G_{B_Q}}(\vartheta))^q + (n^+_{G_{B_Q}}(\vartheta))^q \le 1, -1 \le (\mu^-_{G_{B_Q}}(\vartheta))^q + (n^-_{G_{B_Q}}(\vartheta))^q \le 0 \tag{25}$$

$$0 \le (\mu^+_{G_{B_Q}}(\vartheta))^{2q} + (n^+_{G_{B_Q}}(\vartheta))^{2q} \le 1, 0 \le (\mu^-_{G_{B_Q}}(\vartheta))^{2q} + (n^-_{G_{B_Q}}(\vartheta))^{2q} \le 1 \tag{26}$$

B. M-SWARA WITH BIPOLAR Q-ROFSs

SWARA was introduced by Kersuliene *et al.* [37] for the purpose of evaluating factors by considering hierarchical priorities. In this study, this methodology is extended by the name of M-SWARA to make this evaluation more effectively. Equation (27) gives information about the decision matrix.

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{27}$$

In the following process, bipolar q-ROFSs are created and score functions are calculated. Equations (28)-(30) explain the calculation of importance ratio, coefficient, recomputed weight, and weight that are shown as (s_j, k_j, q_j, w_j).

TABLE 2. Degrees and scales.

Linguistic Scales		Positive Degrees (PT)		Negative Degrees (NG)	
Factors	Alternatives	M	N	M	N
No impact (n)	Weakest (w)	.40	.25	-.60	-.37
Some impact (s)	Poor (p)	.45	.28	-.55	-.34
medium impact (m)	Fair (f)	.50	.31	-.50	-.31
high impact (h)	Good (g)	.55	.34	-.45	-.28
very high impact (vh)	Best (b)	.60	.37	-.40	-.25

TABLE 3. Evaluations.

Decision Maker 1								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
EC			VH	N	VH	N	M	VH
OMC	H	M			M	H	VH	M
CL	H	VH	M	M			M	M
CPL	VH	S	VH	VH	VH	N		
Decision Maker 2								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
EC			H	N	VH	N	M	VH
OMC	M	M			M	H	M	M
CL	H	M	M	M			M	M
CPL	VH	VH	H	VH	VH	M		
Decision Maker 3								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
EC			H	N	VH	S	M	S
OMC	S	H			M	H	M	M
CL	H	VH	M	M			S	S
CPL	VH	S	H	VH	VH	N		

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{28}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{29}$$

If $s_{j-1} = s_j, q_{j-1} = q_j$; *If* $s_j = 0, k_{j-1} = k_j$.

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{30}$$

Stable matrix is constructed by limiting and transposing the matrix to the power of 2t+1.

TABLE 4. Average values.

	EC				OMC				CL				CPL			
	PT		NG		PT		NG		PT		NG		PT		NG	
	M	v	μ	v	μ	V	μ	v	μ	v	μ	v	μ	v	μ	v
EC					.57	.35	-.60	-.37	.60	.37	-.58	-.36	.50	.31	-.45	-.28
OMC	.50	.31	-.48	-.30					.50	.31	-.45	-.28	.53	.33	-.50	-.31
CL	.55	.34	-.43	-.27	.50	.31	-.50	-.31					.48	.30	-.52	-.32
CPL	.60	.37	-.50	-.31	.57	.35	-.40	-.25	.60	.37	-.57	-.35				

C. TOPSIS WITH BIPOLAR Q-ROFSs

TOPSIS aims to select the best alternatives among different factors. Equation (31) includes the decision matrix [38].

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{31}$$

Bipolar q-ROFSs and score functions are generated. Normalization process is implemented in Equation (32) [39].

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{32}$$

Equation (33) shows the weighted values.

$$v_{ij} = w_{ij} \times r_{ij}. \tag{33}$$

Equations (34) and (35) give information regarding positive (A^+) and negative (A^-) optimal solutions [40].

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j} for \forall j \in n\}, \tag{34}$$

$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min v_{1j} for \forall j \in n\}. \tag{35}$$

Distances are computed by Equation (36) and (37).

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^+\right)^2} \tag{36}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^-\right)^2} \tag{37}$$

Equation (38) focuses on the calculation of relative closeness.

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-}. \tag{38}$$

D. VIKOR WITH BIPOLAR Q-ROFSs

VIKOR methodology is taken into consideration for the purpose of ranking different alternatives. Fuzzy best and worst values ($\tilde{f}_j^*, \tilde{f}_j^-$) are used in the analysis process as in Equation (39) [41].

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, and\ \tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{39}$$

TABLE 5. Score function values.

