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Comprehensive Risk Analysis and Decision-Making Model for Hydroelectricity Energy Investments

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ABSTRACT

The risks of hydroelectricity energy investments should be managed effectively to increase the performance of these projects. Thus, more significant risks should be identified to take effective measures for risk management without experiencing high costs. Accordingly, the purpose of this study is to define critical risks in hydroelectricity energy investment projects by making a priority analysis. Within this scope, a new decision-making model is created. In the first stage, five different risks are examined by considering Spherical fuzzy Entropy. Moreover, the second stage consists of ranking emerging seven countries with the help of Spherical fuzzy multi-attribute ideal-real comparative assessment (MAIRCA). The main contribution of this study is that more important risks of hydroelectricity energy investments can be identified by the help of the priority analysis. This situation provides an opportunity to implement effective strategies to increase these investments without having high costs. Additionally, considering Spherical fuzzy sets has a positive impact on the appropriateness of the results. Since these numbers use a wider data range, the effectiveness of the analysis results can increase. It is determined that the most important risk is environmental risk with the highest weight value of 0.2478. Financial risks and personnel risks are other significant factors that affect the performance of the hydroelectricity energy investments. Furthermore, as a result of ranking the alternatives, it is seen that China is the most suitable country for hydroelectric energy investments. India and Mexico are other successful countries in this respect. However, Turkey and Indonesia have lower performance for this situation.

1. Introduction

Hydroelectric energy uses the natural movement and height of water to generate energy. Hydropower is a clean energy that does not require fossil fuels. Furthermore, hydropower plants are also used for energy storage. In addition, it has advantages in irrigation. Therefore, investments in hydropower are an important consideration. Hydroelectric energy projects are a clean type of energy because energy is obtained using natural resources. Therefore, the use of this energy plays a very

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important role in tackling vital problems such as global warming. On the other hand, since the water flow is continuous, it is possible to obtain uninterrupted electricity in hydroelectric energy projects [1]. Moreover, the maintenance costs of hydroelectric power plants are quite low compared to other types of energy. Thus, it is possible to increase the cost effectiveness of these projects.

However, many risks affect investments in hydropower. Hydroelectric energy investments are large-scale projects. This situation increases the financial risks in the projects. In this context, the necessary financial resources must be provided at a reasonable cost. Otherwise, the profitability of the projects will be negatively affected. On the other hand, market risks should also be taken into account in this process. Especially sharp fluctuations in energy prices can negatively affect the performance of projects. In addition, legal risks can also negatively affect the performance of hydroelectric energy investments [2]. In this context, it is important to examine in detail the legal conditions of the country where the investment is made. Moreover, environmental risks are other important issues that should be taken into account in this process. Hydroelectric projects that are not designed correctly can harm the ecosystem. Furthermore, climate change also poses a significant risk in hydroelectric projects. In this context, if the rains are less, the water levels will decrease. This situation may cause a decrease in the amount of energy production.

These risks must be managed effectively to increase the performance of hydroelectric energy investments. On the other hand, the measures taken to minimize each risk create new costs. This situation causes the cost efficiency of businesses to decrease. Therefore, it is necessary to identify the risks that are most important. In this way, investors will be able to take effective measures for risk management without experiencing very high-cost increases. This contributes significantly to increasing the efficiency of the projects. When the studies in the literature are examined, it is seen that there are a limited number of studies focusing on this issue. Therefore, a new study is needed in which priority analysis is made for these risks. Accordingly, this study aims to find critical risks in hydroelectricity energy investment projects by making a priority analysis. In this framework, a new decision-making model is constructed. At the first stage, five different risks are evaluated by considering Spherical fuzzy Entropy. Additionally, the second stage includes ranking emerging seven countries with the help of Spherical fuzzy MAIRCA.

