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Sustainable Energy Planning By A Group Decision Model With Entropy Weighting Method Under Interval-Valued Fuzzy Sets And Possibilistic Statistical Concepts

Nazanin Foroozesh [1*], Behrooz Karimi [1], Ehsan Mirzaei [2]

[1] *Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran*
[2] *Department of Industrial Engineering, Faculty of Engineering, Shahed University, Tehran, Iran*

[*]***Corresponding author:*** *N. Foroozesh (Email: n.foroozesh@aut.ac.ir)*

Abstract *– In this paper, a new interval-valued fuzzy multi-criteria group decision-making model is proposed to evaluate each of the energy plans with sustainable development criteria for proper energy plan selection. The purpose of this study is divided into two parts: first, it is aimed at determining the weights of evaluation criteria for sustainable energy planning and second at rating sustainable energy alternatives by a group decision model under uncertainty. In the proposed method, given the concept of asymmetric data, possibilistic statistical concepts are used to make a more appropriate decision with less uncertainty consideration. A new rating system based on the reference point and a new improved version of Entropy method are introduced as the leading features of this model to determine the weight of criteria and possibilistic statistical concepts, including mean, standard deviation and cube root of skewness in the interval-valued fuzzy form, by considering positive and negative ideal points. Moreover, a practical example in the field of energy is presented and discussed, taking into account the experts experience in different fields and inaccurate concepts of information, efficiency and results of the proposed model.*

Keywords *– Group Decision Making, Interval-Valued Fuzzy Sets, Possibilistic Statistical Concepts, Sustainable Energy Program Selection, System Reference Point*

I. INTRODUCTION

Since economic and social development is affected by the appropriate energy plan, an evaluation of sustainable energy alternatives is crucial while determining a viable strategy. Likewise, evaluating and selecting the type of sustainable energy and necessary geographically areas is a complex issue. Important decisions for governments and businesses include the possible candidate location or areas for an energy production system, the decision regarding the type of energy or a combination of them, and selection of the most appropriate option despite the inherent inconsistency of evaluation criteria from a technical, social, environmental and economic point of view (Banos et al., 2011, Karimi et al., 2011).

In a study to develop a multi-criteria decision support framework for the selection of sustainable electricity technology, different methods, including TOPSIS and MULTIMOORA, are applied for the analysis and decision-making of various alternatives. The results of this study have been to move energy policies towards sustainable

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energy technologies in the near future (Streimikiene et al., 2012). In a study of a new decision tool for ranking the appropriate location among existing facilities and in terms of quantitative and qualitative decision criteria for nuclear power plants in Turkey, the proposed method is based on fuzzy entropy, t-normalization and fuzzy adaptive programming which was mainly to counter ambiguity in human judgments (Erol et al. , 2014).

In a study led by some researchers (Hussain Mirjat et al., 2018), electrical policy recommendations were proposed to undertake integrated energy modeling and decision analysis for sustainable energy planning. Thus, in this research, the Analytical Hierarchy Process (AHP) methodology has been taken into account for the sustainability evaluation of energy modeling outcomes for long-term electricity planning. According to the AHP methodology, four scenario alternatives developed in the energy modeling effort have been ranked using Expert Choice tool. Following by a research also investigated in Pakistan (Solangi et al. , 2019) introduces an integrated methodology based on Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, AHP, and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (F-TOPSIS) to evaluate energy strategies for sustainable energy planning. The results of the study reveal that providing low-cost and sustainable electricity to residential, commercial, and industrial sectors is a highly prioritized energy strategy. In contrast, the utilization of coal resources for electricity generation strategy is the least prioritized lowest strategy in the order ranking.

There are researches in the literature attempted in order to develop an integrated methodology using multi-criteria decision-making and geographical information systems procedures for a renewable energy spatial planning model (Díaz-Cuevas et al. , 2019). In order to identify high potential areas for the construction of single or combined wind power, solar power and biomass generation facilities, criteria and restrictions are defined, weighed, and combined. Finally, to solve the model mentioned above, a cluster analysis is carried out to classify municipalities in the province according to the availability of medium and high potential land for the facility construction.

