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Research Article

Golden Cut-Oriented Q-Rung Orthopair Fuzzy Decision-Making Approach to Evaluation of Renewable Energy Alternatives for Microgeneration System Investments

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This study aims to find an appropriate system for microgeneration energy investments and identify optimal renewable energy alternatives for the effectiveness of these projects. In this context, a model is constructed by multi stepwise weight assessment ratio analysis (M-SWARA) and technique for order preference by similarity to ideal solution (TOPSIS) with q-rung orthopair fuzzy sets (q-ROFSs) and golden cut. At the first stage, five different systems are weighted for the effectiveness of the microgeneration energy investments. Secondly, four different renewable energy alternatives are ranked regarding the performance of these projects. In addition, a comparative analysis is also implemented with intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs). The findings are the same in all different fuzzy sets that demonstrates the reliability of the findings. It is determined that grid-connected with battery backup is the most important system choice. On the other hand, solar energy is the most appropriate alternative for microgeneration system investments. Grid-connected system should be implemented for the performance of the microgeneration projects. Hence, providing a sustainable access to the electricity can be possible. Sufficient amount of electricity may not be obtained from wind and solar energy because of the climate changes. In this process, grid-connected system can handle this problem effectively.

1. Introduction

Microgeneration refers to the small-scale production of energy or heat from renewable sources to a home and business. This system has significant advantages, such as contribution to the clean energy usage. With the help of this issue, carbon emission problems can be reduced in an important manner [1]. Furthermore, by considering microgeneration system, network costs can be decreased. This situation has a positive influence on the profitability of the energy investments. Moreover, consumers can save money by reducing the amounts of the electricity bills [2]. In spite of these advantages, some drawbacks of the microgeneration make people or businesses doubtful regarding microgeneration system investments. For example, high initial cost is an essential barrier for these projects. Moreover, unpredicted energy supply of renewable energy alternatives increases uncertainty about these investments [3]. Additionally, many locations are very limited for different types of microgeneration. For instance, wind turbines are not appropriate for the locations in which there is no powerful wind.

Therefore, microgeneration systems should be designed appropriately to increase the effectiveness of this process. Within this framework, a comprehensive evaluation should be made for the system choices for microgeneration energy investments. These projects can be either "grid-connected" or "off-grid" [4]. Being grid-connected has some advantages, such as having sustainable access to the electricity every time [5]. In other words, regardless of the weather conditions, electricity can always be provided for the parties. However, high cost is a significant disadvantage of this system [6]. On the other side, "off-grid" microgenerators use batteries instead of connecting to a grid [7]. These battery systems can be expensive and require regular maintenance that is accepted as an important drawback of the off-grid systems [8]. Because of this situation, various factors should be taken into consideration to design microgeneration systems efficiently and effectively.

In addition, appropriate renewable energy alternatives should also be selected for the effectiveness of microgeneration system investments. For instance, micro-wind generation is an important alternative of this system. While comparing with traditional wind turbines, it is quite smaller so that it becomes convenient for residential energy production [9]. Moreover, solar energy is also another important alternative for this situation. Within this framework, solar panels can be installed on the roofs [10]. Furthermore, the biomass sources can also be incorporated into microgeneration system. Additionally, micro hydropower can also be considered with respect to the microgeneration alternatives [11]. Nonetheless, each alternative has advantages and disadvantages. For example, to build a small hydropower system for electricity generation, there should be flowing water near the property. Similarly, one of the most fundamental problems of off-grid solar and wind systems is the need for power when the sun is not out, or the wind is not blowing. Hence, while constructing microgeneration system, these alternatives should be evaluated in a detailed manner.

In this study, it is aimed to find appropriate system for microgeneration energy investments and identify optimal renewable energy alternatives for the effectiveness of these projects. In this scope, a unique model is proposed with M-SWARA and TOPSIS by considering q-ROFSs and golden cut. In the first part of this model, five different systems are weighted for the effectiveness of the microgeneration energy investments. Secondly, four different renewable energy alternatives are ranked with respect to the performance of these projects. Moreover, the calculations are also made with IFSs and PFSs. Thus, the main novelty of this study is to make comprehensive examination to increase the performance of microgeneration system with a novel methodology.