The main contributions of this study are given below. (i) More significant risks of hydroelectricity energy investments can be identified with the help of the priority analysis. This condition provides an opportunity to implement effective strategies to increase these investments without having high costs. (ii) Using Spherical fuzzy sets has a positive influence on the appropriateness of the results. Because these sets can consider a wider data range, the effectiveness of the analysis results can increase. (iii) The decision-making methods used in the study also increase the superiority of the model. Since entropy management is an objective method, it is considered to be more valid in weighting. The MAIRCA method, like other ranking methods, prefers the probability distribution instead of the optimal value. This gives the MAIRCA method a significant advantage over others.

Literature review is explained in the second part. Methodology is given in the third section. The fourth section consists of analysis results. Finally, conclusion and discussion are identified.

2. Literature Review

Environmental risks are very crucial for the effectiveness of hydroelectric energy investments [3]. If they are not appropriately designed, hydroelectric energy investments can negatively affect the aquatic ecosystem. These projects can also cause water or soil erosion. If not managed well, it can even lead to a decrease in water quality. Rahman et al. [4] examined the environmental impacts of renewable energies such as solar, wind, and hydropower. In addition, a comparative analysis was conducted for renewable energy types. It is stated that renewable energies such as hydropower directly affect the environment. Özbay et al. [5] conducted a study regarding the relationship between environmental sustainability and hydropower consumption. It is stated that there is a strong relationship between these indicators. Bayazıt [6] carried out the impact of hydroelectric power plants on carbon emissions. It is concluded that hydropower plants directly affect environmental factors. Okang et al. [7] determined that there is a strong relationship between hydropower consumption and environmental sustainability.

Another important issue affecting the performance of hydroelectric power investments is technical risks. Technical risks refer to construction, maintenance, operation, climatic conditions, and geographical location [8]. Furthermore, reductions in water resources due to climate changes can affect hydropower potential [9]. In addition, high technology and qualified personnel are needed in cases such as equipment breakdowns. Repair and maintenance costs can be high [10]. Hashemizadeh et al. [11] examined the risk assessment of renewable energy investments. It is defined that technical risks should be mainly taken into consideration in renewable energy investments. Bai [12] investigated the investment risks in clean energy projects. It is concluded that technical risks should be considered when investing in these projects. Abba et al. [13] conducted a study to present holistic risk management for renewable energy investments. They mentioned that technical risk assessments are a part of holistic risk management. Karamoozian et al. [14] and Zai et al. [15] highlighted that energy investments should consider technical risks.

Financial risks are also critical with respect to the performance improvements of hydroelectric energy investments. These risks can affect the success and sustainability of hydropower investments [16]. The initial investment costs of these projects are quite high [17]. In addition, fluctuations in energy prices will reveal the financing risks in these projects [18]. Additionally, these projects may have high operation and maintenance costs. High technology is needed for the cost decrease in hydroelectric energy projects. At the same time, qualified personnel who can use high technology are also required in this process [19]. İpin and Ercan [20] investigated the financing alternatives of hydroelectric power plants. They emphasized the importance of financial problems in hydroelectric energy investments. Gyanwali et al. [21] conducted a study in Nepal and mentioned the importance of financial factors for the sustainability of these investments. Li et al. [22] made a study to reduce the risks in the hydropower generation system. It is concluded that one of the risks to be reduced is financial risks. Lauro et al. [23] and Martins et al. [24] identified that financial risks should be considered in energy investments.

Legal risks should also be considered to increase the effectiveness of hydroelectric energy projects [25]. There are licenses and permits required for hydroelectric power plants. Obtaining these licenses and meeting the requirements may take time. Moreover, these projects are obliged to comply with environmental regulations [26]. In addition, tax breaks and incentives play an important role in investments [27]. Wojewnik-Filipkowska et al. [28] conducted a study analyzing renewable energy investments under uncertainty and risk conditions. The importance of legal issues is emphasized for these investments to achieve their objectives. Cheng and Zhou [29] investigated the investment barriers of countries along the Maritime Silk Road. One of these barriers for the performance improvements of these projects is legal processes. Wuni et al. [30] examined the risks of green projects in Great Britain. They highlighted the significance of the legal risks in this framework. Słotwiński [31] and Zoričić et al. [32] concluded that legal risks should be primarily considered in energy investments.