In a paper presented by (Simsek et al., 2018), a review of multi-criteria decision methods and sustainability indicators following five pillars were taken into consideration, which includes: technical, economic, social, environmental, and risk. Several articles associated with sustainability and multi-criteria analysis of energy projects were reviewed and classified according to their primary focus, motivation and contribution to achieving a comprehensive summary. Furthermore, the purpose of this research is introducing a framework and providing an understanding of decision-makers to assess the sustainability of Clean Development Mechanism energy projects.

A study investigated by (Aryanpur et al., 2019) provides an overview of the previous energy planning attempts in Iran. It shows that adequate commitment to long-term energy planning could have meaningfully prevented severe difficulties. This paper, therefore, proposes a power planning framework to assess the sustainability of future electricity scenarios for the period 2015–2050. A systems engineering optimization model is applied to evaluate the potential impacts of transitioning to a low-carbon electricity supply system. Applying a combined AHP-TOPSIS method, the scenarios are then ranked based on 18 different techno-economic, environmental, and social dimensions of sustainability.

Multi-criteria group decision-making approaches attempt to use expert group ideas rather than a single decision-maker to obtain reliable results and experiences from different areas of expertise Mohagheghi et al. 2019; Salarpour et al. 2019a,b; Dorfeshan and Mousavi 2019). In this regard, multi-criteria group decision-making attempts to employ techniques that provide a collective response in a situation where a group of experts expresses their views on their priorities (Fu and Yang, 2010; Fu and Yang, 2011). In order to find a proper aggregated solution, it is usually necessary to present and combine the experts' views (Davoudabadi et al., 2019a,b; Haghighi et al., 2019). In a study performed by (Afsordegan et al., 2016), a modified TOPSIS method for multi-criteria group decision making with qualitative linguistic vocabulary has been proposed. That is to say, in this approach, expert judgments are made to evaluate the performance of each alternative according to each criterion with qualitative labels at different levels without aggregating opinions to rank the options. The results and discussion of the application of this method are illustrated by an example in the field of energy planning.

In this study, a version of PROMETHEE-2 approach is presented to solve group decision-making problems. This method uses linguistic variables as membership and non-membership functions to the intuitive fuzzy set to weight all criteria and rank the alternatives. By solving and discussing an example using a sustainable energy ranking algorithm, the results are analyzed, and the features of the method, including providing a conditional Euclidean distance, is used to measure the deviation of each alternative (Montajabiha, 2016).

A review of the existing literature shows that very few studies have been conducted on multi-criteria group decision-making and their application in the field of energy, and the development of fuzzy sets in this method has not been utilized as linguistic variables, despite its high capability to deal with uncertainties and ambiguous judgments of experts. The use of feasible statistical concepts along with interval-valued fuzzy numbers to increase the model flexibility, considering a wider range of data, has not been used so far. Also, in the field of energy selection so far, most of the recent studies have focused more on the impact of one of the sustainable aspects, namely the environment (Ertay et al., 2013; Şengül et al., 2015).

One of the key aspects and also the main innovation of this research is to present a new group decision model in which the uncertainty existing for the problem of determination of the sustainable energy program can be modeled using interpolated value fuzzy sets as well as possible fuzzy statistical concepts. By proposing possible fuzzy statistical concepts, it is possible to make a more appropriate choice with less uncertainty and considering the asymmetry in the data. By defining the performance matrix based on three new statistical concepts of mean, standard deviation, and third-order skewness with interval value and determining the distance between each of the two positive and negative ideals and creating new ranking indices based on the reference point system and defining the final score to parametric form in order to apply the experts' opinions on the final score, it is attempted to comprehensively make group decisions in the field of sustainable energy.

The paper is organized as follows. Section II describes the basic concepts of fuzzy logic and the related definitions used in this research. In section III, the proposed IVF (interval-valued fuzzy) model for sustainable energy plan selection is presented. In section IV, a practical example on selecting a sustainable energy plan and its computational results are discussed, respectively. Finally, the conclusions on this research are discussed in section V.

