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ADDRESSING HIDDEN CHALLENGES IN URBAN RENEWABLE ENERGY INTEGRATION VIA A HYBRID-DECISION MODEL

Gang KOU[1,2], Edmundas Kazimieras ZAVADSKAS[3], Ahmet AYATA[4], Serhat YÜKSEL[5,6,7], Hasan DINÇER[5,6,7]✉, Serkan ETI[8]

[1] *School of Business Administration, Faculty of Business Administration, Southwestern University of Finance and Economics, Chengdu, China*
[2] *School of Digital Media Engineering and Humanities, Hunan University of Technology and Business, Changsha 410205, China*
[3] *Institute of Sustainable Construction, Vilnius Gediminas Technical University, Vilnius, Lithuania*
[4] *Faculty of Economics, Administrative and Social Sciences, Adana Alparslan Türkeş Science and Technology University, Adana, Turkey*
[5] *School of Business, Istanbul Medipol University, Istanbul, Turkey*
[6] *Department of Economics and Management, Khazar University, Baku, Azerbaijan*
[7] *Clinic of Economics, Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan*
[8] *IMU Vocational School, Istanbul Medipol University, Istanbul, Turkey*

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Abstract. The integration of renewable energy into urban development has some critical legal challenges. However, the literature lacks a systematic framework for prioritizing the most critical obstacles. Existing studies generally address the legal barriers to the integration of renewable energy into urban areas at a general level. Therefore, these studies do not provide a systematic framework to prioritize which barriers are more critical. This deficiency creates some important problems such as increasing investor distrust, delays in projects and increasing costs. This study tries to fill this gap by establishing a novel hybrid decision-making model to evaluate hidden legal challenges in renewable energy integration. The proposed model follows a structured methodology by integrating z-scoring method to ensure expert representativeness, p,q,r-Fractional fuzzy sets to handle uncertainties, entropy method to compute the weights of the identified legal barriers and grey relational analysis to identify the most effective strategy alternatives. The main contribution is that prior investment strategies can be identified to overcome these legal challenges regarding the integration of renewable energy into urban development by creating a novel model. The use of p,q,r-Fractional fuzzy sets in this model provides an important contribution to the literature. With the help of considering these sets, more complex and multi-dimensional uncertainties can be managed more effectively. The findings highlight the significance of financial incentives and streamlined regulatory processes to have the sustainable transformation of urban areas.

Keywords: renewable energy integration, urban development; legal challenges, p,q,r-Fractional fuzzy sets.

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✉Corresponding author. E-mail: ***hdincer@medipol.edu.tr***

1. Introduction

Renewable energy integration is a critical strategy that supports the sustainable development of cities. This situation provides very critical advantages. With this application, more renewable energy is used instead of fossil fuels. With the help of this issue, it is possible to reduce the carbon footprint of cities. On the other hand, local energy production is possible with the use of renewable energy (Kabeel et al., 2025). Owing to this condition, countries' external dependence on energy is decreasing. This situation contributes significantly to increasing energy security. Several strategies can be implemented that can provide urban renewable energy integration. Green roof systems and solar panel bus stops and renewable energy projects in public transportation can be taken into consideration. Moreover, providing the lighting system with renewable energy sources can be shown as an example of these strategies. Energy storage systems should also be improved to develop these projects (Enemuo & Ogunmodimu, 2025). This situation seriously supports the minimization of energy outages. The integration of renewable energy in urban development plays a critical role in cities reaching their sustainability goals.

To increase the effectiveness of renewable energy integration, it is of great importance to solve legal challenges. Legal regulations and permit processes should be considered in the integration of renewable energy projects. This situation allows investors to implement their projects faster. Therefore, necessary reforms should be implemented to accelerate the legal processes for renewable energy investments (Myyas et al., 2025). Financial incentives are also of critical importance in this process. Low-interest loans and tax reductions reduce the high costs of these projects and ensure that investors are directed to projects. Carbon tax practices can also be considered in this process. This practice aims to reduce carbon emissions and encourage environmentally friendly investments. Governance issues and policies support the integration of renewable energy into urban development. The consistency of the legal framework facilitates project planning and financing processes. The increase in the use of electric vehicles is of key importance in achieving these goals (Koon Koon & Dias, 2025). On the other hand, appropriate regulations may be lacking for supporting electric vehicle charging stations with renewable energy. Therefore, the development of legal frameworks significantly increases the effectiveness of this process.

The most critical legal challenges need to be identified in the integration of renewable energy into urban development. Failure to identify the most critical legal challenges may cause several problems. As a result of not identifying the most critical factors, projects may be delayed, and costs may increase. Uncertainties in regulations prevent investors from trusting projects. This problem makes it difficult for businesses to find the necessary financing. Failure to identify the most critical challenges increases investor distrust and financial risks may arise. The absence of a legal framework for sustainable finance instruments may jeopardize the financial sustainability of large-scale projects. As a result of not resolving the most critical legal challenges, technological developments may slow down. The lack of clear regulations for energy storage solutions may limit innovation and infrastructure investments. The limited number of studies on this subject in the literature creates a significant missing gap. In this environment of incompleteness, policy makers lack a systematic guide on which legal regulations should be addressed as a priority. Similarly, investors are forced to take significant risks when planning their projects due to legal uncertainties. In summary, a new study should develop a scientific model for prioritizing legal obstacles.

This study tries to analyze the hidden challenges of renewable energy integration in urban development by employing an advanced hybrid decision-making methodology. The key research questions include: (1) What are the most essential hidden challenges affecting renewable energy integration in urban areas? (2) What policy and investment strategies can increase the effectiveness of renewable energy projects in urban development? In this model, firstly, decision makers are selected by z-scoring method, then uncertainties in linguistic expressions are analyzed by using p,q,r-Fractional fuzzy sets. While the weights of the difficulties in renewable energy integration are determined by entropy method, strategy alternatives are ranked by grey relational analysis method. The main motivation of this study is the importance of correctly identifying the legal barriers encountered in renewable energy integration. Legal uncertainties cause a significant decrease in investor confidence. This situation makes it difficult for businesses to access the funds they need. There is no consensus in the literature on which legal barriers are the most critical. This gap causes policy makers to lack a systematic guide on which legal regulations should be prioritized.

