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Integrating Pythagorean Fuzzy SAW and Entropy in Decision-Making for Legal Effectiveness in Renewable Energy Projects

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ABSTRACT

The most important factors must be identified to ensure efficient legal effectiveness for renewable energy projects. However, there are very few studies aimed at determining the most important factors affecting the legal effectiveness of these projects. This situation emerges as a very important gap in the legal effectiveness literature. Accordingly, this study aims to evaluate the most significant indicators of legal effectiveness in renewable energy projects. For this purpose, the main research question of this study is which are the priority strategies to ensure legal effectiveness for these projects. In this scope, four different factors are weighted via Pythagorean fuzzy entropy. Another evaluation was also implemented for the seven emerging (E7) countries in the following process. Within this framework, the Pythagorean fuzzy SAW technique is taken into consideration. The main motivation of this study is the strong need for a comprehensive evaluation to understand the key indicators of the legal effectiveness of renewable energy projects. Hence, the main contribution of this study is the generation of a novel decision-making model to reach this objective. It is concluded that understanding the challenges is the most important criterion.

Similarly, defining comprehensive standards also plays a crucial role in this framework. However, developing long-term policies and a fast and fair licensing process have lower significance weights than the others. On the other side, the ranking results denote that Mexico and Russia are the most successful emerging countries with respect to the performance of legal effectiveness. On the other hand, China and Turkey have lower performance in this context.

1. Introduction

Legal regulations are important in increasing the performance of renewable energy investments. These projects make significant contributions to the social and economic development of countries. However, some disadvantages prevent the development of these projects. A very high number of initial investors is an important example of these obstacles [1]. If legal regulations are effective, incentive mechanisms can be designed correctly. In this context, thanks to practices such as effective

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tax deductions and grant programs, it is possible for investors to focus on renewable energy projects. On the other hand, effective legal regulations play a very important role in the easy implementation of renewable energy projects [2]. By creating these regulations correctly, bureaucratic processes in operational processes can be reduced to a minimum level. This situation contributes to attracting investors' attention to this issue. Similarly, effective legal regulations also enable the development of incentives for research studies. Thus, it is possible to develop renewable energy technologies [3].

There are some important factors that affect the effectiveness of legal regulations in increasing the performance of renewable energy investments. First, to increase the effectiveness of legal regulations, it is necessary to determine what the current difficulties in the sector are [4]. To achieve this goal, a very comprehensive analysis needs to be carried out. Understanding these challenges enables the development of the right strategies [5]. On the other hand, long-term and comprehensive policies and strategies should be developed to encourage renewable energy investments [6]. Thanks to the long-term determination of these policies, investors' confidence in the market increases. This situation provides the opportunity to increase renewable energy projects. The main reason for this is that investors give priority to projects they trust [7]. Fast and fair licensing processes also enable legal regulations for renewable energy projects to be effective. In this context, bureaucratic obstacles to this process should be minimized and the processes should be facilitated [8]. Finally, comprehensive standards and regulations for renewable energy projects should be established [9]. This situation helps reduce uncertainties in the investment process.

It is very important to ensure legal effectiveness for renewable energy projects. To achieve this goal, improvements must be made for many different variables. However, making these improvements can be costly and take a lot of time [10]. Therefore, making too many improvements is not very reasonable from a resource management perspective [11]. In this context, the most important factors need to be identified. In this way, it is possible to make improvements on more important issues [12]. This allows both the budget to be managed more effectively and the time to be used efficiently. However, when the studies in the literature are examined, there are very few studies aimed at determining the most important factors affecting legal effectiveness. This situation emerges as a very important gap in the legal effectiveness literature [13]. A new study on this subject will provide significant guidance to both policy makers and investors.

