Evaluation of Renewable Energy Alternatives for Turkey via Modified Fuzzy AHP

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ABSTRACT

The importance of renewable energy is increasing both with the inadequacy of traditional energy resources and environmental awareness. Turkey has a large potential for renewable energy sources, and utilizing the potential is an inevitable choice for increasing its self-sufficiency with an environmentally friendly way. Therefore, evaluation of renewable energy alternatives for the country and determination of the most suitable renewable energy alternative are important issues to make reasonable energy investment plan. In this study, we evaluate the renewable energy alternatives of Turkey using Modified Fuzzy Analytic Hierarchy Process. Renewable energy alternatives considered in the study are hydro, wind, solar, biomass and geothermal energy. Four main criteria and eight sub criteria are used to evaluate five renewable energy alternatives. The obtained results indicate that solar energy is the best alternative, and wind energy is the second best alternative for Turkey. The conclusion reached by this study is also support successful realization of the Vision 2023 energy targets.

Keywords: Fuzzy Analytic Hierarchy Process, Renewable Energy, Energy Strategy
JEL Classifications: D81, Q20, Q38

1. INTRODUCTION

Turkey has the highest rate of growing energy demand among OECD countries over the last 15 years. Due to the lack of domestic gas sources, the country has become an energy importing country (http://www.mfa.gov.tr/turkeys-energy-strategy.en.mfa, 02.07.2018). This dependence on energy imports combined with increasing energy cost and the serious negative environmental impact of high energy consumption has increased the importance of renewable energy resource.

More countries are focusing on renewable energy beyond traditional energy sources. Renewable energy is an inevitable choice for sustainable economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development. Renewable energy is usually regarded as energy that does not pollute environment and could be recycled in

nature (Ertay et al., 2013. p. 39). Renewable energy technologies are known to be less competitive than traditional electric energy conversion systems, mainly because of their intermittency and the relatively high maintenance cost. However, renewable energy sources (RES) have several advantages, such as the reduction in dependence on fossil fuel resources and the reduction in carbon emissions to the atmosphere (Banos et al., 2011. p. 1754).

Turkey's geographic location has several advantages for extensive use of most of the RES. Turkey has various types of alternative-energy resources such as hydro, solar, wind, biomass, and geothermal energy available in abundance. However, Turkey is an energy importing country with more than half of the energy requirement being supplied by imports, and air pollution is becoming a great environmental concern in the country. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions for sustainable energy

development and environmental pollution prevention in Turkey (Kaygusuz and Sarı, 2003. p. 459). Taking these conditions into account, Turkey government aims to produce 30% of Turkey's electricity demand in 2023 from RES. So, the important decision for Turkey is whether or not to establish renewable energy systems, to decide which RES or combination of sources is the best choice. Also, because of the important investment costs of constructing a renewable energy structure, selecting the best alternative among the different renewable energy resources is a vital from the point of view of long-term planning.

Renewable energy decision-making can be viewed as a multiple criteria decision-making (MCDM) problem with correlating criteria and alternatives. The decision making procedure has to take into account several conflicting aspects because of the increasing importance of the social, technological, environmental, and economic factors. Traditional single-criterion decision-making cannot cope with the complexity of this problem (San Cristobal, 2011. p. 498). A traditional single criteria decision making approach which is aimed at identifying the most efficient supply options at low cost was popular during the 1970s. Growing environmental awareness in the 1980s has modified the decision framework by incorporating environmental and social considerations in energy planning. Thus, the selection among energy alternatives has become a multi-criteria problem with many conflicting criteria such as economic, technical, environmental, political, social (Pohekar and Ramachandran, 2004). Therefore, a multi-criteria approach to decision making appears to be the most appropriate tool to evaluate some alternatives by taking into account their advantages and disadvantages based on selection criteria.

In this study, MCDM model based on the revised fuzzy AHP approach is applied to Turkey's renewable energy optimization problem. The objective of this research is to evaluate the most appropriate renewable energy alternatives to determine ratings of each renewable energy alternatives. For this purpose the revised Fuzzy analytic hierarchy process (AHP) technique (Aydın and Kahraman, 2011; Aydın and Kahraman, 2018) is utilized to get rating of alternatives. The revised fuzzy AHP is an effective and newly published technique. This technique was firstly proposed by Aydın and Kahraman (2011), and later triangular fuzzy scale was revised slightly in their later study published in 2018 (Aydın and Kahraman, 2018).