The main contributions of this study can be explained as follows. (1) The study develops a scientific model for prioritizing the most critical legal barriers encountered in renewable energy integration. The results obtained in this study will provide a systematic guide to which legal barriers need to be resolved more urgently. This can help develop strategies to increase investor confidence in renewable energy projects. (2) The use of p,q,r-Fractional fuzzy sets in this model provides an important contribution to the literature. These sets allow for expressing different degrees of linguistic expressions more flexibly. On the other hand, p,q,r-Fractional fuzzy sets are suitable for managing more complex and multi-dimensional uncertainties. Classical fuzzy sets usually work on a single membership function. In contrast, p,q,r-Fractional fuzzy sets can model different levels of uncertainty with more than one parameter. Using these numbers allows for a more precise analysis of the legal obstacles encountered in renewable energy integration. These projects contain many uncertainties in determining the legal obstacles and ranking the strategy alternatives. The complex structure of the study is suitable for the multi-faceted structure of p,q,r-Fractional fuzzy sets. (3) The preference of the entropy approach in weighting the criteria provides a significant advantage to the model. This technique is especially effective in cases where the number of criteria is very high. Other weighting methods are generally based on expert opinions and subjective values. The entropy method provides an objective weighting obtained directly from the data. This helps the decision-making process to be more consistent and reliable. This method is especially suitable for the analysis of non-objective issues such as legal uncertainties and investment strategies. (4) Consideration of GRA to rank the alternatives provides also some advantages to the proposed model. GRA is particularly powerful when working with uncertain, incomplete or comparable data. In this way, it measures the closeness between alternatives more successfully. Another advantage of GRA is that it has a more flexible and broader application area than other MCDM techniques. AHP and TOPSIS are traditional and widely used decision-making methods. On the other hand, these techniques usually require a clear hierarchy and predetermined criteria weights. These applications can create problems in cases where uncertainty is high. GRA can perform more sensitive analyses because it can handle uncertainties and data gaps more easily. Due to this issue, it can measure the relationships between alternatives more dynamically.

The organization of the study is defined as follows. Section 2 gives information about the main missing gap in the literature. An original model is created to satisfy this missing part, and the details are defined in Section 3. Analysis results are underlined in Section 4. The findings are discussed in the following Section. Section 6 consists of main concluding remarks.

2. Literature review

Some of the challenges encountered in the integration of renewable energy into urbanization processes are related to various legal obstacles. In this context, the necessity for legal reforms to successfully integrate renewable energy projects has become increasingly evident. This article will address the main legal challenges faced by renewable energy projects and the theoretical framework of alternative strategies to address these challenges (Marquez, 2025). The primary focus is on modernizing the relevant regulations and developing innovative approaches. Legal regulations are crucial in determining the success of renewable energy investments (Söderholm & Pettersson, 2025). While varying according to the economic-political approaches adopted, it is widely recognized that constitutional regulations in most countries impose obligations on states to protect the right to live in a healthy environment, use national resources efficiently, and regulate and oversee economic activities (Kreishan, 2025). States should invest in sustainable energy projects or use economic tools to encourage private enterprises to invest. In doing so, market conditions, competition, and transparency must be preserved. This would also contribute to the fulfillment of the state's obligations regarding the right to live in a healthy environment.

Renewable energy projects necessitate detailed and sometimes complex investment processes aimed at balancing the expected public benefit with the right to live in a healthy environment. Bureaucratic barriers, the interdependence of processes, uncertainties regarding authority, legal ambiguities arising from poor quality of legislation, and arbitrariness stemming from these uncertainties make it difficult to invest in renewable energy projects (Shahnazi, 2025). Allowing the simultaneous execution of legal requirements, which consist of a combination of processes such as evaluating the environmental impacts of projects and obtaining permits for the construction site, will accelerate investment processes (Nyarko et al., 2025). Moreover, coordination of these processes through a single authority, resolving inconsistencies between local governments and central administrations, and simplifying expropriation and urban planning procedures will accelerate investment. Additionally, to expedite the processes, it may be possible to introduce mandatory or, if not possible, guiding decision-making timeframes. In this context, the standardization of permitting processes is of great importance (Petrovich et al., 2025). As a legal alternative, a "central regulation to standardize renewable energy projects under a national framework" may be proposed. This regulation will not only ensure coordination between administrative authorities but also increase predictability for investors and provide a framework for timely project completion (Magalhães et al., 2025).

One of the greatest barriers to the realization of renewable energy projects is the insufficiency of financial incentives and the limited effectiveness of existing mechanisms. To address this issue, the development of innovative financing mechanisms is of utmost importance (Abbruzzese et al., 2025). As a legal solution, new financing tools such as the "public-private partnership" (PPP) model, which encourages cooperation between the state and the private sector, can be proposed. Additionally, instruments such as tax reductions, low-interest loan programs, and green bonds can strengthen financial incentive mechanisms. Legal regulations could facilitate the use of such financial tools and ensure investor confidence by introducing special laws and incentives. Furthermore, incentives for different types of renewable energy could also be legally guaranteed (Teng et al., 2025). The existing tariff structures are generally insufficient for the economic sustainability of renewable energy projects. A legal regulation should be made to reshape the tariff structures in a way that ensures the efficient operation of the grid and covers the market and grid costs, allowing energy producers to optimize the revenues from renewable energy production (Dehshiri & Firoozabadi, 2025). In this regard, reforms such as "flexible tariffs based on production costs" and "pricing policies that encourage new types of energy" could be proposed. Legally, regulations based on the principles of transparency and equality should be made in determining these tariffs. Additionally, designing the national tariff on a regional scale to respond to different conditions would be beneficial. Changes made to the tariff system will increase the financial attractiveness of renewable energy projects (Dai et al., 2025).