Accordingly, in this study, it is aimed to make evaluations with respect to the most significant indicators of legal effectiveness in renewable energy projects. In this context, the main research question of this study is which are the priority strategies to ensure legal effectiveness for these projects. For this purpose, a detailed literature evaluation is conducted, and four different factors are identified. These criteria are weighted via Pythagorean fuzzy entropy. After that, another evaluation is also performed for E7 countries. In this framework, Pythagorean fuzzy SAW technique is taken into consideration. The main motivation of this study is the strong need for a comprehensive evaluation to understand the key indicators of the legal effectiveness of the renewable energy projects. Fuzzy decision-making models can be considered to satisfy this situation. Nonetheless, existing models are criticized due to some factors. Hence, the main contribution of this study is the generation of a novel decision-making model by overcoming these criticisms.

Methodology is explained in the following part. Analysis results are demonstrated in the third section. Conclusions are given in the final part.

2. Methodology

The Pythagorean Entropy-SAW approach is recommended in the analysis section. Since the Entropy method uses uncertain measure of data to determine weighting, it is known as an objective weighting technique. This yields criterion weights that are more realistic. The SAW technique's ease of calculation and comprehension make it the useful model for rating the alternatives. Besides, the research is analyzed uncertainty in linguistic terms through the integration of Pythagorean Fuzzy sets. This section contains a presentation of the methods in detail. This section is given information about the hybrid model.

2.1 Pythagorean Fuzzy Entropy Method

The entropy technique is a weighting model that considers the degree of uncertainty in the data [14]. Because of this, this technique is an objective weighting method. Below is a summary of the procedures involved in integrating Pythagorean fuzzy sets [15].

Step 1: The Pythagorean fuzzy decision matrix is created [16].

Step 2: The overall entropy value of each criterion is computed.

Step 3: The weight of each criterion is calculated [17].

2.2 Pythagorean Fuzzy SAW Method

In multi-criteria decision-making techniques, SAW is a ranking model. Every alternative's overall preference value is considered by the approach [18]. Below are the steps to integrate Pythagorean fuzzy numbers [19].

Step 4: The decision matrix is determined.

Step 5: The values are normalized.

Step 6: The weighted normalized decision matrix is computed [20].

Step 7: The total preference values of alternatives are calculated.

Step 8: Alternatives are ranked according to total preference values [21].

3. Results

The findings of the analyzes are reported in this section.

3.1 Weighting Criteria using Pythagorean Fuzzy Entropy

Experts on the subject can be reached via e-mail. The criterion taken into account in the selection of experts is that they are academics who have publications in international indices on this subject. Three experts who return the e-mail evaluate each alternative at the criterion level, using the scale in Figure 1.