The proposed model has also some superiorities by comparing previous ones in the literature. Considering hybrid methodology by using both SWARA and TOPSIS provides some advantages. With the help of this situation, any pre-acceptance regarding criterion weights has not been taken into account so that it positively affects the objectivity of the analysis. Additionally, in this study, SWARA is extended with the name of M-SWARA for the purpose of making more appropriate analysis. Therefore, this proposed model can handle uncertainty in a better way while comparing with other models [12, 13]. Another important benefit of this model is computing degrees with golden cut. This situation has also a positive influence on reaching more precise results and providing methodological originality. These two new implementations increase the originality of the proposed model. In addition, analyses are performed by using q-ROFSs, IFSs and PFSs so that the coherency of the results can be checked. This situation increases the benefits of this model over other models in the literature that considered only one type of fuzzy set [14–16].

The second part is related to the literature examination. Methodology is detailed in the third part. The fourth part includes analysis results. The final parts focus on discussions and conclusions.

2. Literature Review

The literature related to the microgeneration focuses on different topics. Some scholars evaluated the differences between grid-connected or off-grid systems. Having a sustainable access to the electricity is accepted as a significant benefit of the grid-connected system [17]. Even if a sufficient amount of electricity is not obtained from wind and solar energy, energy can always be obtained thanks to this system [18]. Nevertheless, the main drawback of this system is high cost [19, 20]. On the other hand, batteries are used instead of connecting to a grid regarding off-grid microgenerators. In this process, batteries can be expensive, and a regular maintenance can be required. This situation increases the costs of these projects. Khelil et al. [21] focused on the effectiveness of the grid-connected photovoltaic systems. They proposed a new model to minimize the faults in this system so that the effectiveness of the grid-connected microgeneration system can be increased. Akhter et al. [22] assessed the performance of three different grid-connected photovoltaic systems. They claimed that these systems have positive contribution to obtain clean energy. Moreover, Ortega-Arriaga et al. [23] evaluated the economic and environmental impacts of grid and off-grid electricity access options. They pointed out the cost problem of the batteries and regular maintenance of the off-grid systems. Zebra et al. [24] also examined off-grid electrification in developing countries. They reached a conclusion that government support and local community organization play a critical role for the success of this system.

In some studies, micro-wind generation systems were evaluated by considering different issues. In this process, small-scale wind turbines are generated to benefit from the flow of the wind in energy production. Because of its small size, it becomes convenient for residential energy production [25]. While constructing this system, some key issues should be taken into consideration. As an example, rotational wind speeds of the wind turbines should be evaluated for the effectiveness of this system [26]. For this situation, a comprehensive evaluation should be conducted. Micro-wind generation systems have also some disadvantages. The strength of the wind can change during the day [27, 28]. As a result, there may be instability in the amount of energy obtained with this system. This situation both leads to uncertainty and creates extra costs. Tailor et al. [29] focused on the ways to improve microgeneration systems. They underlined that rotational wind speeds should be examined comprehensively for the performance improvement of small-scale wind turbines. Rezaeiha et al. [30] made an evaluation with respect to the roof-mounted wind turbines. They claimed that uncertainties regarding the cost issues should be solved for the effectiveness of these systems.

Gruber et al. [31] also reached a conclusion that wind capacity should be taken into consideration appropriately for the performance of the micro-wind turbines.

Researchers also identified solar energy as another important alternative for microgeneration energy investments. In this context, solar panels are installed on the roofs to generate electricity. The rays from the sun generate electricity through the panels [32]. Thanks to this electric inverter, it meets the electrical needs of the building. Micro solar panels can be designed as on-grid and off-grid. In on-grid systems, excess energy is given to the grid [33, 34]. Similarly, if the energy produced by the micro solar panels does not meet the need, the missing part is supplied from the grid [35]. On the other hand, in off-grid systems, excess electricity is stored in batteries. In the opposite case, the electricity needed is supplied from the battery. Alipour et al. [36] evaluated the key factor of residential solar PV adoption in California. They reached a conclusion that educated households tended to purchase solar panel more in comparison with others. Schulte et al. [37] aimed to examine the acceptance of the people with respect to the micro solar panels. They claimed that technical factors play a crucial role in this situation. Best and Trück [38] evaluated policy impacts on Australian small-scale solar installations. It is concluded that there is a negative relationship among average income and these projects.

In addition, micro hydropower can also be considered with respect to the microgeneration alternatives by many different studies. Within this framework, flowing water is converted into electricity. Micro hydropower system has also some drawbacks [39, 40]. For example, hydropower resources tend to be more seasonal in nature. This situation increases uncertainty in energy generation. In other words, seasonal effects lead to unstable amount of electricity production [41, 42]. Additionally, to build a small hydropower system for electricity generation, there should be flowing water near the property. Hence, it is not possible to build micro hydropower in all locations [43, 44]. Nag and Sarkar [45] made an evaluation of micro-hydropower plants. They claimed that technological development plays a key role for the success of these projects. Clements et al. [46] tried to examine micro-hydropower mini grids in Nepali. They determined that insufficient land for micro hydropower poses an important obstacle to the development of this system. Butchers et al. [47] aimed to identify key issues for the sustainability of the micro-hydropower. They also reached a conclusion that costs of these projects should be decreased with the help of technological development to achieve sustainable energy production by micro-hydropower mini grids.