II. BASIC CONCEPTS AND DEFINITIONS

A. Linguistic variables

The concept of linguistic variables was introduced in previous studies (Zadeh, 1975a,1975b, 1975c). In this respect, linguistic variables are defined as variables whose value is in words, phrases, synthetic or natural language. The concept of a linguistic variable is very suitable for dealing with many real-world decision-making issues that are usually complex, ambiguous, and related to uncertainties. Hence, many researchers consider different scales in their articles(Vahdani et al., 2015, Mousavi et al., 2016). Linguistic variables used in this paper are presented in Table I as follows:

Table I. Experts' linguistic variables

Sign	Explanation	Triangular Fuzzy Number with Interval Value
VP	Very Poor	[(0.0,0.0,1.0) ;(0.0,0.0,1.5)]
P	Poor	[(0.5,1.0,2.5) ;(0.0,1.0,3.5)]
MP	Medium Poor	[(1.5,3.0,4.5) ;(0.0,3.0,5.5)]
F	Fair	[(3.5,5.0,6.5) ;(2.5,5.0,7.5)]
MG	Medium Good	[(5.5,7.0,8.0) ;(4.5,7.0,9.5)]
G	Good	[(7.5,9.0,9.5) ;(5.5,9.0,10.0)]
VG	Very Good	[(9.5,10.0,10.0) ;(8.5,10,10.0)]

A fuzzy number $\xi = (a, b, c)$, where $a \neq b$, $c \neq a$ are established as:

$\alpha_1 = \max\{b - a, c - b\}$ $\gamma = \min\{b - a, c - b\}$
$\sigma = c - b$ $\tau = b - a$

Then the expected value, variance and skewness of the fuzzy variable obtained by (Li, Qin et al. 2010) are defined.

Definition 1. Consider fuzzy variable ξ, the expected value is calculated as (1),

$$M[\xi] = e = \int_0^{+\infty} Cr(\xi \geq r)dr - \int_{-\infty}^{0} Cr(\xi \leq r)dr \tag{1}$$

Note that the expected value of a fuzzy variable is an important concept that represents the center of the distribution, and by using (1) the fuzzy variable expected value $\xi = (a, b, c)$ is simplified to (2).

$$M[\xi] = (a + 2b + c)/4 \tag{2}$$

Definition 2. Consider the fuzzy variable ξ with the expected value e; its variance is calculated by (3),

$$V[\xi] = E[(\xi - e)^2] \tag{3}$$

By using equation (3), the variance of the fuzzy variable $\xi = (a, b, c)$ is simplified to equation (4):

$$V[\xi] = (33\alpha_1^3 + 21\alpha_1^2\gamma + 11\alpha_1\gamma^2 - \gamma^3)/384\alpha_1 \tag{4}$$

The standard deviation of $SD(\xi)$ is also obtained from the squared variance of $\sqrt{V[\xi]}$.

Definition 3. Consider the fuzzy variable ξ with the expected value e, whose skewness is defined as (5),

$$Sk[\xi] = E[(\xi - e)^3] \tag{5}$$

Using equation (3), the variance of the fuzzy variable $\xi = (a, b, c)$ is presented as equation (6).

$$\begin{aligned} Sk[\xi] &= {}^{1}\!/_{8(b-a)}\left[\left({}^{(b-e)}\!/_{4}\right)^4 - \left({}^{(a-e)}\!/_{4}\right)^4\right] \\ &\quad + {}^{1}\!/_{8(b-c)}\left[\left({}^{(b-e)}\!/_{4}\right)^4 - \left({}^{(c-e)}\!/_{4}\right)^4\right] \\ &= \left({}^{(c-a)^2}\!/_{32}\right)(c + a - 2b) \end{aligned} \tag{6}$$

The skewness concept shows the symmetry degree of the data around the expected value, in equation (6) and Fig. (1), if the data are symmetric, the skewness will be zero, and if $\sigma \geq \tau$, the skewness of fuzzy number ξ is positive. And if $\sigma \leq \tau$, the skewness value is negative. If the expert’s decisions are made pessimistically, optimistically, or probable, the concept of skewness can be incorporated into decision making. The third root of skewness is also shown by $Crs(\xi)$.

