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Application of M-SWARA and TOPSIS Methods in the Evaluation of Investment Alternatives of Microgeneration Energy Technologies

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Abstract: Investments in microgeneration technologies help to boost the usage of clean energy while reducing pollution. However, selecting the appropriate investment remains the most critical phase in developing these technologies. This study aims to design a multi-criteria decision-making method (MCDM) to evaluate investment alternatives for microgeneration energy technologies. The proposed MCDM is based on a Multi Stepwise Weight Assessment Ratio Analysis (M-SWARA), to define the relative importance of the factors. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and q-Rung Orthopair Fuzzy Soft Sets (q-ROFSs) are used to rank investment alternatives. Calculations were also made with Intuitionistic Fuzzy Sets (IFSs) and Pythagorean Fuzzy Sets (PFSs). For analysis, five evaluation criteria were selected based on the literature: frequency of maintenance, ease of installation, environmental adaptation, transmission technologies, and efficiency of cost. Similarly, six alternatives for microgeneration technology investments were selected: ground source heat pumps, micro hydroelectric power, micro combined heat and power, micro bioelectrochemical fuel cell systems, small-scale wind turbines, and photovoltaic systems. The results showed that cost efficiency was the most significant factor in the effectiveness of microgeneration energy investments, and the photovoltaic system was the best alternative to increase microgeneration energy technology investment performance. Furthermore, the results were the same for the analyses made with IFSs and PFSs, demonstrating the reliability of the proposed method. Therefore, investors in microgeneration technologies should prioritize photovoltaic systems. This conclusion is supported by the fact that photovoltaic is a renewable energy source that has witnessed the most technological improvements and cost reductions over the last decade.

Keywords: microgeneration technologies; energy investments; renewable energy sources; multi-criteria decision-making method (MCDM); multi stepwise weight assessment ratio analysis (M-SWARA); technique for order preference by similarity to ideal solution (TOPSIS)

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1. Introduction

1.1. Background Information

Microgeneration is a form of energy generation that aims to meet the energy needs of individuals and small-scale companies. If these segments are too far from the grid, energy costs increase significantly. In microgeneration systems, there is proximity to the end consumer. This situation, which increases energy efficiency, is considered the most important advantage of microgeneration systems. In addition, microgeneration systems cover both heat and electrical energy production [1]. This issue also contributes to a more efficient energy production process. Moreover, microgeneration energy systems also help to increase the use of clean energy [2,3]. This issue allows a reduction in the carbon emission problem that threatens the environment significantly. Therefore, for microgeneration energy technology investments to be sustainable, their performance should be increased.

In this context, it is important to determine the main factors affecting the performance of these investments with a detailed analysis. Ease of installation is a significant factor for performance measurement. Efficiency in the process is decreased and extra costs are created when installation is not easy. Environmental compliance is another factor because each energy alternative may not be suitable for all geographies. The frequency of maintenance also plays a key role in the performance measurement of microgeneration energy investments since it creates extra costs for the investors [3]. Cost effectiveness is also an important variable in the performance of these investments. In this context, owing to technological developments, costs of these projects can be managed more effectively.

The renewable energy alternatives preferred in microgeneration systems are also important in the performance analysis of these investments. Small-scale wind turbines can be preferred in this regard. Because they are smaller than typical wind turbines, they can be used on the roofs of buildings. This alternative is appropriate for regions that can obtain high amounts of wind. Similarly, in photovoltaic systems, small-scale solar panels can be built on roofs. However, energy generation from both small-scale wind turbines and solar panels is affected by climate conditions [4]. Micro hydroelectric power is another alternative for this situation; however, there should be flowing water near the building. In summary, all renewable energy alternatives have both benefits and drawbacks. Thus, for the high performance of microgeneration projects, it is necessary to choose the most accurate renewable energy alternative with a comprehensive analysis.

