



Priority ranking for energy resources in Turkey and investment planning for renewable energy resources

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Abstract

Energy has been an essential factor in determining the governments' policies. The countries had to produce their own energy to decrease dependency on external resources. That also provided to gain a great importance on investment on power plants. In this study, a multi-objective Mixed-Integer Linear Programming (MILP) model synchronously optimizing five targets determined as decreasing carbon dioxide (CO₂) emission, increasing power consumption, increasing power plants, increasing energy generation and installed capacity was used. In described model, it was solved by considering renewable power plants in Turkey and fossil fuel-based power plants having most share in Turkey. By trying to minimize deviation values of Turkey's 2023 targets, it aimed to determine which power plants need to be increased. To determine the priorities of these targets, Ranking Approach for fuzzy numbers by Liou and Wang (1992) was used. Besides, Fuzzy Analytic Hierarchy Process (AHP) was used to prioritize investment planning of renewable power plants in Turkey and five different kinds of power plants under the visual pollution criteria based on amount of CO₂ emission released, environmental damage, capital costs, space requirement and provided employment were evaluated.

Keywords Fuzzy Analytic Hierarchy Process · Power plants · Goal programming · Turkey's 2023 targets · Renewable energy

Introduction

Energy is one of the most essential factors for a country's social welfare and sustainable development. Recently, population growth, industry development, and income growth, especially in developing countries, cause the energy need increase.

In view of the distribution of power plants in Turkey and their effects of technologic, economic, socioeconomic and life quality, decision makers have to choose the best alternatives to accomplish their goals to decide which power plant will be built [2].

In this article, Fuzzy Analytic Hierarchy Process (AHP), which is one of the multiple criteria decision-making methods, was used. By considering environmental damage of power plants, capital costs, space requirement, their advantages and used technological development under the main criteria of social acceptance, the power plants in Turkey were ranked and an order of preference was composed. In addition, how many power plants should be built was determined with fuzzy-weighted goal programming method by considering Turkey's installed capacity, number of power plants, energy generation and targets of demands in 2023. The study consisted of an introduction, literature search, multiple criteria decision-making methods and an application. Analytic Hierarchy Process and goal programming that are multiple criteria decision-making methods and fuzzy conditions of these methods were described. Later, it continued with an application and the results were included.

Literature search

Kowalski et al. worked on determining economically best option for sustainable energy using multiple criteria decision-

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making methods for several gas emissions released by power plants. According to the results obtained, natural gas was determined as the best fuel [16]. Pilavachi et al. made a multiple criteria evaluation on nine types of power plants using hydrogen and natural gas as a fuel with AHP method under seven criteria. In this study, combined cycle plant with natural gas was determined as a better alternative [24]. While choosing the best alternative among renewable power plants in Turkey, Kahraman et al. used AHP method. At the end of the study, wind power plant was the best alternative for renewable energy [13]. Liu et al. evaluated the activities of thermal power plants between the years of 2004 and 2006 with respect to increasing electrical demands in Taiwan. According to the results obtained, combined cycle plants were determined as the most effective plants [20]. Shen et al. applied AHP method for determining economically and environmentally the energy value of investment selection for renewable energy resources within the frame of Taiwan Government's sustainable energy policies [29]. Kahraman and Kaya used fuzzy AHP method and VIKOR method to determine the choice of best alternative power plants for İstanbul [15]. Wang et al. applied AHP method for energy resources selection in China [32]. Lee et al. used fuzzy AHP in making a strategic route map of energy technologies to use alternative energy technologies against high oil prices [17]. Çebi et al. used fuzzy AHP and axiomatic design techniques for choosing the best alternative for investment and comparing renewable energy resources [14]. Jeberaj and Iniyar applied fuzzy AHP and AHP method for the choice of sustainable energy [11]. Liang et al. used the general fuzzy theory for energy planning, supply demand, assumption and renewable energy modeling. In the article, especially on the basis of the current situation, they improved a model for evaluating manufacturing projects about the usage of Analytic Hierarchy Process (AHP) and fuzzy evaluation. Later, while choosing manufacturing projects in China, a sample study for the evaluation of optimum manufacturing project showing the activity of the model was presented [18]. Anane et al. explained an innovator method to range the proper lands for watering using fuzzy AHP based on geographical information systems in the basin of TWW Nabeul-Hammamet (Tunisia) chosen as a target region [1]. Nixon et al. evaluated the main current collection of thermal solar energy technologies within the frame of AHP. These technologies were compared with technical, economic and environmental criteria [22]. Jinturkar and Deshmukh. Improved a fuzzy mixed-integer goal programming method for rural sintering and heating energy planning in the center of India [12]. Daim et al., improved a fuzzy goal programming in the state of Oregon to make a renewable portfolio giving an answer to 25% of energy demand obtained by renewable resources in 2025 [5]. San Cristobal applied a goal programming method for layout of five different renewable power plants in the region of Cantabria