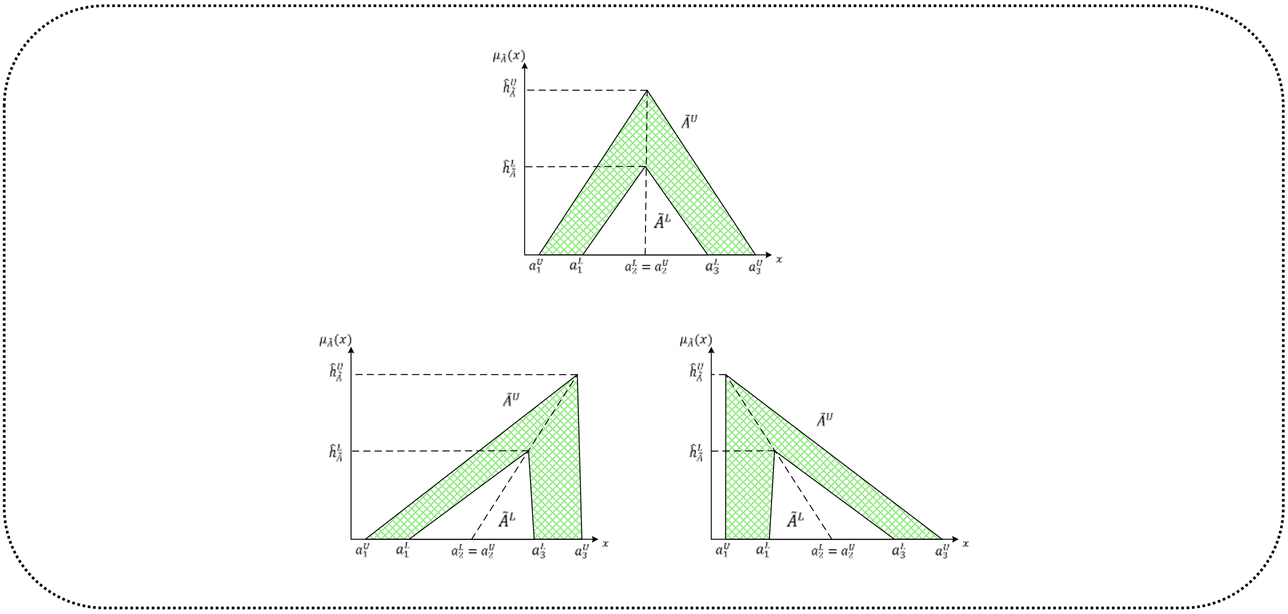

Fig. 1. Interval-valued triangular fuzzy membership function considering pessimistic, probabilistic and optimistic opinions

III. PROPOSED INTERVAL-VALUED FUZZY MODEL FOR SUSTAINABLE ENERGY PLAN SELECTION USING GROUP DECISION MAKING

In this section, a new fuzzy interval-valued approach for evaluating and selecting the appropriate sustainable energy plan based on the theory of possibility and statistical concepts is presented. First, it is assumed that there is a group of decision-makers or experts (DMs) in the energy field shown with index k, which can range from $1\ to\ p$, followed by decision alternatives x_i, which in this case, it is considered as a sustainable energy plan. The index i may range from $1\ to\ m$; finally, c_j is the decision criteria for evaluation, knowing that j can take values from $1\ to\ n$. Since the data used for selecting the sustainable energy plan are uncertain, decision-makers can make their judgments or express their opinions regarding decision alternatives x_i and evaluation criteria c_j by considering interval-valued fuzzy numbers. Therefore, the matrix of opinions related to each expert k is formed, as shown in equation (7).

$$\tilde{A}^k = \left[[(a_{ij_1}^{\ L}, a_{ij_2}^{\ L}, a_{ij_3}^{\ L}), (a_{ij_1}^{\ U}, a_{ij_2}^{\ U}, a_{ij_3}^{\ U})]^k\right]_{m\times n} = = \begin{bmatrix} [(a_{11_1}^{\ L}, a_{11_2}^{\ L}, a_{11_3}^{\ L}), (a_{11_1}^{\ U}, a_{11_2}^{\ U}, a_{11_3}^{\ U})]^k & \cdots & [(a_{1n_1}^{\ L}, a_{1n_2}^{\ L}, a_{1n_3}^{\ L}), (a_{1n_1}^{\ U}, a_{1n_2}^{\ U}, a_{1n_3}^{\ U})]^k \\ \vdots & \ddots & \vdots \\ [(a_{m1_1}^{\ L}, a_{m1_2}^{\ L}, a_{m1_3}^{\ L}), (a_{m1_1}^{\ U}, a_{m1_2}^{\ U}, a_{m1_3}^{\ U})]^k & \cdots & [(a_{mn_1}^{\ L}, a_{mn_2}^{\ L}, a_{mn_3}^{\ L}), (a_{mn_1}^{\ U}, a_{mn_2}^{\ U}, a_{mn_3}^{\ U})]^k \end{bmatrix} \quad (7)$$

