

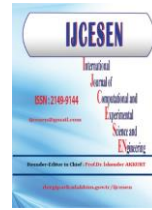


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Research Article

A Fuzzy Hybrid Decision Model for Renewable Energy Sources Selection

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Abstract: The energy needs of the world have been increasing from year on year. Fossil fuels, including coal, oil and natural gas, are currently the world's fundamental energy source. Non-renewable energy sources threaten the world as a result of many problems such as air, water and environmental pollution. For this reason, countries tend towards renewable energy sources. The selection of the most appropriate renewable energy sources is crucial for improving of countries. Different criteria should be considered simultaneously in the selection of renewable energy sources. In this study, a hybrid approach involving Fuzzy AHP and Fuzzy TOPSIS is suggested to select renewable energy sources. Proposed approach is presented with a case study for empirical evidence. In the case study, alternative energy sources were evaluated under four main criteria: (1) Technical, (2) Economical, (3) Environmental, (4) Social and Political. As a result of the 2-stage evaluation method including multi-criteria decision making techniques, wind energy was determined as the most suitable alternative.

1. Introduction

Energy is a mandatory input for the social and economic development of countries. The energy needs of the world have been increasing from day to day due to growing population, developing industry and increasing standards of living [1]. The main energy sources which are currently used are fossil fuels. While meeting energy needs, it is also necessary to reduce the damage to the environment. For this reason, renewable energy (RE) sources become more of an issue. Non-renewable energy sources threaten the world as a result of many problems such as air, water and environmental pollution. For this reason, renewable energy sources are a significant investment for the future.

Turkey has the highest rate of growing energy demand among Organization for Economic Co-operation and Development countries over the last 15 years (Republic of Turkey Ministry of Foreign Affairs). Alternative energy sources are crucial to reducing energy import dependency especially for countries with increasing energy demand. The investment costs of renewable energy sources are

usually high. For this reason, selection of RE sources is a strategic decision and it is necessary to make the right decision at the first time. Investment cost is not the only factor affecting this decision. Effect on the environment, social effect, operating costs, and technological feasibility should be examined. RE source selection problem are frequently encountered in the literature [3–18]. In this study a selection model for RE by using Fuzzy AHP and Fuzzy TOPSIS methods that are often used in the literature among multi-criteria. Proposed approach is presented with a case study.

2. Methods

In this study AHP and TOPSIS methods with Fuzzy theory [19] are used. These methods are explained below.

2.1. Fuzzy AHP

Analytic Hierarchy Process (AHP) [20] is one of the most used multi-criteria decision-making (MCDM) technique for selection, evaluation, and

prioritization alternatives and/or criteria. In the AHP method the priorities are obtained from the results of the pairwise comparisons carried out by the experts (decision makers). With this methodology, both objective and subjective criteria can be evaluated at the same time. Main steps of the methodology are; (1) Define the problem or goal. (2) Establish evaluation criteria including all actors involved in the problem. (3) Structure the problem in a hierarchy including goal, criteria, sub-criteria, and alternatives. (4) Follow the AHP steps and choose the most appropriate one. In the study, Fuzzy AHP was used because the decision makers' (DMs') answers include linguistic expressions. There are several fuzzy form of AHP methods in the literature. In this study, Chang's extent analysis method [21] is used. Since this method is described in detail in many studies in the literature, it is not explained again in this study.

2.2. Fuzzy TOPSIS

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is also a MCDM method that was proposed by Hwang and Yoon (1981). Later, in 2000 and 2006 Chen and Chen et al. proposed extended the TOPSIS method for fuzzy data [22]-[23]. Their model is explained below.

Step 1. Arrange the problem in matrix format as follows;

$$\tilde{D} = \begin{pmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \dots & \tilde{X}_{1m} \\ \tilde{X}_{21} & \tilde{X}_{22} & \dots & \tilde{X}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \dots & \tilde{X}_{mm} \end{pmatrix}$$

$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \tilde{w}_3, \dots, \tilde{w}_n]$, where \tilde{X}_{ij} and \tilde{w}_j are the average rating and the importance weight of the all DMs.