	EC	OMC	CL	CPL
EC	.000	.304	.317	.165
OMC	.182	.000	.165	.211
CL	.189	.191	.000	.192
CPL	.260	.188	.304	.000

Equations (40) and (41) are considered with the aim of calculating mean group utility ($\tilde{S}_i$)and maximal regret ($\tilde{R}_i$). Within this framework, $\tilde{w}_j$ refers to the fuzzy weights [42].

$$\tilde{S}_i = \sum_{i=1}^{n} \tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)} \tag{40}$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)}\right] \tag{41}$$

Equation (42) is taken into consideration to compute the value of $\tilde{Q}_i$. In this context, v demonstrates the strategy weights. On the other hand, 1-v gives information about the regret [43].

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right) / \left(\tilde{S}^- - \tilde{S}^*\right) + (1-v)\left(\tilde{R}_i - \tilde{R}^*\right) / \left(\tilde{R}^- - \tilde{R}^*\right) \tag{42}$$

These values are used for the aim of ranking the alternatives.

IV. ANALYSIS RESULTS

A new model is created to evaluate the levelized cost of RWG alternatives. Figure 1 details the stages of this novel model.

The factors for the levelized cost of RWG alternatives are determined in Table 1.

Establishment costs gives information about the total amount of initial investment cost. Furthermore, operations and maintenance costs include repair, routine service and controlling of the energy equipment. On the other side, capacity loss refers to the potential loss of capacity for generated electricity. Changes in project lifetime explain the deviation of expected service life of the energy plants. Next, evaluations are obtained. In this context, Table 2 explains the degrees and scales used in this process.

Three different experts are selected to evaluate these items. These people have at least 26-year experience. In addition to this situation, two of these people are the top managers

TABLE 6. Essential values.

EC	Sj	kj	qj	wj	OMC	Sj	kj	qj	wj
CL	.317	1.000	1.000	.412	CPL	.211	1.000	1.000	.389
OMC	.304	1.304	.767	.316	EC	.182	1.182	.846	.329
CPL	.165	1.165	.658	.271	CL	.165	1.165	.726	.282
CL	**Sj**	**kj**	**qj**	**wj**	**CPL**	**Sj**	**kj**	**qj**	**wj**
CPL	.192	1.000	1.000	.393	CL	.304	1.000	1.000	.406
OMC	.191	1.191	.840	.330	EC	.260	1.260	.793	.322
EC	.189	1.189	.706	.277	OMC	.188	1.188	.668	.271

TABLE 7. Relation matrix.

	EC	OMC	CL	CPL
EC		.316	.412	.271
OMC	.329		.282	.389
CL	.277	.330		.393
CPL	.322	.271	.406	

TABLE 8. Stable matrix.

	EC	OMC	CL	CPL
EC	.236	.236	.236	.236
OMC	.234	.234	.234	.234
CL	.269	.269	.269	.269
CPL	.261	.261	.261	.261

TABLE 9. Comparative results.

	Bipolar IFSs	Bipolar PFSs	Bipolar q-ROFSs
EC	3	3	3
OMC	4	4	4
CL	1	1	1
CPL	2	2	2

in renewable energy companies. On the other side, the third person of the expert team is the academician who has lots of publishments about the cost management issues of the renewable energy projects. While making analysis by using evaluations, Microsoft Excel program is taken into consideration. Table 3 shows the evaluations.

Average values are demonstrated in Table 4.

Table 5 includes the score function values.

Table 6 explains the essential values considered in the analysis process.

Relation matrix is generated in Table 7.

The results of the stable matrix are indicated in Table 8.

Capacity loss has the highest significance for levelized cost of green energy investments. Additionally, changes in project lifetime play the second most significant role in this regard. Nevertheless, establishment and operational & management costs have the lowest weights. Figure 2 shows the impact results of the items.

Capacity loss and changes in project lifetime have an impact on each other. Also, establishment costs have positive influence on capacity loss. In addition, operations and maintenance costs affect changes in project lifetime. IFSs and PFSs are also used in the calculation process. All results are shown in Table 9.

The degree of importance of the factors is the same in all calculations. This indicates that the obtained results are reliable. In the second stage, RWG alternatives (hydro, geothermal, solar, wind) are ranked according to the levelized

TABLE 10. Evaluations.

