Chapter 2

A Multi-Criteria Decision-Making Methodology Suggestion for Turkey Energy Planning Based Type-2 Fuzzy Sets

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Additional information is available at the end of the chapter

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Abstract

Energy as an essential basis for the social development has a vital role for survival and development of humankind as an environmental factor. Energy consumption of Turkey has become an important problem through the exorbitant price increase in the fundamental energy source of the world and rapid development in the economy of Turkey. The necessity to create correct decision-making processes related to future in order to eliminate this problem has appeared as well. For that reason, views of decision-makers upon the relative importance of selection criteria were determined, using analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) based upon type-2 fuzzy sets (FSs) that were used in order to list the best energy alternatives.

Keywords: energy planning, strategy management, type-2 fuzzy sets, multi-criteria decision-making (MCDM), technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP)

1. Introduction

Energy system plays an important role in the economic and social development of a country and life quality of people. In order to encourage the use of sustainable energy and implementation of energy productivity precautions and technical changes, some new government policies have been adapted. Since the beginning of civilization, energy sources have become important for people [1, 2].

Furthermore, making a decision on energy planning based upon the energy demand includes balancing various ecological, social, technical and economic aspects on time and place. This balance is critical for the survival of nature and welfare of the population dependents to energy [3, 4].

When we try to select any energy alternatives using some criteria, we should regard the inconsistent points between the considered criteria. Making a selection among energy resource alternatives is a multi-criteria decision-making (MCDM) problem including several criteria conflicting with each other. We are obliged to evaluate some alternatives, considering the advantages and disadvantages in terms of selection criteria. Meanwhile, energy evaluations should cope with qualities and components that are hard to define and can include both qualitative and quantitative factors. Accordingly, this problem should be overcome through multi-criteria decision-making (MCDM) method. This method can present alternatives to overcome complicated energy management problems [5, 6].

In 1970s, it was popular to discuss energy problems through mono-criteria approaches aiming to define low-cost most productive energy supply choices. Moreover, in 1980s, common values changed due to the raising awareness on environment. The necessity of considering the environmental and social concerns while performing energy planning required use of multi-criteria approaches. Multi-criteria decision-making (MCDM) methods were commonly performed upon social, economic, industrial, ecological and biological systems besides the energy systems [7, 8].

Some methods have been suggested in order to overcome fuzzy multi-criteria group decision-making problems. Type-2 fuzzy sets (FSs) are more efficient than ordinary FSs in terms of coping with wrong and missing information in real-world practices. A type-2 FS is a membership function (MF) represented by a [0–1] interval FS. Type-2 FSs include membership functions with certain intervals used commonly for high-level FSs due to the relative simplicities [9–11]. Type-2 FSs qualified with primary and secondary membership are an extension of type-1 FSs [12, 13]. In the literature, some articles related to type-2 FSs can be encountered. Chen and Lee [14] suggested a type-2 fuzzy technique for the priority sequence close to an ideal solution (TOPSIS) aiming to overcome group decision-making problems based upon TOPSIS. Chen [15] suggested a beneficial method in order to decrease tolerance prejudice during the decision-making processes based upon type-2 interval FSs and to forecast the importance of criteria in multi-criteria decision-making (MCDM) process. Chen [16] suggested multi-criteria decision making (MCDM) method including fuzzy numbers generalized as intermediate value under incomplete weight. Chen et al. [17] developed a method to discuss multi-quality group decision-making problems depending upon the sequence of type-2 interval FSs. Chen [18] suggested a new method in order to overcome multi-criteria group decision-making problems depending upon type-2 interval FSs and to determine the targeted importance of criteria. Wang et al. [19] suggested multi-criteria decision making (MCDM) methods depending upon arithmetic operations of type-2 interval fuzzy sets and sequence values.

In this chapter, a fuzzy multi-criteria decision making (MCDM) methodology based upon type-2 FSs was suggested for the decision-making problem related to energy alternatives. The suggested methodology will be used in order to determine the most appropriate energy

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alternative for Turkey. In the first stage, criteria weights will be determined with type-2 interval analytical hierarchy process (AHP) method. Then, the sequence of all alternatives will be determined according to their priority determined by type-2 interval fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. In order to meet realizable energy demands for best alternative or alternatives, it was aimed to reveal general energy alternatives of Turkey and to determine consistent strategies, using fuzzy MCDM methodology based upon type-2 interval FSs.

2. Decision-making methods

2.1. Type-2 fuzzy sets

During the decision-making process, because of the increasing complexity of the socio-economic environment and uncertainty of the immanent subjective nature of human thought, the information related to quality values is generally ambiguous, and fuzzy. This reality has caused many researchers to perform fuzzy set (FS) theory in order to model uncertainty and ambiguity during the decision-making processes [18, 19].

Some multi-criteria decision-making (MCDM) methods were suggested depending upon the type-1 FSs. Type-2 FSs include more uncertainty rather than the type-1 FSs. Those provide us more freedom level in order to represent the uncertainty and fuzziness of the real world. Type-2 FSs can be considered as an extension of type-1 FSs. Because type-2 interval FSs are used instead of traditional type-1 FSs in order to represent weights of the qualities and evaluation values, type-2 FSs provide us a more beneficial method for the solution of the fuzzy multi-criteria decision-making problems in a more flexible and intelligent way [20–24].

Basic concepts and processes of type-2 FSs were presented below, and some definitions of type-2 FSs and type-2 interval FSs were analyzed shortly. The fuzziness of type-1 membership function shifting the points on the triangle to the right or left without the obligation of being at the same rate as in **Figure 1 (b)** was presented in **Figure 1 (a)**. Then, there is no even one residual value for the membership function in a specific value of "x" such as "x'". Instead of this, the membership function gains value at the point where vertical line intersects with the

