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Renewable Energy Investment Decision Evaluation for Local Authorities

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Abstract. Currently, increasing urban population creates escalating problems such as housing, infrastructure, transportation, health, environment, safety, and energy consumption. Climate change, emission mitigation, and limited energy supply force urban managers to consider sound measures with the support of technological developments. It is based on data collection and accumulation using IoT, sensors, digital networks, and other means. “Smart urbanism” is a concept that considers predicting, designing, and creating solutions in a systematic, sustainable, and agile manner based on the data collected. Energy is an indispensable dimension in this context. Optimum energy management makes it “smart energy” with the inclusion clean and sustainable renewable energy resources as well as energy efficiency. This study is performed to analyze possible inclusion of geothermal, solar, and wind power. The analyses are based to reveal the best feasible alternative considering the parameters of location, climate, space availability, capital and operational expenditures as well as construction, operation, and maintenance. The Fuzzy Analytic Hierarchy Process (Fussy AHP) technique is used to evaluate the ranking. The proposed method uses fuzzy mathematics for solving problems containing uncertainties as well as less quantifiable. This study proposes a methodological framework for the analysis of competitiveness of alternative renewable energy generations in urban environments. The municipality of Balıkesir is chosen for the case study presented in this work.

Keywords: Fuzzy Analytic Hierarchy Process, wind energy, solar energy, geothermal energy, energy investments, urban energy

1 Introduction

Population increase and industrialization increased energy demand in the World. In the past, Turkey has been relied on imported fossil fuel, coal, oil, and natural gas due to the lack of domestic resources in order to match the domestic energy demand. However, there is a global trend to replace fossil fuel based energy systems with renewable energy to cope with and mitigate climate change. Municipalities have also initiated programs for the inclusion of renewable energy into urban utilization. Of course, the choice of renewable energy is mainly determined by the location and availability of renewable resources. For instance, solar and wind energy are more focused in Aegean and Medi-

terranean regions whereas biomass is more preferred in Marmara region [1]. Geothermal energy is more site dependent and can be utilized wherever it is available [2]. These resources are mostly concentrated in the western regions of Turkey, apart from this, there are also resources in the Northern Anatolian fault line and the volcanic regions in the east [3].

Renewable energy has its own characteristics. The cost of renewable energy becomes more and more affordable as they are widely implemented all around the World. However, renewable energy is mostly site dependent. Wind energy systems may need routine maintenance. Solar energy systems require significant area for implementation. Both solar and wind energy resources are intermittent and not available continuously. On the other hand, geothermal energy has more availability and resources may be stored for proper generation scheduling [4, 5]. Not only the cost, but also characteristics, i.e., local availability, space and maintenance needs, are required for the consideration of renewable energy resources [6].

This study proposes a methodological framework to accurately evaluate the shared economy based on renewable energy resource alternatives. The model is applied for the case of the Municipality of Balıkesir in Turkey. For this reason, within the scope of this study, it will be analyzed which of the renewable energy sources between solar, wind and geothermal energy is more appropriate to invest for the Balıkesir municipality on the Aegean region. In this context, the article proceeds by the literature review, then, methodology, and finally, evaluations by the proposed AHP model. At this point, the Saatty scale is converted Triangular Fuzzy Numbers for the pair wise comparison matrices. Finally, the conclusions refer to the one specific renewable energy alternative that better fits for the use in the Municipality of Balıkesir.

2 Literature Survey

The lack of domestic energy resources in Turkey also influences the country's economy significantly. There is also a motivation to use renewable resources in order to reduce environmental impacts. The decrease in the cost of renewables, especially for solar and wind, further supports the action for decision makers' energy transition policies and increase investors' appetite. Local municipalities are also within the scope for such actions considering their services. The use of renewable energy by municipalities in their services is also well received by the public.

There are many previous studies to determine the potential of energy resources in Turkey. Topcu et al. [7] used a framework including technical, economic, environmental, and social point of view in their analyses covering solar, wind, hydro, biomass, coal, natural gas, and nuclear energy. They concluded that renewable energy (solar, wind, and hydro) would be beneficial for Turkey. In another study, Celik and Ozgur (2020) [8] discussed the current status of solar energy in Turkey with compared to Europe. Emeksiz and Demirci (2019) [9] and Argin et al. [10] studied the wind potential in the coastal regions of Turkey. In a separate study, Melikoglu (2017) pointed out the geothermal energy utilization goal, set for 2023 within the Vision 2023 program, had already been met [11].

There are many studies on energy investments for municipalities. Adam et al. (2015) [12] evaluated the energy resource that would be the right decision to invest in for the City Council of Leed, UK. In a similar study, Taminiou and Byrne (2020) [13] evaluated the solar energy potential of New York City and offered new proposals for the municipality's solar energy approach. In a study conducted in Turkey; Karaca et al. (2011) [14] examined the solar energy potential within the municipality of Konya and provided energy by integrating solar panels on the roofs of the headman's houses in the Selçuklu district. In another study performed by Guven (2017) [15], some solutions are offered to meet the energy needs of the building of Bahcelievler Municipality. In addition, the study done by Biberici, Dogan, Dilber, and Celik (2018) [16] was on the renewable energy utilization of municipalities in Turkey and they concluded that it should be increased.

