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Renewable Energy Investments in Turkey and Evaluation of Selection Criteria under Fuzzy Environment

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ABSTRACT: *Renewable energy is replacing fossil fuels day by day and becoming more efficient and more popular. Effects of global warming and the limited availability of fossil fuel stocks have led the direction of energy production to sources such as wind, solar, geothermal and hydro. Turkey's renewable energy investment and production is not yet sufficient but increasing over time. However, it is important for not only the engineering and economic area but also the social aspect which energy resource is invested in. Determination of important criteria may increase the acceptability of the investments to be made. The main aim of the study is to identify the main criteria and sub-criteria that are effective in the investment to be made for renewable energy production and to present it in a hierarchical structure. In addition, evaluation the weights of the criteria and rank all the criteria according to their importance. For this reason, technical, economic, sociopolitical and environmental aspects were selected as the main criteria in the selection of renewable energy sources in this study. Each main criterion is divided to sub-criteria. The priorities and weights of the criteria were determined by using the Fuzzy AHP method through binary comparisons. Investment costs, production costs and productivity were found as the most important criteria. The renewable energy investment alternatives can be evaluated by using the obtained criteria weights and it will be possible to reach optimum solution. The results may change because of local situations so investors should consider each case separately.*
KEYWORDS: *Renewable Energy, Fuzzy AHP, Energy Investment, MCDM.*

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I. Introduction

Renewable energy is recognized as an important resource for future life and plays an important role in energy supply, reducing air pollutants and greenhouse gas emissions. This has led to increased studies, investments and interest in green energy which has been generated by using renewable energy sources such as solar panels, wind farms, geothermal projects, hydroelectric power and biomass projects. These are environment-friendly and capable of replacing conventional sources in a variety of applications at competitive prices.

Nowadays, in developed and developing countries, there are renewable energy applications and renewable energy sources are expected to become an important part of the total energy supply in the future. Renewable energy systems are environmentally friendly compared to traditional energy systems. They do not create any physical pollution, especially greenhouse gases. They do not consume a natural source and the inputs they use are abundant in nature (Aydin et al., 2013).

Investment of energy production facilities has been increasing rapidly in recent years because of the rapid increase in energy demand in Turkey. Especially in the last decade renewable energy is on the agenda for increase of energy prices, reduction of external dependency on energy and security of energy supply (Karaoğlan & Durukan, 2016). As of October 2016, there are 78434 MW of installed power for total electricity generation in the country, 42% of which belongs to renewable energy plants (Turkish Electricity Transmission Company, 2016). 37.9% of the electricity were produced from natural gas, 29.1% from coal, 25.6% from hydraulic, 4.5% from wind, 1.3% from geothermal, 1.6% from other resources in Turkey in 2015 (Turkish Ministry of Energy, 2016).

Decision analysis can be defined as a method to propose various modes of action by examining the problems that can be encountered in the decision making process by using mathematical models, numerical and statistical techniques. Decision analysis techniques are used in many areas such as human resources management, financial management and production management. This is also the case for enterprises operating in the energy sector. From the 1960s onwards, studies have been carried out in many areas such as planning, investment, technology selection, project evaluation and determination of environmental policies (Atıcı & Ulucan, 2009).

The choice of various energy investment projects is a laborious task. Numerous factors affecting the success of a renewable energy project should be analyzed and taken into account. Decision-making has to take into account various conflicting goals due to the ever increasing complex social, economic, technological and environmental factors (San Cristóbal, 2011).

II. Literature Review

In the literature, multi-criteria decision making studies related to renewable energy sources are frequently encountered recently. The fact that renewable energy is popular and prominent indicates the importance of this decision. If some of the important ones are listed:

Nigim et al. (2004) used the analytic hierarchy process (AHP) as a first tool and the sequential interactive model for urban sustainability (SIMUS) as the second for renewable energy investment.

Atıcı and Ulucan (2009) made this study in Turkey. In the study, there are two applications where several hydroelectric power plant projects are ranked by ELECTRE method and various wind power plant projects are ranked by using PROMETHEE technique.

At Kaya & Kahraman's (2010) study, it is aimed at determining the best renewable energy alternative for Istanbul by using an integrated VIKOR-AHP methodology. Second, a selection among alternative energy production sites in this city is made using the same approach.