in Northern Spain by achieving seven targets about maintenance, management, investment, distances between power plants and energy generation [28]. Ramanathan and Ganesh used a goal programming model to ideally criticize seven energy resources used for lighting at twelve targets-driven houses representing energy, economic and environmental systems [26]. By considering financial and profit risks, Han et al. offered a multi-purpose optimization model for CO₂ minimization infrastructure design and sustainable energy generation [7]. Chang recommended a multiple choice goal programming model to deal with the problem of capacity enhancement plan at the renewable energy sector [4]. Jayaraman et al. offered a goal programming model integrating plentiful allotments of labor resources to reach sustainable, economic, energy and environmental goals of United Arab Emirates [10].

Multiple criteria decision making

Multiple criteria decision making (MCDM), with the briefest definition, is a general name given for problem-solving of multiple and conflicted criteria to be achieved. MCDM explains a top-concept including designed techniques and methods to help people facing the problems being characterized by different size of criteria, and multiple and conflicted criteria [33]. The methods of MCDM are divided into two as multiple criteria and multi-objective. Multi-objective decision making is a model defined by the alternatives as a mathematic model. Multiple criteria decision making is an evaluation process using many criteria taking generally the value of different criteria and weighted, conflicted and even qualitative values on the purpose of eliminating, prioritizing, classifying, sorting and selecting a finite number of the options.

Goal programming (GP)

Goal programming was extended by Ijiri in the middle of 1960s, but it was improved by Ignizio and Lee in 1970s [8,9]. With a different viewpoint from linear programming, goal programming, instead of minimizing or maximizing an objective function, minimizes the deviations from the targets determined within the frame of current limitations. These deviations are shown as a negative deviation and a positive deviation. Since the ratio of these variables' objective functions is 0, they cannot affect the results. Namely, the purpose of the problem in goal programming is to minimize the sum of variables showing the deviation [31]. In addition to this, goal programming combines multiple goals conflicting with decision maker's options. The targets determined in the results may not be reached, so even if there are no optimal results, the most acceptable ones can be obtained. In our article, a

Table 1 Linguistic variables for weight/importance of decision makers and different goals

Linguistic variables	Triangle Fuzzy numbers
Very low (VL)	(0%, 5%, 10%)
Low (L)	(5%, 10%, 25%)
Medium–low (ML)	(20%, 32.5%, 45%)
Medium (M)	(40%, 50%, 60%)
Medium–high (MH)	(55%, 67.5%, 80%)
High (H)	(75%, 85%, 95%)
Very high (VH)	(90%, 100%, 100%)

preemptive goal programming model which is a variety of goal programming was used.