The use of reusable materials in sustainable energy projects ensures environmentally friendly and economic solutions. Despite all the potential benefits, the use of relevant materials in these projects is often insufficient. Legal regulations should be introduced to encourage the use of reusable materials and, if applicable, improve existing regulations (Hu et al., 2025). Incentives could be introduced to increase the use of reusable materials, and in certain cases, a "mandatory reusable material requirement" could be implemented, yielding positive results. Such regulations would increase the number of environmentally friendly projects in the sector while contributing to economic development (Karamoozian & Zhang, 2025). Renewable energy projects often face resistance from local communities, environmentally conscious individuals, or environmental organizations. This resistance may stem from concerns about changes in the areas where local populations reside, the environmental impacts of the projects, or the external effects of energy production. Increasing community participation in these projects is an effective method for combating resistance and ensuring compliance with good governance principles. Regulations could be made to include civil society organizations and local people in decision-making processes (Popa & Szabó, 2025). These regulations should also require transparency, meaning that the public must be informed about the projects. The effectiveness of these regulations in concrete cases can only be ensured if the legal rights of the community to defend their roles and interests in the projects are judicially guaranteed (Dablander et al., 2025).

The implementation of renewable energy projects in urban areas is often confronted with issues of limited space and infrastructure. To solve this problem, legal regulations that optimize land use and strengthen energy infrastructure are needed. In spatial planning, the physical, natural, administrative, and economic structures, disaster risks, military areas, transportation routes, and other environmental factors must be considered (Bampaou & Panopoulos, 2025). The institutions responsible for providing the necessary data in these areas should be explicitly stated in the legislation, and where possible, information request processes should be simplified (Karapidakis et al., 2025). Especially, investments related to modernizing energy distribution networks and developing energy storage solutions require collaboration between the public and private sectors. Improvements aimed at increasing the efficiency and flexibility of the grid and facilitating the establishment of smart grids should be encouraged. Additionally, "regulations related to storage facilities should be detailed in secondary legislation according to the purpose, technology, and location of the storage facility” (Müller et al., 2025).

Alternatives to the legal challenges encountered in renewable energy integration should address the technical characteristics and economic needs of the sector. While doing so, the protection of the environment and the prevention of violations of various rights must also be among the duties of the law. In this context, the modernization of regulations and the development of innovative approaches are of paramount importance. Solutions such as the standardization of permitting processes, diversification of financing models, and restructuring of tariffs will allow these projects to overcome obstacles and be implemented more rapidly and effectively. Furthermore, through transparency, involving local communities and civil society in projects will raise awareness and reduce public resistance. With the implementation of appropriate infrastructure and spatial planning strategies in urban areas, renewable energy projects will contribute to the creation of healthier and more efficient living spaces, thereby enhancing environmental and economic sustainability. Ultimately, legal reforms play a crucial role in both overcoming obstacles in the sector and increasing public trust in renewable energy. The missing gap in the literature is that there are limited studies regarding the priority evaluation for this subject.

To address this missing gap in the literature, a priority analysis should be conducted. Multi-criteria decision-making models can be considered to achieve this objective. However, there are lots of criticisms regarding the existing models. The main criticisms are demonstrated as follows. (1) Ineffective management of uncertainty is an important deficiency for multi-criteria decision-making models. If uncertainties are not managed correctly, the criteria weights and alternative rankings may change. This situation causes the reliability of the results to decrease. These models are established to find solutions to complex and uncertain issues. Therefore, ineffective management of uncertainty cannot adequately reflect the dynamics in the real world. (2) Accepting expert opinion weights equally can be considered as an important deficiency for multi-criteria decision-making models. Experts have different academic backgrounds, sectoral experiences and areas of expertise. This situation can make the opinions of more knowledgeable and experienced experts less important than they should be. In dynamic and complex decision processes, the influence levels of different experts may change. The approaches taken into consideration in this model developed in this study are mainly aimed at satisfying these criticisms. (1) In order to manage uncertainty correctly, it is of critical importance to select appropriate fuzzy numbers for the model. Different types of fuzzy numbers represent different levels of uncertainty and decision environments. Selecting fuzzy numbers that are not suitable for the concept of the study cannot reflect the model uncertainty correctly. For example, triangular fuzzy numbers are only suitable for simple uncertainty situations. In order to effectively manage this uncertainty problem, p,q,r-Fractional fuzzy sets are used in this proposed model. Traditional triangular or trapezoidal fuzzy numbers express uncertainty with a single membership function. In contrast, p,q,r-Fractional fuzzy sets handle uncertainty with a more flexible and multi-dimensional structure. (2) The Z-scoring method can provide an effective solution to the problem of accepting expert opinion weights equally. This approach can normalize the values in a data set. Afterwards, how much they deviate from the mean is calculated. Experts’ experiences in the sector can be statistically analyzed and their weights can be determined. The opinions of more experienced experts can receive higher weights. In the Z-scoring technique, extreme values are also normalized. Owing to this situation, inconsistent or extreme evaluations do not negatively affect the decision model.

3. Methodology

The ranks of strategy alternatives for the efficiency of renewable energy integration in urban development are determined by using fuzzy decision techniques in this study. This fuzzy decision technique includes z-scoring for choosing the decision makers (DMs), fuzzy logic for analyzing the uncertainty of linguistic opinions, entropy for weighting challenges for renewable energy integration and grey rational analysis for ranking the strategy alternatives. The flowchart of fuzzy decision technique is shown in Figure 1.

3.1. Z-Scoring

The Z-scoring method can be applied to data sets that contain numerical measurements, as it allows calculations with quantitative data. In addition, z-scoring has a statistics-based calculation procedure. In other words, it is based on standardized values in statistics. Choosing appropriate DMs and obtaining DMs' opinions for analysis plays an important role in the accuracy of analysis results. For this reason, the DMs whose opinions are received must be determined objectively. Z-scoring is based on the total standardized values of factors that