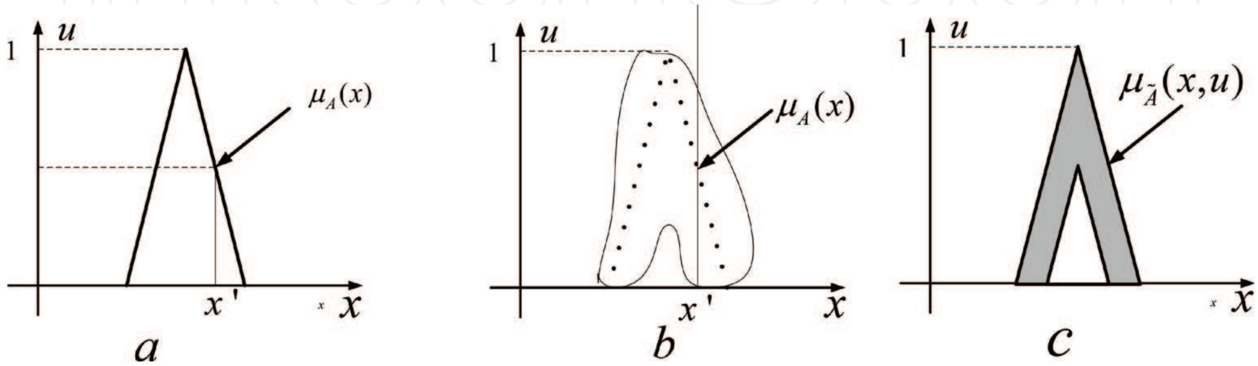

Figure 1. Type-1 and type-2 membership functions [26].

fuzziness. It is not necessary for these values to be weighted similarly. Accordingly, we can provide a width distribution for all these points. Implementing this to all $x \in X$, we create a three-sided membership function-a type-2 membership function- qualifying a type-2 fuzzy set [24, 25].

Let us assume $\tilde{A}$ as a type-1 FS $\tilde{A} = (a_1, a_2, a_3, a_4; H_1(A), H_2(A))$ with isosceles trapezium as shown in **Figure 2**. $H_1(A)$ indicated the membership value of, a_2 element, and $H_2(A)$ indicates the membership value of a_3 element. According to this, it is $0 \le H_1(A) \le 1$ and $0 \le H_2(A) \le 1$. If $a_2 = a_3$, the type-2 FS becomes $\tilde{A}$ triangle-shape type-1 FS [26].

Definition 1: In X universe of discourse, the type-2 FS $\tilde{\tilde{A}}$ can be represented with type-2 membership function $\mu_{\tilde{\tilde{A}}}$ as shown below [13, 25, 27]:

$$\tilde{\tilde{A}} = \left\{ \left((x, u), \mu_{\tilde{\tilde{A}}}(x, u) \right) \middle| \forall x \in X, \forall u \in J_X \subseteq [0, 1], 0 \le \mu_{\tilde{\tilde{A}}}(x, u) \le 1 \right\}$$

Here, $0 \le \mu_{\tilde{\tilde{A}}}(x, u) \le 1$ and J_X indicates an interval in [0, 1]. Moreover, the type-2 FS $\tilde{\tilde{A}}$ can be represented as below:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_X} \mu_{\tilde{\tilde{A}}}(x, u) / (x, u) = \int_{x \in X} \left[\int_{u \in \int_x} \mu_{\tilde{\tilde{A}}}(x, u) / u \right] / x$$

Here, $J_X \subseteq [0, 1]$ and $\iint$ express all combination upon x and u. According to this, x is the primary variable, $J_X \subseteq [0, 1]$ indicates the primary membership of x, u is the secondary variable, and $\int_{u \in \int_x} \mu_{\tilde{\tilde{A}}}(x, u)/u$ indicates the secondary membership function in x (MF). $\iint$ expresses all valid combination on x and u. For different discourse universes, $\sum$ takes place of $\int$.

Definition 2: Let us assume $\tilde{\tilde{A}}$ as a type-2 FS in X discourse universe represented with type 2 membership function $\mu_{\tilde{\tilde{A}}}$. If it is $\mu_{\tilde{\tilde{A}}}(x, u) = 1$, then $\tilde{\tilde{A}}$ is called type-2 interval fuzzy set. $\tilde{\tilde{A}}$ as a type-2 FS can be considered as a special type of type-2 FS indicated as below [13, 18, 25, 28].

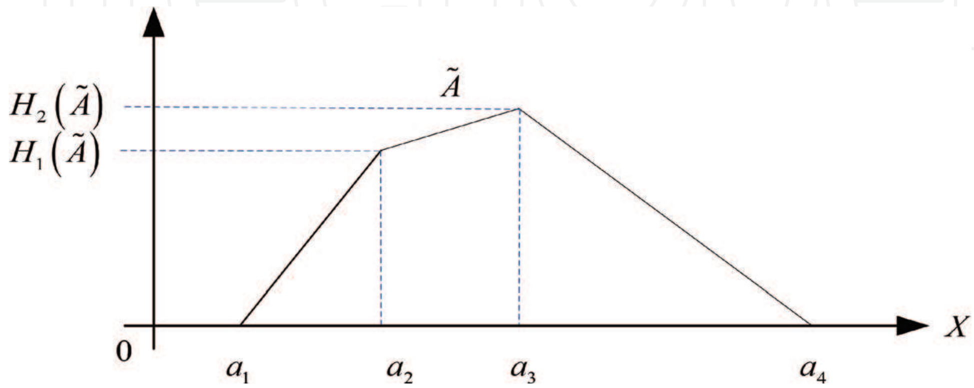

Figure 2. Isosceles trapezium shape type-1 FS [26].

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_X} 1/(x,u) = \int_{x\in X}\left[\int_{u\in j_x} 1/u\right]/x$$

Here, x is the primary variable, $J_X \subseteq [0,1]$ indicates the primary membership of x, u is the secondary variable, and $\int_{u\in j_x} 1/u$ is the second membership function in x.

Definition 3: In this chapter, we evaluated fuzzy MCDM problems using type-2 interval FSs. For the reference point, size of upper and lower membership functions related to type-2 interval FSs was used. Upper membership function and the lower membership function of such type-2 interval FS indicate type-1 membership function. This can be presented as below:

$$\tilde{\tilde{A}}_i = \left(\tilde{A}_i^U, \tilde{A}_i^L\right) = \left(\left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1\left(\tilde{A}_i^U\right), H_2\left(\tilde{A}_i^U\right)\right), \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1\left(\tilde{A}_i^L\right), H_2\left(\tilde{A}_i^L\right)\right)\right)$$

Here, $\tilde{A}_i^U$ and $\tilde{A}_i^L$ are type-1 FSs, and a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U, a_{i1}^L, a_{i2}^L, a_{i3}^L ve a_{i4}^L are the reference points of the type-2 interval $\tilde{\tilde{A}}_i$. $H_j\left(\tilde{A}_i^U\right)$ expresses the membership value of $a_{i(j+1)}^U$ element in $\tilde{A}_i^U$, which is the upper isosceles trapezoid-shape membership function. According to this, $1 \le j \le 2$, $H_j\left(\tilde{A}_i^L\right)$ [13, 25].