Gazhelia and Berghb (2018) [17], Arikan and Pine (2016) [18], Adam et al. (2015) [12], and Guven (2017) [13] conducted studies focused on decision making between solar and wind energies. Among these studies, Gazhelia and Berghb (2018) [17] used the "Real options valuation" technique to make a decision, but this technique did not provide a variety of approaches. On the other hand, Adam et al. (2015) [12] took a decision-making approach based on the "Life cycle cost" in which case social and environmental consequences were also taken into account.

In a study carried out by Yilan et al. (2020) [19], it was analyzed which sustainable resources Turkey should focus on for electricity production, and in this study, Multi-Criteria Decision Making (MCDM) is employed to analyze by comparing Total Cost of Living, Cost-Benefit Analysis and MCDM. MCDM offers a broader perspective as it provides an approach from many different aspects (technical, environmental, economic, social). Similarly, an application of this method was performed by Li, Li and Guo (2020) [20] and calculated the most accurate renewable energy investment for China with MCDM techniques.

The use of MCDM techniques are examined by Pohekar and Ramachandran (2003) [21] and they concluded that this technique was very useful for energy planning and found that it was being used more and more frequently in this field.

Some studies can be found confirming this result; Dogrusoy and Serin (2013) [22] evaluated the city of Izmir on the basis of districts and calculated its energy potentials using the Analytical Hierarchy Process (AHP), which is a MCDM technique. Likewise, Karatop et al. [23] analyzed most suitable energy investment for Turkey using MCDM techniques including Fuzzy AHP. In a similar study Wang et al. [24] use the same technique for select an energy source for Pakistan.

In this study, it will be evaluated which renewable energy source would be more beneficial for a selected municipality on the Aegean region of Turkey. Balikesir is located at the north-west of Anatolia, the coordinates are 270530' N and 390390' E, the height above the sea level is 600 meters [25]. The total area is 14,292 km² and the population is 215,000, the density of population per km² is 15 [26].

In this sense, a decision will be made between the solar energy potential that is left behind in use, the wind energy potential that is frequently used in coastal areas and the geothermal energy which Turkey has a big potential especially in the western side of

the country. Within the scope of this decision, economic, environmental and social impacts will be considered. To achieve this, an appropriate MCDM technique will be determined. The decision for method selections explained in detail in the Methodology section. The sources mentioned in the literature review are listed chronologically in Table 1.

Table 1. Source table for literature survey

Author	Article	Purpose	MCDM Method	Contribution
Pohekar and Ramachandran (2003)	Application of multi-criteria decision making to sustainable energy planning—A review	The applications of MCDM in energy planning have been examined	PROMETHEE (Preference ranking organization method for enrichment evaluation) and ELECTRE (The elimination and choice translating reality)	A literature review on sustainable energy planning existing shows uncountable applicability of MCDM methods in socio-economic scenario.
Karaca, Gurkan and Yazar (2011)	Solar Energy Potential of Konya and Its Surroundings and Application of Solar Electricity Production System in Selçuklu Municipality Headman's Houses	The solar energy potential of Konya was calculated and solar panel application was made in the headman's houses	Analysis	It constitutes an example of renewable energy use for the district municipality.
Dogrusoy and Serin (2013)	Architectural Examination of the Potential of Renewable Energy Resources in the City of Izmir	İzmir districts were evaluated in terms of energy potential using one of the MCDM techniques.	MCDM AHP	It sets an example for the use of MCDM on a district basis.
Adam, Hoolohan, Gooding, Knowland, Bale and Tomlin (2015)	Methodologies for city-scale assessment of renewable energy generation potential to inform strategic energy infrastructure investment	Energy investment decision has been made for Leeds city council..	Mapping	It is an example of energy use in international municipalities.
Arikan and Cam (2016)	Web Based Feasibility Analysis of Wind and Solar Energy Systems	Amasrada made a potential analysis of solar and wind energies.	Rayleigh statistical method	It constitutes an example of decision making on a district basis.
Güven (2017)	Meeting the Energy Need of Bahçelievler Municipality Building with Solar and Wind System, Optimization and Cost Analysis	Energy source decision has been made for Bahçelievler municipality building	Analysis	It constitutes an example of renewable energy use for the district municipality.