For convenience, a fuzzy number $[(a_{ij_1}^{\ L}, a_{ij_2}^{\ L}, a_{ij_3}^{\ L}), (a_{ij_1}^{\ U}, a_{ij_2}^{\ U}, a_{ij_3}^{\ U})]^k$ is represented as $[(a_{ij}^L - \tau_{ij}^L, a_{ij}^L, a_{ij}^L + \sigma_{ij}^L), (a_{ij}^U - \tau_{ij}^U, a_{ij}^U, a_{ij}^U + \sigma_{ij}^U)]^k$ for each decision maker.

The steps regarding the proposed group decision model are as follows:

Step 1. Identify the C_j evaluation criteria in order to select a sustainable energy plan.

Step 2. Provide a fuzzy-value estimation matrix evaluating the interval for selecting each of the sustainable energy programs (X_i) for each decision maker k and converting them to the interval-valued fuzzy numbers using Table I and integrating their opinions using the mean of judgments given in equation (8).

$$a_{ijl}^{L}=\frac{1}{p}\sum_{k=1}^{p}\left(a_{ijl}^{L}\right)^{p};l=1,2,3\quad,\quad a_{ijl}^{U}=\frac{1}{p}\sum_{k=1}^{p}\left(a_{ijl}^{U}\right)^{p};l=1,2,3 \tag{8}$$

Step 3. Convert the integrated matrix in the previous step to a normalized matrix of selection evaluation using two categories, including cost and benefit. This conversion is given in relations (9) and (10). Generally speaking, the higher the profit margin, the lower the cost.

$$\begin{aligned}\left(\tilde{a}'_{ij}=\left[\left(\left(a'_{ij}\right)_1^L,\left(a'_{ij}\right)_2^L,\left(a'_{ij}\right)_3^L,\left(a'_{ij}\right)_1^U,\left(a'_{ij}\right)_2^U,\left(a'_{ij}\right)_3^U\right)\right]\right)\\=\left[\left(\frac{a_{ij}^L-\tau_{ij}^L}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+},\frac{a_{ij}^L}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+},\frac{a_{ij}^L+\sigma_{ij}^L}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+}\right),\right.\\\left.\left(\frac{a_{ij}^U-\tau_{ij}^U}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+},\frac{a_{ij}^U}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+},\frac{a_{ij}^U+\sigma_{ij}^U}{\left(a_{ij}^U+\sigma_{ij}^U\right)^+}\right)\right],j\in\Omega_b\end{aligned} \tag{9}$$

$$\begin{aligned}\left(\tilde{a}'_{ij}=\left[\left(\left(a'_{ij}\right)_1^L,\left(a'_{ij}\right)_2^L,\left(a'_{ij}\right)_3^L,\left(a'_{ij}\right)_1^U,\left(a'_{ij}\right)_2^U,\left(a'_{ij}\right)_3^U\right)\right]\right)\\=\left[\left(\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^L+\sigma_{ij}^L},\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^L},\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^L-\tau_{ij}^L}\right),\right.\\\left.\left(\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^U+\sigma_{ij}^U},\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^U},\frac{\left(a_{ij}^U-\tau_{ij}^U\right)^-}{a_{ij}^U-\tau_{ij}^U}\right)\right],j\in\Omega_c\end{aligned} \tag{10}$$

The symbols Ω_b and Ω_c are profit and expense sets, respectively, and equations $(a_{ij}^U+\sigma_{ij}^U)^+=max_i(a_{ij}^U+\sigma_{ij}^U)$ and $(a_{ij}^U-\tau_{ij}^U)^-=max_i(a_{ij}^U-\tau_{ij}^U)$ are also defined.