As a result of the literature review, the following conclusions can be achieved. Hydroelectric energy plays a crucial role for the economic and social improvements. The number of studies on this subject has increased especially in recent years. Most of the studies are related to the importance of hydroelectric energy investments. However, studies on the issues affecting this process are quite limited. Therefore, a prioritization study should be conducted for this situation, which is missing in the literature. Accordingly, this study aims to develop a strategy against the most important risks of hybrid energy investments.

3. Methodology

In this section, information is given about the techniques used to weighting of criteria and to ranking of the alternatives. First, the decision matrix that is used jointly in both methods is created. For this purpose, experts' opinions are collected with the scales in Table 1. Then, it is converted into the Spherical fuzzy numbers where μ refers to membership degree, v denotes a non-membership degree and π shows hesitancy degree of set.

Table 1
Linguistic Variables

Scale-Term	μ	v	π
1	0.1	0.9	0.1
2	0.2	0.8	0.2
3	0.3	0.7	0.3
4	0.4	0.6	0.4
5	0.5	0.5	0.5
6	0.6	0.4	0.4
7	0.7	0.3	0.3
8	0.8	0.2	0.2
9	0.9	0.1	0.1

Then, the decision matrix (D) is created by taking the average of expert opinions with Equation (1). The decision matrix is expressed with Equation (2).

$$SWAM(D_{s1}, D_{s2}, \dots, D_{sk}) = \left\{ \left[1 - \prod_{i=1}^{n} \left(1 - \mu_{D_{si}}^2\right)^{1/k}\right]^{1/2}, \prod_{i=1}^{n} v_{D_{si}}^{1/n}, \left[\prod_{i=1}^{n} \left(1 - \mu_{D_{si}}^2\right)^{1/k} - \prod_{i=1}^{n} \left(1 - \mu_{D_{si}}^2 - \pi_{D_{si}}^2\right)^{1/k}\right]^{1/2} \right\} \tag{1}$$

$$D = \begin{bmatrix} (\mu_{11}, v_{11}\pi_{11}) & \cdots & (\mu_{m1}, v_{m1}, \pi_{m1}) \\ \vdots & \ddots & \vdots \\ (\mu_{1n}, v_{1n}, \pi_{1n}) & \cdots & (\mu_{mn}, v_{mn}, \pi_{1mn}) \end{bmatrix} \tag{2}$$

3.1 Spherical Fuzzy Entropy

The entropy method is preferred as an objective weighting method in multi-criteria decision making. The basic logic of this method is to calculate the uncertainty value in the criteria. In the proposed model, spherical fuzzy numbers and the entropy method are integrated. The steps of the model are given below [33]. First, the entropy values (E) of the criteria are calculated with the help of Equation (3).

$$E_j = \frac{1}{n} \sum_{i=1}^{n} \left(1 - \frac{4}{5}\left[\left|\mu_{ij}^2 - v_{ij}^2\right| + \left|\pi_{ij}^2 - 0.25\right|\right]\right) \tag{3}$$

Divergence value (div) is calculated by Equation (4).

$$div_j = 1 - E_j \tag{4}$$

Finally, the weights (w) of the criteria are calculated by Equation (5).

$$w_j = \frac{div_j}{\sum_{j=1}^{m} div_j} \tag{5}$$

3.2 Spherical Fuzzy MAIRCA

MAIRCA method is used to ranking of alternatives. In the calculation of this method, the theoretical evaluation obtained from uniform distribution is taken into account. The alternatives are ranked by taking the difference between the theoretical evaluation and the actual evaluation. In the second method of the study, MAIRCA and spherical fuzzy numbers are integrated. The steps of this integrated method are as follows [34]. First, the preference probabilities (P_{Bi}) are calculated with Equation (6). Uniform distribution is used for this issue.