1.2. Literature Evaluation

Researchers regard the subject of performance measurement factors in microgeneration technology investment performance as important. In this framework, cost efficiency is stated as an important indicator. For the sustainability of these projects, profitability conditions should be provided [4]. Otherwise, despite the positive impacts on the environment, the investors will prefer not to focus on these projects [5]. For this purpose, technological developments can contribute to cost reduction so that investors follow the recent trends in microgeneration energy technologies [6]. Pearce and Slade [7] focused on the effectiveness of microgeneration energy technology investments. They discussed that cost effectiveness is a key issue to increase the performance of these projects. For this situation, they identified that tax advantages should be provided for the investors to overcome this problem. Gabderakhmanova and Popel [8] evaluated photovoltaic microgeneration systems in the Russian federation. They made a detailed competitive analysis and concluded that cost-efficiency should be provided to increase these projects. Saleme et al. [9] examined the Brazilian energy market. They claimed that for the improvement of photovoltaic microgeneration, costs should be minimized.

The installation of microgeneration energy systems should be very easy. Microgeneration energy projects can be established with different types of energy. However, not every type of energy is easy to install. Small-scale solar panels and wind turbines can be built on the roofs of buildings. This ease of installation means microgeneration technology investment systems can be improved [10]. However, for the establishment of micro hydropower, there should be flowing water near the property. Additionally, micro hydropower systems need a turbine and a pump [11]. These difficulties create some barriers for the development of these systems. Karytsas [12] examined the motivational factors behind microgeneration systems in Greece. They identified that energy systems should be easy to install. Bao et al. [13] focused on the key factors in micro solar systems. They claimed that a difficult installation process leads to some barriers regarding the improvement of these systems.

The frequency of maintenance is another significant issue that affects the performance of microgeneration investments. With respect to the sustainability of these projects, they should be profitable [14]. In this context, the costs of these investments should be minimized. However, frequent maintenance leads to increased costs [15]. Therefore, because of this problem, investors will panic, and this will hinder the development of microgeneration projects. Hence, to increase the performance of microgeneration energy technology projects, an energy alternative with a low-maintenance frequency can be selected. Virupaksha et al. [6] examined solar photovoltaic-based microgeneration systems in Ireland. They discussed that frequency of maintenance has a negative influence on the effectiveness of these systems. Su et al. [11] evaluated renewable microgeneration technologies in Lithuania. They reached the conclusion that maintenance costs should be taken into consideration in these systems.

Technological development also plays an essential role with respect to the performance improvement of microgeneration energy investments. Microgeneration systems consider renewable energy types that contain complex processes [16]. As a result of this issue, investors should have the necessary technological developments. Some recent developments in energy technologies can decrease costs [17]. This situation provides important advantages for the efficiency of these projects. Aquila et al. [18] analyzed small-scale solar microgeneration systems in Brazil. They claimed that investors should have sufficient technological improvements. Piterou and Coles [19] evaluated decentralized renewable energy projects. They identified that technological development is a crucial performance measurement indicator in microgeneration energy investments. Zhang et al. [20] assessed renewable microgeneration technologies and reached similar findings.

1.3. The Purpose and Novelty of This Study

Literature evaluations demonstrate that different issues have a significant influence on the performance of microgeneration technology investments. However, for the effectiveness of these projects, more important determinants should be identified. For this purpose, a new study is needed that makes a prioritization analysis regarding performance measurement indicators. Key performance indicators and appropriate renewable energy alternatives are evaluated in this manuscript which considers the effectiveness of microgeneration energy technology investments.

Key performance indicators and appropriate renewable energy alternatives are examined in microgeneration energy technology investments. In this scope, a model is generated that consists of two stages. Firstly, selected criteria are weighted using a SWARA. Additionally, technology investment alternatives are ranked using TOPSIS. In this process, q-ROFSs and the golden cut are taken to consideration. Additionally, comparative evaluations are performed with IFSs and PFSs to check the validity of the findings. Analysis results provide critical information for microgeneration technology investors. Hence, the efficiency of these projects can be increased so that carbon emission problems can be reduced with the help of clean energy consumption.

The proposed model has some advantages when compared with similar models in the literature. There are limited studies in which the degrees in the analysis process are calculated by considering the golden cut. Similarly, SWARA is extended, in this study, to M-SWARA to reach more precise findings. These issues contribute to the methodological originality of this study. Moreover, the SWARA method is used for weighting items to increase objectivity. Additionally, because q-ROFSs are the extension of both IFSs and PFSs, they become helpful to minimize uncertainty in this respect [21–23]. The TOPSIS method also has some benefits over similar techniques. For instance, in some models, only the positive ideal solution is considered [24,25]. However, the TOPSIS method also uses negative ideal solutions, contributing to more accurate results [26].