Step 4. Generate the interval matrix for sustainable energy plan selection. Calculate the probability mean $\overline{m_{ij}}$ of a fuzzy number with an interval value as$[(a_{ij}^L-\tau_{ij}^L,a_{ij}^L,a_{ij}^L+\sigma_{ij}^L),(a_{ij}^U-\tau_{ij}^U,a_{ij}^U,a_{ij}^U+\sigma_{ij}^U)]$ using equation (2) as follows:

$$\overline{m_{ij}}=\left[m_{ij}^L,m_{ij}^U\right]=\left[\frac{\left(a'_{ij}\right)_1^L+2\times\left(a'_{ij}\right)_2^L+\left(a'_{ij}\right)_3^L}{4},\frac{\left(a'_{ij}\right)_1^U+2\times\left(a'_{ij}\right)_2^U+\left(a'_{ij}\right)_3^U}{4}\right] \tag{11}$$

Then, the average matrix with interval value is formed.

$$\bar{M}=[\overline{m_{ij}}]_{m\times n}=\begin{bmatrix}\overline{m_{11}} & \overline{m_{12}} & \cdots & \overline{m_{1n}}\\ \vdots & & \ddots & \vdots\\ \overline{m_{m1}} & \overline{m_{m2}} & \cdots & \overline{m_{mn}}\end{bmatrix} \tag{12}$$

Step 5. Construct the standard deviation matrix as interval for the selection of the sustainable energy program, the possible standard deviation $\overline{Sd_{ij}}$ values of a fuzzy interval value $[(a_{ij}^L-\tau_{ij}^L,a_{ij}^L,a_{ij}^L+\sigma_{ij}^L),(a_{ij}^U-\tau_{ij}^U,a_{ij}^U,a_{ij}^U+\sigma_{ij}^U)]$ are calculated using the square of relation (4) as follows.

$$\overline{Sd_{ij}} = [Sd_{ij}^L, Sd_{ij}^U] = \left[\sqrt{(33(\alpha_1^L)^3 + 21(\alpha_1^L)^2\gamma^L + 11\alpha_1^L(\gamma^L)^2 - (\gamma^L)^3)/384\alpha_1^L}, \sqrt{(33(\alpha_1^U)^3 + 21(\alpha_1^U)^2\gamma^U + 11\alpha_1^U(\gamma^U)^2 - (\gamma^U)^3)/384\alpha_1^U}\right] \tag{13}$$

Then, the standard deviation matrix of the interval value is constructed into the following form.

Step 6. Construct the third root skewness matrix to select the sustainable energy plan by using the possibilistic values of the third root skewness of $\overline{Crs_{ij}}$ from a fuzzy interval value $[(a_{ij}^L - \tau_{ij}^L, a_{ij}^L, a_{ij}^L + \sigma_{ij}^L), (a_{ij}^U - \tau_{ij}^U, a_{ij}^U, a_{ij}^U + \sigma_{ij}^U)]$ that are calculated using the third root of the defined equation (6) as follows:

$$\overline{Crs_{ij}} = [Crs_{ij}^L, Crs_{ij}^U] = \left[\sqrt[3]{\frac{\left((a'_{ij})_3^L - (a'_{ij})_1^L\right)^2}{32}\left((a'_{ij})_3^L + (a'_{ij})_1^L - 2\times(a'_{ij})_2^L\right)}, \sqrt[3]{\frac{\left((a'_{ij})_3^U - (a'_{ij})_1^U\right)^2}{32}\left((a'_{ij})_3^U + (a'_{ij})_1^U - 2\times(a'_{ij})_2^U\right)}\right]. \tag{14}$$

Then, the third skew root matrix with the interval value is constructed as follows:

$$\overline{Crs} = [\overline{Crs}_{ij}]_{m\times n} = \begin{bmatrix} \overline{Crs}_{11} & \overline{Crs}_{12} & \cdots & \overline{Crs}_{1n} \\ \vdots & & \ddots & \vdots \\ \overline{Crs}_{m1} & \overline{Crs}_{m2} & \cdots & \overline{Crs}_{mn} \end{bmatrix} \tag{15}$$

Step 7. Calculate the modified entropy value based on three statistical values, including possibilistic mean, standard deviation and third root of skewness in an interval form.

Step 7.1. Calculate the entropy value based on the interval value for each evaluation criterion.

$$\overline{E(M)_J} = [E(M)_j^L, E(M)_j^U] = \left[-\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{m}_{ij}^U Ln(\acute{m}_{ij}^U), -\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{m}_{ij}^L Ln(\acute{m}_{ij}^L)\right] \tag{16}$$

Where, $\bar{\acute{m}}_{ij} = [\acute{m}_{ij}^L, \acute{m}_{ij}^U] = \left[\frac{m_{ij}^L}{max_i\, m_{ij}^U}, \frac{m_{ij}^U}{max_i\, m_{ij}^U}\right]$.