$$P_{Bi} = \frac{1}{m} \tag{6}$$

Then, the theoretical evaluation matrix (Kp) is created by Equation (7). For this, criteria weights and the preference probabilities are multiplied. Here, w_i is the weights of the criteria.

$$K_p = \begin{bmatrix} k_{p11} & \cdots & k_{p1n} \\ \vdots & \ddots & \vdots \\ k_{pm1} & \cdots & k_{pmn} \end{bmatrix} = \begin{bmatrix} P_{B1}w_1 & \cdots & P_{B1}w_n \\ \vdots & \ddots & \vdots \\ P_{Bm}w_1 & \cdots & P_{Bm}w_n \end{bmatrix} \tag{7}$$

The decision matrix in Equation (3) is defuzzified with score function (S). Score function is given by Equation (8).

$$S(\check{A}_s) = (\mu_{\widetilde{A_s}} - \pi_{\widetilde{A_s}})^2 - (v_{\widetilde{A_s}} - \pi_{\widetilde{A_s}})^2 \tag{8}$$

The actual evaluation matrix (Kr) is calculated by the help of Equations (9) and (10) where $\boldsymbol{d_{ij}}$ is the element of the decision matrix.

$$k_{rij} = k_{pij}\left(\frac{S(\widetilde{d_{ij}}) - \min\left(S(\widetilde{d_{ij}})\right)}{\max\left(S(\widetilde{d_{ij}})\right) - min\left(S(\widetilde{d_{ij}})\right)}\right) \qquad for\ benefit\ criteria \tag{9}$$

$$k_{rij} = k_{pij}\left(\frac{S(\widetilde{d_{ij}}) - \max\left(S(\widetilde{d_{ij}})\right)}{\min\left(S(\widetilde{d_{ij}})\right) - max\left(S(\widetilde{d_{ij}})\right)}\right) \qquad for\ cost\ criteria \tag{10}$$

Total gap matrix (G) is created with Equation (11).

$$G = K_p - K_r = \begin{bmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mn} \end{bmatrix} = \begin{bmatrix} k_{p11} - k_{r11} & \cdots & k_{p1n} - k_{r1n} \\ \vdots & \ddots & \vdots \\ k_{pm1} - k_{rm1} & \cdots & k_{pmn} - k_{rmn} \end{bmatrix} \tag{11}$$

Finally, the final score (Ui) for each alternative is calculated with Equation (12). The value with the lowest final score is determined as the best alternative.

$$U_i = \sum g_{ij} \tag{12}$$

4. Analysis Results

In the findings section, calculation of the decision matrix, determination of criterion weights and ranking of alternatives are discussed, respectively. Each analysis is given as subtitles.

4.1 Creating Decision Matrix

First of all, the main risks that affect the performance of hydroelectricity investments are defined based on the literature review results. In this framework, five main risks are selected that are technical risks, financial risks, environmental risks, personnel risks, and legal risks. Decision matrix is obtained by using expert opinions. Expert opinions are provided from three decision-makers according to the scale in Table 1. The evaluations are denoted in Table 2.

Table 2
Expert Opinions

	Technical Risk	Financial Risk	Environmental Risk	Personnel Risk	Legal Risk
Expert 1					
Brazil	5	4	9	1	6
China	1	3	7	6	2
India	6	1	3	1	4
Indonesia	7	6	3	4	7
Mexico	4	5	1	6	5
Russia	5	6	1	6	7
Turkey	6	2	2	4	5
Expert 2					
	Technical Risk	Financial Risk	Environmental Risk	Personnel Risk	Legal Risk
Brazil	4	3	3	2	6
China	2	6	2	1	5
India	7	2	1	6	7
Indonesia	5	5	5	9	5
Mexico	5	2	3	3	1
Russia	6	3	4	5	6
Turkey	4	1	3	1	7
Expert 3					
	Technical Risk	Financial Risk	Environmental Risk	Personnel Risk	Legal Risk
Brazil	7	4	1	3	3
China	1	1	3	3	1
India	5	6	9	4	1
Indonesia	5	6	7	6	7
Mexico	8	6	4	5	5
Russia	2	1	3	4	7
Turkey	6	6	8	7	4

Expert opinions are converted into spherical fuzzy numbers using the Table 1 and averaged with the help of Equation (1). Decision matrix is shown in Table 3.