This article is organized in four main sections. First, a review of the literature on renewable energy selection problem is presented. Especially, extensive literatures concerning the evaluation of RES in Turkey are given. Second, description of the selection criteria and alternatives are given and the Fuzzy AHP methodology is presented. Third, results are presented together with the discussion in relation to the literature. Finally, conclusions are given.

2. LITERATURE REVIEW

Decision-making is the process of finding the best option from all of the feasible alternatives. Decision-making problems considering several criteria are called MCDM problems. There are various decision-making methodologies developed by researches in the

literature. Most frequently used methods for renewable energy selection are analytical hierarchical process (AHP), analytical network process (ANP), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), elimination and choice expressing reality (ELECTRE), preference ranking organization method for enrichment of evaluations. In addition, during the recent years, some researchers take renewable energy selection problem as Fuzzy MCDM problem (FMCDM). Therefore, MCDM techniques are applied to solve energy decision making problems in different countries such as Iran, Greece, India, Spain and China. Due to importance of energy for sustainable development, countries desire to utilize analytical methods to determine energy policy.

Beccali et al. (2003) assessed renewable energy technologies by using ELECTRE-III method under fuzzy environment for the island of Sardinia. Sadeghi et al. (2012) suggested a FMCDM approach to assess four renewable energy alternatives in Yazd province in Iran. They used fuzzy AHP (FAHP) method to determine weights of criteria and ranked alternatives with fuzzy TOPSIS method. They concluded solar energy as the most appropriate alternative for the selected area. Tasri and Susilawati (2014), focused on determining the most appropriate renewable energy alternative for electricity production in Indonesia using fuzzy AHP. Al Garni et al. (2016) used a MCDM methodology based on AHP to rank renewable power generation alternatives taking into account economic, environmental, socio-political and technical criteria. And then, they applied their proposed methodology to rank renewable sources for Saudi Arabia. Algarin et al. (2017) used the AHP to prioritize criteria, subcriteria and alternatives for renewable energy supply in rural areas of the Caribbean region of Colombia. They concluded that solar energy was the best renewable energy alternatives for the region (Algarin et al., 2017).

There are many studies about MCDM application of renewable energy modeling in the literature. More studies can be found in review articles about MCDM application in renewable energy selection. Pohekar and Ramachandran (2004) discussed renewable energy applications with MCDM. Taha and Daim (2013) presented a literature review in which MCDM applications in renewable energy are divided into four main categories: Renewable energy planning and policy, renewable energy evaluation and assessment, technology and project selection, and environmental aspects.

In this section, available MCDM studies in renewable energy selection for Turkey are given in detail. Ulutaş (2005) aimed to determine the appropriate energy sources for Turkey using ANP. Both RES and the other sources were considered as energy alternatives. The results of the study indicated that biogass is the most attractive source for the country. Kahraman et al. (2009) proposed two FMCDM methods to select the most appropriate renewable energy in Turkey. The first method was Fuzzy AHP, while the other was Fuzzy axiomatic design (AD). They considered biomass, hydropower, geothermal, wind and solar renewable energy as alternatives. Wind energy was selected as the best renewable energy alternative in both methods. Kahraman et al. (2010) determined the best energy alternative of Turkey