Literature review shows that microgeneration system investments were examined in various studies. They mainly focused on the advantages and disadvantages of grid-connected and off-grid systems. Furthermore, different renewable energy alternatives for microgeneration were also taken into consideration. Comparing different microgeneration systems and renewable energy alternatives can make a contribution to the literature. In this study, it is aimed to find appropriate system for microgeneration energy investments and identify optimal renewable energy alternatives for the effectiveness of these projects. In this scope, a unique model is proposed by M-SWARA and TOPSIS with q-ROFSs and golden cut.

3. Methodology

In this part, q-ROFSs with golden cut, M-SWARA and TOPSIS techniques are identified.

3.1. q-ROFSs with Golden Cut. IFSs considers membership and non-membership degrees ($\mu_I(\vartheta)$ and $n_I(\vartheta)$) to have better solutions as in equation (1). The circumstance of $0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1$ should be met [48].

$$I = \left\{ \frac{\vartheta, \mu_I(\vartheta), n_I(\vartheta)}{\vartheta \epsilon U} \right\}. \tag{1}$$

PFS also identify new grades ($\mu_P(\vartheta)$ and $n_P(\vartheta)$) for this purpose as in equation (2) [49].

$$P = \left\{ \frac{\vartheta, \mu_P(\vartheta), n_P(\vartheta)}{\vartheta \epsilon U} \right\}. \tag{2}$$

The condition is given in equation.

$$0 \leq \left(\mu_P(\vartheta)\right)^2 + \left(n_P(\vartheta)\right)^2 \leq 1. \tag{3}$$

q-ROFSs are generated with the extension of IFSs PFSs with the degrees ($\mu_Q(\vartheta)$ and $n_Q(\vartheta)$) as in equation (4) [50].

$$Q = \left\{ \frac{\vartheta, \mu_Q(\vartheta), n_Q(\vartheta)}{\vartheta \epsilon U} \right\}. \tag{4}$$

Equation (5) includes the condition of these sets.

$$0 \leq \left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q \leq 1, \quad q \geq 1. \tag{5}$$

Indeterminacy degree is detailed in equation

$$\pi_Q(\vartheta) = \left(\left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q - \left(\mu_Q(\vartheta)\right)^q \left(n_Q(\vartheta)\right)^q \right)^{1/q}. \tag{6}$$

Equations (7)–(11) represent computational details.

$$\begin{aligned} Q_1 &= \left\{ \frac{\vartheta, Q_1\left(\mu_{Q_1}(\vartheta), n_{Q_1}(\vartheta)\right)}{\vartheta \epsilon U} \right\}, \\ Q_2 &= \left\{ \frac{\vartheta, Q_2\left(\mu_{Q_2}(\vartheta), n_{Q_2}(\vartheta)\right)}{\vartheta \epsilon U} \right\}, \end{aligned} \tag{7}$$

$$Q_1 \oplus Q_2 = \left(\left(\mu_{Q_1}^q + \mu_{Q_2}^q - \mu_{Q_1}^q \mu_{Q_2}^q \right)^{1/q}, n_{Q_1} n_{Q_2} \right), \tag{8}$$

$$Q_1 \otimes Q_2 = \left(\mu_{Q_1} \mu_{Q_2}, \left(n_{Q_1}^q + n_{Q_2}^q - n_{Q_1}^q n_{Q_2}^q \right)^{1/q} \right), \tag{9}$$

$$\lambda Q = \left(\left(1 - \left(1 - \mu_Q^q \right)^{\lambda} \right)^{1/q}, \left(n_Q \right)^{\lambda} \right), \quad \lambda > 0, \tag{10}$$

$$Q^{\lambda} = \left(\left(\mu_Q\right)^{\lambda}, \left(1 - \left(1 - n_Q^q\right)^{\lambda}\right)^{1/q} \right), \quad \lambda > 0, \tag{11}$$

where λ is positive real numbers.