Table 3
Decision Matrix

	Technical Risk			**Financial Risk**			**Environmental Risk**			**Personnel Risk**			**Legal Risk**		
Brazil	0.56	0.45	0.51	0.37	0.63	0.40	0.67	0.40	0.12	0.22	0.80	0.10	0.53	0.48	0.40
China	0.14	0.87	0.10	0.41	0.63	0.30	0.49	0.55	0.31	0.41	0.63	0.40	0.33	0.71	0.20
India	0.61	0.39	0.40	0.39	0.66	0.10	0.67	0.40	0.37	0.44	0.60	0.10	0.50	0.55	0.41
Indonesia	0.58	0.42	0.30	0.57	0.43	0.40	0.54	0.47	0.31	0.73	0.29	0.50	0.65	0.36	0.30
Mexico	0.62	0.39	0.42	0.48	0.54	0.51	0.30	0.72	0.10	0.49	0.52	0.40	0.42	0.61	0.50
Russia	0.48	0.54	0.51	0.41	0.63	0.40	0.30	0.72	0.10	0.51	0.49	0.40	0.67	0.33	0.30
Turkey	0.55	0.46	0.40	0.39	0.66	0.20	0.57	0.48	0.21	0.50	0.55	0.41	0.56	0.45	0.51

4.2 Computing the Weights of the Indicators

Entropy value of each criterion is calculated by Equation (3). Then, the divergence value is obtained with the help of Equation (4). Finally, the weights of each criterion are calculated using Equation (5). The values obtained in the calculations are given in Table 4.

Table 4
Entropy, Divergence Values and Weights

Criteria	E	Div	Weights	Rank
Technical Risk	0.7393	0.2607	0.1873	4
Financial Risk	0.7285	0.2715	0.1950	2
Environmental Risk	0.6550	0.3450	0.2478	1
Personnel Risk	0.7304	0.2696	0.1937	3
Legal Risk	0.7548	0.2452	0.1762	5

Table 4 denotes the most important risk is environmental risk with the highest weight value of 0.2478. Financial risks and personnel risks are other critical issues that affect the performance of the hydroelectricity energy investments.

4.3 Ranking of Alternatives

Firstly, the preference probability value is calculated with Equation (6) as 0.1429. Then, the theoretical evaluation matrix is calculated by Equation (7). The weights used here are the weights obtained by the Spherical fuzzy entropy method. The theoretical evaluation matrix is given in Table 5.

Table 5
Theorical Evaluation Matrix

Country	Technical Risk	Financial Risk	Environmental Risk	Personnel Risk	Legal Risk
Brazil	0.0268	0.0279	0.0354	0.0277	0.0252
China	0.0268	0.0279	0.0354	0.0277	0.0252
India	0.0268	0.0279	0.0354	0.0277	0.0252
Indonesia	0.0268	0.0279	0.0354	0.0277	0.0252
Mexico	0.0268	0.0279	0.0354	0.0277	0.0252
Russia	0.0268	0.0279	0.0354	0.0277	0.0252
Turkey	0.0268	0.0279	0.0354	0.0277	0.0252

The decision matrix given in Table 3 is defuzzified by Equation (8). Afterwards, the actual evaluation matrix is obtained with Equation (10). The criteria in the study are cost criteria. The actual evaluation matrix is shown in Table 6.