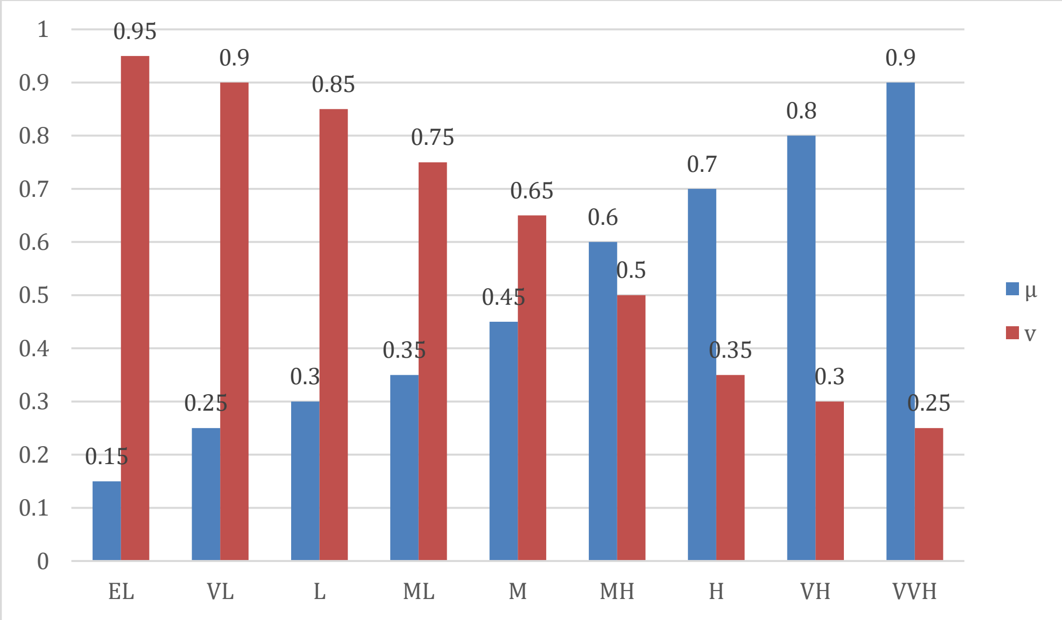

Fig. 1. Linguistic scale

Seven alternatives determined by three experts are evaluated at four criterion levels. In this process, selected criteria are given in Table 1.

Table 1
Criteria List

Criteria	Codes
Understanding the challenges	C1
Developing long-term policies	C2
Fast and fair licensing process	C3
Defining comprehensive standards	C4

E7 countries are defined as the alternatives that are Brazil (E1), China (E2), India (E3), Indonesia (E4), Mexico (E5), Russia (E6) and Turkey (E7). Evaluation results are shared in Table 2.

Table 2
Evaluations

	CR1	CR2	CR3	CR4
Expert1				
E1	M	M	MH	MH
E2	ML	M	L	MH
E3	VH	VH	MH	MH
E4	H	VL	M	H
E5	ML	MH	VH	VH
E6	VVH	MH	VH	H
E7	M	VVH	M	L
Expert2				
	CR1	**CR2**	**CR3**	**CR4**
E1	VH	ML	M	H
E2	ML	H	VH	ML
E3	VH	ML	VH	EL
E4	M	VH	L	VVH
E5	VVH	VVH	VH	M
E6	MH	MH	VH	H
E7	EL	VVH	MH	ML
Expert3				
	CR1	**CR2**	**CR3**	**CR4**
E1	H	ML	VL	MH
E2	EL	M	VL	VH
E3	ML	VL	M	ML
E4	L	EL	VVH	VVH
E5	EL	VVH	VVH	MH
E6	M	EL	H	H
E7	L	MH	M	MH

Fuzzy number equivalents of expert evaluations are obtained. Next, the decision matrix is created by averaging the fuzzy evaluation numbers. The decision matrix is summarized in Table 3.

Table 3
The Pythagorean Fuzzy Decision Matrix

	CR1		CR2		CR3		CR4	
E1	.6877	.4087	.3873	.7151	.4667	.6638	.6377	.4440
E2	.3006	.8115	.5594	.5288	.5704	.6122	.6427	.4827
E3	.7180	.4072	.5774	.5872	.6569	.4603	.4257	.7089
E4	.5311	.5783	.5559	.6354	.6953	.5169	.8579	.2797
E5	.6736	.5627	.8457	.3150	.8421	.2823	.6569	.4603
E6	.7352	.4331	.5128	.6193	.7718	.3158	.7000	.3500
E7	.3288	.8067	.8457	.3150	.5088	.5956	.4478	.6831

After the Pythagorean fuzzy decision matrix is created, the entropy value of each evaluation is calculated. Entropy values are given in Table 4.

Table 4
The Entropy Values

	CR1	CR2	CR3	CR4
E1	.8884	.8630	.9181	.9282
E2	.7451	.9889	.9810	.9352
E3	.8646	.9958	.9208	.8761
E4	.9820	.9631	.9107	.6711
E5	.9422	.6979	.6975	.9208
E6	.8554	.9568	.7957	.8679
E7	.7568	.6979	.9672	.9004

By averaging the entropy values, the entropy values of the criteria are obtained. Finally, the weights of the criteria are found. Entropy and weights of the criteria are depicted in Figure 2.