by considering interactions among criteria via Choquet integral methodology. They concluded that the wind energy is the best alternative for Turkey. Kaya and Kahraman (2010) proposed a methodology based on an integrated fuzzy AHP-VIKOR method to determine the best renewable energy alternative for Istanbul. They also used the proposed methodology for selection among alternative energy production sites in Istanbul. The following year, Kaya and Kahraman (2011) focused on the energy technology selection problem for Turkey considering modified fuzzy TOPSIS. They determined frequently used criteria in the literature and used these criteria while selecting best energy alternatives. They suggested wind energy as the best energy alternatives for Turkey. Boran et al. (2012) evaluated renewable energy technology for Turkey using intuitionistic fuzzy TOPSIS. They considered hydro, wind, photovoltaic, and geothermal as the renewable energy technologies in Turkey. The results indicated that hydro is the best alternative and wind power ranked as the second best alternative for Turkey. Erol and Kılkış (2012) developed an AHP method to facilitate energy resource planning for Aydın distinct in Turkey. They considered geothermal power, lignite, natural gas, wind, hydroelectric, and hydrokinetic powers as energy alternatives. Solar energy was found as best energy sources. Barış and Küçükali (2012), developed a multi-criteria analysis tool to evaluate the performance of different RES technologies under technical, economic, environmental and social aspects. They suggested biaogass as the best possible RES option for Turkey. Demirtaş (2013) considered technical, economic, environmental and social criteria and applied AHP to determine best renewable energy alternatives for Turkey. The results of the study suggested that wind energy was the best renewable energy alternative and the ranking of the other alternatives in descending order was determined as biomass, geothermal, solar and hydropower. Ertay et al. (2013) evaluated the renewable energy alternatives; wind, solar, biomass, geothermal, and hydropower by using two MCDM methods. The ranking order of alternatives obtained by MACBETH is wind, solar, biomass, geothermal, hydropower. When they applied fuzzy AHP, they concluded the same ranking result. Kabak and Dağdeviren (2014) proposed a hybrid model based on analytic network process (ANP) and benefits, opportunities, costs and risks to determine the energy state of Turkey and to prioritize alternative RES. They evaluated five alternatives in terms of nineteen criteria and determined hydro power as the best alternative for Turkey. Büyüközkan and Güleryüz (2014) aimed to build up a model to help investors by prioritizing renewable energy alternatives. They suggested a new group decision making approach based on FAHP with linguistic interval fuzzy preference and fuzzy TOPSIS. They obtained weights of evaluation criteria using FAHP and ranking of the alternatives is determined using fuzzy TOPSIS. Şengül et al. (2015) presented a multi-criteria decision support framework for ranking renewable energy supply systems in Turkey. They used Shannon's entropy methodology to determine criteria weights and fuzzy TOPSIS method to prioritize alternatives. They concluded that the amount energy produced is the most important criterion and hydro power was the most important supply system followed by geothermal power, regulator and wind power. Balin and Baraçli (2015) offered a MCDM model based on interval type-2 fuzzy TOPSIS and interval type-2 fuzzy AHP. They calculated the criteria weights by using interval type-2 fuzzy AHP method, and then

they calculated ranking of alternatives according to the ranking vector determined by interval type-2 fuzzy TOPSIS method. Kuleli et al. (2015) modeled energy selection problem integrating ANP and TOPSIS methods. They considered social, economic, and environmental factors and concluded that Hydro energy is the most appropriate RES for Turkey. Also, they performed a sensitivity analysis to monitor the influence of criteria weights on the model results. Erdogan and Kaya (2015) clarified ranking of energy alternatives for Turkey by developing an integrated FMCDM methodology. They used type-2 fuzzy AHP to weight the criteria and then used type-2 fuzzy TOPSIS to rank energy alternatives. The results showed that wind energy is the most appropriate energy alternatives. Büyüközkan and Güleryüz (2016) developed an integrated MCDM model combining the Decision Making Trial and Evaluation Laboratory (DEMATEL) and ANP methods in order to determine the most suitable renewable energy resource for Turkey in Turkey from an investor perpective. Wind energy is selected as best renewable energy alternatives for Turkey. Çelikbilek and Tuysuz (2016) presented a grey based MCDM methodology which integrates DEMATEL, ANP and VIKOR methods. Grey DEMATEL is used to determine relations among evaluation criteria, grey ANP is used determine the weights of the evaluation criteria, and also grey VIKOR is used finally to rank renewable energy alternatives. They demonstrated the effectiveness of the improved model with the application for RE in Turkey. They concluded that solar energy is best alternative followed by wind, hydroelectric, biomass, geothermal. Büyüközkan and Güleryüz (2017) integrated DEMATEL-ANP-TOPSIS methodologies with linguistic interval fuzzy preference relations. The results revealed that the best renewable energy technology for Turkey was geothermal sources, followed by biogas. Çolak and Kaya (2017) proposed a hybrid MCDM method based on AHP with interval type-2 fuzzy sets and TOPSIS with hesitant fuzzy sets. The ranking of energy alternative is determined as wind, solar, hydraulic, biomass, geothermal, wave and hydrogen energy.

3. METHOD

In this paper, an analysis is performed to determine the ranking of RES in Turkey. Turkey has significant renewable energy potential, whose realizable renewable energy potential is equal to 13% of EU-27's total potential. Turkey's total electricity generation potential from RES is 240,165 GWh/yr for 138,000 MW economic potential. Potential for various RES types have important role to find a solution to the current economical and environmental problems of Turkey (Özcan, 2018. p. 2630).