Definition 4: $Rank\left(\tilde{\tilde{A}}_i\right)$ as the $\tilde{\tilde{A}}_i$ sequence value, which is type-2 interval FS in isosceles trapezoid shape is defined as below [13, 28].

$$\begin{aligned} Rank\left(\tilde{\tilde{A}}_i\right) &= M_1\left(\tilde{A}_i^U\right) + M_1\left(\tilde{A}_i^L\right) + M_2\left(\tilde{A}_i^U\right) + M_2\left(\tilde{A}_i^L\right) + M_3\left(\tilde{A}_i^U\right) + M_3\left(\tilde{A}_i^L\right) \\ &-\frac{1}{4}\left(S_1\left(\tilde{A}_i^U\right) + S_1\left(\tilde{A}_i^L\right) + S_2\left(\tilde{A}_i^U\right) + S_2\left(\tilde{A}_i^L\right) + S_3\left(\tilde{A}_i^U\right) + S_3\left(\tilde{A}_i^L\right) + S_4\left(\tilde{A}_i^U\right) + S_4\left(\tilde{A}_i^L\right)\right) \\ &+H_1\left(\tilde{A}_i^U\right) + H_1\left(\tilde{A}_i^L\right) + H_2\left(\tilde{A}_i^U\right) + H_2\left(\tilde{A}_i^L\right) \end{aligned}$$

Here, $M_p\left(\tilde{\tilde{A}}_i^j\right)$ indicates the average of a_{ip}^j and $a_{i(p+1)}^j$ elements, $M_p\left(\tilde{\tilde{A}}_i^j\right) = \left(a_{ip}^j + a_{i(p+1)}^j\right)/2, 1 \le p \le 3,$ indicates the standard deviation of a_{iq}^j and $a_{i(q+1)}^j$ elements, $S_q\left(\tilde{A}_i^j\right) = \sqrt{\frac{1}{2}\sum_{k=q}^{q+1}\left(a_{ik}^j - \frac{1}{2}\sum_{k=q}^{q+1} a_{ik}^j\right)^2}, 1 \le q \le 3,$ indicates the standard deviation of $S_4\left(\tilde{A}_i^j\right)$, $a_{i1}^j, a_{i2}^j, a_{i3}^j, a_{i4}^j$ elements, $S_4\left(\tilde{A}_i^j\right) = \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} a_{ik}^j\right)^2}$ $H_p\left(\tilde{A}_i^j\right)$ indicates the membership value of $a_{i(p+1)}^j$ element in in $\tilde{A}_i^j$, $1 \le p \le 3, j \in \{U, L\}$, ve $1 \le i \le n$. as an isosceles trapezoid shaped membership function; and **Figure 3** represents a type-2 interval FS in an isosceles trapezoid shape.

For the formation of type-2 interval FSs, $\tilde{A}_i^U$ as isosceles trapezoid shaped upper membership function and $\tilde{A}_i^L$ as isosceles trapezoid shaped lower membership function were used. $\tilde{\tilde{A}}$ created using type-2 interval FS is as below [13, 25, 30].

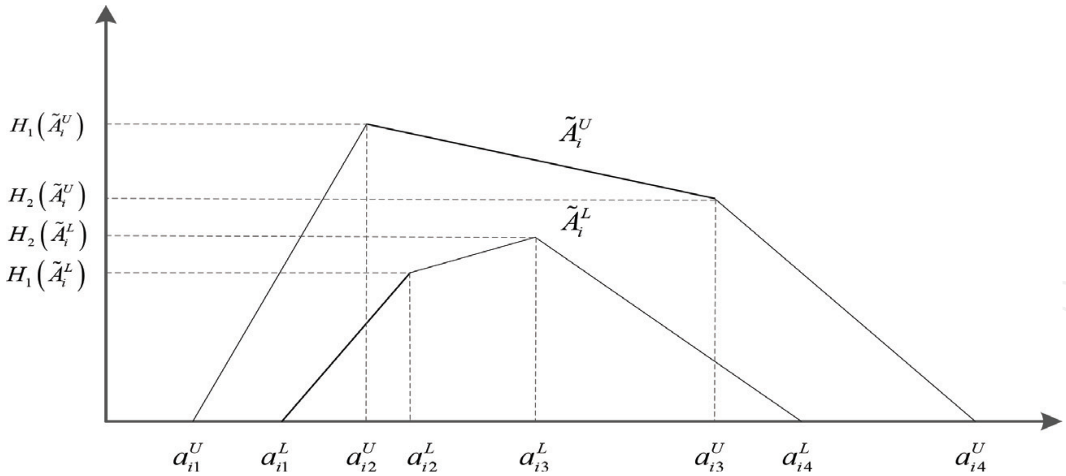

Figure 3. Isosceles trapezoid shaped membership function of the type-2 interval FS $\tilde{\tilde{A}}$ [29].

Addition:

$$\tilde{\tilde{A}}_1 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) = \left(\left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \left(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right)\right)$$

$$\tilde{\tilde{A}}_2 = \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\left(a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1\left(\tilde{A}_2^U\right), H_2\left(\tilde{A}_2^U\right)\right), \left(a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1\left(\tilde{A}_2^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right)$$

$$\tilde{A}_1 \oplus \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \oplus \left(\tilde{A}_2^U, \tilde{A}_2^L\right)$$

$$= \begin{pmatrix} \left(a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), \min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right)\right), \\ \left(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), \min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right) \end{pmatrix}$$

Subtraction:

$$\tilde{A}_1 \Theta \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \Theta \left(\tilde{A}_2^U, \tilde{A}_2^L\right)$$

$$= \begin{pmatrix} \left(a_{11}^U - a_{21}^U, a_{12}^U - a_{22}^U, a_{13}^U - a_{23}^U, a_{14}^U - a_{24}^U; \min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), \min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right)\right), \\ \left(a_{11}^L - a_{21}^L, a_{12}^L - a_{22}^L, a_{13}^L - a_{23}^L, a_{14}^L - a_{24}^L; \min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), \min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right) \end{pmatrix}$$

Multiplication:

$$\tilde{\tilde{A}}_1 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) = \left(\left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \left(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right)\right)$$

$$\tilde{\tilde{A}}_2 = \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\left(a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1\left(\tilde{A}_2^U\right), H_2\left(\tilde{A}_2^U\right)\right), \left(a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1\left(\tilde{A}_2^L\right), H_2\left(\tilde{A}_2^L\right)\right)\right)$$

Arithmetic operation:

$$\tilde{\tilde{A}}_1 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) = \left(\left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \left(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right)\right)$$

$$k\tilde{\tilde{A}}_1 = \begin{pmatrix} \left(k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \\ \left(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \end{pmatrix}$$

$$\frac{\tilde{\tilde{A}}_1}{k} = \begin{pmatrix} \left(\frac{1}{k} \times a_{11}^U, \frac{1}{k} \times a_{12}^U, \frac{1}{k} \times a_{13}^U, \frac{1}{k} \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \\ \left(\frac{1}{k} \times a_{11}^L, \frac{1}{k} \times a_{12}^L, \frac{1}{k} \times a_{13}^L, \frac{1}{k} \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \end{pmatrix}$$

Here, k > 0.