Equation (12) gives information about defuzzification calculation.

$$S(\vartheta) = \left(\mu_Q(\vartheta)\right)^q - \left(n_Q(\vartheta)\right)^q. \tag{12}$$

However, one of the most prominent issues in the fuzzy decision-making models is to determine the membership and non-membership degrees properly. The fuzzy preferences are generally defined by only considering the essential limitations of the selected fuzzy methodology such as the sum of membership and non-membership degrees. Indeed, the optimal rate and sum of membership and non-membership degrees for the fuzzy sets could be explained by using the assumptions of golden ratio more accurately. In this process, the degrees are calculated with golden ration to reach accurate solutions. Golden cut includes specific patterns of geometry problems. This ration is also associated with Fibonacci numbers [51, 52]. Equation (13) details this ratio whereas a and b define the large and small quantities.

$$\varphi = \frac{a}{b} \text{ where } a > b > 0, \tag{13}$$

where, $a > b > 0$ and φ is golden cut, a defines the large quantity and b is the small quantity of the straight line.

Equation (14) explains the algebraic form.

$$\varphi = \frac{1 + \sqrt{5}}{2} = 1.618\ldots. \tag{14}$$

The degrees generated by golden cut are shown in equation.

$$\varphi = \frac{\mu_G}{n_G}. \tag{15}$$

Equations (15) and (16) explains the revitalization of golden cut with q-ROFSs with new degrees (μ_{Q_G} and n_{Q_G}.)

$$Q_G = \left\{ \frac{\vartheta, \mu_{Q_G}(\vartheta), n_{Q_G}(\vartheta)}{\vartheta \epsilon U} \right\}, \tag{16}$$

$$0 \le \left(\mu_{Q_G}(\vartheta)\right)^q + \left(n_{Q_G}(\vartheta)\right)^q \le 1, \quad q \ge 1. \tag{17}$$

3.2. M-SWARA with q-ROFSs. SWARA weights the items by considering hierarchical priorities of the experts [53]. In the analysis process, SWARA is extended with the name of multi-SWARA (M-SWARA) for the purpose of making more appropriate analysis. Relation matrix is constructed by the evaluations as in equation.

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix}. \tag{18}$$

Next, q-ROFSs and score functions are generated with equations (5) and (12). Then, the values of s_j (comparative importance rate), k_j (coefficient), q_j (recalculated weight), and w_j (weight) are identified with equations (19)–(21).

$$k_j = \begin{cases} 1, & j = 1, \\ s_j + 1, & j > 1, \end{cases} \tag{19}$$

$$q_j = \begin{cases} 1, & j = 1, \\ \dfrac{q_{j-1}}{k_j}, & j > 1, \end{cases} \tag{20}$$

$$\begin{gathered} \text{If } s_{j-1} = s_j, q_{j-1} = q_j; \text{If } s_j = 0, k_{j-1} = k_j, \\ w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}. \end{gathered} \tag{21}$$

Later, the values in the matrix are transposed and limited to the power of 2t+1. Finally, by threshold values, impact-relation degrees are defined.

3.3. TOPSIS with q-ROFSs. TOPSIS is considered by ranking different alternatives. In this process, evaluations of the experts are taken and decision matrix is generated in equation (22) [54].

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix}. \tag{22}$$

Later, q-ROFSs and score functions are constructed with equations (5) and (12). Also, equation (23) is used for normalization.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{23}$$

Weighted values are computed by equation.

$$v_{ij} = w_{ij} \times r_{ij}. \tag{24}$$

Equations (25) and (26) demonstrate positive (A^+) and negative (A^-) ideal solutions.

$$A^+ = \left\{ v_{1j}, v_{2j}, \ldots, v_{mj} \right\} = \left\{ \max v_{1j} \text{for} \forall j \in n \right\}, \tag{25}$$

$$A^- = \left\{ v_{1j}, v_{2j}, \ldots, v_{mj} \right\} = \left\{ \min v_{1j} \text{ for } \forall\, j \in n \right\}. \tag{26}$$

Equations (27) and (28) indicate the distances to the best (D_i^+) and worst alternatives (D_i^-).