3.1. Renewable Energy Alternatives and Selection Criteria
Turkey has different type of RES potantial. According to Turkey's Ministry of Energy and Natural Resources data, Turkey has 144,000 GWh/yr hydro (for 36,000 MW), 14,665 GWh/yr geothermal (for 2000 MW), 60,000 GWh/yr wind (for 48,000 MW), 14,000 GWh/yr biomass (for 2000 MW), and 7500 GWh/yr solar (for 50,000 MW) renewable energy potential (Sirin and Ege, 2012. p. 4922). By considering RES potential in Turkey, RES alternatives are determined as hydro energy, wind, solar, biomass and geothermal. Hydro energy exploits the potential energy

that is contained in flowing waters like rivers and reservoirs in mountainous regions (Büyüközkan and Güleryüz, 2017. p. 151). The potential of hydropower resource relies on the amount of available water and suitable land. Hydropower potential for Turkey is not yet to be exploited fully. The goal of the Turkish government is to utilize all technically and economically available hydropower by 2023 (Melikoğlu, 2013. p. 504).

Solar energy is obtained by collecting sunlight through solar or photovoltaic cells, and then focused with mirror to create a high-intensity heat source which runs a generator to produce electricity. Solar energy can be utilized for cooling, lighting, heating and other energy demands (Kabak and Dağdeviren, 2014. p. 26). Turkey has high solar energy potential due to its geographical location. According to the solar energy map of Turkey prepared by the Renewable Energy General Directorate, it has been determined that the total annual insolation time is 2741 h (a total of 7.5 h per day), and the total solar energy derived per year is 1527 kWh/m^2 per year (total 4.18 kWh/m^2 per day). As of the end of 2017, there were 3616 solar power plants with a total installed capacity of 3421 MW. This is the equivalent of 4% of the total potential. In 2017, electricity production based on solar energy have realized 2684 GWh and 0.91% of our electricity production was obtained from solar energy (http://www.enerji.gov.tr/en-US/Pages/Solar, 02.07.2018).

Wind energy is derived from air masses encountering different temperature ranges and is converted to electricity by means of wind turbines. By the end of 2017, installed wind power in Turkey reached 6516 MW. This is the equivalent of 7.6% of the total potential. In 2017, electricity production from wind energy have realized 17,909 GWh and 6.06% of electricity production was obtained from wind energy (http://www.enerji.gov.tr/en-US/Pages/Wind, 02.07.2018).

Biomass can be defined as the total mass of living organisms that belong to a society consists of species or consist of several species. Biomass is also defined as an organic carbon. Biomass potential in Turkey is estimated about 8.6 million tonnes of equivalent petrol (MTEP), and biogas quantities that can be produced from biomass is 1.5–2 MTEP. As of the end of 2017, there were 122 renewable waste power plants with a total installed capacity of 634.2 MW. This is the equivalent of 0.7% of the total potential (http://www.enerji.gov.tr/en-US/Pages/Bio-Fuels, 02.07.2018).

Geothermal power is the energy generated by heat stored beneath the Earth's surface or the collection of absorbed heat derived from underground in the atmosphere and oceans (Kahraman and Kaya, 2010. p. 6271). Turkey has important geothermal potential for its direct use and for electricity generation. With the end of the year 2017, there were 40 geothermal power plants with a total installed capacity of 1,064 MW (http://www.enerji.gov.tr/en-US/Pages/Geothermal, 02.07.2018).

In the evaluation phase, these RES alternatives are assessed in light of four main criteria and eight sub criteria. The criteria are determined with respect to relevant literature. Kaya and Kahraman (2011) introduced the most frequently used criteria by considering the criteria used in the literature. We also used these main and subcriteria, and the descriptions of the criteria are given as follows.

Efficiency (C11): Efficiency refers to how much useful energy can be extracted from an energy source and is measured generally using efficiency ratio. Efficiency ratio is defined as the ratio of output energy to input energy (Kaya and Kahraman, 2011; Mourmouris and Potolias, 2013). Exergy efficiency (C12): Exergy efficiency or rational efficiency investigates the efficiency of a renewable energy technology regarding to the second law of thermodynamics. It means there is always an exergy loss when a process involves a temperature change. Exergy is the net energy that is left to be used (Kaya and Kahraman, 2011. p. 6582).