Preemptive GP formulation:

$$\text{Min } Z = \sum_{i=1}^p W_i^+ \delta_i^+ + W_i^- \delta_i^-$$

s.t.

$$f_i(x) + \delta_i^+ - \delta_i^- = g_i, i = 1 \dots p;$$

$$x \in D;$$

$$\delta_i^+, \delta_i^- \geq 0, i = 1 \dots p$$

W_i^- and W_i^+ are priority values being associated with negative and positive deviations. The numerical value of the target achieved by decision maker is showed with g_i . The number of the targets determined by decision maker is showed with p . While being done an order of priority of a hierarchical structure by decision makers, Liou and Wang’s Sorting Approach determining to reach different goals for fuzzy numbers was used here [19]. Linguistic variables are given for weight/importance of decision makers and different goals in Table 1.

As showed in Table, these linguistic variables are characterized by triangle fuzzy numbers. In the method of Liou and Wang’s total integral value, $a \in [0, 1]$ as an optimism index; for fuzzy numbers given as $(\tilde{A}) = (a, b, c)$, total integral value is calculated in this way [19].

$$\begin{aligned} I_T^a(\tilde{A}) &= aI_R(\tilde{A}) + (1 - a)I_L(\tilde{A}) \\ &= a \int_0^1 g_A^R(y) dy + (1 - a) \int_0^1 g_A^L(y) dy \\ &= a \int_0^1 [c + (b - c)y] dy \\ &\quad + (1 - a) \int_0^1 [a + (b - a)y] dy \\ &= \frac{1}{2}[a.c + b + (1 - a)a] \end{aligned} \tag{3.1}$$

Suppose that $(\tilde{A}), d_{\tilde{A}}(x)$ is a triangle fuzzy number having membership function $d_{\tilde{A}}^L$ and $d_{\tilde{A}}^R$ are the right and left membership functions of the triangle fuzzy number. At last, the right and left integral values of (\tilde{A}) are defined as below.

$$I_L(\tilde{A}) = \int_0^1 g_A^L(y) dy \text{ and } I_R(\tilde{A}) = \int_0^1 g_A^R(y) dy \tag{3.2}$$

$g_A^L(y)$ ve $g_A^R(y)$, respectively, shows inverse functions of $d_{\tilde{A}}^L$ ve $d_{\tilde{A}}^R$. These inverse functions are formulated like the following equation.

$$g_A^L(y) = a(b - a)y \text{ and } g_A^R(y) = c + (b - c)y \tag{3.3}$$

While $y \in [0, 1], a \in [0, 1]$ as an optimistic index, the total integral value of \tilde{A} is calculated below.

$$\begin{aligned} I_T^a(\tilde{A}) &= aI_R(\tilde{A}) + (1 - a)I_L(\tilde{A}) \\ &= \frac{1}{2}[a(b + c) + (1 - a)(a + b)] \\ &= \frac{1}{2}[ac + b + (1 - a)a] \end{aligned} \tag{3.4}$$

While $a = 0$, the total integral value represents optimistic decision maker and it is calculated in the following equation.

$$I_T^0(\tilde{A}) = \frac{1}{2}[b + a] \tag{3.5}$$

Total integral value of $a = 0.5$ represents moderate decision maker and it is calculated in the following equation.

$$I_T^{0.5}(\tilde{A}) = \frac{1}{2}[0.5c + b + 0.5a] \tag{3.6}$$

Total integral value of $a = 0.5$ represents optimistic decision maker and it is calculated in the following equation.

$$I_T^1(\tilde{A}) = \frac{1}{2}[c + b] \tag{3.7}$$

$I_T^a(\tilde{A}) = a_{ik}$ ith for decision maker and j . for fuzzy goal are the performances [19].

Analytic Hierarchy Process (AHP)

AHP is a decision-making technique determining the order of importance by finding the priorities according to each other’s criteria and making paired comparisons with objective and subjective criteria [30]. In these paired comparisons, it is preferred in terms of which one of them is more important than the other. By determining them, it is based on a numerical

Table 2 Comparison matrix according to the weights given by decision makers

	1st Decision maker	2nd Decision maker	3rd Decision maker
Installed capacity increased	MH	M	L
Energy generation increased	H	VH	M
Power plants increased	M	H	ML
Power consumption increased	VH	H	L
CO ₂ emission decreased	M	VH	VH