2.2. Type-2 fuzzy analytic hierarchy process (AHP) methodology

Analytic Hierarchy Process (AHP) is an analysis instrument related to decision making used commonly to model non-structured problems in real life. AHP depending upon binary comparison values for a target set is performed in order to reveal a similar priority vector representing the preferences. Due to the difficulty in determining the numerical preferences for scoring the forecasts, uncertainty at a specific amount will identify with all or some of the paired comparison values in an AHP problem. A priority vector created with paired comparisons within uncertainties expresses fuzzy AHP problems. The primary task of fuzzy AHP method is to make a decision related to the relative importance of each factor pair in the same hierarchy [24, 29, 31].

In this chapter, AHP method was developed to overcome multi-criteria decision-making (MCDM) problems depending upon type-2 interval FSs for determining the weight matrix of the criteria. Fuzzy AHP stages depending upon type-2 FSs are shortly as below tip-2 [18, 24]:

Stage 1: Type-2 interval fuzzy paired comparison matrixes are created among all criteria in the hierarchical structure.

$$\tilde{\tilde{M}} = \begin{pmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ \tilde{\tilde{a}}_{21} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ 1/\tilde{\tilde{a}}_{12} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{\tilde{a}}_{1n} & 1/\tilde{\tilde{a}}_{2n} & \cdots & 1 \end{pmatrix} \quad (1)$$

Here,

$$1/\tilde{\tilde{a}}_{ij} = \left(\left(\frac{1}{\tilde{\tilde{a}}_{ij4}^U}, \frac{1}{\tilde{\tilde{a}}_{ij3}^U}, \frac{1}{\tilde{\tilde{a}}_{ij2}^U}, \frac{1}{\tilde{\tilde{a}}_{ij1}^U}; H_1\left(\tilde{\tilde{a}}_{ij}^U\right), H_2\left(\tilde{\tilde{a}}_{ij}^U\right)\right), \left(\frac{1}{\tilde{\tilde{a}}_{ij4}^L}, \frac{1}{\tilde{\tilde{a}}_{ij3}^L}, \frac{1}{\tilde{\tilde{a}}_{ij2}^L}, \frac{1}{\tilde{\tilde{a}}_{ij1}^L}; H_1\left(\tilde{\tilde{a}}_{ij}^L\right), H_2\left(\tilde{\tilde{a}}_{ij}^L\right)\right)\right)$$

Stage 2: Geometrical average technique is used as below in order to find the fuzzy geometric average:

$$\tilde{\tilde{r}}_i = \left(\tilde{\tilde{a}}_{i1} \otimes \tilde{\tilde{a}}_{i2} \otimes \cdots \otimes \tilde{\tilde{a}}_{in}\right)^{1/n} \tag{2}$$

Here,

$$\sqrt[n]{\tilde{\tilde{a}}_{i1}} = \left(\left(\sqrt[n]{\tilde{\tilde{a}}^U_{ij4}}, \sqrt[n]{\tilde{\tilde{a}}^U_{ij3}}, \sqrt[n]{\tilde{\tilde{a}}^U_{ij2}}, \sqrt[n]{\tilde{\tilde{a}}^U_{ij1}}; H_1\left(\tilde{\tilde{a}}^U_{ij}\right), H_2\left(\tilde{\tilde{a}}^U_{ij}\right)\right), \left(\sqrt[n]{\tilde{\tilde{a}}^L_{ij4}}, \sqrt[n]{\tilde{\tilde{a}}^L_{ij3}}, \sqrt[n]{\tilde{\tilde{a}}^L_{ij2}}, \sqrt[n]{\tilde{\tilde{a}}^L_{ij1}}; H_1\left(\tilde{\tilde{a}}^L_{ij}\right), H_2\left(\tilde{\tilde{a}}^L_{ij}\right)\right)\right)$$

Stage 3: Type-2 interval fuzzy weight of each criteria is calculated using the equation below:

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

2.3. Type-2 fuzzy TOPSIS methodology

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is a technique used for a priority sequence close to an ideal solution. TOPSIS method is a popular approach related to MCDM and has been commonly performed in the literature. TOPSIS method was firstly revealed by Yoon and Hwang [32]. The leading feature of this method is selected alternatives' having the closest distance to the positive ideal solutions, and the furthest distance to negative ideal solutions [32]. Fuzzy TOPSIS method was revealed aiming to eliminate or minimize the deficiencies in traditional TOPSIS method using oral variables called as fuzzy numbers for the comparison of alternatives and weighing of criteria [18]. A fuzzy TOPSIS method provides an opportunity to cope with uncertainty related to a decision-making problem. In this chapter, TOPSIS method was also used in order to overcome MCDM problems depending upon type-2 interval FSs.

The stages of the suggested method are as below [13]:

Stage 1: Y_p decision matrix and $\overline{Y}$ average matrix of the p$^{\text{th}}$ decision maker are created as shown below.

$$Y_p = \left(\tilde{\tilde{f}}^p_{ij}\right)_{m\times n} = \begin{array}{c} \\ f_1 \\ f_2 \\ \dots \\ f_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \dots & x_n \end{array} \\ \begin{bmatrix} \tilde{\tilde{f}}^p_{11} & \tilde{\tilde{f}}^p_{12} & \dots & \tilde{\tilde{f}}^p_{1n} {}^{p} \\ \tilde{\tilde{f}}^p_{21} & \tilde{\tilde{f}}^p_{22} & \dots & \tilde{\tilde{f}}^p_{1n} \\ \dots & \dots & \dots & \dots \\ \tilde{\tilde{f}}^p_{m1} & \tilde{\tilde{f}}^p_{m1} & \dots & \tilde{\tilde{f}}_{mn} \end{bmatrix} \end{array} \tag{4}$$

$$\overline{Y} = \left(\tilde{\tilde{f}}_{ij}\right)_{m\times n}$$

Here,

$\tilde{\tilde{f}}_{ij} = \left(\frac{\tilde{\tilde{f}}^1_{ij} \oplus \tilde{\tilde{f}}^2_{ij} \oplus \dots \oplus \tilde{\tilde{f}}^k_{ij}}{k}\right), \tilde{\tilde{f}}_{ij}$, is a type-2 interval FS; $1 \le i \le m, 1 \le j \le n, 1 \le p \le k$ and k express the number of decision makers.