Investment cost (C21): Investment cost includes all type of cost occurred for establishing the energy technology such as engineering services, road construction or other construction work, purchase of mechanic equipment, legislative authorization (Büyüközkan and Güleryüz, 2017; Mourmous and Potolias, 2013). Operation and maintenance cost (C22): Operation and maintenance cost includes all production costs that are associated with running a power plant. The components of operations costs are salaries, energy expenses, expenditure on products and services. Also, maintenance costs are the funds spent to ensure reliable plant operations and to avoid failure and damage (Büyüközkan and Güleryüz, 2017; Kaya and Kahraman, 2011).

Particles emmision (C31): Particle emission criterion consists of gas release to atmosphere, such as CO_2, N_2O and CH_4, which are the results of combustion process, liquid wastes related to secondary products by fumes treatment or with process water, and solid wastes. The evaluation of the criteria includes type and quantity of emissions, and costs associated with wastes treatments. Also the electro-magnetic interferences, bad smells, and microclimatic changes for energy investment are taken into account while evaluating this criterion (Kahraman and Kaya, 2010; Kahraman et al., 2009). Land Use (C32): Energy systems need some land to be built, however different energy systems may occupy different land while the products are same. The environment and landscape are affected directly by the land occupied by energy systems (Wang et al., 2009). A strong demand for land can also determine the economic losses (Kahraman et al., 2009).

Social acceptability (C41): Social acceptability is defined as the overview of opinions related to the energy systems by the local population. The overall opinion of local populations and of pressure groups can heavily influence the progress with investment decisions. Social acceptance could not be expressed by quantitative way but qualitative. To transforming qualitative decisions into quantitative, survey method could be used (Büyüközkan and Güleryüz, 2017; Wang et. al., 2009). Job creation (C42): Job creation includes direct and indirect employment, as well as creation of new professional areas indirectly. Energy systems employ many people during their life cycle, from construction and operation till decommissioning. Job opportunities for local societies improve the living quality of local people. However each energy source creates different job opportunities and decision makers should select energy source and plant type by considering local community (Büyüközkan and Güleryüz, 2017; Wang et. al., 2009).

By considering the RES potential in Turkey, energy alternatives are evaluated from environmental, socio-political, economic, technical and technological aspects by experts. Figure 1 shows hierarchical structure of energy decision making problem. Three experts are utilized to evaluate the considered criteria and alternatives with respect to Figure 1. One of them is an academic in Energy Systems Engineering Department and the others have work experience on energy policy and planning. Equal weight was given to each expert.

3.2. The Fuzzy AHP Method

In this study the Fuzzy AHP method proposed by Aydın and Kahraman (2011) is utilized. The researchers slightly revised their triangular fuzzy scale in their later studies (Aydın and Kahraman, 2018). We use this fuzzy scale as given in Table 1.

The procedure of the Fuzzy AHP method can be explained as follows (Aydın and Kahraman, 2011; Aydın and Kahraman, 2018).

The weights (e) are allocated to experts on the basis of their knowledge, experience, etc. Suppose that m experts exist in the group and the kth expert is E_k is assigned an expert weight e_k,

Where $e_k \in [0,1]$, $e_1 + e_2 + ... + e_m = 1$ (1)

To obtain a group preference from individual preferences, the aggregation of TFNs scores is performed as following equation:

$$\hat{a}_{ij} = \hat{a}_{ij1} \otimes e_1 \oplus \hat{a}_{ij2} \otimes e_2 ... \oplus \hat{a}_{ijm} \otimes e_m \quad (2)$$

Where $\tilde{a}_{ij}$ is the aggregated fuzzy score from all comparisions. $\tilde{a}_{ij1}$, $\tilde{a}_{ij2}$ ... $\tilde{a}_{ijm}$ are corresponding TFN scales assigned by experts E_1, E_2, ... E_m, respectively. $\otimes$ and $\oplus$ symbols refer fuzzy multiplication and fuzzy addition operators, respectively.