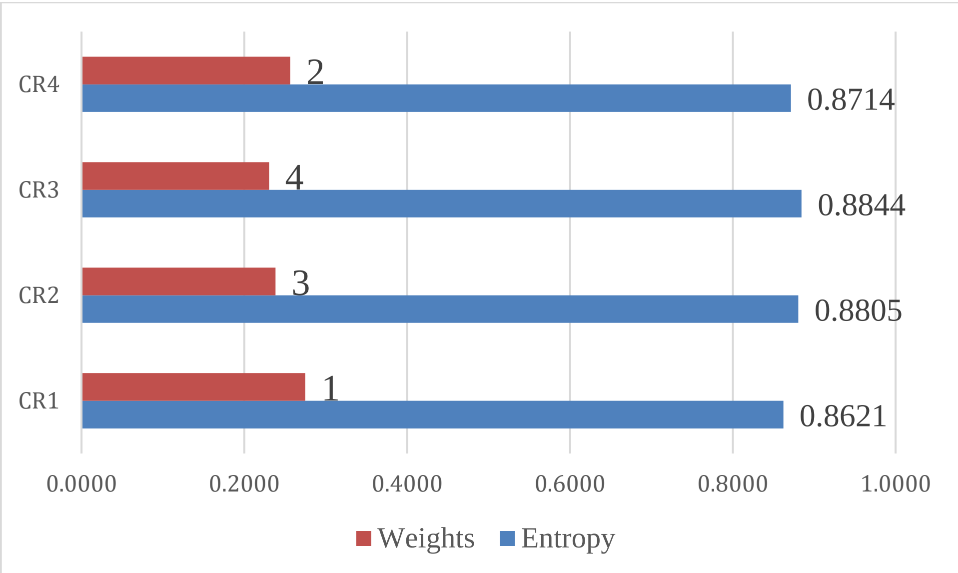

Fig. 2. The Entropy Values and Weights of the Criteria

According to the weights of the criteria in Figure 2, understanding the challenges is the most important criterion. Similarly, defining comprehensive standards also plays a crucial role in this framework. However, developing long-term policies and fast and fair licensing process have lower significance weights in comparison with the other ones.

3.2 Ranking the Alternatives using Pythagorean Fuzzy SAW

Since the SAW method is preferred for ranking the alternatives, as a first step, the values in Table 3 are normalized. For the normalization process, the highest score value of the evaluations for each criterion is calculated. Each evaluation is divided by the highest score value of its criterion. For division operation, the values are multiplied by the score value divided by 1. The normalized matrix is presented in Table 5.

Table 5
Normalized Matrix

	CR1		CR2		CR3		CR4	
E1	.9149	.0792	.4816	.5801	.5685	.5215	.7401	.2909
E2	.4851	.5533	.6755	.3555	.6818	.4586	.7451	.3305
E3	.9336	.0784	.6945	.4214	.7696	.2914	.5119	.5927
E4	.7803	.2119	.6717	.4789	.8061	.3505	.9316	.1441
E5	.9054	.1961	.9326	.1533	.9270	.1341	.7591	.3074
E6	.9432	.0934	.6250	.4593	.8734	.1602	.8005	.2027
E7	.5262	.5440	.9326	.1533	.6154	.4389	.5370	.5602

Afterwards, the normalized values are multiplied by the weights of the criteria to obtain the weighted normalized matrix. The weighted normalized matrix is illustrated in Table 6.

Table 6
The Weighted Normalized Matrix

	CR1		CR2		CR3		CR4	
E1	.6267	.4981	.2468	.8783	.2933	.8607	.4291	.7286
E2	.2667	.8498	.3676	.7816	.3663	.8356	.4331	.7528
E3	.6568	.4966	.3810	.8139	.4322	.7527	.2738	.8745
E4	.4769	.6527	.3650	.8391	.4634	.7854	.6364	.6085
E5	.6129	.6389	.6203	.6397	.6030	.6294	.4445	.7389
E6	.6741	.5211	.3336	.8308	.5312	.6558	.4805	.6641
E7	.2920	.8459	.6203	.6397	.3223	.8272	.2890	.8619

Finally, row totals are calculated for each alternative. Pythagorean fuzzy row sums are defuzzified. Alternatives are ranked according to the magnitude of the defuzzified row totals. The ranking of the alternatives is visualization in Figure 3.

