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APPLICATION OF THE FUZZY TOPSIS METHOD FOR RANKING RENEWABLE ENERGY ELECTRICITY GENERATION PROJECTS

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Abstract

An imperative placed on companies in the electricity power sector is to invest in new capacities for electricity generation from renewable energy sources, with the aim of increasing energy portfolio flexibility, improving energy efficiency, and reducing emission of pollutants and greenhouse gases. These objectives are also pursued through the acquisition of projects via public tender, based on predefined evaluation criteria. Due to budget constraints for this purpose, it is necessary to rank the offered renewable energy electricity generation projects (hydropower, wind, and photovoltaic). The paper proposes an effective solution to project ranking problem based on the use of the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) method with an illustrative case study. The findings are presented, and additional research implications outlined.

Keywords: Renewable energy projects; Ranking problem; Fuzzy Technique for Order Preference by Similarity to Ideal Solution.

1. Introduction

The Energy Community Treaty signed in 2006, between the European Union (EU) and the countries of Southeast Europe, aims to generate an integrated energy market and assist in the integration of these nations into the energy structure of the EU. Another major goal of the Treaty is to improve the environmental situation in terms of energy sources provision and promote renewable energy sources (RES) and energy efficiency. The EU has announced its intentions of becoming climate-neutral by 2050, as part of the European Green Deal. The way to accomplish this objective is by reducing dependency on fossil fuel, and by using more clean technologies, as well as by making energy more efficient. Potential candidate and candidate countries to EU membership like Bosnia and Herzegovina, are expected to embrace and follow EU policies on climate and energy. Slow progress in this process may hurt their EU membership endeavours. The Indicative Energy Strategy of Bosnia and Herzegovina up to 2035 envisages priorities in the development of the energy sector, grouped around three pillars - supply security, competitive pricing and decarbonization [1]. The business strategy of the leading electric utility in the country Elektroprivreda Bosne i Hercegovine (EPBiH) uses these principles as well. However, EPBiH works in a difficult political and legal environment which often creates delays in the planning and implementation of renewable energy projects. Such an environment slows the rate of energy transition. To increase renewable energy holdings, EPBiH was inspired by the example of Hrvatska elektroprivreda (HEP) that has attempted to develop superior renewable energy sources via acquisitions. The level of use of RES, especially solar energy, is still not at a satisfactory level in Bosnia and Herzegovina [2].

In 2020, EPBiH announced its first public tender to buy RES projects to generate electricity from independent producers. Since funding on such investments is limited, the evaluation criteria should be defined to maintain transparency in the selection process, supported by a suitable ranking method. EPBIH ranked the projects by deploying a linear combination of predefined, fixed weight criteria, considering levelized cost of electricity, installed capacity, and the project implementation stage [3].

The paper [4] illustrates application of multi-criteria decision analysis, which is a combination of Analytic Hierarchy Process (AHP) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). AHP is used as a tool to generate relative importance of the criteria and PROMETHEE is applied to evaluate and rank alternatives (small hydropower projects).

In the paper [5], the criteria for RES electricity generation projects ranking are comprehensively defined, and their relative weights were computed using the Fuzzy Analytic Hierarchy Process (FAHP), with local weights derived through Buckley's geometric mean method.

This paper addresses the problem of ranking renewable energy projects for electricity generation in the acquisition process through a public tender. Project ranking is based on nine criteria categorized into three groups: technical, economic, and environmental criteria [5]. Due the nature of the criteria and the incompleteness of available information, a fuzzy approach is applied because it can handle uncertain and imprecise data [6]. The Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) method is used in this paper for ranking problem solving in fuzzy environment.

2. FTOPSIS method

Fuzzy TOPSIS is a multi-criteria method that integrates fuzzy approach and TOPSIS method to be more effective with imprecise data. This method allows ranking alternatives when the data is either unclear or not precise enough. In contrast to the traditional TOPSIS method which operates only using the correct and precise information (classical numbers), fuzzy TOPSIS considers uncertainty and imprecision of the information based on the concepts of fuzzy logic [7]. Chen extended the TOPSIS method with triangular fuzzy numbers which in general can be from various fuzzy scales [8]. The fuzzy scale (linguistic variable values and corresponding fuzzy numbers) used by Chen are shown in Table 1. The application of Chen's fuzzy TOPSIS method consists of six steps [9].

Linguistic variable values	Fuzzy number
Very low importance	(0,0,0.1)
Low importance	(0,0.1,0.3)
Medium-low importance	(0.1,0.3,0.5)
Medium importance	(0.3,0.5,0.7)
Medium-high importance	(0.5,0.7,0.9)
High importance	(0.7,0.9,1)
Very high importance	(0.9,1,1)

Table 1. Fuzzy linguistic variable values

Step 1. Construction of the fuzzy decision matrix

Considering m alternatives, n criteria, and k decision-makers, a multi-criteria group fuzzy decision-making problem can be formally expressed in matrix form (1):

$$\tilde{D}=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array}, i=1,2,\dots,m;\ j=1,2,\dots,n \tag{1}$$

where $A_1, A_2, \dots A_m$ represent set of the alternatives, $C_1, C_2, \dots, C_m$ are criteria, and $\tilde{x}_{ij}$ corresponds to the evaluation of alternative A_i with respect to criterion C_j as assessed by the decision-makers.