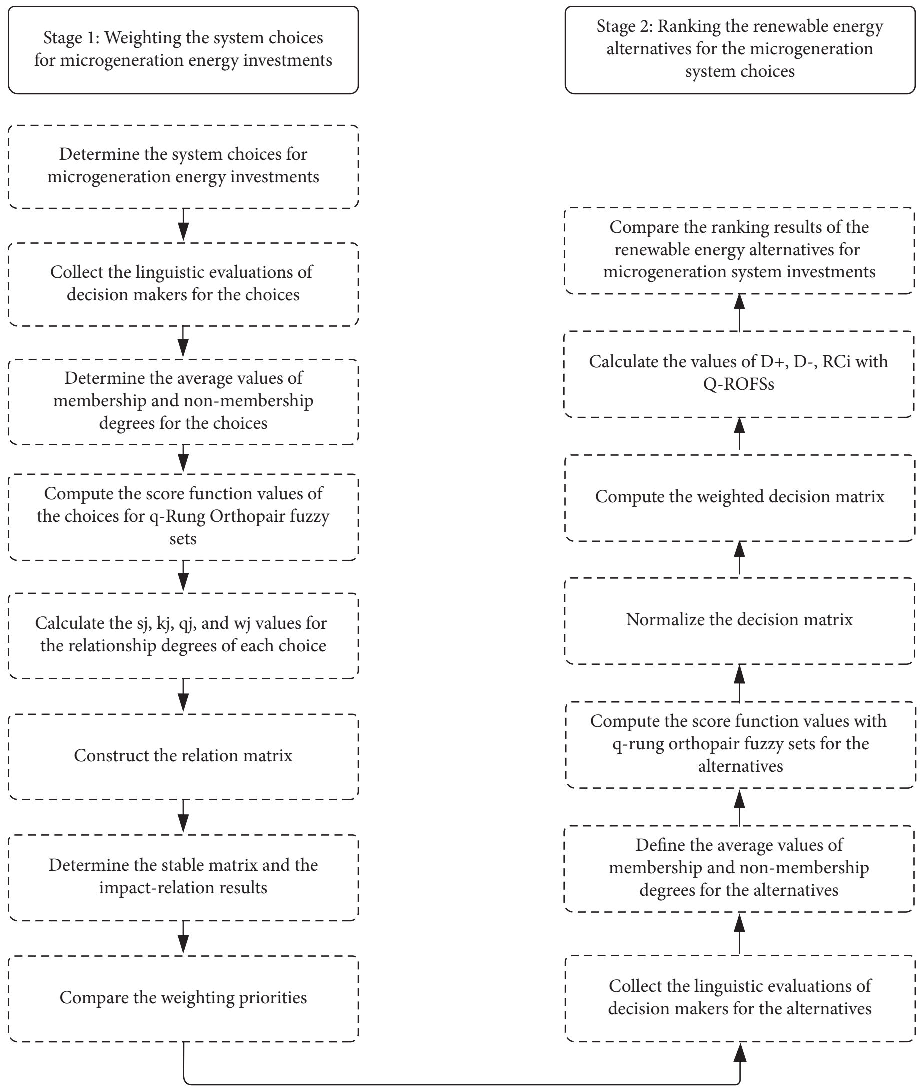

Figure 1: Proposed model.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^+\right)^2}, \quad (27)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^-\right)^2}. \quad (28)$$

Relative closeness (RC_i) is defined with equation.

$$\mathrm{RC}_i = \frac{D_i^-}{D_i^+ + D_i^-}. \quad (29)$$

4. Analysis Results

In this study, renewable energy alternatives are evaluated for effective microgeneration system investments. Within this context, a unique model is constructed by M-SWARA and TOPSIS with q-ROFSs and golden cut. Figure 1 illustrates the details of the model.

Table 1 includes selected system choices for microgeneration energy investments.

Table 1 indicates that system choices are related to grid or off-grid and with battery or without battery. Evaluations are provided from three experts by considering the scales in Table 2. The expert team consists of three different decision makers. These people have minimum 19-year experience with respect to the microgeneration systems. Two of them work as top managers in the energy investment companies. On the other hand, the third decision maker is an academician regarding energy investments.

Evaluations are presented in Table 3.

Average values are computed as in Table 4.

Score function values are given in Table 5.

Table 6 demonstrates s_j, k_j, q_j, and w_j values.

Relation matrix is constructed as in Table 7.

Table 1: Selected system choices for microgeneration energy investments.

System choices	References
Off-grid including battery ($C1$)	Singh et al. [18]
Off-grid excluding battery ($C2$)	Weschenfelder et al. [19]
Grid-connected with battery backup ($C3$)	Mazzeo et al. [17]
Grid-connected without battery backup ($C4$)	Kazem et al. [4]
Grid-connected with net energy metering ($C5$)	Khezri and Mahmoudi [6]

Table 2: Scales and degrees.

Linguistic scales for choices	Linguistic scales for alternatives	Membership degrees	Non-membership degrees
No influence (n)	Weakest (w)	0.40	0.25
Somewhat influence (s)	Poor (p)	0.45	0.28
Medium influence (m)	Fair (f)	0.50	0.31
High influence (h)	Good (g)	0.55	0.34
Very high influence (vh)	Best (b)	0.60	0.37

Source: Abdullah and Najib [55].