Decision Maker 1								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
Hydro	P	W	G	G	G	F	B	G
Geothermal	W	F	P	G	G	B	W	F
Solar	P	P	B	W	G	F	B	F
Wind	G	G	B	P	P	G	B	B
Decision Maker 2								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
Hydro	B	W	G	F	G	F	B	G
Geothermal	W	F	B	W	G	F	W	F
Solar	P	P	B	W	B	W	G	F
Wind	G	P	B	G	G	G	B	G
Decision Maker 3								
	EC		OMC		CL		CPL	
	PT	NG	PT	NG	PT	NG	PT	NG
Hydro	P	F	P	F	G	G	B	G
Geothermal	P	F	G	G	G	F	W	G
Solar	P	P	P	W	P	F	G	F
Wind	G	W	B	F	P	W	B	F

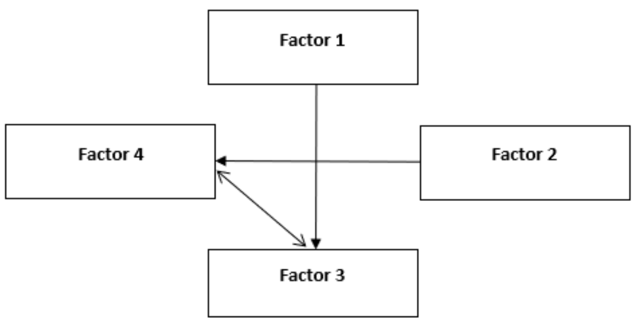

FIGURE 2. Impact results.

TABLE 11. Average values.

	EC				OMC				CL				CPL			
	PT		NG		PT		NG		PT		NG		PT		NG	
	μ	v	μ	v	μ	v	μ	v	μ	v	μ	v	μ	v	μ	V
Hydro	.50	.31	-.57	-.35	.52	.32	-.48	-.30	.55	.34	-.48	-.30	.60	.37	-.45	-.28
Geothermal	.42	.26	-.50	-.31	.53	.33	-.50	-.31	.55	.34	-.47	-.29	.40	.25	-.48	-.30
Solar	.45	.28	-.55	-.34	.55	.34	-.60	-.37	.53	.33	-.53	-.33	.57	.35	-.50	-.31
Wind	.55	.34	-.53	-.33	.60	.37	-.50	-.31	.48	.30	-.50	-.31	.60	.37	-.45	-.28

TABLE 12. Score function values.

	EC	OMC	CL	CPL
Hydro	.234	.192	.213	.235
Geothermal	.151	.211	.205	.135
Solar	.197	.292	.232	.234
Wind	.243	.260	.182	.235

TABLE 13. Normalized matrix.

	EC	OMC	CL	CPL
Hydro	.560	.396	.511	.548
Geothermal	0,360	.436	.490	.316
Solar	.470	.603	.555	.548
Wind	.580	.538	.435	.548

TABLE 14. Weighted matrix.

Alternatives	EC	OMC	CL	CPL
Hydro	.132	.093	.138	.143
Geothermal	.085	.102	.132	.082
Solar	.111	.141	.150	.143
Wind	.137	.126	.117	.143

TABLE 15. Distances and relative closeness.

Alternatives	D+	D-	RCi
Hydro	.050	.079	.613
Geothermal	.091	.018	.163
Solar	.026	.088	.771
Wind	.036	.086	.708

cost performance. Evaluations of the experts are shown in Table 10.

Average values are calculated as in Table 11.

Table 12 demonstrates the score function values.

Normalized matrix is given in Table 13.

Table 14 includes weighted matrix.

Distances and relative closeness values are demonstrated in Table 15.

Comparative ranking results are stated in Table 16.

Solar is found as the best clean energy type with respect to the levelized cost management performance. Wind is also another successful energy type in this issue. However, hydro and geothermal have the last ranks. Additionally, the comparative ranking results are coherent with the extended method of VIKOR.

Sensitivity analysis is also applied to check the consistency of the hybrid decision making model. So, the weights of the criteria are consecutively changed in the weighted matrix and 4 cases are defined to measure the ranking alternatives. The comparative sensitivity results are given in Table 17.

In Table 17, the sensitivity analysis results are presented with 4 cases comparatively. It is seen that the ranking results are almost same for each case. This is clear evidence that our proposed model is consistent even if the weighting priorities are iteratively changed.

V. CONCLUSIONS AND DISCUSSIONS

A novel model is constructed to examine the levelized cost of RWG alternatives by using bipolar and q-ROFSs with golden cut. At the first stage, bipolar q-ROF M-SWARA is considered for weighting the selected criteria of levelized costs. At the following stage, bipolar q-ROF TOPSIS is employed to rank the alternatives in terms of the levelized cost performance. It is identified that capacity loss has the greatest importance regarding the levelized cost of RWG projects. Furthermore, changes in project lifetime also play an important role in this respect. However, establishment and operational & management costs have the lowest weights. On the other hand, solar is found as the best clean energy type with respect to the levelized cost management performance. Wind is also another successful energy type in this situation.