Section 2 includes a literature review. Section 3 explains the methodology. Section 4 includes analysis results. Section 5 gives information about discussions and conclusions.

2. Materials and Methods

Microgeneration energy systems contribute to the use of clean energy so that carbon emission problems can be minimized. Within this framework, a detailed evaluation should be carried out to understand key performance indicators of these systems. This situation helps to achieve sustainability of these investments. However, all renewable energy alternatives have both benefits and drawbacks. Thus, for the high performance of microgeneration projects, it is necessary to choose the most accurate renewable energy alternative with a comprehensive analysis. Therefore, there is a need for a new study which makes a prioritization analysis regarding performance measurement indicators. In this study, a hybrid fuzzy decision-making model is created to solve these problems. This part explains q-ROFs, M-SWARA, and TOPSIS, with the golden cut.

2.1. q-ROFs with the Golden Cut

Atanassov [27] generated IFSs by using both membership ($\mu_I(\vartheta)$) and non-membership ($n_I(\vartheta)$) degrees. In this context, it aims to provide precise solutions. These sets are demonstrated in Equation (1). The required condition of these sets is stated as $0 \le \mu_I(\vartheta) + n_I(\vartheta) \le 1$.

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

PFSs is created as a generalization of IFSs with new degrees (μ_P and n_P) [28]. Equation (2) represents these sets.

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

In this process, the condition in Equation (3) must be fulfilled.

$$0 \le (\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \le 1 \tag{3}$$

q-ROFSs are created by the extension of IFSs to manage uncertainty more appropriately by using new grades (μ_Q, n_Q). Equation (4) gives information about these sets [29].

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

Equation (5) includes the required condition.

$$0 \le (\mu_Q(\vartheta))^q + (n_Q(\vartheta))^q \le 1,\ q \ge 1 \tag{5}$$

Equation (6) includes indeterminacy degree.

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

Computational details are shown in Equations (7)–(10).

$$Q_1 = \left\{ \frac{\langle \vartheta, Q_1(\mu_{Q_1}(\vartheta), n_{Q_1}(\vartheta)) \rangle}{\vartheta \epsilon U} \right\} \text{ and } Q_2 = \left\{ \frac{\langle \vartheta, Q_2(\mu_{Q_2}(\vartheta), n_{Q_2}(\vartheta)) \rangle}{\vartheta \epsilon U} \right\}$$

$$Q_1 \oplus Q_2 = \left(\left(\mu_{Q_1}^q + \mu_{Q_2}^q - \mu_{Q_1}^q \mu_{Q_2}^q \right)^{\frac{1}{q}},\ n_{Q_1} n_{Q_2} \right) \tag{7}$$

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

$$\lambda Q = \left(\left(1 - \left(1 - \mu_Q^q \right)^{\lambda} \right)^{\frac{1}{q}},\ (n_Q)^{\lambda} \right), \lambda > 0 \tag{9}$$

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

Defuzzification is performed with Equation (11).

$$S(\vartheta) = \left(\mu_Q(\vartheta)\right)^q - \left(n_Q(\vartheta)\right)^q \tag{11}$$

In this study, the degrees are defined with the golden cut to make more effective examinations [30]. Equation (12) indicates the details where $a > b > 0$ and φ represents the golden cut. Additionally, a and b demonstrate large and small quantities.

$$\Phi = a/b \tag{12}$$

Equation (13) states the algebraic form:

$$\Phi = \left(1 + \sqrt{5}\right)/2 = 1.618 \tag{13}$$

The degrees obtained from the golden cut (μ_G and n_G) are given in Equation (14).

$$\Phi = \frac{\mu_G}{n_G} \tag{14}$$

Additionally, q-ROFSs are defined with the degrees obtained by the golden cut as in Equations (15) and (16).

$$Q_G = \left\{ \frac{\langle \vartheta, \mu_{Q_G}(\vartheta), n_{Q_G}(\vartheta) \rangle}{\vartheta \epsilon U} \right\} \tag{15}$$

$$0 \leq \left(\mu_{Q_G}(\vartheta)\right)^q + \left(n_{Q_G}(\vartheta)\right)^q \leq 1, q \geq 1 \tag{16}$$

2.2. M-SWARA with q-ROFSs

Keršuliene et al. [31] generated a SWARA for finding the weights of the items by considering hierarchical priorities of the experts. SWARA is extended in this study by the name of multi-SWARA (M-SWARA) to obtain better results. In this process, evaluations are taken from the experts so that a decision matrix is created as in Equation (17).