In the paper some renewable energy options for electricity generation for Pakistan are explored from multiple perspectives comprising technical, economical, social, environmental and political aspects at study of Amer and Daim (2011). Analytic hierarchy process (AHP) has been used for the first time for the energy sector of Pakistan

San Cristóbal (2011) apply the method in the selection of a Renewable Energy project corresponding to the Renewable Energy Plan launched by the Spanish Government. The method is combined with the Analytical Hierarchy Process method for weighting the importance of the different criteria, which allows decision-makers to assign these values based on their preferences.

The aim of the Sadeghi et al. (2012) study is to propose a Fuzzy multi-criteria decision-making approach (FMCDM) in order to evaluate 4 alternative renewable energies (solar, geothermal, hydropower and wind energies) in Yazd province in Iran. Two FMCDM methods are proposed for this problem: Fuzzy Analytic Hierarchy Process (FAHP) is applied to determine the relative weights of the evaluation criteria and the extension of the Fuzzy TOPSIS is applied to rank the alternatives.

Yazdani-Chamzini et al. (2013) used an integrated COPRAS-AHP methodology is proposed to select the best renewable energy project. They compared their model with five MCDM tools in order to validate the output of the proposed model.

Erdem et al. (2013) determined 6 alternative energy sources and 5 criteria. Authors evaluated them by AHP method for selecting renewable energy power plant in Turkey.

The aim of the Şengül et al. (2015) paper is to develop the multi-criteria decision support framework for ranking renewable energy supply systems in Turkey. Given the selection of renewable energy supply systems involves many conflicting criteria, multi criteria decision methods (Fuzzy TOPSIS) were employed for the analysis.

In the study that made by Sağır and Doğanalp (2016), in particular for energy production Turkey fuzzy multi-criteria for the assessment of different energy sources offers a decision-making model. The main purpose is to determine the importance of the decision criteria by using the Fuzzy TOPSIS method to evaluate the various energy alternatives and to evaluate these energy sources according to the determined decision criteria.

Analytic Network Process is used for weighting criteria and TOPSIS method is used for evaluating alternatives by Özcan et al. (2017). Study is determining priorities for renewable energy investments.

Çolak and Kaya (2017) made a real case application for Turkey by Fuzzy AHP based on interval type-2 fuzzy sets and hesitant Fuzzy TOPSIS methods.

Numerous methods have been developed to solve the MCDM problems encountered in almost every area of decision making. Some of the methods weight the criteria while others serve to evaluate alternatives. Some methods, such as AHP and ANP, can be used both in benchmark weighting and in alternative assessment (Karaoğlan & Şahin, 2018)

III. FUZZY AHP

It is not always possible to reach exact data in decision making problems in real World. The purpose and parameters of such problems are not known exactly. The decision maker fails to make numerical estimates, but qualitative estimates are more effective than numerical estimates.

The Analytical Hierarchy Process (AHP), one of the most commonly used and most well-known multi-criteria decision-making methods, was developed by Thomas L. Saaty. The qualitative and quantitative variables can be evaluated at the same time and it is a suitable method to solve the problems in the complex structure (Zahedi, 1986). A large number of hybrid and integrated applications are seen in the literature because of its compatibility with fuzzy logic, linear programming and other multi-criteria decision making methods.

The AHP method has applications in many areas from marketing to management, from economics to politics. Traditional AHP acts on certain judgments. However, because of the nature of the comparison process, decision-makers prefer to express or make a verbal statement over a range rather than as a fixed value. It is more appropriate to use fuzzy decision-making methods as classical decision-making problems are insufficient in real-life problems involving indefinite and uncertain situations. Therefore, in this study, Fuzzy AHP method was preferred.

Fuzzy AHP technique can be considered as an advanced analytical technique developed from AHP method. The fuzzy AHP method differs from the AHP method in the pairwise comparison of the criteria. Since it is more realistic for the experts to give their opinions on a subject rather than a definite number with verbal evaluations, triangular fuzzy numbers are used to determine the range of judgment of these verbal evaluations (Sofyalıoğlu, 2009).

Steps of The Fuzzy AHP method according to Buckley (1985) are as follows (Ayhan, 2013; Işık et. Al. 2018):

Step 1: Decision-makers compare the criteria or alternatives according to Table 1 below.