The mean value method for aggregating the fuzzy performance evaluations $\tilde{x}_{ij}$ of decision-maker k with respect to the same criterion is calculated according (2):

$$\tilde{x}_{ij}=\frac{1}{k}\left(\tilde{x}_{ij}^{1}+\tilde{x}_{ij}^{2}+\dots\tilde{x}_{ij}^{k}\right) \tag{2}$$

where $\tilde{x}_{ij}$ is the evaluation of alternative A_i with respect to criterion C_j given by the k-th decision-maker, and is expressed as a triangular fuzzy number $\tilde{x}_{ij}^k=\left(\tilde{a}_{ij}^k, \tilde{b}_{ij}^k, \tilde{c}_{ij}^k\right)$.

Step 2. Normalization of the fuzzy decision matrix given by (1)
Normalization of the fuzzy decision matrix is given by (3) [10].

$$\tilde{R}=[r_{ij}]_{mxn}, i = 1,2, \dots, m; \ j = 1,2, \dots, n \tag{3}$$

The normalization of the criteria to be maximized is given by (4):

$$r_{ij}=\left(\frac{x_{1ij}}{x_{3j}^*},\frac{x_{2ij}}{x_{3j}^*},\frac{x_{3ij}}{x_{3j}^*}\right), x_{3j}^*=max x_{3ij}. \tag{4}$$

The equation (5) is used for the criteria to be minimized:

$$r_{ij}=\left(\frac{x_{1j}^-}{x_{3ij}},\frac{x_{1j}^-}{x_{2ij}},\frac{x_{1j}^-}{x_{1ij}}\right), x_{1j}^-=min x_{1ij}. \tag{5}$$

Step 3. Forming of the weighted normalized fuzzy decision matrix
The values of the elements in the weighted fuzzy decision matrix $\tilde{V}$ (6) are calculated according to (7):

$$\tilde{V}= [\ \tilde{v}_{ij}]_{mxn}, \quad i = 1,2, \dots, m; \ j = 1,2, \dots, n \tag{6}$$

$$\tilde{v}_{ij}=\tilde{r}_{ij} \otimes \tilde{w}_j\ . \tag{7}$$

Values $\tilde{w}_j$ represent the weighting factors.

Step 4. Determination of the positive and negative ideal solution
The positive ideal solution A^* is given by (8), and the negative ideal solution A^- is given by (9):

$$A^*=\left(v_1^*,v_2^*,\dots,v_n^*\right) \tag{8}$$

$$A^-=\left(v_1^-,v_2^-,\dots,v_n^-\right) \tag{9}$$

where are $v_j^*=(1,1,1)$, $v_j^- = (0,0,0)$, and j=1,2, ..., n.

Step 5. Determination of the distance of alternatives from the A^* and A^-
The distance of alternatives from the A^* and A^- are given by (10) and (11) respectively:

$$d_i^*=\sum_{j=1}^n d(\tilde{v}_{ij}, v_j^*), i = 1,2,3, \dots, m, j = 1,2,3, \dots, n \tag{10}$$

$$d_i^-=\sum_{j=1}^n d(\tilde{v}_{ij}, v_j^-), i = 1,2,3, \dots, m, j = 1,2,3, \dots, n \tag{11}$$

Step 6. Determination of the relative closeness of the alternatives to the ideal solution
The relative distance of each alternative is calculated according to (12):

$$CC_i=\frac{d_i^-}{d_i^*+d_i^-}, i = 1,2,3, \dots, m \tag{12}$$

The alternative with the index CC_i approaching the value 1 indicates that this alternative is close to the fuzzy positive ideal solution and far from the fuzzy negative ideal solution. In other words, a high value of the index CC_i indicates good performance of the alternative A_i.

3. Data for practical example and results

The FAHP method was used on a case study to five energy projects (two hydroelectric power plants (HPPs), two wind farms (WFs), and one photovoltaic power plant (PVPP)) in Bosnia and Herzegovina. To respect confidentiality, the raw data was a little changed yet in a manner that maintained their overall integrity. Table 2, Table 3, and Table 4 contain the data on these projects.