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Stage 2: W_p weighting matrix and $\overline{W}$ average weighting matrix of p^th^ decision maker are created as shown below:

$$W_p = \left(\tilde{\tilde{w}}_i^p\right)_{1\times m} = \begin{matrix} f_1 & f_2 & \dots & f_m \\ \end{matrix} \left[\tilde{\tilde{w}}_1^p \; \tilde{\tilde{w}}_2^p \; \dots \; \tilde{\tilde{w}}_m^p\right] \tag{5}$$

$$\overline{W} = \left(\tilde{\tilde{w}}_i\right)_{1\times m}$$

Here, $\tilde{\tilde{w}}_i = \left(\frac{\tilde{\tilde{w}}^1{}_i \oplus \tilde{\tilde{w}}^2{}_i \oplus \dots \oplus \tilde{\tilde{w}}^k{}_i}{k}\right)$, $\tilde{\tilde{w}}_i$ is a type-2 interval FS; and $1 \le i \le m$, $1 \le p \le k$ and k expresses the number of decision makers.

In this chapter, the weights of criteria were determined using type-2 interval fuzzy AHP.

Stage 3: Weighting decision matrix of $\overline{Y}_w$ is created.

$$\overline{Y}_w = \left(\tilde{\tilde{v}}_{ij}\right)_{m\times n} = \begin{matrix} f_1 \\ f_2 \\ \dots \\ f_m \end{matrix} \begin{bmatrix} \tilde{\tilde{v}}_{11} & \tilde{\tilde{v}}_{12} & \dots & \tilde{\tilde{v}}_{1n} \\ \tilde{\tilde{v}}_{21} & \tilde{\tilde{v}}_{22} & \dots & \tilde{\tilde{v}}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{\tilde{v}}_{m1} & \tilde{\tilde{v}}_{m2} & \dots & \tilde{\tilde{v}}_{mn} \end{bmatrix} \tag{6}$$

Here, $\tilde{\tilde{v}}_{ij} = \tilde{\tilde{w}}_i \otimes \tilde{\tilde{f}}_{ij}$, $1 \le i \le m \;\; ve \; 1 \le j \le n$

Stage 4: Based on Definition 4, $\tilde{\tilde{v}}_{ij}$ as the sequence level of type-2 fuzzy set $\tilde{\tilde{v}}_{ij}$ in which $1 \le j \le n$ is calculated. $\overline{Y}^*{}_w$ as the decision matrix weight listed according to the sequence is created.

$$\overline{Y}^*{}_w = \left(Rank\left(\tilde{\tilde{v}}_{ij}\right)\right)_{m\times n} \tag{7}$$

Here, $1 \le i \le m \;\; ve \; 1 \le j \le n$

Stage 5: $x^+ = \left(v_1^+, v_2^+, \dots, v_m^+\right)$ as the positive ideal solution and $x^- = \left(v_1^-, v_2^-, \dots, v_m^-\right)$ negative ideal solution are found.

Here,

$$v_i^+ = \begin{cases} \underset{1\le j\le n}{Max} \left\{Rank\left(\tilde{\tilde{v}}_{ij}\right)\right\}, & \text{if } f_i \in F_1 \\ \underset{1\le j\le n}{Min} \left\{Rank\left(\tilde{\tilde{v}}_{ij}\right)\right\}, & \text{if } f_i \in F_2 \end{cases} \tag{8}$$

$$v_i^- = \begin{cases} \underset{1\le j\le n}{Min} \left\{Rank\left(\tilde{\tilde{v}}_{ij}\right)\right\}, & \text{if } f_i \in F_1 \\ \underset{1\le j\le n}{Max} \left\{Rank\left(\tilde{\tilde{v}}_{ij}\right)\right\}, & \text{if } f_i \in F_2 \end{cases} \tag{9}$$

Here, F_1 indicates the set of advantage qualities and F_2 indicates the set of disadvantage qualities; and $1 \le i \le m$.

Stage 6: $d^+(x_j)$ distance between each alternative x_j and positive ideal x^+ is calculated as shown below:

$$d^+(x_j) = \sqrt{\sum_{i=1}^{m} \left(Rank(\tilde{\tilde{v}}_{ij}) - v_i^+\right)^2} \tag{10}$$

Here, it is $1 \leq j \leq n$. $d^+(x_j)$ distance between each alternative x_j and negative ideal x^- is calculated as shown below:

$$d^-(x_j) = \sqrt{\sum_{i=1}^{m} \left(Rank(\tilde{\tilde{v}}_{ij}) - v_i^-\right)^2} \tag{11}$$

Here, it is $1 \leq j \leq n$.

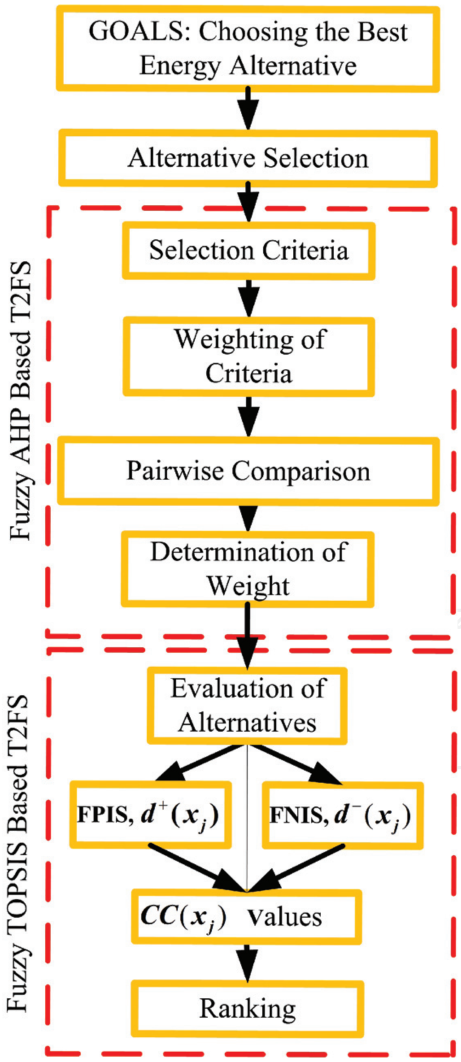

Figure 4. Suggested type-2 fuzzy AHP-TOPSIS hybrid methodology.