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{17}$$

Next, q-ROFSs and score functions are defined with Equations (5) and (11). Later, s_j, k_j, q_j, and w_j values are computed by Equations (18)–(20).

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{18}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{19}$$

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

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{20}$$

Comparative importance rate is shown as s_j whereas the coefficient value is stated as k_j. Additionally, recalculated weight is given as q_j while w_j indicates the criteria weights under the q-ROFNs. Additionally, stable values are identified by transposing and limiting the matrix to the power of 2t + 1.

2.3. TOPSIS with q-ROFSs

The TOPSIS ranks alternatives by importance. In this study, this technique is extended with q-ROFSs. After providing the evaluations, a decision matrix is constructed as in Equation (21) [26].

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

Next, Equation (22) is used to normalize this matrix.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{22}$$

Weighted values are computed as in Equation (23).

$$v_{ij} = w_{ij} \times r_{ij} \tag{23}$$

Equations (24) and (25) include the computation of the positive (A^+) and negative (A^-) solutions.

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j} \text{ for } \forall j \in n\} \tag{24}$$

$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min v_{1j} \text{ for } \forall j \in n\} \tag{25}$$

Distances to the best (D_i^+) and worst (D_i^-) alternatives are identified by Equations (26) and (27).

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^+\right)^2} \tag{26}$$

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

Relative closeness (RC_i) is defined with Equation (28).

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{28}$$

3. Analysis

In this study, a model is constructed to understand critical performance measurement factors in microgeneration energy technology investments. The relative importance of the factors is defined with an M-SWARA, and investment alternatives are evaluated using the TOPSIS method, while considering q-ROFSs and the golden cut. All details of this model are presented in Figure 1.