Table 1: Linguistic Expressions and Fuzzy AHP Scale

	Fuzzy AHP	
Linguistic Expressions	**Scale**	**Reciprocal Scale**
Just equal	1, 1, 1	1, 1, 1
Weakly more important	2, 3, 4	1/4, 1/3, 1/2
Strongly more important	4, 5, 6	1/6, 1/5, 1/4
Very strongly more important	6, 7, 8	1/8, 1/7, 1/6
Absolutely more important	9, 9, 9	1/9, 1/9, 1/9

After the pairwise comparisons, the Fuzzy Pairwise Comparison Matrix is generated. If the number of decision makers is more than one, the geometric averages of the numerical values of the responses of the decision makers are taken. $\tilde{A}$ Matrix is obtained as a result.

$$\tilde{A} = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \tilde{d}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{d}_{m1} & \tilde{d}_{m2} & \cdots & \tilde{d}_{mn} \end{bmatrix} \tag{1}$$

Step 2: The geometric means of the fuzzy values are calculated with the following equation. Here $\tilde{r}_i$stands for triangular values.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, \qquad i = 1,2,\dots,n \tag{2}$$

Step 3: To obtain the fuzzy weights of each criterion, $lw_i, mw_i\ ve\ uw_i$ values are obtained with the help of Equation-3.

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \tag{3}$$

Step 4: $\widetilde{w}_i(lw_i, mw_i\ ve\ uw_i)$ values are still triangular fuzzy numbers. M_i values are obtained for recover these numbers from fuzziness with the equation:

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{4}$$

And these values normalized with the equation:

$$w_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{5}$$

The weights for each criterion or alternatives are then obtained.

IV. APPLICATION

In this study, criteria weights are tried to evaluate for selecting renewable energy invesmtents, with multi-criteria decision making methods. In the first phase of the study, experts that working or studying about energy were interviewed to determine criteria. Then, literature was reviewed for the same reason. Main criteria and sub-criteria are given in Figure-1.

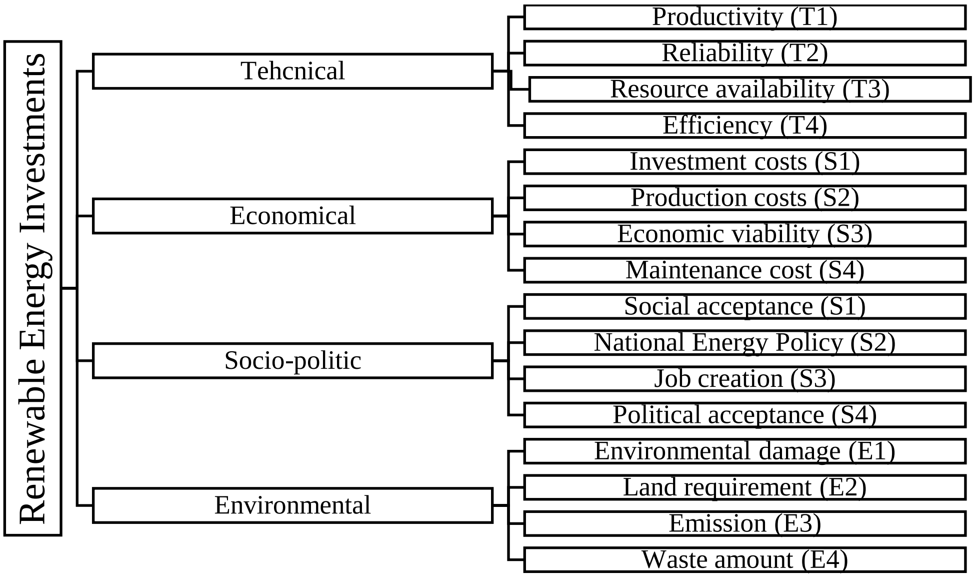

Figure 1: Main criteria and sub-criteria for selecting renewable energy invettments

After criteria were determined, they were evaluated by experts using the pairwise comparison scale. Following the evaluations, the decision matrices were created by taking the geometric means of responses.