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Stage 7: $CC(x_j)$ as the relative distance according to x^+ positive and negative ideal solution of x_j is calculated as below:

$$CC(x_j) = \frac{d^-(x_j)}{d^-(x_j) + d^+(x_j)} \tag{12}$$

Here, it is $1 \le j \le n$.

Stage 8: The values of $CC(x_j)$ are sequenced from small to large where $1 \le j \le n$. As the value of $CC(x_j)$ increases, x_j preference grades of the alternatives increases, and here it is $1 \le j \le n$.

Suggested fuzzy methodology:

In this chapter, fuzzy TOPSIS and AHP depending upon MCDM methodology were developed according to type-2 FSs. The steps of the suggested methodology were presented in **Figure 4**.

3. An implementation of related to decision-making on energy alternatives in Turkey

Energy is one of the most important inputs of economy affecting the development level of countries as in any stages of life. Although Turkey has several energy resources, those resources have not been adequately used up to now. Turkey that has recently been dependent on outside for energy as in the past meets nearly one-third of the energy demand from domestic production. Because fossil fuel energy has gradually decreased, within the following 10 years, Turkey most probably will encounter with problems such as high energy prices, energy insecurity, and energy shortage. For those reasons, in Turkey, it is necessary to plan all energy resources within the framework of a specific policy. In order to manage these resources, developing necessary technologies and providing to popularize the use of those will be vital for the economic development of the country. The results revealed in this study suggest the perspectives related to future and provide an opportunity to produce new energy policies appropriate for the conditions of today.

In details, Turkey needs to provide its energy requirement using its energy resources. The aforementioned energy resources are as below: geothermal energy (A1), solar energy (A2), wind energy (A3), hydraulic energy (A4), bioenergy (A5), hydrogen energy (A6), nuclear energy (A7), petrol (A8), natural gas (A9), and coal-lignite (A10). The hierarchy of the decision-making problem related to the energy planning mentioned in this study was presented in **Figure 5**.

The criteria used in this study are as below [24]:

Productivity (C1): productivity is the amount of beneficial energy obtained from an energy resource. Namely, a stable productivity development by means of the reliability of a big power plant and inexpensiveness of the raw material depends upon its being economical and deriving profits.

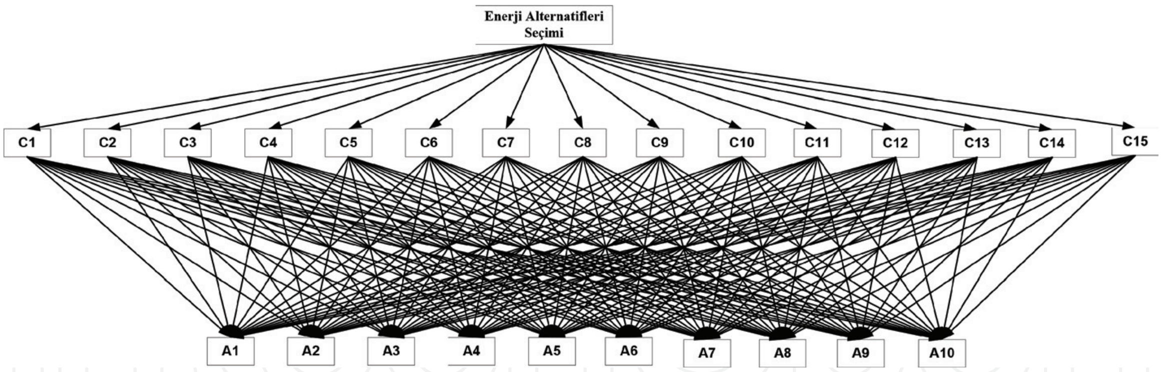

Figure 5. Hierarchical structure of selecting energy alternatives.

Exergy productivity (C2): energy productivity is calculation of the productivity according to the second thermodynamic law of a process. The energy including the heat change generally runs to waste.

Investment cost (C3): the investment cost includes the purchase of mechanical tools, installment of technological instruments, construction of roads, connection of roads to the international lines, engineering studies, and additional operation processes.

Cost of operation and maintenance (C4): operating and maintenance costs include two items: the first is the money spent on wages of employees and energy. The second is the operation cost including raw materials and services necessary for operating the power plant.

NOx release (C5): it is a general term referring to NOx, NO and NO2, it has a direct effect upon the health of people, and indirectly affects the social status of the society.

CO2 release (C6): carbon dioxide gas without color, odor, and the taste is nearly 1.5 times more intense than air under normal pressure and temperature conditions.

Required area (C7): the surrounding and panorama of the areas where power plants are built totally affect the area where they have been built. Moreover, the areas where power plants will be built have the same standards.

Social acceptability (C8): social acceptability is determining the perception assumed of the projects by the society revising the views of consumers. In other words, this term refers to a summary of local people's views related to the power plants.

Employment creation (C9): economic development and welfare of the local people in areas where power plants have been established depend upon this power plant for decades. Long-term power plants providing employment for the society and stabilizing local people to a more desirable life standard are more convenient.

Net current profit (C10): NCP can be explained as a current profit of the time interval when cash flow is maintained. It is a typical method used to find the value of time-based money in long-term energy studies.

Risk (C11): this choice represents the number of distinguishable problems during the implementation of energy policy.

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Reliability (C12): this criterion evaluates the technological adequacy for implementing the energy policy. The implemented technology can be the one tested only in the laboratory, performed just in pilot factories, or not developed exactly.

Implementation period (C13): this choice reveals the minimum cost purposed monthly or annual applicable minimum status of an applicable alternative energy policy.

Waste disposal reliability (C14): this choice tries to decrease damage to nature. It expresses the studies carried out to rectify a situation through a sustainable study.

Compatibility to energy policies (C15): this criterion presented the distance of suggested policy targets to international energy policy or state policy.

After determining the set of criteria and alternatives, stages of developed type-2 FS AHP algorithm is implemented to the criteria. In order to determine the relative importance of each evaluation criterion, experts used a nine-item scale presented in **Table 1**.

Seven-item scale represented in **Table 2** reveals the oral expressions used by the energy planning experts for creating an alternative criteria matrix.