Kumar, Sah, Singh, Dneg, He, Kumar and Bansal (2017)	A review of multi criteria decision making (MCDM) towards sustainable renewable energy development	Comparisons were made between MCDM techniques	Analysis	In this study several MCDM methods are introduced and the possibility of usage is searched to find the future optimal renewable energy application procedure.
Biberici, Dogan, Dilber and Celik (2018)	Local Alternative Renewable Energy Sources Use in Administration and Financial Returns	An investigation has been made on the use of renewable energy in Turkey's local governments.	Analysis	It shows the lack of use of renewable energy.
Gazhelia and Berghb (2018)	Real options analysis of investment in solar vs. wind energy: Diversification strategies under uncertain prices and costs	It has decided to invest between solar and wind energies.	Real Option Analysis	It constitutes an example of investment decision between two energy sources.
Topcu, Ulengin, Kabak, Isik, Unver and Ekici (2019)	The evaluation of electricity generation resources: The case of Turkey	Turkey's energy resources have been compared and evaluated in number of ways.	MADM (Multiple-attribute decision making)	It affords robust recommendations for energy policymakers in Turkey by taking into account by several dimensions. It is seen that Turkey has to grow the share of original and renewable electricity generation resources.
Emeksiz and Demirici (2019)	The determination of offshore wind energy potential of Turkey by using novelty hybrid site selection method	The wind potential of the coastal regions of Turkey has been examined..	MCDM	The methodology suggested in this study can be used to attain a decision making process at the regional level for offshore wind farm planning.
Argin, Yerci, Erdogan, Kucuksari and Cali (2019)	Exploring the offshore wind energy potential of Turkey based on multicriteria site selection	The wind potential of the coastal regions of Turkey has been examined.	Mapping	The proposed methodology can be applied to make a decision to solve a problem about offshore wind energy plant in the regional base.
Taminiau and Byrne (2020)	City-scale urban sustainability: Spatiotemporal mapping of distributed solar	The solar energy potential of New York City was evaluated.	Geographic information system (GIS)	The interrelations between the production and consump-

		power for New York City			tion across the energy networks are not searched in this study since more detailed works are required to see the opportunities for development of solar cities.
Li, Li and Guo (2020)	The sustainable development-oriented development and utilization of renewable energy industry-A comprehensive analysis of MCDM methods	An energy investment analysis has been made for China.	MCDM		It presents its application by comparing different techniques of MCDM
Yilan, Kadirgan and Ciftcioglu (2020)	Analysis of electricity generation options for sustainable energy decision making: The case of Turkey	Turkey has been evaluated in terms of energy potentials.	MCDM		It shows the energy potential of Turkey.
Celik and Ozgur (2020)	Review of Turkey's photovoltaic energy status: Legal structure, existing installed power and comparative analysis	The development of Turkey's PV use was examined and compared with 5 European countries.	Analysis		It shows the situation of Turkey in terms of solar energy according to European standards.

3 Methodology

Although renewable energy is preferred more due to the increasing energy demand and the limited use of fossil fuels, it has disadvantages due to intermittency and low efficiency. In addition, the dependence of renewable energy sources on climatic and geographical conditions makes the source from which the highest efficiency can be obtained different for each region.

In this case, it is necessary to apply optimization methods in order to make the most proper choices (source, location, size) according to the conditions of the region where the power plant will be established. This approach has shown a geometric increase over the last 20 years [27]. The reason for this is the development of optimization techniques and computer technology over time, and problems that were once considered impossible to solve can be easily solved by computer algorithms.

Since switching to a new renewable energy source instead of fossil fuels in current use will cause radical change in the long run; It is a situation that affects many areas, both economic, environmental and social. Various approaches have emerged to take

the right decision. While methods such as linear programming and mix-integer are used for problems such as region determination and system capacity increase [29], genetic algorithms are preferred for problems such as calculating plant dimensions that will optimize cost and emissions [29].

MCDM is the mostly used method to decide on the source to be used. As mentioned earlier, making this decision will affect many different areas; therefore, a multidimensional assessment is needed.

MCDM is a method that deals with the decision-making process between multiple conflicting objectives. This method needs a decision maker to decide. There are many different MCDM techniques and the most suitable one among these techniques should be chosen in order to find an optimum solution [21].

MCDM techniques have a wide area of use outside of energy systems. There are usage examples in many fields such as agriculture, industry, and economy. Examples include the selection and layout of storage areas [30], maritime operations and maritime logistics [31], placing distribution centers of some warehouses in the best possible locations in the military logistics system [32], portfolio optimization related to risk and return [33].

At this point, it is useful to mention MCDM techniques. It is not right to distinguish between good and bad for any technique because each technique has its own advantages and disadvantages [20]. Among the techniques those are used to decide on the energy source, it is clear that AHP is the widely used technique among all. [21] and [34] reached conclusions that confirm this.

However, it cannot be denied the fact that in recent years, the fuzzy extension of AHP became more and more popular. Although this technique has been known since Zadeh's proposal at 1965 [34] and acceleration on development is recorded after Chang's [35] study at 1996. As explained in the study of Liu et al. [36], Fuzzy AHP has a wide range of uses. This includes the energy sector. It has been supported by many studies in the literature that it is very suitable for decision-making problems between energy sources, as in the study of Ligus and Peternek [37].

Since this study also includes an energy source decision, it was decided to determine the decision by using one of the MCDM methods, Fuzzy AHP. This method is one of the most common MCDM techniques in the literature and it is examined the usage examples in similar studies in Literature Survey.

3.1 Fuzzy AHP

The AHP is one of the many MCDM methods. By using AHP, criteria weight calculation can be made to be used in other weighted decision making methods and calculations can be made to decide between these criteria. AHP was first developed by Thomas L. Saaty in the 1970s and is a method that enables the decision maker to make a decision by placing a complex problem in a hierarchy [38].