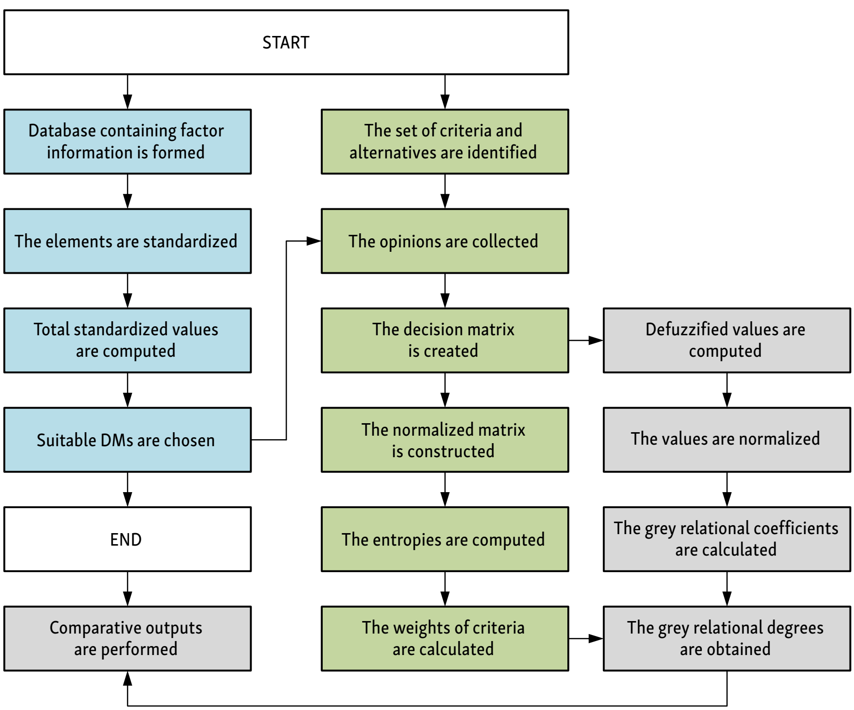

Figure 1. The flowchart of fuzzy decision technique

have an impact on DMs' expertise. If these total standardized values are positive, it indicates that the DM is more successful than the average of the team members. DMs that are above average are defined as suitable DMs. The choosing of DMs by Z-scoring is introduced below (Ramezani et al., 2025).

Initially, a database containing factor information for all DMs is created. The database is formed as Equation (1).

$$\mathcal{F} = \begin{bmatrix} b_{11} & \cdots & b_{1v} \\ \vdots & \ddots & \vdots \\ b_{d1} & \cdots & b_{dv} \end{bmatrix}. \tag{1}$$

Where the valuies of d and v equal to the numbers of DMs and factor information, respectively. b means the factor information of DMs. Next, the elements of $\mathcal{F}$ are standardized using Equation (2).

$$z_{ij} = \frac{b_{ij} - \mu_j}{\sigma_j}. \tag{2}$$

Where μ and σ represent the arithmetic average and standard deviation of factor information, respectively. Finally, the total standardized values are computed with the help of Equation (3).

$$tz_i = \sum_j z_{ij}. \tag{3}$$

DMs with positive total standardized values are chosen as suitable DMs. Since these experts are experts above the general average, these experts are selected for evaluation.

3.2. p, q, r-Fractional Fuzzy Sets (p, q, r-FFS)

Fuzzy set theory is a mathematical concept developed for the measurement of uncertainty. According to fuzzy set theory, the boundaries of a set are fuzzy. This approach builds different fuzzy set theories. p,q,r-FFS is one of the current theories. According to this set, an element has components as membership, neutral and non-membership functions. The set is defined through these components. A p,q,r-fractional fuzzy sets on a $\tilde{A}_s$ of the universe of discourse X is identified using Equation (4) (Narayanan et al., 2025):

$$\tilde{A}_s = \left\{ x, \left(m_{\tilde{A}_s}(x), n_{\tilde{A}_s}(x), h_{\tilde{A}_s}(x) \right)_{p,r,q} \middle| x \in X \right\}, \tag{4}$$

where $m_{\tilde{A}_s}(x), n_{\tilde{A}_s}(x), h_{\tilde{A}_s}(x) \in [0,1]$ represent the membership, neutral and non-membership functions. The elements of this set satisfy the condition in Equation (5):

$$0 \le \frac{1}{p} m_{\tilde{A}_s}(x) + \frac{1}{r} n_{\tilde{A}_s}(x) + \frac{1}{q} h_{\tilde{A}_s}(x) \le 1, \tag{5}$$

where $p,q \ge 1$ and are integer numbers. $r = LCM(p,q)$. According to these definitions, the arithmetic operations defined by any two p,q,r-FFN are summarized in Equations (6)–(9).

$$\tilde{A}_{s1} + \tilde{A}_{s2} = \left(\frac{1}{p} m_1 + \frac{1}{p} m_2 - \frac{1}{p} m_1 m_2,\ \frac{1}{r} n_1 n_2,\ \frac{1}{q} h_1 h_2 \right); \tag{6}$$

$$\tilde{A}_{s1} \times \tilde{A}_{s2} = \left(\frac{1}{p} m_1 m_2,\ \frac{1}{r} n_1 + \frac{1}{r} n_2 - \frac{1}{r} n_1 n_2,\ \frac{1}{q} h_1 + \frac{1}{q} h_2 - \frac{1}{q} h_1 h_2 \right); \tag{7}$$

$$\tilde{A}_s{}^w = \left(\frac{1}{p}m^w,\ \frac{1}{r}n^w,\ 1-\left(1-\frac{1}{q}h\right)^w\right); \tag{8}$$

$$w\tilde{A}_s = \left(1-\left(1-\frac{1}{p}m\right)^w,\ 1-\left(1-\frac{1}{r}n\right)^w,\ \frac{1}{q}h^w\right). \tag{9}$$

Let $\tilde{A}_s = (m,\ n,\ h)_{p,r,q}$ be a p,q,r-FFN. The score function is calculated with Equation (10) and the accuracy function is computed by Equation (11).

$$Sc\left(\tilde{A}_s\right) = \frac{1+\frac{1}{p}m+\frac{1}{r}n-\frac{1}{q}h}{3}; \tag{10}$$

$$Ac\left(\tilde{A}_s\right) = \frac{1+\frac{1}{p}m+\frac{1}{r}n+\frac{1}{q}h}{3}. \tag{11}$$

Assume $\tilde{A}_{si} = (m_i,\ n_i,\ h_i)_{p,r,q}$ be a collection of p,q,r-FFNs and w_i is the weights. Then, the fuzzy weighted averaging operator is identified with Equation (12):

$$p,q,r-FFWA\left(\tilde{A}_{s1},\tilde{A}_{s2},\ldots,\tilde{A}_{sn}\right) = \left(1-\prod_{i=1}^{n}\left(1-\frac{1}{p}m_i\right)^{w_i},\ 1-\prod_{i=1}^{n}\left(1-\frac{1}{r}n_i\right)^{w_i},\ \prod_{i=1}^{n}\frac{1}{q^n}h_i^{w_i}\right). \tag{12}$$

With its discrete structure, p,q,r-FFN offers a wider range of linguistic expressions. This makes the results of analyses performed under uncertainty more realistic.