As known, the scores in the classical AHP method are also based an exponantial importance. So, to convert negative fuzzy TFNs to positive TFNs, corresponding exponantial values of negative scores are calculated. The conversion is obtained by following equation.

$$\tilde{a}_{ij}^* = e^{(\frac{\hat{a}_{ij}}{4})} \quad (3)$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

Triangular fuzzy comparision matrix is demonstrated by,

$$\tilde{A} = \tilde{a}_{ij} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & ... & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{121}) & (1,1,1) & ... & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{1n}, m_{1n}, l_{ij}) & (l_{1n}, m_{1n}, u_{1n}) & ... & (1,1,1) \end{bmatrix} \quad (4)$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $\tilde{a}_{ij}^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}})$ for $i,j = 1,...,n$ and $i \neq j$. A normalized matrix $\tilde{N}$ is calculated,
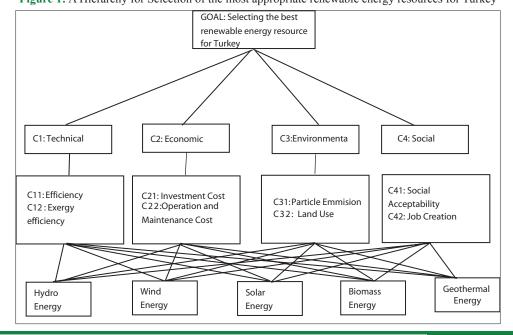
$$\tilde{N}_{ij} = [\tilde{n}_{ij}]_{m \times n} \quad (5)$$

$$\tilde{N}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u_{ij}}{u_j^*} \right) \quad (6)$$

$$u_j^* = \max_i u_{ij} \quad (7)$$

The importance weights of the factors are calculated ussing following equation:

$$W_i' = \frac{\sum_{j=1}^n \tilde{n}_{ij}}{\sum_{k=1}^n \sum_{j=1}^n n_{kj}} \quad k = 1, 2, ... n \quad (8)$$

Figure 1: A Hierarchy for Selection of the most appropriate renewable energy resources for Turkey

The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to obtain global ratings.

In the last step, we rank the obtained fuzzy numbers. In order to rank the fuzzy numbers, we use the signed distance value developed by Yao and Wu (2000).

4. RESULTS AND DISCUSSION

As referred, mainly five RESs (hydro energy, wind, solar, biomass and geothermal) alternatives have exploting possibilities on Turkey. As known, first step of any multicriteria approach is defination of alternatives and criteria. The definition of alternatives and the evaluation criteria are previously described. The second step is the weighting of each criterion to express their relative importance. Comparison matrix of main citeria is given in Table 2. To analyze the consistency of the fuzzy pair-wise comparison matrices, we converted the fuzzy numbers into crisp numbers using a defuzzification technique. Many techniques are used for defuzzification in the literature. The most used approaches are Mean-of-Maximum, Center-of-Area, and Alpha-cut Method (Zhao and Govind, 1991). In this study, we utilized the Center-of-Area method because of its calculation easiness (Yalcın et al., 2012).

After obtaining the aggregation of TFNs scores using Eq. 2, we converted negative fuzzy numbers in Table 2 to positive fuzzy numbers via Eq. 3. As a result, the comparision matrix is revised as Table 3.

Then, normalized matrix given in Table 4 is obtained using Eqs. 5-7.

Finally, we obtained importance weights of main criteria by using Eq. 8.

$$W'_{C1} = (0.170, 0.284, 0.535), \ W'_{C2} = (0.060, 0.096, 0.179),$$
$$W'_{C3} = (0.279, 0.505, 0.816), \ W'_{C4} = (0.061, 0.113, 0.216)$$

We found that experts considered the criterion of 'environmental' more important than others. Also, the second important criterion was determined as "technical." This result means the experts were more interested in environment and technical factors. The same procedures are repeated for the sub-criteria and the weights of the sub-criteria are calculated as in the following Tables 5 and 6.

All the importance weights of the hierarchy have been calculated as following the same steps, and finally importance weights of the alternatives are obtained and given in Table 7.