Table 3: Evaluations.

			Decision maker 1		
	$C1$	$C2$	$C3$	$C4$	$C5$
$C1$		M	VH	H	M
$C2$	H		M	M	VH
$C3$	S	VH		N	S
$C4$	M	VH	VH		VH
$C5$	S	H	VH	H	
			Decision maker 2		
	$C1$	$C2$	$C3$	$C4$	$C5$
$C1$		H	VH	H	H
$C2$	H		M	M	VH
$C3$	VH	S		S	H
$C4$	M	VH	VH		H
$C5$	S	H	VH	H	
			Decision maker 3		
	$C1$	$C2$	$C3$	$C4$	$C5$
$C1$		H	VH	H	H
$C2$	H		M	H	VH
$C3$	VH	N		N	H
$C4$	M	VH	VH		H
$C5$	H	H	VH	H	

No influence (n); somewhat influence (s); medium influence (m); high influence (h); very high influence (vh); criterion (C).

Table 4: Average values.

	$C1$		$C2$		$C3$		$C4$		$C5$	
	μ	v	μ	v	μ	v	μ	v	μ	v
$C1$			0.53	0.34	0.60	0.37	0.55	0.34	0.53	0.33
$C2$	0.55	0.34		0.34	0.50	0.31	0.52	0.32	0.60	0.37
$C3$	0.55	0.34	0.48	0.31			0.42	0.26	0.52	0.32
$C4$	0.50	0.31	0.60	0.30	0.60	0.37			0.57	0.35
$C5$	0.48	0.30	0.55	0.34	0.60	0.37	0.55	0.34		

Criterion (C).

Stable matrix is created as in Table 8.

Figure 2 explains the results of causal relationship. In this framework, impact-relation degrees are defined based on the threshold values. Threshold value is calculated as the average value of the values of the relation matrix stated in Table 7. The values that are greater than this threshold value gives information about the influencing impact.

Figure 2 demonstrates that there is a mutual relationship between off-grid including battery ($C1$) and grid-connected with battery backup ($C3$). Additionally, off-grid excluding

Table 5: Score function values.

	*C*1	*C*2	*C*3	*C*4	*C*5
*C*1	0.000	0.116	0.165	0.127	0.116
*C*2	0.127	0.000	0.095	0.105	0.165
*C*3	0.127	0.086	0.000	0.055	0.105
*C*4	0.095	0.165	0.165	0.000	0.139
*C*5	0.086	0.127	0.165	0.127	0.000

Criterion (*C*).

Table 6: S_j, k_j, q_j, and w_j values.

*C*1	S_j	k_j	q_j	w_j	*C*2	S_j	k_j	q_j	w_j
*C*3	0.165	1.000	1.000	0.288	*C*5	0.165	1.000	1.000	0.292
*C*4	0.127	1.127	0.887	0.255	*C*1	0.127	1.127	0.887	0.259
*C*2	0.116	1.116	0.795	0.229	*C*4	0.105	1.105	0.803	0.235
*C*5	0.116	1.116	0.795	0.229	*C*3	0.095	1.095	0.733	0.214
*C*3	S_j	k_j	q_j	w_j	*C*4	S_j	k_j	q_j	w_j
*C*1	0.127	1.000	1.000	0.284	*C*2	0.165	1.000	1.000	0.303
*C*5	0.105	1.105	0.905	0.257	*C*3	0.165	1.165	0.858	0.260
*C*2	0.086	1.086	0.833	0.236	*C*5	0.139	1.139	0.754	0.228
*C*4	0.055	1.055	0.789	0.224	*C*1	0.095	1.095	0.688	0.208
*C*5	S_j	k_j	q_j	W_j					
*C*3	0.165	1.000	1.000	0.278					
*C*2	0.127	1.127	0.887	0.247					
*C*4	0.127	1.127	0.887	0.247					
*C*1	0.086	1.086	0.817	0.227					

Criterion (*C*); s_j: comparative importance rate; k_j: coefficient; q_j: recalculated weight; w_j: weight.

Table 7: Relation matrix.

	*C*1	*C*2	*C*3	*C*4	*C*5
*C*1		0.229	0.288	0.255	0.229
*C*2	0.259		0.214	0.235	0.292
*C*3	0.284	0.236		0.224	0.257
*C*4	0.208	0.303	0.260		0.228
*C*5	0.227	0.247	0.278	0.247	

Criterion (*C*).

Table 8: Stable matrix.