3.3. p, q, r-FFNs entropy

Entropy is a method that examines uncertainty in the data and determines the weight of the criterion objectively according to the diversity in the criterion. The most basic feature of the method is that it is an objective weighting model. Thus, the results are more realistic. The version integrated with p,q,r-FFN is introduced below (Yang et al., 2025).

Firstly, the opinions are collected from DMs about alternatives according to criteria. Then, these opinions are transformed to p,q,r-FFN and averaged values are computed with Equation (12). Thus, the decision matrix is created from these averaged values as Equation (13):

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1c} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{a1} & \cdots & \tilde{x}_{ac} \end{bmatrix}, \tag{13}$$

where $\tilde{x}_{ij} = (m_{ij},\ n_{ij},\ h_{ij})$ and the numbers of alternatives and criteria are symbolized by a and c, respectively. Afterwards, the elements are normalized using Equation (14):

$$\eta_{ij} = \begin{cases} \left(m_{ij}, n_{ij}, h_{ij}\right) & \text{for } B \\ \left(h_{ij}, n_{ij}, m_{ij}\right) & \text{for } C \end{cases}. \tag{14}$$

After the normalized decision matrix is constructed, the entropies are computed with the help of Equation (15):

$$E_j = \frac{-1}{\ln(a)} \sum_{i=1}^{a} \frac{1+\frac{1}{p}m_{\eta_{ij}} + \frac{1}{r}n_{\eta_{ij}} - \frac{1}{q}h_{\eta_{ij}}}{3} \ln\left(\frac{1+\frac{1}{p}m_{\eta_{ij}} + \frac{1}{r}n_{\eta_{ij}} - \frac{1}{q}h_{\eta_{ij}}}{3}\right). \quad (15)$$

Finally, the weights of criteria are calculated by Equation (16):

$$w_j = \frac{1-E_j}{\sum_{j=1}^{c}\left(1-E_j\right)}. \quad (16)$$

3.4. p, q, r-FFS grey relational analysis

This method, which is based on grey system theory and examines the grey area between two extreme scenarios, is preferred for ranking alternatives. Its integrated form with p,q,r-FFN is shared below (Yan et al., 2025).

Opinions are collected from DMs, transformed into fuzzy numbers, and the elements of decision matrix in Equation (13) are obtained using Equation (12). Next, the defuzzified values are computed with Equation (10). The defuzzified decision values are shown in Equation (17):

$$A = \begin{bmatrix} Sc\left(\tilde{x}_{11}\right) & \cdots & Sc\left(\tilde{x}_{1c}\right) \\ \vdots & \ddots & \vdots \\ Sc\left(\tilde{x}_{a1}\right) & \cdots & Sc\left(\tilde{x}_{ac}\right) \end{bmatrix}. \quad (17)$$

Afterwards, the defuzzified decision values are normalized by Equations (18)–(20):

$$p_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}; \quad (18)$$

$$p_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}; \quad (19)$$

$$p_{ij} = \frac{\left|a_{ij} - a_j^*\right|}{\max_i a_{ij} - \min_i a_{ij}}. \quad (20)$$

Equation (18) is used for benefit, Equation (19) is used for cost and Equation (20) is used for reference value. Later, the reference set is determined as 1 for benefit. ζ is between 0 and 1, grey relational coefficients are calculated using Equations (21) and (22):

$$\Delta_{0i,j} = \left|p_{0j} - p_{ij}\right|; \quad (21)$$

$$\gamma_{0i,j} = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i,j} + \zeta\Delta_{\max}}. \quad (22)$$

Finally, the grey relational degrees are computed by Equation (23):

$$\Gamma_i = \sum_{j=1}^{c}\left(w_j \gamma_{0i,j}\right). \quad (23)$$

4. Analysis

The outputs of strategy alternatives for the efficiency of renewable energy integration in urban development are summarized in this Section.

4.1. Choosing the DMs using Z-scoring

People who are DMs in the efficiency of renewable energy integration are determined. When determining these people, it is taken into consideration that they have at least 5 years of experience in the relevant field and have a managerial background. The factor information of the DMs who meet the constraints, represented by Equation (1), is shared in Table 1.

Table 1. The factor information

	Age	Exp in Sector	Exp in Total	Number of Cert.	Exp as Manager
DM1	30	6	9	0	4
DM2	35	10	14	2	6
DM3	32	8	11	1	5
DM4	45	17	24	4	10
DM5	42	15	21	4	9
DM6	43	15	22	3	9
DM7	32	8	11	3	5
DM8	38	12	17	2	7
DM9	39	13	18	2	8
DM10	44	16	23	3	10

Basic statistical values such as arithmetic average and standard deviation of factor information are given in Table 2.

Table 2. The basic statistic values of factor information

	Age	Exp in sector	Exp in total	Number of cert.	Exp as manager
Mean	38.000	12.000	17.000	2.400	7.300
S.d	5.215	3.633	5.215	1.200	2.100
Max	45.000	17.000	24.000	4.000	10.000
Min	30.000	6.000	9.000	0.000	4.000

According to the basic statistics in Table 2, the age range of DMs is between 30 and 45 years. In addition, the average experience of ten DMs in the sector is 12 years. Using these statistics, standardized values of factor information are obtained with the help of Equation (2). Then, total standardized values are calculated using Equation (3). Standardized values of factor information and total standardized values of DMs are presented in Table 3.