Step 2. Calculate the fuzzy decision matrix (\tilde{R}) by using the linear-scale transformation [22].

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (1)$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \quad \tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), J \in C$$

$$C_j^* = \max_i c_{ij} \text{ if } j \in B$$

$$C_j^* = \min_i a_{ij} \text{ if } j \in C$$

Step 3. Calculate the weighted normalized decision matrix as;

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m \quad J = 1, 2, \dots, n \quad (2)$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot) \tilde{w}_j$$

Step 4. Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) [23] as;

$$FPIS(P^*) = (\tilde{V}_1^*, \tilde{V}_2^*, \tilde{V}_3^* \dots \tilde{V}_n^*) \text{ and}$$

$$FNIS(P^-) = (\tilde{V}_1^-, \tilde{V}_2^-, \tilde{V}_3^- \dots \tilde{V}_n^-) \quad \text{where} \quad \tilde{V}_j^* =$$

$$\max_i \{V_{ij3}\} \text{ and}$$

$$\tilde{V}_j^- = \min_i \{V_{ij1}\}; i=1,2,\dots,m \text{ and } j=1,2,\dots,n$$

Step 5. Calculate the distance of each alternative from FPIS and FNIS as;

$$d_i^+ = \sum_{j=1}^n d_v(\tilde{v}_{ij}, v_j^*); i=1,2,3,\dots,m \quad (3)$$

$$d_i^- = \sum_{j=1}^n d_v(\tilde{v}_{ij}, v_j^-); i=1,2,3,\dots,m \quad (4)$$

Step 6. Calculate the closeness coefficient (CC_i) [22] as;

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad i=1,2,3,\dots,m \quad (5)$$

Finally, sort the alternatives by CC_i value and select the alternative with the highest CC_i value.

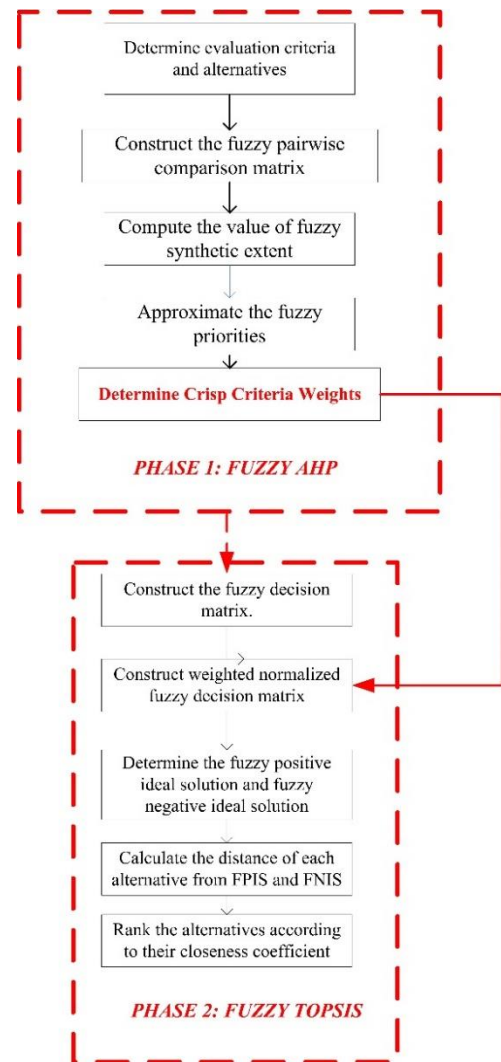


Figure 1. Phases of proposed model

3. An Application: Renewable Energy Source Selection for Turkey

In this study, the proposed model includes 2 main phases. The first phase is about identifying the criteria weights by using fuzzy AHP method and the second phase is about selecting the RE source with fuzzy TOPSIS method (Figure 1). MCDM techniques need pairwise comparisons to evaluate the criteria set and alternatives. Pairwise comparisons are performed by DMs. The evaluation criteria of the proposed model were

determined based on the most commonly used criteria in Table 1 and DMs' opinions. Afterwards, local and global weights of evaluation criteria were calculated by applying fuzzy AHP steps. Table 2 represents the evaluation criteria of the proposed model and their local and global weights.