The pairwise comparison is performed by employing a ratio scale in the conventional AHP. To emphasize the decision or preference a nine-point scale is used between

choices those may be defined as equally, moderately, strongly, very strongly, or extremely preferred. This nine-point discrete scale is simple and easy to use, but it does not evaluate the uncertainty coming from the identifying the choices as a number. It is not disregarded subjectivity and imprecision of human decisions on relative importance of criteria. The verbal expressions are always related to the sensations and are not precise every time [39]. Instead of defining verbal expressions and representing the importance level of criteria, it is easy to represent them by using objective, incalculable and precise numbers. These problems can be converted a fuzzy model, if its boundaries became unclear. Because of this reason, the Saaty scale is replaced Triangular Fuzzy Numbers for the pair wise comparison part [40].

In the AHP method, the purpose is determined first. The top rung of the hierarchy is purpose. The next step is criteria and sub-criteria; the last step is definition and evaluation of alternatives [41].

Please note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

Each a_{ij} term in this matrix represents the importance value of criterion i relative to criterion j . This significance value is decided according to Table 2.

Table 2. AHP Saaty's scale of importance and corresponding triangular fuzzy numbers [41]

Importance Value	Meaning	Triangular Fuzzy Numbers
1	Equally important	1,1,1
2	Intermediate value between 1 and 3	1,2,3
3	Slightly important	2,3,4
4	Intermediate value between 3 and 5	3,4,5
5	Important	4,5,6
6	Intermediate value between 5 and 7	5,6,7
7	Strongly important	6,7,8
8	Intermediate value between 7 and 9	7,8,9
9	Strongly important	9,9,9

$\mu_M(x): R \rightarrow [0, 1]$ is equal to the membership function:

$$\mu_{Mx} = \begin{cases} \frac{x-l}{m-l} - \frac{l}{m-l}, & x \in [l, m], \\ \frac{x-u}{m-u} - \frac{u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

where $l \leq m \leq u$, l and u denote the lowest and highest values of the support of M , respectively, and m is the mid-value of M . When $l = m = u$, it is a non-fuzzy number traditionally. The triangular numbers M_1, M_3, M_5, M_7, M_9 are used to show the choice from “equal to extremely preferred,” and M_2, M_4, M_6 , and M_8 are interim values. Figure 1 shows the triangular fuzzy

numbers $M_t = (l_t, m_t, u_t)$ where $t = 1, 2, \dots, 9$ and where l_t and u_t are the lower and upper values of the fuzzy number M_t respectively [39]:

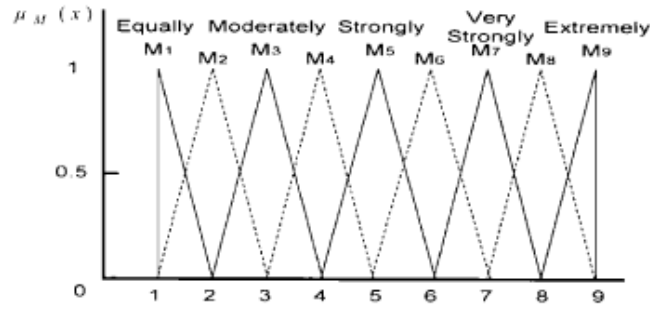


Fig. 1. The membership functions of the triangular numbers [39]

For the consistency check, first need to find the λ_{\max} eigenvector. After λ_{\max} is found, the following operations are performed in order to obtain the consistency ratio;

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

In this equation, RI is a constant determined by n . The RI constant to be used according to the number n is given in Table 3 [41].

Table 3. : RI Constants for the AHP Consistency Check [39]

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,46	1,49

Then to calculate the weights, the following equation is applied for each criterion;

$$\tilde{r} = \left(\prod_{j=1}^n \tilde{d}_{ij} \right)^{1/n}, i = 1, 2, \dots \quad (5)$$

Here d is the average triangular fuzzy number and n stands for the size of the matrix. After this process, \tilde{w}_i is found by [33];

$$\tilde{w}_i = \tilde{r}_i \times \left(\sum_{j=1}^n \tilde{r}_j \right)^{-1} = (lw_i, mlw_i, ulw_i) \quad (6)$$

Finally, the relative non fuzzy weight is calculated for each criterion [42];

$$M_i = \frac{lw_i + mlw_i + ulw_i}{3} \quad (7)$$

M_i is normalized;

$$M_{i_n} = \frac{M_i}{\sum_{i=1}^n M_i} \quad (8)$$

4 Model Application and Results

To implement the Fuzzy AHP method at first a hierarchy diagram must be constructed. In this diagram, the target is specified in the first layer and criteria are determined in the second layer in order to reach this target. There may be as many sub-criteria as necessary from the main criteria. In the last layer, the alternatives are determined and the diagram is completed. Then, pairwise comparisons of these alternatives and criteria will be made in the mathematical model [42].