Table 3. The standardized values and total standardized values

	Age	Exp in sector	Exp in total	Number of cert.	Exp as manager	Total
DM1	–1.534	–1.651	–1.534	–2.000	–1.571	–8.291
DM2	–0.575	–0.550	–0.575	–0.333	–0.619	–2.653
DM3	–1.150	–1.101	–1.150	–1.167	–1.095	–5.664
DM4	1.342	1.376	1.342	1.333	1.286	6.680
DM5	0.767	0.826	0.767	1.333	0.810	4.503
DM6	.959	0.826	0.959	0.500	0.810	4.053
DM7	–1.150	–1.101	–1.150	0.500	–1.095	–3.997
DM8	.000	0.000	0.000	–.0333	–0.143	–0.476
DM9	.192	0.275	0.192	–0.333	0.333	0.659
DM10	1.150	1.101	1.150	0.500	1.286	5.188

When the total values in Table 3 are examined, the DMs with positive values are the fourth, fifth, sixth, ninth and tenth DMs. In other words, opinions are collected from these five DMs and analyses are performed with these opinions.

4.2. Weighting the challenges using p, q, r-FFN entropy

There are numerous challenges in renewable energy integration. The challenges identified in terms of urban development are displayed in Table 4.

Table 4. The challenges

Challenges	Table representation
Complex regulatory process	CRP
Insufficient financial incentives	IFI
Fragmented governance	FG
High initial costs	HIC
Space constraints for infrastructure	SCI
Public resistance	PR

All criteria are considered as benefit. Similarly, strategy alternatives for the efficiency of renewable energy integration in urban development are identified. These strategies are exhibited in Table 5.

Once the alternative and criteria sets are defined, opinions are performed by the five chosen DMs. The opinions are tabulated in Table 6.

Afterwards, these linguistic terms are transformed into p, q, r-FFN. Next, Equation (12) are used for computing the averaged values and the decision matrix in Equation (13) are constructed for $p = q = 1$. The decision matrix is illustrated in Table 7.

Table 5. The strategy alternatives

Strategy alternative	Table representation
Standardizing the permitting processes	SPP
Implementing legal mandates	ILM
Innovative financing mechanisms	IFM
Revising tariff structures	RTS
Upgrading urban energy grids	UUEG
Maximizing space utilization	MSU
Engaging communities in energy planning	ECEP
Integrating reusable materials in sustainable energy projects	IRMSEP

Table 6. The opinions

DM4	CRP	IFI	FG	HIC	SCI	PR
SPP	VB	MG	G	G	VB	VB
ILM	VVG	VVG	VVB	B	EG	VG
IFM	VVG	VVG	VG	VVG	VVG	VVG
RTS	VVG	VVG	VG	VG	VG	VG
UUEG	MG	MG	B	MB	M	VG
MSU	VB	VVB	M	MB	VVB	VG
ECEP	VVG	VVG	EG	VVG	MB	MB
IRMSEP	MG	VVB	G	M	VVB	G
DM5	**CRP**	**IFI**	**FG**	**HIC**	**SCI**	**PR**
SPP	MG	MG	G	VVB	MB	MB
ILM	VVG	VVG	M	VVG	G	VVB
IFM	VVG	VVG	VVG	VG	VVG	VVG
RTS	VVG	VVG	VG	VG	VG	VG
UUEG	VB	MG	VVG	MB	VVB	VVG
MSU	MG	VVB	B	EG	VB	VG
ECEP	VVG	VVG	G	VG	MB	B
IRMSEP	VB	VVB	B	EG	VVB	EG
DM6	**CRP**	**IFI**	**FG**	**HIC**	**SCI**	**PR**
SPP	VVG	MG	MG	VB	VVB	EG
ILM	MG	VVG	VVG	VG	VB	G
IFM	VVG	VVG	VVG	VVG	VVG	VVG
RTS	VVG	VVG	VG	VG	VG	VG
UUEG	MG	MG	VVG	VVB	VG	MB
MSU	VB	VVB	EG	B	VG	M
ECEP	VVG	VVG	B	VVB	VB	B
IRMSEP	VB	VVB	VB	B	MB	VVB
DM9	**CRP**	**IFI**	**FG**	**HIC**	**SCI**	**PR**
SPP	VVG	MG	EG	VVG	B	MB
ILM	VB	VVG	M	M	VB	EG

End of Table 6

IFM	VVG	VVG	VVG	VVG	VVG	VVG
RTS	VVG	VVG	VG	VVG	VG	VG
UUEG	MG	MG	VVG	MB	MB	VB
MSU	VB	VVB	VVG	VB	VG	MG
ECEP	VVG	VVG	VG	MB	VVG	G
IRMSEP	VB	VVB	B	EG	M	VG
DM10	**CRP**	**IFI**	**FG**	**HIC**	**SCI**	**PR**
SPP	VVG	MG	M	G	VVB	G
ILM	VVG	VVG	VVG	VVB	M	VVB
IFM	VVG	VVG	VG	VG	VVG	VVG
RTS	VVG	VVG	VG	VG	VG	VG
UUEG	MG	MG	EG	VVG	G	VVG
MSU	VB	VVB	MG	VVB	G	EG
ECEP	MG	VVG	M	VG	VVB	VB
IRMSEP	VB	VVB	VB	VVB	B	B

Table 7. The Decision Matrix ($p = q = 1$)

	CRP			IFI			FG			HIC			SCI			PR		
SPP	0.998	0.000	0.000	0.972	0.000	0.001	1.000	0.000	0.000	0.981	0.000	0.000	0.429	0.010	0.005	0.999	0.000	0.000
ILM	0.998	0.000	0.000	1.000	0.000	0.000	0.984	0.000	0.000	0.974	0.000	0.000	0.999	0.000	0.000	1.000	0.000	0.000
IFM	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000
RTS	1.000	0.000	0.000	1.000	0.000	0.000	0.999	0.000	0.000	0.999	0.000	0.000	0.999	0.000	0.000	0.999	0.000	0.000
UUEG	0.946	0.000	0.002	0.972	0.000	0.001	1.000	0.000	0.000	0.922	0.000	0.000	0.953	0.000	0.000	0.995	0.000	0.000
MSU	0.617	0.004	0.006	0.185	0.010	0.010	1.000	0.000	0.000	0.997	0.000	0.000	0.981	0.000	0.000	1.000	0.000	0.000
ECEP	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.992	0.000	0.000	0.905	0.000	0.000	0.816	0.003	0.001
IRMSEP	0.617	0.004	0.006	0.185	0.010	0.010	0.777	0.004	0.002	1.000	0.000	0.000	0.551	0.006	0.003	1.000	0.000	0.000

In another step, the normalized matrix is computed with Equation (14). Then, the entropies are calculated using Equation (15). Finally, the weight values of criteria are obtained by Equation (16). The outputs are summarized in Table 8.