Table 3 Fuzzy evaluation matrix for decision makers

	1st Decision maker (moderate) (a)	2nd Decision maker (optimistic) (b)	3rd Decision maker (pessimistic) (c)
Installed capacity increased	0.55,67.5,80	40,50,60	5,15,25
Energy generation increased	75,85,95	90,100,100	40,50,60
Power plants increased	40,50,60	75,85,95	20,32.5,45
Power consumption increased	90,100,100	75,85,95	5,15,25
Installed capacity increased	0.55,67.5,80	40,50,60	5,15,25
Energy generation increased	75,85,95	90,100,100	40,50,60
Power plants increased	40,50,60	75,85,95	20,32.5,45
Power consumption increased	90,100,100	75,85,95	5,15,25
CO ₂ emission decreased	40,50,60	90,100,100	90,100,100

evaluation of them. AHP enables to make an order between options as well as determining the best option for a person who is about to make a decision. For the reason that this method which considers both quantitative and qualitative factors is used widely and is applied simply, it is applied easily even in the most complicated problems. In that being widely and flexible, AHP makes it a great convenient [6].

Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

An enhanced fuzzy AHP method suggested by Chang was used in many problems, which fuzzy AHP was used. In this method, the cutting levels of “a” were not necessary. Besides using the values of artificial ratings, this method comes to the forefront with simple level sequencing and integrated sequencing. The most advantageous side of this method is that calculation requirement is low and it does not need any additional process by following the steps of classical AHP. The disadvantage of it is that it only uses fuzzy triangle numbers [6]. Pairwise comparisons matrices are arranged to determine the weights of criteria and these comparisons

Table 4 Fuzzy numbers used in criteria comparisons

Linguistic variable	Fuzzy values	Reciprocal values
Equally important	(1, 1, 1)	(1/1, 1/1, 1/1)
Weakly important	(1, 3, 5)	(1/5, 1/3, 1)
Essentially important	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strongly important	(5, 7, 9)	(1/9, 1/7, 1/5)
Absolutely important	(7, 9, 11)	(1/11, 1/9, 1/7)

will be made using fuzzy triangle numbers in Table 1. These fuzzy numbers were developed to be based on Saaty’s 1–9 importance scale by Prakash [25,27] (Tables 2, 3, 4). The Algorithm of Chang’s fuzzy AHP where the disadvantages of traditional fuzzy AHP methods are not valid is used and calculations are made with the techniques of intersections of fuzzy numbers. X composes the object cluster and G composes a target cluster. According to Chang’s enlarged analysis method, g_i values were composed for each target. Thus, enlarged values of m ’s enlarged analysis for each object are below.

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m, \quad i = 1, 2, \dots, n \tag{3.8}$$

All values of M_{gi}^j ($j = 1, 2, \dots, m$) given here are fuzzy numbers. The steps of Chang’s enlarged analysis method are below;

Step 1 The value of fuzzy artificial size is defined according to the object i .

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \tag{3.9}$$

To obtain $\sum_{j=1}^m M_{gi}^j$, we carry on the addition on fuzzy numbers on m values for a determined matrix;

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right) \tag{3.10}$$

To obtain $\left[\sum_{j=1}^m M_{gi}^j \right]^{-1}$, Fuzzy additions are made on the values of M_{gi}^j ($j = 1, 2, \dots, m$)

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left(\sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i \right) \tag{3.11}$$

And vector’s reverse in the equation is calculated below.

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i} \right) \tag{3.12}$$

Step 2 $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangle fuzzy numbers.

The degree of probability is defined below;

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{3.13}$$

And expressed below.

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & M_2 \geq M_1 \\ 0 & l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{diğer} \end{cases} \tag{3.14}$$

$V(M_1 \geq M_2)$, $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are the ordinates of junction points of triangle fuzzy numbers. In other words, these are the values of membership the function. To compare M_1 and M_2 , the values of both $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are required to be found.