In the proposed model, the goal is to determine the renewable energy source to be invested for the province of Balıkesir. Criteria for this target have been determined as technical, economic, environmental and social. There are sub-criteria for each main criterion. Some judgements will be prepared between 3 alternative energy sources, namely solar, geothermal and wind (Figure 2).

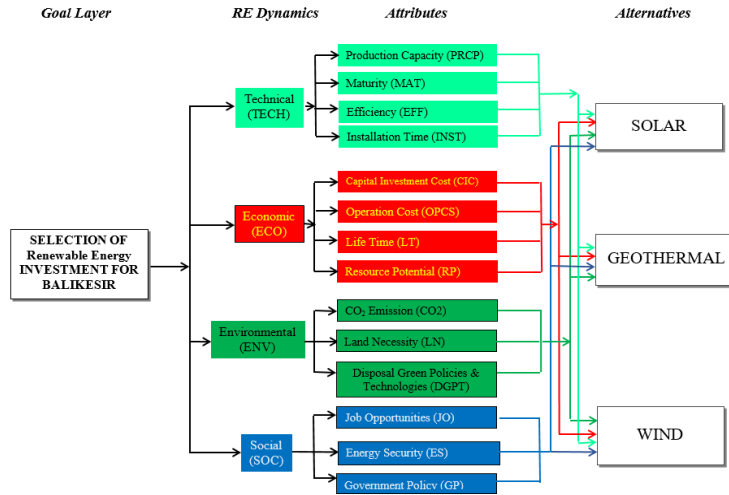


Fig. 2. A hierarchy of renewable energy source alternatives for Balıkesir

4.1 Criteria

When the similar studies in the literature are evaluated to determine the criteria, it is seen that 4 main criteria are used in previous studies [19] and [43] mentioned earlier in this article. As it is mentioned before, these criteria are technical, economic, environmental and social criteria. Stein's study [44] also chose the same main criteria, supporting this decision. The explanation of the sub-criteria for each criterion is given below.

Table 4. Importance weights for the fuzzy AHP model

Criteria	Description	Benefit Attribute	Reference
Technical			
Production Capacity	Corresponds to the amount of energy to be produced by the power plant to be established.	Positive	[20], [45]
Maturity	It expresses the recognition of technology and the awareness of its weak points.	Positive	[43], [20], [45], [35], [46], [47]
Efficiency	Refers to the technology's percentage of efficiency.	Positive	[19], [43], [20], [45], [33], [46], [47]
Installation Time	Time: It is the criterion that measures how long the plant can be installed.	Negative	[45]
Economic			
Capital Investment	The capital required for the establishment of the power plant.	Negative	[43], [20], [45], [35], [46], [47]
Operation Cost	It refers to all the costs to be incurred each year to maintain the power plant (such as the energy it spends to operate, maintenance costs..)	Negative	[43], [20], [45], [35], [46], [47]
Life Time	The time that the plant can spend in operation after its installation.	Positive	[35], [46]
Resource Potential	The criterion expressing the availability of the selected resource in the region.	Positive	[20], [35]
Environmental			
CO2 Emission	It refers to the carbon emission that will occur during production.	Negative	[19], [20], [45], [35], [46], [47]
Land Necessity	The size of the land needed for the installation of the power plant.	Negative	[19], [43], [20], [35], [46], [47]
Disposal Green Politics and Technologies	It refers what kind of policies are followed on the recycling of the wastes to be generated and what level of technology is available in this regard.	Positive	[47], [48], [49], [50]
Social			

Job Opportunities	The employment rate to be created by the power plant to be established.	Positive	[19], [43], [20], [35], [46], [47]
Energy Security	It refers to the degree of continuity that energy can be obtained.	Positive	[47], [51], [52], [53]
Government Policy	It is the criterion that measures how supportive the policies of the state towards the resource to be selected are.	Positive	[20], [47]

4.2 Evaluation Weights of Individual Levels of Proposed Hierarchy

The succeeding charge of the decision makers is the comparison of the elements for a defined level of a pairwise base after construction the hierarchy, to foresee the relation between the relative importance and the proceeded element of the model. The Renewable Energy Dynamics of proposed AHP model is evaluated by three experts in energy. These experts are elected from the pool of the persons who are experienced about the region and the energy. After their evaluation, the mean of pairwise comparison results is calculated. The weights of criteria at each level are determined by using these results of calculations and the triangular fuzzification values seen at Table 2. Moreover, the desired choice is the one having the highest weight between the alternatives. The normalized energy dynamics and their characteristics can be obtained by Fuzzy AHP as shown at Table. 5.

Table 5. Importance weights for the fuzzy AHP model

<i>RE Dynamics</i>	<i>Normalized Weights</i>	<i>Attributes</i>	<i>Normalized Weights</i>
Technical	0,37	Efficiency	0,062
		Production Capacity	0,051
		Installation Time	0,069
		Maturity	0,068
Economic	0,29	Capital Investment	0,116
		Operation cost	0,033
		Lifetime	0,051
		Resource Potential	0,049
Social	0,35	Job opportunities	0,103
		Energy Security	0,069
		Government Policies	0,079
Environmental	0,37	CO2 Emission	0,103
		Disposal green policies and Technologies	0,113
		Land Necessity	0,033

The aggregated result for each alternative according to the normalized weight of each criterion is seen in Table 6.