Table 8. The entropies and weights of criteria

	CRP	IFI	FG	HIC	SCI	PR
E	0.997	0.9900	0.9997	1.0000	0.998	0.9998
p	0.2089	0.6357	0.0214	0.0024	0.1173	0.0143

As can be seen in Table 8, the most important challenges for renewable energy integration are IFI and CRP. For validation check, CRITIC and AHP are used. The priority orders of the three methods are shown in Figure 2.

According to Figure 2, the ranking of the criteria is the same in all three methods, so the results are valid.

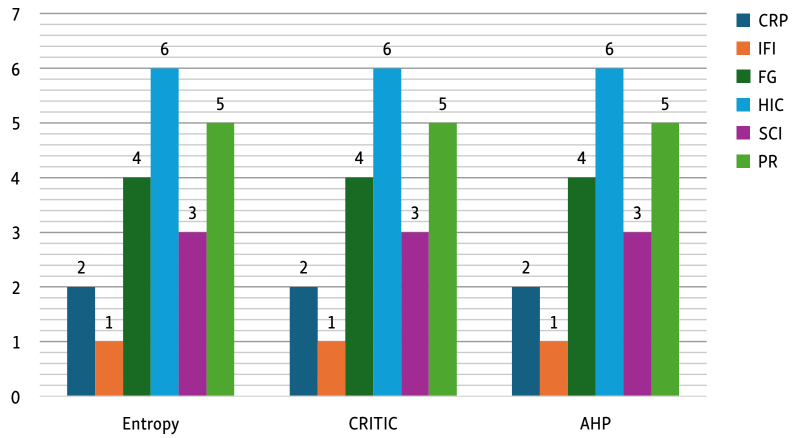

Figure 2. Orders of criteria by three methods

4.3. Ranking the strategy alternatives using p, q, r-FFN GRA

The values in Table 7 are defuzzified with Equation (11). The defuzzified values are shown in Table 9.

Table 9. The defuzzified values

	CRP	IFI	FG	HIC	SCI	PR
SPP	0.666	0.657	0.667	0.660	0.478	0.666
ILM	0.666	0.667	0.661	0.658	0.666	0.667
IFM	0.667	0.667	0.667	0.667	0.667	0.667
RTS	0.667	0.667	0.666	0.666	0.666	0.666
UUEG	0.648	0.657	0.667	0.641	0.651	0.665
MSU	0.538	0.395	0.667	0.666	0.660	0.667
ECEP	0.667	0.667	0.667	0.664	0.635	0.606
IRMSEP	0.538	0.395	0.593	0.667	0.518	0.667

Afterwards, the elements in Equation (17) are normalized using Equations (18)–(20). The Normalized matrix is displayed in Table 10.

Table 10. The Normalized Matrix

	CRP	IFI	FG	HIC	SCI	PR
SPP	0.994	0.964	0.999	0.752	0.000	0.995
ILM	0.994	1.000	0.928	0.668	0.998	0.998
IFM	1.000	1.000	0.999	0.996	1.000	1.000
RTS	1.000	1.000	0.996	0.992	0.999	0.996
UUEG	0.856	0.964	1.000	0.000	0.917	0.971
MSU	0.000	0.000	0.999	0.962	0.967	1.000
ECEP	0.999	1.000	0.999	0.900	0.833	0.000
IRMSEP	0.000	0.000	0.000	1.000	0.211	0.999

Then, the grey relational coefficients are estimated with Equations (21) and (22). For ζ = 0.5, the output is illustrated in Table 11.

Table 11. The grey relation coefficients (ζ = 0.5)

	CRP	IFI	FG	HIC	SCI	PR
SPP	0.988	0.934	0.998	0.668	0.333	0.990
ILM	0.988	1.000	0.873	0.601	0.997	0.997
IFM	1.000	1.000	0.997	0.992	1.000	0.999
RTS	1.000	1.000	0.992	0.984	0.997	0.992
UUEG	0.776	0.934	1.000	0.333	0.857	0.944
MSU	0.333	0.333	0.998	0.929	0.938	1.000
ECEP	0.998	1.000	0.998	0.833	0.749	0.333
IRMSEP	0.333	0.333	0.333	1.000	0.388	0.997

Finally, the grey relational degrees computed by Equation (23). For this, the values in Table 8 are used as weights. The grey relational degrees are exhibited in Table 12.

Table 12. The grey relational degrees

	Γ
SPP	0.816
ILM	0.994
IFM	1.000
RTS	0.999
UUEG	0.899
MSU	0.485
ECEP	0.937
IRMSEP	0.356

According to Table 12, the most suitable strategy alternatives for the efficiency of renewable energy integration in urban development are IFM and RTS.

4.4. Comparative outputs

For consistency and reliability of the results, the analyses are repeated with different p and q values. The ranking of the alternatives for different *p*, *q*, *r* values is shown in Table 13.

When the rankings are examined, it is seen that the results are the same for different fraction values. This makes the importance of the strategies clear.

Table 13. Comparative outputs

	$p = q = 1$	$p = q = 2$	$p = q = 3$	$p = 2vq = 3$	$p = 3vq = 2$	$p = 3vq = 4$	$p = 4vq = 3$
SPP	6	6	6	6	6	6	6
ILM	3	3	3	3	3	3	3
IFM	1	1	1	1	1	1	1
RTS	2	2	2	2	2	2	2
UUEG	5	5	5	5	5	5	5
MSU	7	7	7	7	7	7	7
ECEP	4	4	4	4	4	4	4
IRMSEP	8	8	8	8	8	8	8

4.5. Sensitivity analysis

Sensitivity analysis is applied to check the stability of the rankings when the criteria weights change slightly. For this, small changes such as 1%, 5%, etc. are made in the criteria weights and the analysis is repeated. The results for the six cases created with these small changes are visualized in Figure 3.

As can be seen from the sensitivity analysis in Figure 3, a change slightly in the criteria weights does not change the ranking of the alternatives.