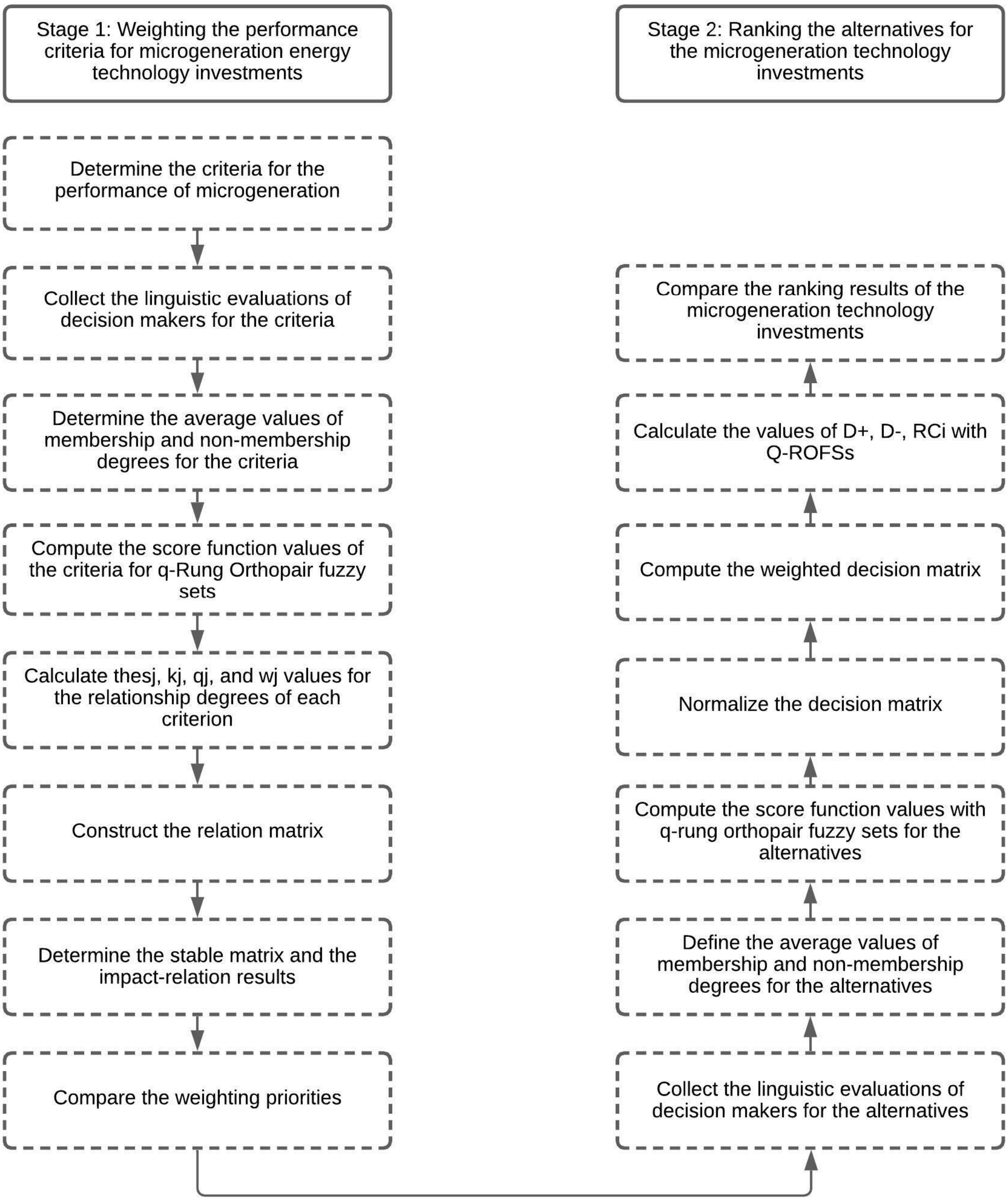

Figure 1. Algorithm of proposed decision-making model.

3.1. Finding Relative Importance of the Factors

Based on the evaluation of the literature, a criteria list was created as in Table 1 regarding the performance measurement of microgeneration.

Table 1. Criteria List.

Criteria	References
Frequency of maintenance (Criterion 1)	[32]
Ease of installation (Criterion 2)	[33]
Environmental adaptation (Criterion 3)	[34]
Transmission technologies (Criterion 4)	[35]
Efficiency of cost (Criterion 5)	[36]

Cost effectiveness is an important variable in the performance of microgeneration energy technology investments. Technological developments are expected to reduce costs. If the technological investments to be made do not contribute positively to the reduction in costs, the efficiency of microgeneration energy investments will decrease. In this process, the ease of installation of projects is another important factor for performance measurement. Alternatives that are not easy to install will both reduce the efficiency in the process and create extra costs. Environmental compliance is another factor that can be effective in this context. All energy alternatives may not be suitable for all geographies. Therefore, it would be appropriate to choose the energy alternative that is suitable for the climatic conditions of the region where microgeneration projects will be established. Microgeneration energy investments are projects with comprehensive processes. In this context, the subject of transmission technologies is very important. On the other hand, frequent maintenance leads to increased costs. Table 2 states the degrees and scales used in the analysis process.

Table 2. Scales and degrees.

Scales for Factors	Scales for Alternatives	Membership Degrees	Non-Membership Degrees
No (n)	Weakest (w)	0.40	0.25
Some (s)	Poor (p)	0.45	0.28
Medium (m)	Fair (f)	0.50	0.31
High (h)	Good (g)	0.55	0.34
Very High (vh)	Best (b)	0.60	0.37

In this process, an expert team is generated that consists of three people with significant experience in microgeneration technology investments. Their evaluations are shown in Table 3.

Table 3. Evaluations.

			Decision Maker 1		
	C1	**C2**	**C3**	**C4**	**C5**
C1		N	VH	VH	M
C2	VH		M	M	VH
C3	N	VH		N	M
C4	M	VH	VH		VH
C5	VH	M	VH	VH	
			Decision Maker 2		
	C1	**C2**	**C3**	**C4**	**C5**
C1		S	VH	VH	S
C2	M		M	S	VH
C3	N	VH		N	M
C4	S	VH	VH		VH
C5	H	M	VH	H	
			Decision Maker 3		
	C1	**C2**	**C3**	**C4**	**C5**
C1		S	N	VH	S
C2	M		M	S	VH
C3	S	S		N	M
C4	VH	VH	VH		VH
C5	H	M	VH	H	
			C: Criterion		

Average values are computed as in Table 4.