Table 6. Aggregated results for each alternative according to each attribute

	Attribute weights	Weights	Solar	Geothermal	Wind
Efficiency	0,246	0,062	0,461	0,227	0,312
Production Capacity	0,205	0,051	0,358	0,507	0,135
Installation Time	0,276	0,069	0,521	0,300	0,179
Maturity	0,273	0,068	0,442	0,442	0,116
Capital Investment	0,463	0,116	0,294	0,541	0,165
Operation cost	0,133	0,033	0,306	0,495	0,199
Lifetime	0,206	0,051	0,495	0,199	0,306
Resource Potential	0,198	0,049	0,315	0,411	0,275
Job opportunities	0,411	0,103	0,315	0,411	0,275
Energy Security	0,275	0,069	0,589	0,239	0,178
Government Policies	0,315	0,079	0,306	0,495	0,199
CO2 Emission	0,414	0,103	0,294	0,541	0,165
Disposal green policies and Technologies	0,453	0,113	0,306	0,495	0,199
Land Necessity	0,133	0,033	0,729	0,186	0,085
Total	4,000	1,000	0,384	0,416	0,200

After computing the CR of all pairwise comparison matrices, it was seen that all of them are less than 10% [37]. Consequently, it can be said that the consistency of the decision in all the pairwise comparison matrices is acceptable.

5 Conclusions and Future Work

Solar, wind, hydro, and geothermal heat are the natural sources to generate the renewable energy. It is seen that the renewable energy usage is making important contributions by supplying the energy requirements and offering chance for new establishments and employments to the economies of the developing countries. Turkey is also a developing country but the depending on the energy import to supply the requirement. The most energy consuming and one of the most populated city of north-west region is Balikesir. In the future sight, it is seen that Balikesir will be keep its position in energy consumption. Because of this reason, this study is focused on the energy demand and supply of Balikesir. The selection between the renewable energy sources is performed by using the fuzzy AHP technique.

Determining the relative importance of renewable energy resource alternatives is a fundamental problem in selection for local authorities. The AHP supplies the required abilities for solving this problem. Besides the disadvantage of using one to nine discrete

scale in conventional AHP method, the uncertainty and conflicts of the resources alternatives are not evaluated. The determination of relative importance of resources preferences is depend on the subjective sight and judgements. Here, in this study the importance weighting for alternative renewable energy sources is identified by a fuzzy AHP having an extend analysis which is an effective technique since it can overcome the conflicts in human decisions. The fuzzy AHP algorithm having extend analysis simplifies the establishment of weight vectors then application of them will be easier by eliminating the depressing calculation of eigenvectors necessary in the conventional AHP. In this paper, to exhibit of method, a renewable energy source selection problem is modelled.

When technical dynamics is considered in this model, the ranking of attributes is similar with all other criterion. When Economic dynamics is reflected, the ranking order of attributes in descending order as capital investment, lifetime, resource potential and operation cost. Capital investment is observed as the most dominant. When Social dynamics is measured, the job opportunities and government policies has higher priority than energy security attribute. When Environmental dynamics is considered, the ranking of attributes is the similar as all other attributes.

The optimal renewable energy resource for the location under consideration is selected as the geothermal energy according to the MCDM analysis results. The alternative resources are sorted in the descending order are geothermal, solar, and wind. The geothermal energy resource to generate electricity, is detected as important from the point of investment. The solar resource can be evaluated as another investment alternative since it has just close weight with the geothermal. The result of this study is consistent with actual situation, i.e., solar and geothermal resources are being preferred in Turkey since they are more effective and clean for environment discussed by Hepbasli & Utlu (2004) [54].

As explained by Dursun and Alboyacı, the power density, average speed and the capacity of wind have the most preferable values in some regions of Balıkesir that has the best conditions to generate electricity with the wind tribunes [25]. However, in this proposed model, it is observed that the model followed a holistic approach because the dynamics weights, which are considered technical, economic, social and environmental, is very close.

This study is limited since the evaluated criteria in the prioritization analysis are restricted. If required, these evaluations can be performed by developing the further criteria in the future. Numerous MCDM methods as Fuzzy VIKOR, fuzzy PROMETHEE, fuzzy ELECTRE, or fuzzy TOPSIS can be employed in the future studies to comparing their outputs. The techniques of establishing the correct fuzzy numbers can be explained in the further studies.

References

1. Khalil HB, Zaidi SJ.: Energy crisis and potential of solar energy in Pakistan. *Renewable and Sustainable Energy Reviews*, vol. 1;31, pp.194-201 (2014).