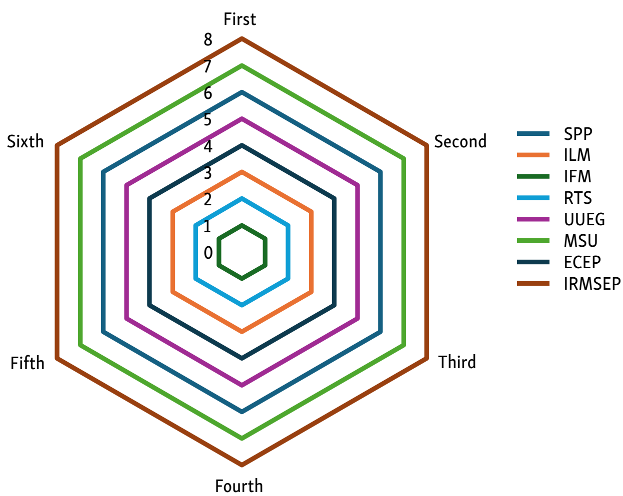

Figure 3. Sensitivity analysis

5. Discussion

Financial incentives play a critical role in ensuring sustainable transformation in urban development for renewable energy integration. In case of insufficient financial incentives, high initial costs may occur for investors. This situation will make investors significantly nervous and therefore interest in projects decreases. The basic principles of investment theory can clearly explain this situation. According to this theory, the absence of financial incentives leads to an increase in investors' risk perception. Some policy recommendations can be presented to improve this issue. Renewable energy subsidies should be increased. Selim and Alshareef (2025) highlighted that interest-free or low-interest loan programs should be established. Activating carbon tax policies also supports achieving this goal. Legal regulations for the integration of renewable energy into urban development are also critical in terms of ensuring the effective implementation of financial incentives. Amin et al. (2025) defined that special financing laws should be enacted for renewable energy investments. On the other hand, it is also necessary to update existing legislation and provide legal security for financial incentives. Similarly, Osuma and Yusuf (2025) denoted that regulations should be made to facilitate the allocation of suitable lands for renewable energy projects in cities for the public good. Moreover, a special legal regulation should be made to determine the legal framework for cooperation between municipalities and the private sector (Dinçer et al., 2025). These regulations can increase energy security by accelerating urban renewable energy transformation.

The integration of renewable energy into urban development is of great importance for sustainable cities and energy security. On the other hand, complex regulatory processes are a significant obstacle that slows down this transformation. This situation creates bureaucratic obstacles and administrative burdens. Bozelli et al. (2025) identified that regulatory obstacles can increase the financial risks of investors. These issues can negatively affect the development of projects as they reduce the anxiety of investors. According to innovation theory, flexible and innovation-supporting regulatory frameworks are necessary for the successful integration of these projects. Mathew et al. (2025) underlined that the complexity of these regulations is a significant obstacle to the development of new technologies. Several policy and strategy suggestions can be developed to solve this problem. Digital permit platforms should be established for renewable energy projects. This situation also supports the acceleration of application processes significantly. On the other hand, according to Capellaro et al. (2025), regulatory incompatibilities between the central government and municipalities should be eliminated. Owing to this regulatory harmony, it is possible to develop projects more quickly. Furthermore, Lyridis and Kostidi (2025) denoted that regulatory laws specific to renewable energy should be updated and legal frameworks supporting innovation should be created. In this context, a special law can be created to ensure simpler permitting processes for these projects. These reforms will accelerate the integration of renewable energy in cities.

Germany's renewable energy law and the support of renewable energy projects in cities are very important in this regard. This law has become one of the most important components of the Energiewende process over time (Rahman, 2024). This application basically aims to reduce dependency on fossil fuels. This contributes to a significant reduction in the carbon emission problem. Another important feature of this application is that it offers a fixed price guarantee for renewable energy producers (da Silva et al., 2024). This situation significantly increases the interest of investors in this area. Community-supported energy cooperatives in cities accelerate the integration of renewable energy. In this context, solar panels, energy-efficient buildings and microgrids are supported in the city. Various states in the United States implement different financial incentive mechanisms to encourage renewable energy projects. In this context, it provides financial support to homeowners and businesses that install solar panels on their roofs (Abbruzzese et al., 2025). This situation contributes to a significant reduction in the costs of the projects. Denmark is also taking important steps in urban planning and renewable energy integration. Major investments are being made in the fields of wind energy and solar energy. With the help of this issue, various policies are being developed to meet the energy needs of cities from renewable sources (Tiwari et al., 2024).

6. Conclusions

This study generates a systematic framework to determine the most critical legal barriers of renewable energy integration into urban development using a hybrid decision-making model. This model employs the z-scoring method for expert selection, p,q,r-Fractional fuzzy sets to manage uncertainties, the entropy technique for weighting, and grey relational analysis for ranking strategies. The main contribution is that prior investment strategies can be identified to overcome these legal challenges regarding the integration of renewable energy into urban development by creating a novel model. It is concluded that financial incentives and streamlined legal processes are significant for facilitating the sustainable transformation of urban areas. The main limitation is that the study mainly relies on expert evaluations to examine the legal challenges. An approach based on expert opinions has been adopted in your study. It is possible to mention some advantages of this application. However, using empirical data ensures that the results are more objective and generalizable. Using empirical data allows the information obtained from real-world data to be analyzed. As a result of this issue, the findings can become much more concrete. This also contributes to the decision-making process being more reliable. Future studies could focus on alternative weighting mechanisms to reduce reliance on expert judgments. On the other side, the model primarily utilizes expert evaluations rather than objective legal and economic data. Considering quantitative indicators in the following studies has a positive influence on the objectivity of the findings. In this context, data showing the effects of legal regulations and practices related to renewable energy integration can be used. To achieve this goal, publicly available reports, legal data sets or data obtained from government sources can be used. On the other hand, statistical data on incentives given by states for renewable energy projects can be used to address the effects of this practice on economic development. Another limitation of this study is that it focuses on the model, especially on legal processes. However, economic factors are another important dimension affecting renewable energy integration. Future studies may include financial sustainability and cost-effectiveness of renewable energy projects. On the other hand, social acceptance and social impacts of renewable energy projects can also be taken into account in this context. With the help of this condition, it can be understood how social dynamics shape decision-making processes.

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