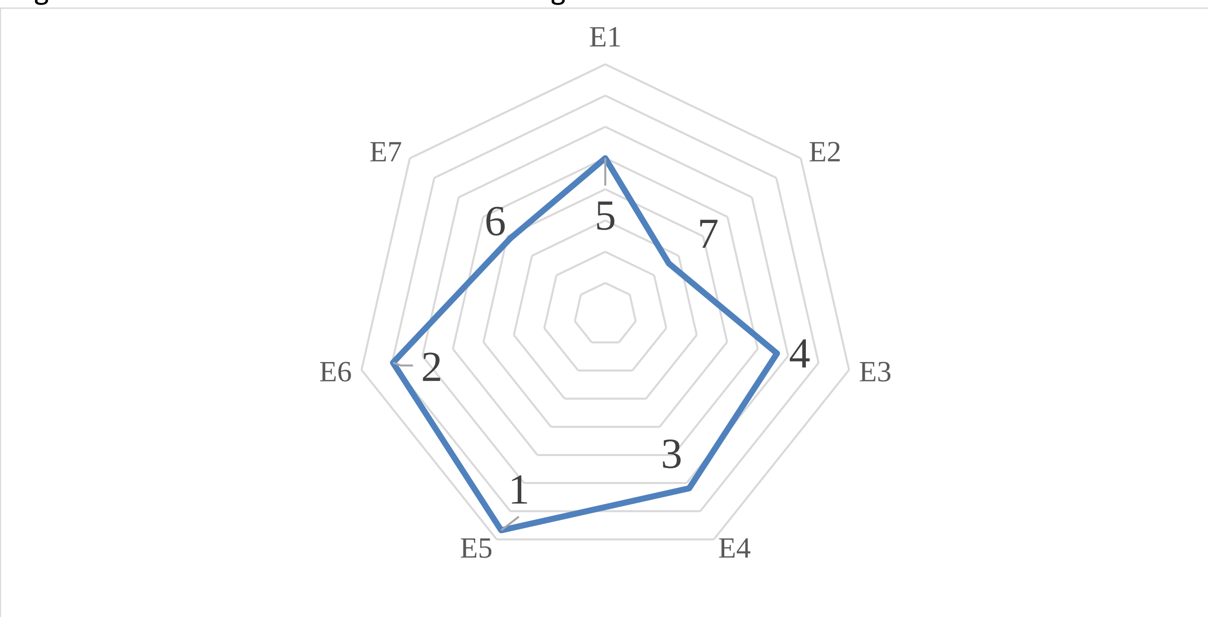

Fig. 3. The Rankings of the Alternatives

According to Figure 3, the most successful emerging countries with respect to the performance of the legal effectiveness are Mexico and Russia. On the other hand, China and Turkey have lower performance in this context.

3.3 Sensitivity Analysis

In the multi-criteria decision-making literature, results are compared with different weighting scenarios for the consistency and sensitivity of the results of ranking models. SAW results for five scenario situations are plotted in Figure 4.