Oral terms	Type-2 fuzzy sets											
Absolutely strong (AS)	((4.00,	5.00,	5.00,	6.00;	1.00	1.00),	(4.50,	5.00,	5.00,	5.50;	1.00	1.00))
Very strong (VS)	((3.00,	4.00,	4.00,	5.00;	1.00	1.00),	(3.50,	4.00,	4.00	4.50;	1.00	1.00))
Fairly strong (FS)	((2.00,	3.00,	3.00,	4.00;	1.00	1.00),	(2.50,	3.00,	3.00,	4.50;	1.00	1.00))
Semi-strong (SS)	((1.00,	2.00,	2.00,	3.00;	1.00	1.00),	(1.50,	2.00,	2.00,	3.50;	1.00	1.00))
Equal (E)	((1.00,	1.00,	1.00,	1.00;	1.00	1.00),	(1.00,	1.00,	1.00,	1.00;	1.00	1.00))
Semi-weak (SW)	((0.33,	0.50,	0.50,	1.00;	1.00	1.00),	(0.29,	0.50,	0.50,	0.67;	1.00	1.00))
Fairly weak (FW)	((0.25,	0.33,	0.33,	0.50;	1.00	1.00),	(0.22,	0.33,	0.33,	0.40;	1.00	1.00))
Very weak (VW)	((0.20,	0.25,	0.25,	0.33;	1.00	1.00),	(0.22,	0.25,	0.25,	0.29;	1.00	1.00))
Absolutely weak (AW)	((0.17,	0.20,	0.20,	0.25;	1.00	1.00),	(0.18,	0.20,	0.20,	0.22;	1.00	1.00))

Table 1. Fuzzy values used for the paired comparison of the criteria.

Oral terms	Type-2 fuzzy sets											
Very low: (VL)	((0.00,	0.00,	0.00,	0.10;	1.00,	1.00),	(0.00,	0.00,	0.00,	0.05;	0.90	0.90))
Low: (L)	((0.00,	0.10,	0.10,	0.30;	1.00,	1.00),	(0.05,	0.10,	0.10,	0.20;	0.90	0.90))
Mid-low: (ML)	((0.10,	0.30,	0.30,	0.50;	1.00,	1.00),	(0.20,	0.30,	0.30,	0.40;	0.90	0.90))
Medium: (M)	((0.30,	0.50,	0.50,	0.70;	1.00,	1.00),	(0.40,	0.50,	0.50,	0.60;	0.90	0.90))
Mid-high: (MH)	((0.50,	0.70,	0.70,	0.90;	1.00,	1.00),	(0.60,	0.70,	0.70,	0.80;	0.90	0.90))
High: (H)	((0.70,	0.90,	0.90,	1.00;	1.00,	1.00),	(0.80,	0.90,	0.90,	0.95;	0.90	0.90))
Very high:(VH)	((0.90,	1.00,	1.00,	1.00;	1.00,	1.00),	(0.95,	1.00,	1.00,	1.00;	0.90	0.90))

Table 2. Fuzzy values used for the paired comparison of the alternatives.

		C1	C2	C3	C4	…	C12	C13	C14	C15
C1	**D1**	1	FW	FW	FW	…	FW	FW	AW	E
	D2	1	SW	SW	VW	…	FW	FW	VW	SS
	D3	1	SW	SW	VW	…	FW	FW	AW	E
C2	**D1**	FS	1	E	SW	…	E	E	FW	FS
	D2	SS	1	E	FW	…	SW	SW	FW	FS
	D3	SS	1	E	FW	…	SW	SW	VW	SS
C3	**D1**	FS	E	1	SW	…	E	E	FW	FS
	D2	SS	E	1	FW	…	SW	SW	FW	FS
	D3	SS	E	1	FW	…	SW	SW	VW	SS
…	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…
C13	**D1**	FS	E	E	SW	…	E	1	FW	FS
	D2	FS	SS	SS	SW	…	E	1	SW	VS
	D3	FS	SS	SS	SW	…	E	1	FW	FS
C14	**D1**	AS	FS	FS	SS	…	FS	FS	1	AS
	D2	VS	FS	FS	E	…	SS	SS	1	AS
	D3	AS	VS	VS	SS	…	FS	FS	1	AS
C15	**D1**	E	FW	FW	VW	…	FW	FW	AW	1
	D2	SW	FW	FW	AW	…	VW	VW	AW	1
	D3	E	SW	SW	VW	…	FW	FW	AW	1

Table 3. Oral expression of the paired comparison matrix for the evaluation criteria.

Table 3 present the results of the paired comparison of oral expressions related to the evaluation criteria performed by three energy planning experts.

It has been mentioned that AHP method suggests a consistency index for determining whether there is an inconsistency in each comparison matrix. The inconsistency rate (CR) value is accepted to be lower than 10%, and it means consistency. Inconsistency analysis performed for this study, CR value was obtained as (0.084), and it was concluded that the evaluations were acceptable and consistent.

When **Table 4** was considered, influence grade of all criteria upon our energy resources and policies to be created were very close to each other. When the results in this table are analyzed, we can conclude that all determined criteria are essential for us and the determined criteria are selected accurately. Although all criteria were very important, the criteria mostly affecting the energy alternative selection or our energy policy were "CO_2" C6 (4.594), "Waste Disposal Reliability" C14 (4.581), and "NOx" C5 (4.491), respectively. On the other hand, the criteria

	$\tilde{\tilde{W}}$	BNP
C1	((0.32,0.41,0.41,0.58;1,1),(0.31,0.41,0.41,0.48;0.9,0.9))	3.927
C2	((0.6,0.8,0.8,1.14;1,1),(0.62,0.8,0.8,1.02;0.9,0.9))	4.051
C3	((0.6,0.8,0.8,1.13;1,1),(0.61,0.8,0.8,1.02;0.9,0.9))	4.048
C4	((1.35,1.91,1.91,2.53;1,1),(1.6,1.91,1.91,2.56;0.9,0.9))	4.396
C5	((1.62,2.22,2.22,2.83;1,1),(1.92,2.22,2.22,2.89;0.9,0.9))	4.491
C6	((1.83,2.55,2.55,3.23;1,1),(2.2,2.55,2.55,3.35;0.9,0.9))	4.594
C7	((0.95,1.33,1.33,1.83;1,1),(1.06,1.33,1.33,1.72;0.9,0.9))	4.213
C8	((0.49,0.66,0.66,0.94;1,1),(0.5,0.66,0.66,0.83;0.9,0.9))	4.005
C9	((1.24,1.76,1.76,2.35;1,1),(1.44,1.76,1.76,2.31;0.9,0.9))	4.346
C10	((0.38,0.49,0.49,0.69;1,1),(0.38,0.49,0.49,0.59;0.9,0.9))	3.952
C11	((0.49,0.67,0.67,0.96;1,1),(0.5,0.67,0.67,0.84;0.9,0.9))	4.007
C12	((0.78,1.12,1.12,1.61;1,1),(0.85,1.12,1.12,1.51;0.9,0.9))	4.149
C13	((0.76,1.1,1.1,1.58;1,1),(0.84,1.1,1.1,1.48;0.9,0.9))	4.143
C14	((1.82,2.51,2.51,3.17;1,1),(2.17,2.51,2.51,3.27;0.9,0.9))	4.581
C15	((0.29,0.37,0.37,0.52;1,1),(0.29,0.37,0.37,0.43;0.9,0.9))	3.914