	*C*1	*C*2	*C*3	*C*4	*C*5
*C*1	0.197	0.197	0.197	0.197	0.197
*C*2	0.202	0.202	0.202	0.202	0.202
*C*3	0.206	0.206	0.206	0.206	0.206
*C*4	0.194	0.194	0.194	0.194	0.194
*C*5	0.201	0.201	0.201	0.201	0.201

Criterion (*C*).

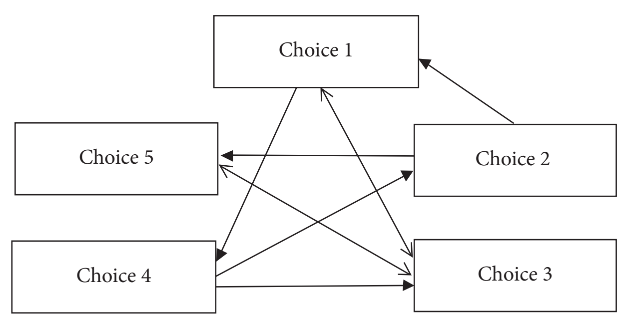

Figure 2: Impact-relation map.

Table 9: Comparative results.

	IFSs	PFSs	q-ROFSs
*C*1	4	4	4
*C*2	3	3	2
*C*3	1	1	1
*C*4	5	5	5
*C*5	2	2	3

Criterion (*C*).

battery (*C*2) has an influence on both grid-connected with net energy metering (*C*5) and off-grid including battery (*C*1). Table 9 includes comparative results.

Ranking results are the same in all different fuzzy sets that demonstrates the reliability of the findings. It is found that grid-connected with battery backup (*C*3) is the most important system choice. The second stage of the model is related to the ranking alternatives. In this scope, four different renewable energy alternatives are selected for the microgeneration system choices as in Table 10.

Table 10: Selected renewable energy alternatives.

Alternatives	References
Wind (alternative 1)	Tasneem et al. [9]
Biomass (alternative 2)	Inderberg et al. [10]
Hydro (alternative 3)	Asanov et al. [11]
Solar (alternative 4)	Bao et al. [35]

Table 11: Evaluations.

	C1	C2	C3	C4	C5
Decision maker 1					
	C1	C2	C3	C4	C5
A1	P	W	G	P	B
A2	G	B	G	W	P
A3	P	F	W	P	B
A4	G	B	P	B	P
Decision maker 2					
	C1	C2	C3	C4	C5
A1	F	G	G	P	B
A2	G	B	G	W	P
A3	F	F	W	P	F
A4	G	B	G	F	P
Decision maker 3					
	C1	C2	C3	C4	C5
A1	F	G	P	P	P
A2	W	B	G	W	P
A3	P	F	W	P	F
A4	P	B	G	P	W

Criterion (*C*); alternative (*A*); fair (F); poor (P); weak (W); good (G); best (B).

Table 12: Average values.

	C1		C2		C3		C4		C5	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
A1	0.48	0.30	0.50	0.31	0.52	0.32	0.45	0.28	0.55	0.34
A2	0.50	0.31	0.60	0.37	0.55	0.34	0.40	0.25	0.45	0.28
A3	0.47	0.29	0.50	0.31	0.40	0.25	0.45	0.28	0.53	0.33
A4	0.52	0.32	0.60	0.37	0.52	0.32	0.52	0.32	0.43	0.27

Criterion (*C*); alternative (*A*).

Table 13: Score function values.

System choices/renewable alternatives	C1	C2	C3	C4	C5
A1	0.086	0.095	0.105	0.070	0.127
A2	0.095	0.165	0.127	0.049	0.070
A3	0.078	0.095	0.049	0.070	0.116
A4	0.105	0.165	0.105	0.105	0.062

Criterion (*C*); alternative (*A*).

Table 14: Normalized matrix.

System choices/renewable alternatives	C1	C2	C3	C4	C5
A1	0.470	0.354	0.522	0.457	0.649
A2	0.520	0.612	0.630	0.321	0.356
A3	0.423	0.354	0.242	0.457	0.592
A4	0.574	0.612	0.522	0.692	0.318

Criterion (*C*); alternative (*A*).

Table 11 indicates evaluations for the alternatives.

Average values are defined as in Table 12.

Score values are computed and shown in Table 13.

This matrix is normalized as in Table 14.

Table 15 includes weighted matrix.

The values of D+, D−, RCi are shown in Table 16.

Table 15: Weighted matrix.