Table 6
Actual Evaluation Matrix

Country	**Technical Risk**	**Financial Risk**	**Environmental Risk**	**Personnel Risk**	**Legal Risk**
Brazil	0.0027	0.0087	0.0000	0.0277	0.0083
China	0.0268	0.0135	0.0155	0.0033	0.0252
India	0.0009	0.0279	0.0084	0.0083	0.0097
Indonesia	0.0000	0.0000	0.0120	0.0000	0.0013
Mexico	0.0010	0.0031	0.0354	0.0006	0.0093
Russia	0.0027	0.0086	0.0354	0.0001	0.0000
Turkey	0.0019	0.0219	0.0106	0.0009	0.0091

In the last step of the method, the difference between the theoretical evaluation matrix and the actual evaluation matrix is taken by the help of Equation (11). Thus, the gap matrix (*G*) is calculated.

Then, the *U* values are obtained by taking the row sums of the G matrix with Equation (12). G matrix and U values are given in Table 7.

Table 7
Gap Matrix and U values

Country	Technical Risk	Financial Risk	Environmental Risk	Personnel Risk	Legal Risk	U	Rank
Brazil	0.0240	0.0191	0.0354	0.0000	0.0168	0.0954	4
China	0.0000	0.0144	0.0199	0.0244	0.0000	0.0586	1
India	0.0259	0.0000	0.0270	0.0194	0.0155	0.0878	2
Indonesia	0.0268	0.0279	0.0234	0.0277	0.0239	0.1296	7
Mexico	0.0257	0.0248	0.0000	0.0270	0.0159	0.0934	3
Russia	0.0241	0.0193	0.0000	0.0276	0.0252	0.0961	5
Turkey	0.0248	0.0059	0.0248	0.0268	0.0161	0.0984	6

Table 7 demonstrates that China is the most suitable country for hydroelectric energy investments. India and Mexico are other successful countries in this respect. However, Turkey and Indonesia have lower performance for this situation.

5. Discussion and Conclusion

The aim of this study is to identify the critical risks in hydroelectricity energy investment projects by making a priority analysis. For this purpose, a new decision-making model is generated. Firstly, five different risks are examined by Spherical fuzzy Entropy. On the other side, the second stage consists of ranking emerging seven countries with the help of Spherical fuzzy MAIRCA. It is determined that the most important risk is environmental risk with the highest weight value of 0.2478. Financial risks and personnel risks are other significant factors that affect the performance of the hydroelectricity energy investments. Furthermore, as a result of ranking the alternatives, it is seen that China is the most suitable country for hydroelectric energy investments. India and Mexico are other successful countries in this respect. However, Turkey and Indonesia have lower performance for this situation.

It is understood that environmental risks are of great importance in increasing the performance of hydroelectric energy projects. These projects are directly related to the surrounding ecosystem because they use natural water resources. The biggest risk of established dams is that they change the direction of water resources. Adebayo et al. [35] discussed that if the necessary measures are not taken, there is a risk that certain areas will be submerged. This situation causes many people to lose their lives and many buildings to be damaged. As a result, the effectiveness of hydroelectric energy projects will decrease, and their image will be negatively affected in people's eyes. To effectively manage this risk, it is important to carry out periodic maintenance works. On the other hand, Cribari-Neto et al. [36] identified that since these projects change the flow of water, significant decreases in water quality may occur. This situation negatively affects regional agriculture. Therefore, before the establishment of this project, a comprehensive environmental analysis is required. In addition, the quality of the water should be analyzed periodically. This allows precautions to be taken early in case of a possible problem.

The main contribution of this study is that more important risks of hydroelectricity energy investments can be identified by the help of the priority analysis. This situation provides an opportunity to implement effective strategies to increase these investments without having high costs. Additionally, considering Spherical fuzzy sets has a positive impact on the appropriateness of the results. Since these numbers use a wider data range, the effectiveness of the analysis results can increase. Finally, entropy is considered as more valid in weighting because it makes an objective assessment. However, the main limitation is that the evaluation is made only for emerging economies. Hydroelectricity energy investments play a crucial role for developed economies as well. There are many energy dependent developed economies although they have powerful economies. Hence, a new study can be carried out for these economies to increase the effectiveness of the hydroelectricity energy projects.

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Conflicts of Interest

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