2. Mertoglu O, Simsek S, Basarir N, Paksoy H.: Geothermal energy use, country update for Turkey. In Proceedings of the European Geothermal Congress, pp. 11-14, Den Haag, The Netherlands (2019).
3. Kaygusuz A.: Geothermal energy for clean and sustainable development in Turkey. *Journal of Engineering Research and Applied Science*, 8(1), 1041-50 (2019).
4. Lakatos L, Hevessy G, Kovács J.: Advantages and disadvantages of solar energy and wind-power utilization. *World Futures*, 67(6), 395-408 (2011).
5. Brophy P.: Environmental advantages to the utilization of geothermal energy. *Renewable Energy*, 10(2-3), 367-77 (1997).
6. Dincer I and Ozturk M. *Geothermal Energy Systems*. Elsevier, pp. 57-83 (2021).
7. Topcu I, Ülengin F, Kabak Ö, Isik M, Unver B, Ekici SO.: The evaluation of electricity generation resources: The case of Turkey. *Energy*, 167, 417-27 (2019).
8. Celik AN, Özgür E.: Review of Turkey's photovoltaic energy status: Legal structure, existing installed power and comparative analysis. *Renewable and Sustainable Energy Reviews*, 134, 110344 (2020).
9. Emeksiz C, Demirci B.: The determination of offshore wind energy potential of Turkey by using novelty hybrid site selection method. *Sustainable Energy Technologies and Assessments*, 36, 100562 (2019).
10. Argin M, Yerci V, Erdogan N, Kucuksari S, Cali U.: Exploring the offshore wind energy potential of Turkey based on multi-criteria site selection. *Energy Strategy Reviews*, 23, 33-46 (2019).
11. Melikoglu M.: Geothermal energy in Turkey and around the World: A review of the literature and an analysis based on Turkey's Vision 2023 energy targets. *Renewable and Sustainable Energy Reviews*, 76, 485-492 (2017).
12. Adam K, Hoolohan V, Gooding J, Knowland T, Bale CS, Tomlin AS.: Methodologies for city-scale assessment of renewable energy generation potential to inform strategic energy infrastructure investment, *Cities*, 54, 45-56 (2016).
13. Taminiou J, Byrne J.: City-scale urban sustainability: Spatiotemporal mapping of distributed solar power for New York City. *Wiley Interdisciplinary Reviews: Energy and Environment*, 9(5), e374 (2020).
14. Karaca İH, Gürkan EC, YAPAR H.: Konya ve Civarının Güneş Enerjisi Potansiyeli ve Selçuklu Belediyesi Muhtar Evlerinde Güneşten Elektrik Üretim Sistemi Uygulaması. I Konya Kent Sempozyumu, pp. 275-292 (2011).
15. Güven AF.: Bahçelievler Belediye Başkanlık Binasının Enerji İhtiyacının Güneş ve Rüzgar Sistemi ile Karşlanması, Optimizasyonu ve Maliyet Analizi. *Sinop Üniversitesi Fen Bilimleri Dergisi*. 2(1), 24-36 (2016).
16. Biberici M., Doğan M. Dilber C. Çelik M.: Alternatif Yenilenebilir Enerji Kaynaklarının Yerel Yönetimlerde Kullanımı Ve Mali Getirileri, *Belediyelerin Geleceği ve Yeni Yaklaşımlar*, pp. 541-560 (2017).
17. Gazheli A, van den Bergh J.: Real options analysis of investment in solar vs. wind energy: Diversification strategies under uncertain prices and costs. *Renewable and Sustainable Energy Reviews*, 82, pp. 2693-2704 (2018).
18. ARIKAN Y, Ertuğrul ÇA.: Implementation of feasibility analysis of wind and solar energy on the web base. *International Journal of Engineering Research and Development*, 9(1), 1-10 (2017).
19. Yılan G, Kadirgan MN, Çiftçiöğlü GA.: Analysis of electricity generation options for sustainable energy decision making: The case of Turkey. *Renewable Energy*, 146, 519-529 (2020).