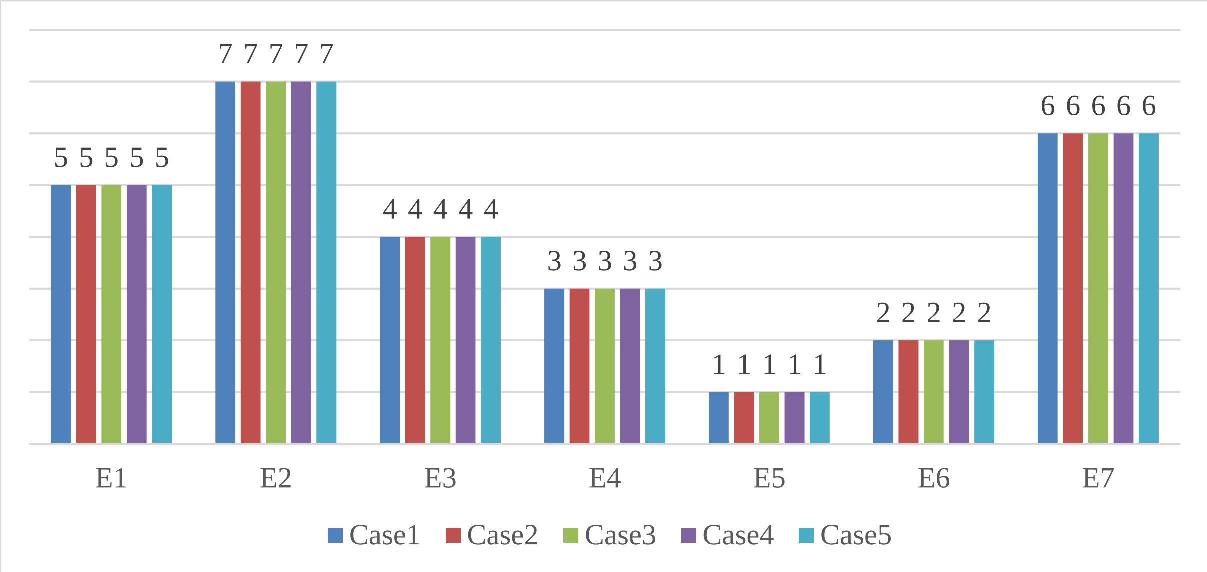

Fig. 4. The Result of Sensitivity Analysis

As can be seen from the sensitivity analysis, the ranking of the alternatives is similar. There is no change in the priority order for different scenarios. This situation gives information about the coherency and reliability of the findings.

4. Conclusions

This study makes evaluations with respect to the most significant indicators of legal effectiveness in renewable energy projects. In this process, the main research question of this study is which are the priority strategies to ensure legal effectiveness for these projects. Within this scope, four different factors are weighted via Pythagorean fuzzy entropy. In the following process, another evaluation is also implemented for E7 countries. In this framework, Pythagorean fuzzy SAW technique is taken into consideration. It is identified that understanding the challenges is the most important criterion. Similarly, defining comprehensive standards also plays a crucial role in this framework. However, developing long-term policies and fast and fair licensing process have lower significance weights in comparison with the other ones. On the other side, the ranking results denote that the most successful emerging countries with respect to the performance of the legal effectiveness are Mexico and Russia. On the other hand, China and Turkey have lower performance in this context.

The main motivation of this study is the strong need for a comprehensive evaluation to understand the ley indicators of the legal effectiveness of the renewable energy projects. Fuzzy decision-making models can be considered to satisfy this situation. Nonetheless, existing models are criticized due to some factors. Hence, the main contribution of this study is the generation of a novel decision-making model by overcoming these criticisms. However, the main limitation of this study is that a general evaluation is conducted for the renewable energy projects. Nevertheless, the results can be different for each type of renewable energy investments. Hence, a specific evaluation can be conducted in the following studies. On the other side, the main limitation of the proposed model is that the significance weights of each expert are assumed as equal. Thus, for future research direction, artificial intelligence or machine learning approaches can be integrated into fuzzy decision-making modelling for the purpose of calculating the weights of these people.

Author Contributions

Conceptualization, S.E. and S.Y.; methodology, S.E. and S.Y.; software, S.E. and S.Y.; validation, S.E. and S.Y.; formal analysis, S.E. and S.Y.; investigation, S.E. and S.Y.; resources, S.E. and S.Y.; data curation, S.E. and S.Y.; writing—original draft preparation, S.E. and S.Y.; writing—review and editing, S.E. and S.Y.; visualization, S.E. and S.Y.; supervision, S.E. and S.Y.; project administration, S.E. and S.Y.; funding acquisition, S.E. and S.Y. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

There is no data in this study.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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