After the local and global weights were determined, the steps of the fuzzy TOPSIS method were applied (Eq.1-5) to select the most appropriate source between alternatives. Table 3 gives the final results of the RE source selection problem.

Table 1. RE Sources Evaluation Criteria in the Literature(*Used in proposed model)

Criteria	Sub-Criteria	Ref
Technical	Energy Production Capacity	[14] [24]
	Technological Maturity*	[14] [18] [25][15]
	Reliability*	[14] [17][18][25][24]
	Safety	[14] [18]
	Efficiency*	[17][13] [16] [25][15] [24]
	Exergy Efficiency	[17]
	Accident Risk and effects	[16]
	Availability of sources	[13] [18]
Economical	Investment Cost*	[14] [17][26] [18] [16] [25] [24]
	Operation and Maintenance Cost*	[14] [17] [18] [16]
	R&D Cost	[18]
	Service life	[14]
	Payback Period	[14]
	Source potential	[15]
	Return on Investment*	[17] [18]
Environmental	Environmental Impact on Ecosystem	[14] [18] [15] [24]
	CO ₂ Emission*	[14] [17][25] [15] [24]
	No _x emission*	[17] [25]
	GHGs Greenhouse emissions	[13] [18]
	Land use requirement*	[17] [18] [25] [15]
Social	Social Benefits	[14] [17]
	Social Acceptability*	[14] [17] [15] [24]
	Job creation*	[17][26] [25] [15] [24]
Political	Foreign dependency	[18]
	Compatibility with political legislative situation	[18]
	Public policy and financial support	[18]
	Alignment with the country's strategic objectives*	

Table 2. Weights of the Evaluation Criteria of the Proposed Model

Aspect	Local weights	Sub- Criteria	Local Weights	Global Weights
Technical	0,423	Technological structure	0,363	0,154
		Reliability	0,192	0,081
		Efficiency	0,445	0,188
Economical	0,255	Investment Cost	0,375	0,096
		Operation and Maintenance Cost	0,051	0,013
		Return on Investment	0,573	0,146
Environmental	0,255	Land use requirement	0,182	0,046
		CO ₂ Emission	0,409	0,104
		No _x emission	0,409	0,104
Social and Political	0,067	Social Acceptability	0,375	0,025
		Job creation	0,051	0,003
		Alignment with the country's strategic objectives	0,573	0,039

Table 3. Computations of d^* , d and CC_i

RE Sources	d^*	d	CC_i	Rank
Hydropower	0,39	0,26	0,405	3
Solar	0,25	0,40	0,618	2
Wind	0,17	0,47	0,739	1
Nuclear	0,44	0,23	0,343	4
Biomass	0,47	0,19	0,294	6
Geothermal	0,44	0,21	0,325	5

4. Results and Conclusions

The purpose of this study is to select most appropriate RE alternative by using fuzzy AHP and fuzzy TOPSIS methods. Evaluation of the RE alternatives involves subjective and qualitative judgments. For this reason, energy source selection problem is a MCDM problem [17]. In Turkey, as the end of 2016, the installed capacity of the wind energy plants in operation is 5.751,3 MW (Republic of Turkey Ministry of Energy and Natural Resources). As a result of this study, wind energy was determined as the most suitable energy for Turkey (Table 3). However, changing the priorities of the criteria in the model and/or adding new alternatives to the model may change this ranking. In addition, changes in the expression of DMs may also change the result. For this reason, sensitivity analysis can be realized in the future study. The proposed model can be re-evaluated by adding hybrid alternatives. Different hybrid system that can be achieved using two or more different energy sources [28]. Alternatives can also be tested with a simulation model.

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