20. Li T, Li A, Guo X.: The sustainable development-oriented development and utilization of renewable energy industry—A comprehensive analysis of MCDM methods. *Energy*, 212, 118694 (2020).
21. Pohekar SD.: Ramachandran M. Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and sustainable energy reviews*, 8(4), 365-381 (2004).
22. Türkseven Dogrusoy İ, Serin E.: İzmir kentindeki yenilenebilir enerji kaynaklarının potansiyelinin mimari açıdan irdelenmesi,[Analysis of the potentials of renewable energy sources in Izmir city in architectural point of view]. *Dokuz Eylül Üniversitesi Mühendislik Fakültesi Mühendislik Bilimleri Dergisi*, 15(3), 1-25 (2013).
23. Karatop B, Taşkan B, Adar E, Kubat C.: Decision analysis related to the renewable energy investments in Turkey based on a Fuzzy AHP-EDAS-Fuzzy FMEA approach. *Computers & Industrial Engineering*, 151, 106958 (2021).
24. Wang Y, Xu L, Solangi YA.: Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach. *Sustainable Cities and Society*, 52, 101861(2020).
25. Dursun B, Alboyaci B.: An evaluation of wind energy characteristics for four different locations in Balıkesir. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 33(11), 1086-1103 (2011).
26. Itlen N, Selici AT.: Investigating the impacts of some meteorological parameters on air pollution in Balıkesir, Turkey. *Environmental monitoring and assessment*, 140(1), 267-277 (2008).
27. Banos R, Manzano-Agugliaro F, Montoya FG, Gil C, Alcayde A, Gómez J.: Optimization methods applied to renewable and sustainable energy: A review. *Renewable and sustainable energy reviews*, 15(4), 1753-1766 (2011).
28. Cai YP, Huang GH, Yang ZF, Lin QG, Tan Q.: Community-scale renewable energy systems planning under uncertainty—An interval chance-constrained programming approach. *Renewable and Sustainable Energy Reviews*, 13(4), 721-735 (2009).
29. Soroudi A, Ehsan M, Zareipour H.: A practical eco-environmental distribution network planning model including fuel cells and non-renewable distributed energy resources. *Renewable energy*, 36(1), 179-188 (2011).
30. Chang NB, Parvathinathan G, Breeden JB.: Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. *Journal of environmental management*, 87(1), 139-153 (2008).
31. Chou CC.:vA fuzzy MCDM method for solving marine transshipment container port selection problems. *Applied Mathematics and Computation*, 186(1), 435-444 (2007).
32. Farahani RZ, Asgari N.: Combination of MCDM and covering techniques in a hierarchical model for facility location: A case study. *European Journal of Operational Research*, 176(3), 1839-1858 (2007).
33. Ehrgott M, Klamroth K, Schwehm C.: An MCDM approach to portfolio optimization. *European Journal of Operational Research*, 155(3), 752-770 (2004).
34. Zadeh LA.: Fuzzy sets. In *Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers by Lotfi A Zadeh*, pp. 394-432 (1996).
35. Wang JJ, Jing YY, Zhang CF, Zhao JH.: Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and sustainable energy reviews*, 13(9), 2263-78 (2009)
36. Liu Y, Eckert CM, Earl C.: A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert Systems with Applications*, pp. 113738 (2020).

37. Ligus M, Peternek P.: Determination of most suitable low-emission energy technologies development in Poland using integrated fuzzy AHP-TOPSIS method. *Energy Procedia*, 153, 101-6 (2018).
38. Saaty TL.: *Fundamentals of decision making and priority theory with the analytic hierarchy process*. RWS publications; 2000.
39. Kwong CK, Bai H.: Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach. *Iie transactions*, 35(7), 619-26 (2003).
40. Moayeri M, Shahvarani A, Behzadi MH.: The application of fuzzy analytic hierarchy process in high school math teachers ranking. *Mathematics Education Trends and Research*, (1), 20-30 (2016).
41. Kaganski S, Majak J, Karjust K.: Fuzzy AHP as a tool for prioritization of key performance indicators. *Procedia Cirp*, 72, 1227-32 (2018).
42. Soberi MS, Ahmad R.: Application of fuzzy AHP for setup reduction in manufacturing industry. *J. Eng. Res. Educ*, 8, 73-84 (2016).
43. Lee HC, Chang CT.: Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. *Renewable and Sustainable Energy Reviews*, 92, 883-96 (2018).
44. Stein EW.: A comprehensive multi-criteria model to rank electric energy production technologies. *Renewable and Sustainable Energy Reviews*, 22, 640-654 (2013).
45. Cavallaro F, Ciraolo L.: A multicriteria approach to evaluate wind energy plants on an Italian island. *Energy policy*, 33(2), 235-44 (2005).
46. Şengül Ü, Eren M, Shiraz SE, Gezder V, Şengül AB.: Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renewable energy*, 75, 617-625 (2015).
47. Alipour M, Alighaleh S, Hafezi R, Omranievardi M.: A new hybrid decision framework for prioritizing funding allocation to Iran's energy sector. *Energy*, 121, 388-402 (2017).
48. Coyle G. The not-so-green renewable energy: Preventing waste disposal of solar photovoltaic (PV) panels. *Golden Gate U. Envtl. LJ.*, 4, 329 (2010).
49. Recycling revolution necessary to complete the clean energy transition <<https://www.cleanenergywire.org/news/recycling-revolution-necessary-complete-clean-energy-transition>> 2021 [accessed 18.07.2021].
50. EPA Releases Briefing Paper on Renewable Energy Waste Management <<https://www.epa.gov/newsreleases/epa-releases-briefing-paper-renewable-energy-waste-management>> 2021 [accessed 18.07.2021].
51. Augutis J, Martišauskas L, Krikštolaitis R.: Energy mix optimization from an energy security perspective. *Energy Conversion and Management*, 90, 300-314 (2015).
52. Francés GE, Marín-Quemada JM, González ES.: RES and risk: Renewable energy's contribution to energy security. A portfolio-based approach. *Renewable and sustainable energy reviews*, 26, 549-559 (2013).
53. Johansson B. Security aspects of future renewable energy systems—A short overview. *Energy*, 61, 598-605 (2013).
54. Hepbasli A, Utlu Z.: Evaluating the energy utilization efficiency of Turkey's renewable energy sources during 2001. *Renewable and Sustainable Energy Reviews*, 8(3):237-55 (2004).