The intersection of triangle fuzzy numbers is given in Fig. 1

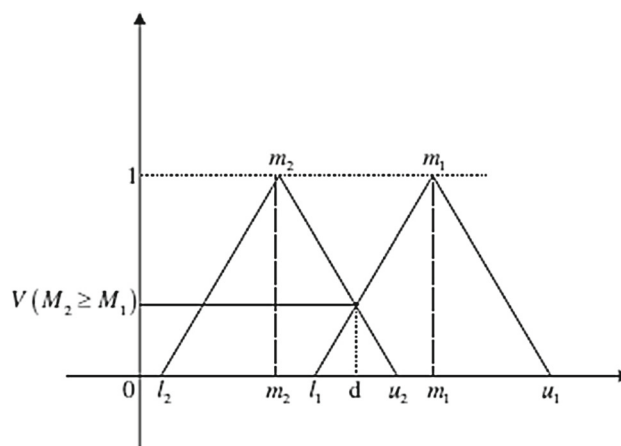


Fig. 1 M_1 and M_2 the intersection of triangle fuzzy numbers [3]

Step 3 That the degree of probability of a convex fuzzy number is bigger than the convex number of M_1 ($i = 1, 2, \dots, k$) is defined below.

$$V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \dots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), \quad i = 1, 2, 3, \dots, k \tag{3.15}$$

For $k = 1, 2, \dots, n; k \neq i$, calculated as d'' , the weighting vector is obtained below.

$$W^i = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \tag{3.16}$$

Here A_i ($i = 1, 2, \dots, n$) consists of the members.

Step 4 When normalizing the weighting vector given above,

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \tag{3.17}$$

The vector above is obtained. Now, this W weighting vector is not a fuzzy number [27].

Application

The Preemptive Goal Programming application

In our study, seven power plants were analyzed; S_1 as a coal plant, S_2 as a natural gas combined cycle power plant, S_3 as a hydropower plant, S_4 as wind plant, S_5 as a geothermal plant, S_6 as a solar plant and S_7 as a biomass plant were defined. Turkey’s installed capacity, energy generation, energy demand and greenhouse gas emission defined as its sectorial indicators were divided into the numbers of power plants and the obtained values are given in Table 5 [21].

Table 5 Energy indicators

Power plants	The number of current power plants	Installed capacity/the number of current power plants	Energy generation/the number of current power plants	Energy demand/the number of current power plants	Greenhouse gas emission/the number of current power plants
Coal	38	0.423	2282.6	1.2	1.4
Natural gas	213	0.109	672.6	0.109	0.419
Hydro	562	0.047	124.7	0.106	0.0026
Wind	130	0.035	93.4	0.010	0.00066
Geothermal	22	0.029	158	0.0025	0.004
Solar	113	0.0036	5.28	0.067	–
Biomass	68	0.0049	23.69	0.012	0.00058

It was calculated using (3.4), (3.5) and (3.6)’s priority values of goals and fuzzy evaluation matrix in Table 4 below.

$$\frac{1}{2} [0.5c + b + 0.5a] + \frac{1}{2} [c + b] + [b + a]$$

Goal Programming Model:

Objective Function;

Min

$$0, 441d_{11} + 0, 441d_{12} + 0, 766d_{21} + 0, 766d_{22} + 0, 523d_{31} + 0, 523d_{32} + 0, 875d_{41} + 0, 875d_{42} + 0, 816d_{51} + 0, 816d_{52}$$

Constraints;

$$0, 423x_1 + 0, 109x_2 + 0, 047x_3 + 0, 035x_4 + 0, 029x_5 + 0, 0036x_6 + 0, 0049x_7 + d_{11} - d_{12} = 120$$

$$2282, 6x_1 + 672, 6x_2 + 124, 7x_3 + 93, 4x_4 + 158x_5 + 5, 28x_6 + 23, 69x_7 + d_{21} - d_{22} = 416000$$

$$1, 2x_1 + 0, 109x_2 + 0, 106x_3 + 0, 010x_4 + 0, 0025x_5 + 0, 067x_6 + 0, 012x_7 + d_{31} - d_{32} = 218$$