Table 4. Average values.

	C1		C2		C3		C4		C5	
	μ	v	μ	v	μ	v	μ	v	μ	v
C1			0.43	0.27	0.53	0.33	0.60	0.37	0.47	0.29
C2	0.53	0.33			0.50	0.31	0.47	0.29	0.60	0.37
C3	0.42	0.26	0.55	0.34			0.40	0.25	0.50	0.31
C4	0.52	0.32	0.60	0.37	0.60	0.37			0.60	0.37
C5	0.57	0.35	0.50	0.31	0.60	0.37	0.57	0.35		

C: Criterion

Table 5 includes score function values.

Table 5. Score function values.

	C1	C2	C3	C4	C5
C1	0.000	0.062	0.116	0.165	0.078
C2	0.116	0.000	0.095	0.078	0.165
C3	0.055	0.127	0.000	0.049	0.095
C4	0.105	0.165	0.165	0.000	0.165
C5	0.139	0.095	0.165	0.139	0.000

C: Criterion

The sj, kj, qj, and wj values are calculated in Table 6.

Table 6. Sj, kj, qj, and wj values.

C1	Sj	kj	qj	wj	C2	Sj	kj	qj	wj
C4	0.165	1.000	1.000	0.285	C5	0.165	1.000	1.000	0.288
C3	0.116	1.116	0.896	0.255	C1	0.116	1.116	0.896	0.258
C5	0.078	1.078	0.832	0.237	C3	0.095	1.095	0.818	0.236
C2	0.062	1.062	0.783	0.223	C4	0.078	1.078	0.759	0.219
C3	**Sj**	**kj**	**qj**	**wj**	**C4**	**Sj**	**kj**	**qj**	**wj**
C2	0.127	1.000	1.000	0.278	C2	0.165	1.000	1.000	0.256
C5	0.095	1.095	0.913	0.253	C3	0.165	1.165	1.000	0.256
C1	0.055	1.055	0.865	0.240	C5	0.165	1.165	1.000	0.256
C4	0.049	1.049	0.825	0.229	C1	0.105	1.105	0.905	0.232
C5	**Sj**	**kj**	**qj**	**wj**					
C3	0.165	1.000	1.000	0.281					
C1	0.139	1.139	0.878	0.247					
C4	0.139	1.139	0.878	0.247					
C2	0.095	1.095	0.801	0.225					

C: Criterion

Table 7 includes the relation matrix.

Table 7. Relation matrix.

	C1	C2	C3	C4	C5
C1		0.223	0.255	0.285	0.237
C2	0.258		0.236	0.219	0.288
C3	0.240	0.278		0.229	0.253
C4	0.232	0.256	0.256		0.256
C5	0.247	0.225	0.281	0.247	

C: Criterion

Table 8 gives information about the stable matrix.

Table 8. Stable matrix.

	C1	C2	C3	C4	C5
C1	0.195	0.195	0.195	0.195	0.195
C2	0.197	0.197	0.197	0.197	0.197
C3	0.204	0.204	0.204	0.204	0.204
C4	0.196	0.196	0.196	0.196	0.196
C5	0.205	0.205	0.205	0.205	0.205

C: Criterion

Figure 2 represents the impact-relation map.

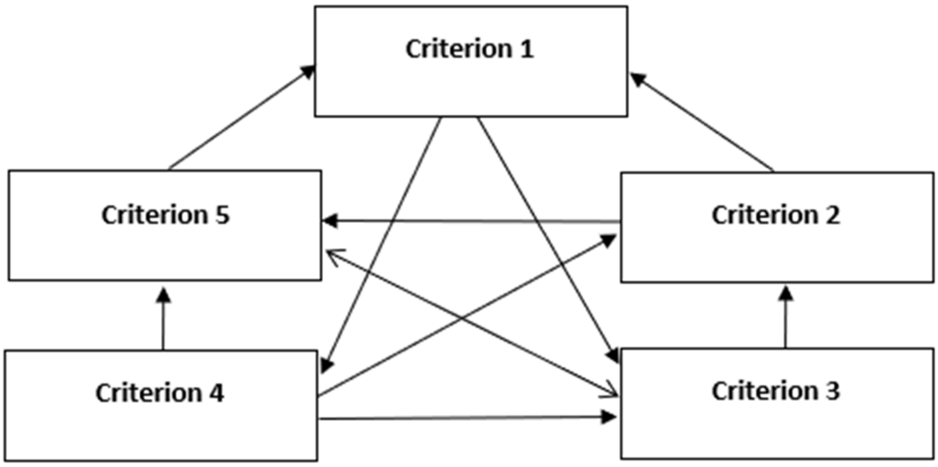

Figure 2. Impact-relation map.