Table 2: Fuzzy Pairwise Comparison Scale for Main Criteria

	Technical			**Economical**			**Socio-politic**			**Environmental**		
Technical	1.00	1.00	1.00	0.76	0.88	1.00	1.68	2.28	2.83	2.38	3.41	4.43
Economical	1.00	1.14	1.32	1.00	1.00	1.00	2.83	3.87	4.90	2.38	3.41	4.43
Socio-politic	0.35	0.44	0.59	0.20	0.26	0.35	1.00	1.00	1.00	2.00	2.59	3.13
Environmental	0.23	0.29	0.42	0.23	0.29	0.42	0.32	0.39	0.50	1.00	1.00	1.00

Then, the values showing the fuzzy weights with Equality 3, the values showing the weights with Equation 4 and the values showing the normalized weights that is criteria weights with Equation 5 were obtained and these values are given in Table 3. The values in Table 8 give the weight percentage of each criterion in the system and their sum is equal to 1.

Table 3: Fuzzy Weights and Criteria Weights

Criteria	lw_i	mw_i	uw_i	M_i	w_i
Technical	0.23	0.34	0.48	0.35	**0.34**
Economical	0.29	0.41	0.59	0.43	**0.41**
Socio-politic	0.11	0.16	0.23	0.16	**0.16**
Environmental	0.06	0.09	0.14	0.10	**0.09**

After creating the pairwise comparison matrices of all sub-criteria, the AHP method was followed by calculation steps. Criteria weights are calculated for each matrix and the following criteria weights (w) were obtained.

As seen in the table, technical and economical main criteria are the most important ones with weights 0.412 and 0.337 respectively. When we examine the sub-criteria, production costs, investment costs and productivity are the most important criteria for renewable energy investments. Their weights are 0.158, 0.148 and 0.115. This shows financial values are seen still important for the renewable energy. Then, the reliability and social acceptance criteria have importance with weights of 0.085 and 0.077. Unfortunately, environmental main criterion and environmental damage, land requirement, emission and waste amount sub-criteria are the least important criteria with job creation and political acceptance sub-criteria from socio-politic main criterion.

Table 4: Criteria Weights

Main Criteria	Weight	Sub-Criteria	Local Weight	Global Weight	Priority
Technical	0.337	**Productivity**	0.340	0.115	3
		Reliability	0.253	0.085	4
		Resource availability	0.194	0.065	7
		Efficiency	0.213	0.072	6
Economic	0.412	**Investment costs**	0.358	0.148	2
		Production costs	0.384	0.158	1
		Economic viability	0.116	0.048	9
		Maintenance cost	0.142	0.058	8
Socio-politic	0.158	**Social acceptance**	0.486	0.077	5
		National energy policy	0.260	0.041	10
		Job creation	0.130	0.021	15
		Political acceptance	0.124	0.020	16
Environmental	0.093	**Environmental damage**	0.293	0.027	11
		Land requirement	0.256	0.024	12
		Emission	0.226	0.021	13
		Waste amount	0.225	0.021	14

V. CONCLUSION

As in all sectors, decision making and planning are important in the energy sector. The importance given in the literature of decision theory on energy and environment has been increasing in recent years. The need for forward planning and the need to improve the quality of the decisions made in the energy field brings about the application of mathematical decision-making techniques to this sector. Seen from the energy sector in Turkey, the judiciary's decision is notable that decision-makers are widely taken using the scoring method which is highly dependent. This study aims to show that more analytical decisions can be made by decreasing the decision making judgment by using the decision analysis techniques in the literature.

As a result of the work, criteria and their weights are tried to determine for renewable energy investments. Criteria are determined by experts and weighted by the Fuzzy AHP method with the help of experts’ opinion. Consequently, financial criteria are still important for evaluating renewable energy investments. Environmental issues are still in the background. Investors who want to establish renewable energy production areas have to take into account technical and economical criteria. With the help of this study, it will be easier to evaluate renewable energy investment alternatives. Because, alternatives may be evaluated by the criteria that used in this study with weights.

Taking some measures in the context of global warming and climate change is important for the future of our world. It is also believed that some actions to reduce emissions will have some economic impact. Investments in emerging market economies such as Turkey, economic growth, increasing energy demand can affect conditions such as environmental thinking. Therefore, technological developments and cost reductions in renewable energy investments are important for many countries in the world. Renewable energy investments in Turkey are still to be seen from the results of the study seem to depend heavily on productivity and costs. Both the government and non-governmental organizations will be more aware of the environment and will raise environmental awareness.

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