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + d_{41} - d_{42} = 2148$$

$$1, 4x_1 + 0, 419x_2 + 0, 0026x_3 + 0, 00066x_4 + 0, 004x_5 + 0, 00058x_7 + d_{51} - d_{52} = 240$$

- 0, 423x₁ ≥ 30
- 0, 109x₂ ≥ 37
- 0, 047x₃ ≥ 36
- 0, 035x₄ ≥ 20
- 0, 029x₅ ≥ 0, 6
- 0, 0036x₆ ≥ 3
- x₁ ≥ 38
- x₂ ≥ 213
- x₃ ≥ 562

Table 6 Lindo outputs

Variable	Value	Variable	Value
x ₁	71,00000	d ₁₁	0,000000
x ₂	340,0000	d ₁₂	7,088600
x ₃	766,0000	d ₂₁	0,000000
x ₄	572,0000	d ₂₂	133184,0
x ₅	22,00000	d ₃₁	47,92500
x ₆	834,0000	d ₃₂	0,000000
x ₇	68,00000	d ₄₁	0,000000
		d ₄₂	525,0000
		d ₅₁	0,000000
		d ₅₂	4,356560

- x₄ ≥ 130
- x₅ ≥ 22
- x₆ ≥ 113
- x₇ ≥ 68
- x_i ≥ 0
- d_i ≥ 0

Priority values obtained were used in minimization row. The values obtained in Table 6 were used in constraints under 2023 targets and it was solved in Lindo Software. Lindo output is shown in Table 6.

According to the results, in view of the numbers of the available power plant, the power plants that are required to be built must have been the solar power plant with the unit 834 and wind power plant with the unit 572. The first goal shows that the deviation in d₁₂ stayed under the targeted installed capacity. d₂₂, i.e., high deviation value at energy generation, is shown that energy need will be increased in the long term until 2023. Non-renewable fossil resources cannot supply energy demands in the long term. According to 2023 targets, the deviation demand in d₃₂ will stay under 47,92500 toe (tone of oil equivalent). The deviation in fourth goal, d₄₂

Table 7 The pairwise comparison matrix among the criteria [23]

Criteria	ED	IC	SR	PE	VP
Environmental damage (ED)	(1, 1, 1)	(1/5, 1/3, 1)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)
Investment cost (IC)	(1, 3, 5)	(1, 1, 1)	(7, 9, 11)	(3, 5, 7)	(3, 5, 7)
Space requirement (SR)	(1/9, 1/7, 1/5)	(1/11, 1/9, 1/7)	(1, 1, 1)	(1, 3, 5)	(1/5, 1/3, 1)
Provided employment (PE)	(1/7, 1/5, 1/3)	(1/7, 1/5, 1/3)	(1/5, 1/3, 1)	(1, 1, 1)	(3, 5, 7)
Visual pollution (VP)	(1/5, 1/3, 1)	(1/7, 1/5, 1/3)	(1, 3, 5)	(1/7, 1/5, 1/3)	(1, 1, 1)

Table 8 The synthesis values related to criteria

Criteria	l	m	u
SED	0.117	0.295	0.665
SIC	0.190	0.420	0.890
SSR	0.030	0.080	0.210
SPE	0.060	0.120	0.280
SVP	0.030	0.090	0.220

shows that the numbers of power plants are required to be increased 525 units. Finally, the deviation value in d_{51} shows that greenhouse gas emission is deficient almost 4,356560 Tone-CO₂/Gwh and these are needed to be reduced using renewable energy resources.

Fuzzy AHP application

After the application of project investment, according to the model results of available energy alternatives in Turkey, it was seen to make an investment in renewable energy resources. In the second stage, it was analyzed which renewable energy resources were made an investment on and it was ordered. The used power plants are below.