The energy loss in this process should be minimized to manage levelized costs effectively. One of the problems of RWG alternatives is that they are affected by climatic conditions. Since this situation will create instability in energy production, there is a significant loss of energy. Therefore, to increase the efficiency of these projects, investors should focus on the energy loss problem. One of the reasons for energy loss is the distance between the supply and production points. In this context, it would be appropriate for investors to design projects close to the center. This will contribute to increasing the efficiency and productivity of these projects. Therefore, renewable energy investors should choose a location close to the usage area while generating electricity. In this context, a comprehensive analysis should be made and places close to the city center and industrial zone should be determined. In this way, the losses in the transfer of the produced energy will be minimized. Hamilton *et al.* [44] and Bandeiras *et al.* [45] also claimed that for the effective management of the levelized energy costs, investors should

TABLE 16. Ranking results.

Alternatives	Bipolar q-ROF Multi SWARA-TOPSIS	Bipolar q-ROF Multi SWARA-VIKOR	Bipolar PF Multi SWARA-TOPSIS	Bipolar PF Multi SWARA-VIKOR	Bipolar IF Multi SWARA-TOPSIS	Bipolar IF Multi SWARA-VIKOR
Hydro	3	3	3	2	3	2
Geothermal	4	4	4	4	4	4
Solar	1	1	1	1	1	1
Wind	2	2	2	3	2	3

TABLE 17. Sensitivity results.

Alternatives	Bipolar q-ROF Multi SWARA-TOPSIS				Bipolar q-ROF Multi SWARA-VIKOR			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Hydro	3	3	2	2	3	2	3	3
Geothermal	4	4	4	4	4	4	4	4
Solar	1	1	1	1	1	1	1	1
Wind	2	2	3	3	2	3	2	2
Alternatives	Bipolar PF Multi SWARA-TOPSIS				Bipolar PF Multi SWARA-VIKOR			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Hydro	3	3	3	2	2	3	3	2
Geothermal	4	4	4	4	4	4	4	4
Solar	1	1	1	1	1	1	1	1
Wind	2	2	2	3	3	2	2	3
Alternatives	Bipolar IF Multi SWARA-TOPSIS				Bipolar IF Multi SWARA-VIKOR			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Hydro	3	3	3	3	2	2	3	2
Geothermal	4	4	4	4	4	4	4	4
Solar	1	1	1	1	1	1	1	1
Wind	2	2	2	2	3	3	2	3

mainly focus on the ways to reduce energy loss in the projects. On the other hand, renewable energy investment companies should also follow new technologies for energy transfer. In this context, it is possible to reduce the losses in energy transfer thanks to new research and development studies. Thanks to these technologies, it will be possible to establish energy production in areas farther from the city center.

Another important issue in this process is the selection of the most suitable RWG alternative. The findings of this study indicate that solar energy is the optimal alternative to increase levelized cost management performance. Technological developments, especially in recent years, have helped to significantly increase the efficiency of solar energy investments. In this context, small-scale solar panels can be installed at close distances to solar energy usage areas. This also contributes to the minimization of energy loss. Another issue that causes energy loss in solar energy is pollution or damage to the panels. As a result of the fact that these problems are not easy to detect, energy loss is experienced in solar panels. Thanks to new technological developments, it is possible to detect these problems early. This enables levelized costs to be managed more effectively. Therefore, it is vital for solar energy investors to follow up-to-date technologies. Thanks to new technologies in this field, it is possible to install solar panels in every building. On the other hand, these new technologies also allow to obtain energy from solar panels more efficiently. In this context, it would be appropriate to focus on research and development studies for these projects for sustainable development. Hosseini *et al.* [46] and Zayed *et al.* [47] also identified that with the help of the recent technological improvements, solar energy is an optimal choice to manage levelized energy costs more appropriately.

The novelty of this study is to recommend an integrated decision-making model based on bipolar and q-ROFSs with golden cut. Despite this situation, only important criteria are presented in this study. In other words, no on-site application has been made for energy investment projects which can be accepted as an important limitation. Therefore, in new studies, the effects of the factors suggested in this study can be tested. Furthermore, the findings of this study can also be compared with different fuzzy numbers. For example, Spherical fuzzy sets can be taken into consideration to make this comparative examination. In addition to this issue, different techniques can also be taken into consideration with respect to the future research directions.

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