Alternative	Project	Project implementation status	Projected annual production (GWh/year)	Installed capacity (MW)
1	HPP1	Construction	95	20
2	HPP2	Permitting process	45	10
3	WF1	Construction	165.17	50.6
4	WF2	Planning stage	145	54
5	PVPP1	Planned	17.2	13.54

Table 2. Project implementation status, projected annual production and installed capacity of the projects

Alternative	Project	CAPEX (mill. EUR)	Payback period (years)	Efficiency
1	HPP1	70	7	80%
2	HPP2	40	6	70%
3	WF1	81	6	55%
4	WF2	80	5	53%
5	PVPP1	11.1	8	20%

Table 3. CAPEX, payback period and efficiency of the projects

Alternative	Project	Impact on ecosystem	Location	Spatial requirements (ha/MW)
1	HPP1	Large impact	L1	160
2	HPP2	Very large impact	L2	80
3	WF1	Large impact	L3	66
4	WF2	Moderate impact	L4	78
5	PVPP1	Moderate impact	L5	25

Table 4. Impact on ecosystem, location and spatial requirements of the projects

One decision-maker participated in the evaluation, and the fuzzy ratings of the alternatives according to individual criteria from the technical, economic, and environmental groups are given in Table 5, Table 6, and Table 7, respectively.

Alternative	Project	Project implementation status			Projected annual production			Installed capacity		
1	HPP1	0.90	1.00	1.00	0.50	0.70	0.90	0.70	0.90	1.00
2	HPP2	0.10	0.30	0.50	0.00	0.10	0.30	0.10	0.30	0.50
3	WF1	0.70	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90
4	WF2	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90
5	PVPP1	0.10	0.30	0.50	0.10	0.30	0.50	0.10	0.30	0.50

Table 5. The fuzzy ratings of the alternatives according to individual criteria from the technical group

Alternative	Project	CAPEX			Payback period			Efficiency		
1	HPP1	0.30	0.50	0.70	0.50	0.70	0.90	0.90	1.00	1.00
2	HPP2	0.30	0.50	0.70	0.10	0.30	0.50	0.70	0.90	1.00
3	WF1	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.70	0.90
4	WF2	0.50	0.70	0.90	0.70	0.90	1.00	0.50	0.70	0.90
5	PVPP1	0.70	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90

Table 6. The fuzzy ratings of the alternatives according to individual criteria from the economic group

Alternative	Project	Impact on ecosystem			Location			Spatial requirements		
1	HPP1	0.50	0.70	0.90	0.70	0.90	1.00	0.90	1.00	1.00
2	HPP2	0.70	0.90	1.00	0.30	0.50	0.70	0.70	0.90	1.00
3	WF1	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90
4	WF2	0.30	0.50	0.70	0.70	0.90	0.10	0.70	0.90	1.00
5	PVPP1	0.30	0.50	0.70	0.50	0.70	0.90	0.30	0.50	0.70

Table 7. The fuzzy ratings of the alternatives according to individual criteria from the environmental group

Table 8 contains relative proximities of each alternative to the ideal solution (CC_i values), and their normalized values.

Alternative	Project	CC_i	Normalized value
1	HPP1	0.0924	0.2130
2	HPP2	0.0865	0.1993
3	WF1	0.0857	0.1977
4	WF2	0.0876	0.2021
5	PVPP1	0.0815	0.1879

Table 8. Relative closeness of each alternative to the ideal solution

In Table 9, the alternatives are presented, ranked from the best to the worst.

Rank	Alternative	Project	CC_i	Normalized value
1	1	HPP1	0.092	0.2130
2	4	WF2	0.087	0.2021
3	2	HPP2	0.086	0.1993
4	3	WF1	0.085	0.1977
5	5	PVPP1	0.081	0.1879

Table 9. Alternatives ranked from the best to the worst

The findings of the implemented ranking process showed that the score of Project 1 (HPP1) is the highest in the way of relative proximity to the ideal solution, and, therefore, the most desirable among the given projects. The following three ranked projects, Projects 4 (WF2), 2 (HPP2), and 3 (WF1), indicate a high index of alignment to the criteria as well but not as strongly as the project with the highest rank. Project 5 (PVPP1) has the lowest value of relative closeness, making it the least favourable option in this evaluation process.

The obtained results were influenced by the established criteria and their assigned values. Looking at the technical group of criteria, which carries the greatest weight, a noticeable difference among the alternatives is evident. HPP1 and WF2 are in construction phase, HPP2 is in the permitting phase, WF1 is in the planning stage, while PVPP1 is still only planned for construction. Additionally, WF1 and WF2 have higher projected annual output than both HPP1 and HPP2, while the projected annual output off HPP1 is higher than that of HPP2.

In addition to the technical criteria group, an important criterion is CAPEX, where HPP1 has a higher CAPEX than HPP2, but significantly lower than WF1 and WF2.

4. Conclusion

The problem of ranking electricity generation projects acquired through a public tender is considered in this paper as a fuzzy multicriteria decision-making problem. The criteria (both quantitative and qualitative) and their corresponding weights were predetermined, and the fuzzy TOPSIS method is selected for ranking the projects. The method is implemented on case study of five projects in Bosnia and Herzegovina (two hydropower plants, two wind farms and one photovoltaic power plant) at different levels of development. The findings clearly show the differences in project performance as per the stated criteria with some important information in influencing decisions in the renewable energy project acquisitions process. Project evaluations were provided by a single decision-maker, so future research could involve experts for each specific aspect: technical, economic, and environmental.

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