According to Table 7, the ranking of the alternatives from the best to the worst is solar, wind, geothermal, hydropower and biomass. So, the best renewable alternative in Turkey is solar energy. This result is also parallel with the finding of Erol and Kılkış (2012) and Celikbilek and Tuysuz (2016). Solar energy has many advantages. It causes no emissions like carbon dioxide, nitrogen oxide or sulphur oxide. Although, the initial cost of a solar system is high, maintenance cost of solar system is very low. Also, technology

Table 1: Triangular fuzzy coversion scale

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(0,0,0)	(0,0,0)
Weakly important	(0,1,3)	(−3,−1,0)
important	(1,3,5)	(−5,−3,−1)
Strongly more important	(3,5,7)	(−7,−5,−3)
Very strongly more important	(5,7,9)	(−9,−7,−5)
Absolutely more important	(7,9,9)	(−9,−9,−7)

Source: Aydın and Kahraman, 2018

Table 2: Comparison matrix of main criteria

Expert	Weight	C1	C2	C3	C4
C1					
1	0.3333	(0,0,0)	(1,3,5)	(0,1,3)	(0,1,3)
2	0.3333	(0,0,0)	(7,9,9)	(0,1,3)	(1,3,5)
3	0.3333	(0,0,0)	(1,3,5)	(−9,−9,−7)	(3,5,7)
C2					
1	0.3333	(−5,−3,−1)	(0,0,0)	(−5,−3,−1)	(0,0,0)
2	0.3333	(−9,−9,−7)	(0,0,0)	(−9,−9,−7)	(−3,−1,0)
3	0.3333	(−5,−3,−1)	(0,0,0)	(−9,−9,−7)	(1,3,5)
C3					
1	0.3333	(−3,−1,0)	(1,3,5)	(0,0,0)	(3,5,7)
2	0.3333	(−3,−1,0)	(7,9,9)	(0,0,0)	(5,7,9)
3	0.3333	(7,9,9)	(7,9,9)	(0,0,0)	(3,5,7)
C4					
1	0.3333	(−3,−1,0)	(0,0,0)	(−7,−5,−3)	(0,0,0)
2	0.3333	(−5,−3,−1)	(0,1,3)	(−9,−7,−5)	(0,0,0)
3	0.3333	(−7,−5,−3)	(−5,−3,−1)	(−7,−5,−3)	(0,0,0)

of solar energy is continuously developing regarding innovations in nanotechnology. Technological development probably would increase the effectiveness of solar system and and decrease in investment cost in near future. Among the alternative RES in Turkey, the most important one is solar energy. Turkey has more chance than the other countries in terms of solar energy potential due to its geographic situation (Balat, 2005). Result of the study also confirms that solar energy is the most suitable alternative to meet growing energy demand. In addition, the second best alternative is wind energy. The main advantages of wind energy is that it does not harm the environment, the production of electricity with wind energy does not cause to the CO_2 emissions, acid rain and atmospheric warming (Erdogan and Kaya, 2015). Also, wind energy may play a critical role in both strengthening energy security of Turkey and thus decreasing energy dependency. Some RER selection publications for Turkey (Kahraman et al., 2009; Kahraman et al., 2010; Kaya and Kahraman, 2011; Ertay et al., 2013; Çolak and Kaya, 2017) concluded that the second best alternative is solar energy after wind energy. Both solar and wind energy are very important to realize Turkey's RER energy targets.

Taking economic potential of renewable resource into account, the utilization rate of wind power and solar power is very low. As mentioned before, there were 3616 solar power plants with a total installed capacity of 3421 MW, which is the equivalent of 4% of the total potential. Also, by the end of 2017, installed wind power in Turkey reached 6516 MW. This is the equivalent of 7.6% of the total potential. Therefore, it can be seen that utilization rate of both solar and wind energy alternatives are very low when compared to their potential. Also, Turkey has also attained 21.41% of its

Table 3: Aggregated fuzzy comparision matrix for main criteria

	C1	C2	C3	C4
C1	(1,1,1)	(2.117,3.490,4.871)	(0.472,0.558,0.920)	(1.395,2.117,3.490)
C2	(0.205,0.287,0.472)	(1,1,1)	(0.147,0.174,0.287)	(0.846,1.181,1.516)
C3	(1.086,1.792, 2.117)	(3.490,5.754,6.798)	(1,1,1)	(2.500,4.123,6.798)
C4	(0.287, 0.472,0.716)	(0.659,0.846,1.181)	(0.147,0.242,0.399)	(1,1,1)

Table 4: Normalized fuzzy comparision matrix for main criteria

	C1	C2	C3	C4
C1	(0.472,0.472,0.472)	(0.311,0.513,0.716)	(0.472,0.558,0.920)	(0.205,0.311,0.513)
C2	(0.096,0.135,0.223)	(0.147,0.147,0.147)	(0.147,0.174,0.287)	(0.124,0.174,0.223)
C3	(0.513,0.846, 1)	(0.513,0.846,1)	(1,1,1)	(0.368, 0.607,1)
C4	(0.135, 0.223,0.338)	(0.096,0.124,0.173)	(0.147,0.242,0.399)	(0.147,0.147,0.174)