System choices/renewable alternatives	C1	C2	C3	C4	C5
A1	0.093	0.072	0.108	0.088	0.131
A2	0.102	0.124	0.130	0.062	0.072
A3	0.083	0.072	0.050	0.088	0.119
A4	0.113	0.124	0.108	0.134	0.064

Criterion (*C*); alternative (*A*).

Table 16: D+, D− and, RCi values.

Alternatives	D+	D−	RCi
A1	0.075	0.093	0.551
A2	0.094	0.098	0.511
A3	0.110	0.061	0.357
A4	0.070	0.110	0.610

Alternative (*A*).

Comparative ranking results of the renewable energy alternatives for microgeneration system investments are presented in Table 17.

Table 17 demonstrates that solar energy is the most appropriate alternative (*A*4) for microgeneration system investments. Similarly, wind is another significant alternative for this purpose.

Table 17: Comparative ranking results.

Alternatives	q-ROF multi SWARA-TOPSIS	PF multi SWARA-TOPSIS	If multi SWARA-TOPSIS
$A1$	2	2	2
$A2$	3	3	3
$A3$	4	4	4
$A4$	1	1	1

Alternative (A).

5. Discussions

The findings demonstrate that the grid-connected system should be implemented for the performance of the microgeneration projects. Thus, providing a sustainable access to the electricity can be possible. This situation has a positive impact on the performance of this system. Sufficient amount of electricity may not be obtained from wind and solar energy because of the climate changes. In this process, grid-connected system can handle this problem effectively. Singh et al. [18]; Xie et al. [56] and Weschenfelder et al. [19] claimed that grid-connected system should be preferred for the microgeneration energy investments due to having uninterrupted energy. Additionally, Mazzeo et al. [17] also discussed that batteries create high costs, and they also need periodical maintenance. Because of this situation, they highlighted the significance of the grid-connected system. According to the results of this study, it is also seen that micro solar panels should be mainly preferred for microgeneration projects. By technological improvements, the cost of solar energy decreases importantly by comparing with other renewable energy types. Papurello et al. [32] and Zare et al. [33] underlined the importance of micro solar panels for the microgeneration systems. However, there are also opposite views in the literature regarding this issue. For instance, Meng et al. [57]; Shang et al. [58] and Pellegrini et al. [25] focused on micro wind generation system and Tapia et al. [39] considered micro hydropower with respect to the microgeneration alternatives.

6. Conclusions

In this study, it is aimed to define optimal microgeneration energy system investments and determine appropriate renewable energy alternatives for the performance improvements of these projects. A model is made by M-SWARA and TOPSIS with q-ROFSs and golden cut. Firstly, five different systems are weighted for the effectiveness of the microgeneration energy investments. In the second part, four different renewable energy alternatives are ranked regarding the performance of these projects. Furthermore, a comparative analysis is also implemented with IFSs and PFSs. Weighting results are the same in all different fuzzy sets that demonstrates the reliability of the findings. It is defined that grid-connected with battery backup is the most important system choice. On the other hand, solar energy is the most appropriate alternative for microgeneration system investments. In addition, wind is another significant alternative in this regard.

The main novelty of this study is to make comprehensive examination to increase the performance of microgeneration system with a novel methodology. On the other hand, the main limitation of this study is to just provide recommendations for the effectiveness of the microgeneration systems. In other words, an implementation has not been made in the industry about the effectiveness of these issues. Hence, for the future research direction, a case study can be conducted to evaluate the effectiveness this system. In the next studies, different fuzzy sets can also be preferred such as, Gaussian fuzzy sets. This situation provides to make comparative evaluations so that more specific results can be conducted.

Abbreviations

$\mu_I(\vartheta)$: Membership degrees of IFS
$n_I(\vartheta)$: Non-membership degrees of IFS
$\mu_p(\vartheta)$: Membership degrees of PFS
$n_P(\vartheta)$: Non-membership degrees of PFS
$\mu_Q(\vartheta)$: Membership degrees of q-ROFS
$n_Q(\vartheta)$: Non-membership degrees of q-ROFS
$S(\vartheta)$: Score function
φ: Golden cut
a: Large quantity
b: Small quantity
$\mu_G(\vartheta)$: Membership degrees of q-ROFS based on golden cut
$n_G(\vartheta)$: Non-membership degrees of q-ROFS based on golden cut
Q_k: Relation matrix
s_j: Comparative importance rate
k_j: Coefficient
q_j: Recalculated weight
w_j: Weight
X_k: Decision matrix
A^+: Positive ideal solution
A^-: Negative ideal solution
RC_i: Relative closeness.

Data Availability

All information and data are given in the text completely.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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