- S₁: Hydro
- S₂: Wind
- S₃: Geothermal
- S₄: Solar
- S₅: Biomass

To compare these power plants, at first, the vectors were determined. Later, the vectors were compared dynamically with a point scoring system obtained with an expert opinion working at department of energy. Here below, it was given the statement of fuzzy values of the pairwise comparisons matrix. The pairwise comparison matrix among the criteria is given in Table 7.

According to the matrix above, the synthesis value of each criterion was calculated. The Eq. (3.9) was used (Table 8).

Using the values obtained, the comparisons of fuzzy values were made with Eq. (3.14) and the values below were found.

Table 9 The membership function values according to pairwise comparisons of criteria

V	SED	SIC	SSR	SPE	SVP
SED	–	0.79	1	1	1
SIC	1	–	1	1	1
SSR	0.3	0.06	–	0.79	0.95
SPE	0.48	0.23	1	–	1
SVP	0.33	0.08	1	0.84	–

Table 10 The weights of alternatives for each criterion

Criteria	ED	IC	SR	PE	VP
Hydro	0.244	0.311	0.423	0	0
Wind	0.381	0.338	0.017	0.104	0.581
Geothermal	0.068	0.017	0.309	0.313	0
Solar	0.091	0.196	0.237	0.336	0.419
Biomass	0.213	0.135	0.012	0.245	0

To calculate the vector in Table 9, the minimum one of priority values related to the alternatives from the obtained values is taken.

Priority vector was given below.

$$W = (0,06; 0,08; 0,23; 0,79; 1)$$

When the result of the calculation of priority vector, the vector below is obtained.

$$W' = (0,365; 0,463; 0,027; 0,106; 0,037)$$

After determining the weights belonging to the criteria, taking an expert opinion working at an energy company and verbalization of numeric data of criteria, pairwise comparisons of five power plants were made.

After all calculations, by making a matrix applied by multiplication the criteria weights and alternatives weights, and total superiority weights of alternatives are calculated. In Table 10, the weights of alternatives were shown according to each criterion. Main criteria weights are given in Table 11. Total superiority weights of alternatives are given in Table 12.

After determining evaluation results of alternatives under the criteria 5, by making a multiplication value related to each criterion with the obtained values, the weights were

Table 11 Criteria weights according to pairwise comparison matrix

Criteria Weights	0.365	0.463	0.027	0.106	0.037
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Table 12 Total superiority weights of alternatives

	Total superiority weights of alternatives
Hydro	0.244
Wind	0.327
Geothermal	0.072
Solar	0.179
Biomass	0.167

calculated. So, total superiority weights were calculated. According to the values, the wind power plant was determined as the best plant to be made an investment on. Hydropower plant follows it as rank number 2 and solar power plant follows it as rank number 3.

The conclusion

At the first stage of the application, using ranking approach for fuzzy numbers and the determined targets composing of a multi-objective mixed-integer programming model of the fossil power plants consumed most and renewable energy resources in Turkey, as a result comparisons made by decision makers, the priority values were calculated with Liou and Wang's total integral value method. In the research conducted, the target of energy demand has been the highest priority. Under the limitations composed using the data targeted in 2023, the model was solved with Lindo software. According to 2023 targets, the solar power plant is a plant which is required to be made an investment on according to the results obtained by Lindo software. The wind power plant followed it as rank number two.

In the other stage of the application, by taking an expert opinion working at the department of energy under the criteria of space requirement, provided employment, investment cost, environmental damage of power plants in Turkey, Saaty's fuzzy number approach was used. The pairwise comparisons for first criteria and for second power plants for each criterion were made. Later, according to Chang's grading analysis method, the priority values of alternatives were calculated. In the criteria, weights were obtained after calculating the priority vector. Investment cost having the highest ratio was the first criteria; as second, the environmental damage followed it. The wind power plant was determined as the most proper option. Hydropower plants and solar power plants followed it.

The study can be taken into account as an important resource for decision makers, but, in addition to these, a

country's geopolitical position, inter-countries treaties, and financial status are considered for the decision of investment.

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