Table 5: Fuzzy weights of main criteria

Main criteria	Fuzzy weights	Signed distance value
C1	(0.170,0.284,0.535)	0.318
C2	(0.060,0.096,0.179)	0.108
C3	(0.279,0.505,0.816)	0.526
C4	(0.061,0.113,0.216)	0.126

Table 6: Fuzzy weights of sub-criterisa

Sub-criteria	Fuzzy weights
C11	(0.313,0.417,0.582)
C12	(0.437,0.582,0.747)
C21	(0.611,0.871,1.215)
C22	(0.089,0.128,0.211)
C31	(0.460,0.679,0.947)
C32	(0.217,0.320,0.529)
C41	(0.595,0.851,1.187)
C42	(0.103,0.148,0.244)

Table 7: Importance weights of alternatives

Alternatives	Fuzzy weights	Signed distance value
Hydro	(0.0433,0.174,0.768)	0.289
Wind	(0.054,0.236,0.994)	0.380
Solar	(0.062,0.275,1.139)	0.439
Biomass	(0.028,0.122,0.587)	0.150
Jeothermal	(0.047,0.193,0.839)	0.318

2023 target in wind energy and 4.52% of its 2023 target in solar energy (Özcan, 2018. p. 2635). So, increasing the utilization rates of wind and solar energy would make an important contribution to realize Turkey's 2023 renewable energy targets.

According to the result, geothermal energy is the third best energy alternatives and its score is very close to wind energy. Economic potential of geothermal energy is estimated to be 2000 W, with an annual average generation potential of 14,665 GWh/yr (Özcan, 2018. p. 2635) and as of the end of 2017, there are 40 geothermal power plants with a total installed capacity of 1,064 MW. This is the equivalent of 1.2% of the total potential (http://www.enerji. gov.tr/en-US/Pages/Geothermal, 02.07.2018). The government aims to achieve 1000 MW installed power by the year 2023 (Özcan, 2018. p. 2635). In this case, it seems that the government has already achieved its 2023 target for geothermal energy. However, the utilization rate of geothermal energy is still low when taken into account of the total potential. For this reason, it

may be an option to update targets related to geothermal energy in the future.

5. CONCLUSIONS

Awareness of renewable energy importance on both environment and energy security has been increasing in Turkey. In parallel, Turkey government aims to produce 30% of Turkey's electricity demand in 2023 from RES. Therefore, the determination of the most suitable renewable energy alternative is an important issue to plan energy investment. In this study, the evaluation of renewable energy resources in Turkey accomplished via modified fuzzy AHP method proposed by Aydın and Kahraman (2011; 2018). There are two mains reasons for the use of the revised fuzzy AHP method. Firstly, this method use both positive fuzzy numbers and negative fuzzy numbers in fuzzy scale and thus it presents more understandable scales for comparing alternatives. Secondly, this method is very easy to apply because it is based on simple arithmetic operations of fuzzy numbers. Also, this study also demonstrates the effectiveness and applicability of revised fuzzy AHP method, which has been newly published and less known.

The energy alternatives considered in the study are hydro, wind, solar, biomass and geothermal, which are mentioned in Turkey's 2023 energy targets. Renewable energy alternatives were evaluated by considering four main criteria and eight sub criteria. The criteria are determined with respect to relevant literature. The results suggested that experts consider the criterion of "environmental" more important than others. Also, the second important criterion was determined as "technical." This result means that the experts were more interested in environmental and technical factors. After, weights of the criteria are calculated, the ranking of alternatives are determined as solar, wind, geothermal, hydropower and biomass in descending order. The results are also parallel with some similar studies in the literature. Although their order changes, wind energy and solar energy have been found to be the most suitable renewable energy alternatives in most of the studies for Turkey. Because the utilization rates of these resources are low, increasing the utilization rates of wind and solar energy would make an important contribution to realize Turkey's 2023 renewable energy targets.

In the future research, we are planning to carry out a mathematical model in order to determine optimal investment amount for each

renewable alternatives taking into account weights of alternatives obtained in the study.

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