It is identified that environmental adaptation (criterion 3) and efficiency of cost (criterion 5) are the most influenced items. Additionally, the most influential criterion is transmission technologies (criterion 4). Weighting priorities are shown in Table 9.

Table 9. Weights.

	IFSs	PFSs	q-ROFSs
C1	5	5	5
C2	3	3	3
C3	2	2	2
C4	4	4	4
C5	1	1	1

C: Criterion

The results are the same for the analyses made by IFSs, PFSs, and q-ROFSs. Efficiency of cost (criterion 5) is the most significant factor for the effectiveness of microgeneration energy technology investments. Environmental adaptation (criterion 3) has the second highest weight. Frequency of maintenance (criterion 1) is the least important item.

3.2. Ranking the Alternatives for Microgeneration Technology Investments

Based on the literature examination, six different microgeneration technology investment alternatives are selected as in Table 10.

Table 10. Selected alternatives of microgeneration technology investments.

Alternatives	References
Ground source heat pumps (Alternative 1)	[37]
Micro hydroelectric power (Alternative 2)	[38]
Micro combined heat and power (Alternative 3)	[39]
Micro bioelectrochemical fuel cell systems (Alternative 4)	[40]
Small-scale wind turbines (Alternative 5)	[41]
Photovoltaic systems (Alternative 6)	[42]

An expert team also evaluated these alternatives as in Table 11.

Table 11. Evaluations for the alternatives.

	Decision Maker 1				
	C1	**C2**	**C3**	**C4**	**C5**
A1	F	B	W	P	G
A2	W	P	F	W	P
A3	P	F	W	P	B
A4	W	P	P	W	P
A5	P	F	F	B	F
A6	B	F	F	B	B
	Decision Maker 2				
	C1	**C2**	**C3**	**C4**	**C5**
A1	P	G	W	P	G
A2	W	P	F	W	P
A3	P	P	G	P	B
A4	W	P	P	P	G
A5	P	F	F	B	F
A6	B	F	F	B	B
	Decision Maker 3				
	C1	**C2**	**C3**	**C4**	**C5**
A1	P	B	F	P	G
A2	B	F	F	W	P
A3	P	P	B	F	B
A4	B	F	B	F	G
A5	P	F	F	B	F
A6	B	F	F	B	B
A: Alternative					

Average values are given in Table 12.

Table 12. Average values for the alternatives.

	C1		**C2**		**C3**		**C4**		**C5**	
	μ	**v**	**μ**	**v**	**μ**	**v**	**μ**	**v**	**μ**	**v**
A1	0.47	0.29	0.58	0.36	0.43	0.27	0.45	0.28	0.55	0.34
A2	0.47	0.29	0.47	0.29	0.50	0.31	0.40	0.25	0.45	0.28
A3	0.45	0.28	0.47	0.29	0.52	0.32	0.47	0.29	0.60	0.37
A4	0.47	0.29	0.47	0.29	0.50	0.31	0.45	0.28	0.52	0.32
A5	0.45	0.28	0.50	0.31	0.50	0.31	0.60	0.37	0.50	0.31
A6	0.60	0.37	0.50	0.31	0.50	0.31	0.60	0.37	0.60	0.37
A: Alternative										

Score function values are computed as in Table 13.

Table 13. Score function values for the alternatives.

	C1	C2	C3	C4	C5
A1	0.078	0.152	0.062	0.070	0.127
A2	0.078	0.078	0.095	0.049	0.070
A3	0.070	0.078	0.105	0.078	0.165
A4	0.078	0.078	0.095	0.070	0.105
A5	0.070	0.095	0.095	0.165	0.095
A6	0.165	0.095	0.095	0.165	0.165

A: Alternative

Decision matrix is normalized as in Table 14.

Table 14. Normalized matrix.