Table 4. Results of type-2 fuzzy AHP method implemented for determining the weights.

affecting our energy policy or energy alternative selection as the least were "Compatibility to energy policies" C15 (3.914), "Productivity" C1 (3.927), and "Net current profit" C10 (3.952), respectively.

The subsequent stage is to determine the best energy alternatives developing TOPSIS method for the solution of fuzzy multi-criteria decision-making problems based upon type-2 interval FSs method. **Table 5** represented paired comparison matrix performed with the oral expression of alternatives criteria matrix carried out by energy planning experts. The experts evaluated the energy alternatives according to each criterion using **Table 2**. The experts also assumed all criteria as beneficial while evaluating the alternatives.

In the subsequent stage, evaluation matrix is created calculating the arithmetic average of the scores related to the evaluation results obtained by the experts. After this stage, a weighted type-2 fuzzy decision matrix is obtained.

After creating fuzzy weighted decision table, fuzzy positive ideal solutions (FPIS, d_i^+) and fuzzy negative ideal solutions (FNIS, d_i^-) are obtained as shown in **Table 6**. Finally, correlation coefficient (CC_i) of each alternative is calculated.

According to **Table 6**, evaluation of appropriate energy alternatives was carried out, and the sequence was determined as A3-A2-A4-A1-A5-A9-A8-A10-A7 and A6. It was revealed that the best energy alternative with investment priority was wind. The priority sequence of the rest alternatives was solar energy, hydraulic energy, geothermal energy, bioenergy, natural gas, petrol, coal-lignite, nuclear energy, and hydrogen energy.

		C1	C2	C3	C4	…	C12	C13	C14	C15
A1	**D1**	H	M	M	M	…	M	MH	MH	H
	D2	MH	M	MH	MH	…	MH	M	MH	VH
	D3	H	MH	MH	M	…	H	M	H	VH
A2	**D1**	MH	VH	H	MH	…	H	H	VH	VH
	D2	M	MH	MH	M	…	VH	H	VH	VH
	D3	M	MH	H	H	…	VH	M	H	VH
A3	**D1**	H	L	H	H	…	MH	H	VH	VH
	D2	MH	ML	H	M	…	H	ML	H	H
	D3	H	MH	MH	MH	…	H	M	VH	VH
…	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…
A8	**D1**	M	M	M	ML	…	M	M	ML	ML
	D2	MH	MH	H	H	…	MH	M	M	M
	D3	M	MH	M	M	…	MH	M	ML	ML
A9	**D1**	M	M	M	ML	…	M	M	ML	ML
	D2	VH	H	H	MH	…	M	M	M	ML
	D3	MH	MH	M	ML	…	M	M	ML	ML
A10	**D1**	ML	L	ML	L	…	M	ML	VL	MH
	D2	M	M	MH	M	…	M	MH	ML	VH
	D3	ML	ML	M	ML	…	M	M	ML	VH

Table 5. Oral expression matrix for evaluation results of the alternatives.

Alternatives	$d^+(x_j)$	$d^-(x_j)$	$CC(x_j)$
Geothermal energy (A1)	1.4622	1.6557	0.5310
Solar energy (A2)	0.7137	2.1241	0.7485
Wind energy (A3)	0.3499	2.5486	0.8793
Hydraulic energy (A4)	1.4593	1.6908	0.5367
Bioenergy (A5)	1.5981	1.6925	0.5143
Hydrogen energy (A6)	2.6897	0.3579	0.1174
Nuclear energy (A7)	3.1515	0.8478	0.2120
Petrol (A8)	2.4740	1.0384	0.2956
Natural gas (A9)	2.3925	1.1328	0.3213
Coal-lignite (A10)	3.0036	0.8270	0.2159

Table 6. The results obtained through fuzzy multi-criteria decision-making method based upon type-2 interval FSs.

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4. Conclusion and suggestions

Energy is one of the fundamental inputs of social and economic development all around the world; the importance of energy has increased day by day, and its strategic place in the world is considered to be maintained for long years. This fact highlighted the necessity for all countries to use their energy resources they have productively. While actualizing this, it should adopt being more qualified, more productive, more reliable, more efficient, cheaper, more environment-friendly, more uninterrupted, and sustainable as a principle.

When considering all these aforementioned situations, it is necessary for the energy sector to be developed for all energy resources. In order for the companies and investors to compete in energy markets, policies should be established to restructure the energy sector.

For that purpose;

- Wind energy and solar energy should be focused on short and long-term energy planning to be made by Turkey in order to meet increasing energy demand by 9% on average every year. In order to meet the energy need in the system, Turkey should provide incentives putting these two energy resources on top of the list. When considering the parameters such as risk minimization, waste disposal reliability, and CO_2 and NOX release as the expectations of the society for short and long-term planning, the necessity got evaluating the wind energy and solar energy as the leading emerges.
- In long-term energy planning, technological investment should also be provided on hydraulic energy, geothermal energy, and bioenergy resources besides the wind and solar energy, and these energy resources should be put into use carrying out private sector encouragement studies.
- Bioenergy on the fifth-rank should be encouraged from investor "raw material producer to bioenergy user" through government supports and incentives creating appropriate strategies and action plans in order to maximize the use of "biogas, biofuel, and biomass."

In future, the suggested method can also be performed to the other decision-making problems related to the issues such as the selection of suppliers, selection of facility area, selection of material, and selection of software. In addition to these, the subsequent study should be carried out upon evaluating regional energy resource tendency of Turkey and revealing the demand. In accordance with the obtained results, it can also be revealed, which energy resource in which area should be invested as more advantageously.

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