	C1	C2	C3	C4	C5
A1	0.331	0.623	0.274	0.258	0.411
A2	0.331	0.319	0.421	0.182	0.225
A3	0.297	0.319	0.465	0.288	0.533
A4	0.331	0.319	0.421	0.258	0.341
A5	0.297	0.392	0.421	0.613	0.309
A6	0.704	0.392	0.421	0.613	0.533

A: Alternative

Table 15 shows the weighted matrix.

Table 15. Weighted matrix.

	C1	C2	C3	C4	C5
A1	0.065	0.123	0.056	0.051	0.084
A2	0.065	0.063	0.086	0.036	0.046
A3	0.058	0.063	0.095	0.057	0.110
A4	0.065	0.063	0.086	0.051	0.070
A5	0.058	0.077	0.086	0.120	0.063
A6	0.138	0.077	0.086	0.120	0.110

A: Alternative

Significant values for ranking the items are computed as in Table 16.

Table 16. The values of D+, D-, and RCi.

Alternatives	D+	D-	RCi
A1	0.111	0.073	0.396
A2	0.142	0.031	0.178
A3	0.118	0.077	0.395
A4	0.124	0.042	0.251
A5	0.103	0.093	0.473
A6	0.046	0.137	0.747

A: Alternative

Ranking summaries are shown in Table 17.

Table 17. Ranking results.

Alternatives	q-ROF Multi SWARA-TOPSIS	PF Multi SWARA-TOPSIS	IF Multi SWARA-TOPSIS
A1	3	4	4
A2	6	6	6
A3	4	3	3
A4	5	5	5
A5	2	2	2
A6	1	1	1

A: Alternative

It is determined that a photovoltaic system (alternative 6) is the most critical alternative to increase the performance of microgeneration energy technology investment. Additionally, small-scale wind turbines (alternative 5) can also be considered in this framework.

4. Discussions

The most important advantage of microgeneration technology investments is that they contribute to the increase in clean energy use. Different types of renewable energy are considered in these projects. On the other hand, it is very important that the costs are reasonable to ensure the continuity of these investments. When cost efficiency cannot be achieved, investors will not prefer these projects, even though there are many benefits to the environment. Furthermore, it would be appropriate for investors to prioritize photovoltaic systems. Thanks to technological developments, there are serious decreases in the costs of these projects. Therefore, photovoltaic systems, which have a cost advantage, should be preferred in projects to develop microgeneration technology investments.

In the literature, there are different views regarding this issue. For instance, Schulte et al. [43], Judson and Zirakbash [3], and Du et al. [37] identified that small-scale solar microgeneration systems should be considered for the effectiveness of these projects. Furthermore, researchers underlined the importance of other renewable energy alternatives for microgeneration projects, such as small-scale wind turbines [44] and micro hydroelectric powers [45]. Similarly, Dong et al. [46] and Yüksel and Ubay [47] also highlighted the significance of wind energy systems, with the aim of increasing the efficiency of renewable energy investments.

5. Conclusions

In this study, a model was created to identify critical performance measurement factors in microgeneration energy technology investments. Relative importance of the factors was determined with an M-SWARA, and investment alternatives were examined using the TOPSIS method, considering q-ROFSs and the golden cut. It is concluded that environmental adaptation and efficiency of cost are the most influential items. Additionally, the most influential criterion is transmission technologies. Efficiency of cost is the most significant factor for the effectiveness of microgeneration energy technology investments. Environmental adaptation has the second highest weight. Frequency of maintenance is the least important item. It is determined that a photovoltaic system is the most critical alternative to increase the performance of microgeneration energy technology investment. Additionally, small-scale wind turbines can also be considered in this framework. The results are the same for the analyses made by IFSs, PFSs, and q-ROFSs, which demonstrates the reliability of findings.

Focusing on microgeneration projects in a general manner is an important limitation of this study. Specific evaluations can be considered in future studies, such as performance measurements of small-scale wind turbines, micro hydroelectric power, or photovoltaic systems. With the help of this issue, unique strategies can be presented for each type of energy alternative. Additionally, different methodologies can be used in the following research. This situation helps to make a comparative examination. Furthermore, in this study only the analysis results of the proposed model are presented. However, the findings cannot be compared with real data. Therefore, in future studies, a case study can be conducted in which the findings can be compared with data from real microgeneration energy technology investments, located in different geographical locations.

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