Step 7.2. The entropy value is calculated based on the standard deviation of the interval value for each evaluation criterion.

$$\overline{E(Sd)_J} = [E(Sd)_j^L, E(Sd)_j^U] = \left[-\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{Sd}_{ij}^U Ln(\acute{Sd}_{ij}^U), -\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{Sd}_{ij}^L Ln(\acute{Sd}_{ij}^L)\right] \tag{17}$$

Where, $\overline{\acute{Sd}_{ij}} = \left[\acute{Sd}_{ij}^{L}, \acute{Sd}_{ij}^{U}\right] = \left[\frac{Sd_{ij}^{L}}{max_i\, Sd_{ij}^{U}}, \frac{Sd_{ij}^{U}}{max_i\, Sd_{ij}^{U}}\right]$.

Step 7.3. Calculate the entropy value based on the third root of skewness, considering interval value for each evaluation criterion.

$$\overline{E(Crs)_j} = [E(Crs)_j^L, E(Crs)_j^U] = \left[-\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{Crs}_{ij}^{U} Ln\left(\acute{Crs}_{ij}^{U}\right), -\frac{1}{Ln(m)}\sum_{i=1}^{m} \acute{Crs}_{ij}^{L} Ln\left(\acute{Crs}_{ij}^{L}\right)\right] \tag{18}$$

Where, $\overline{\acute{Crs}_{ij}} = \left[\acute{Crs}_{ij}^{L}, \acute{Crs}_{ij}^{U}\right] = \left[\frac{Crs_{ij}^{L}}{max_i\, Crs_{ij}^{U}}, \frac{Crs_{ij}^{U}}{max_i\, Crs_{ij}^{U}}\right]$.

Step 8. Determining the modified entropy weight based on the equations specified in Step 7.

Step 8.1. The Modified weight based on the mean using equation (16) is equal to,

$$W(M)_j = [W(M)_j^L, W(M)_j^U] = \left[1 - E(M)_j^U, 1 - E(M)_j^L\right] \tag{19}$$

Step 8.2. Modified weight based on standard deviation and by using equation (17),

$$W(Sd)_j = [W(Sd)_j^L, W(Sd)_j^U] = \left[1 - E(Sd)_j^U, 1 - E(Sd)_j^L\right] \tag{20}$$

Step 8.3. Modified weight based on third root of skewness and also using equation (18),

$$W(Crs)_j = [W(Crs)_j^L, W(Crs)_j^U] = \left[1 - E(Crs)_j^U, 1 - E(Crs)_j^L\right] \tag{21}$$

Step 9. Definition of Ideal Positive and Negative Vector (PIV and NIV) based on the probability mean interval, in order to select a sustainable, positive and negative ideal energy program, is calculated using the defined matrix.

$$\overline{M^*} = \left[\left(m_j^*\right)^L, \left(m_j^*\right)^U\right] = \{\overline{M_1^*}, \overline{M_2^*}, \dots, \overline{M_n^*}\} = \{max_i\, \overline{m_{ij}} | i = 1,2,\dots,m\} \tag{22}$$

$$\overline{M^-} = \left[\left(m_j^-\right)^L, \left(m_j^-\right)^U\right] = \{\overline{M_1^-}, \overline{M_2^-}, \dots, \overline{M_n^-}\} = \{max_i\, \overline{m_{ij}} | i = 1,2,\dots,m\} \tag{23}$$

Step 10. Define a positive and a negative ideal based on the possibilistic standard deviation of the interval in order to select a sustainable energy plan, then calculate the positive and negative ideals using the defined matrix.

$$\overline{Sd}^* = \left[\left(Sd_j^*\right)^L, \left(Sd_j^*\right)^U\right] = \left\{\overline{Sd}_1^*, \overline{Sd}_2^*, \dots, \overline{Sd}_n^*\right\} = \{min_i\, \overline{Sd_{ij}} | i = 1,2,\dots,m\} \tag{24}$$

$$\overline{Sd}^- = \left[\left(Sd_j^-\right)^L, \left(Sd_j^-\right)^U\right] = \left\{\overline{Sd}_1^-, \overline{Sd}_2^-, \dots, \overline{Sd}_n^-\right\} = \{max_i\, \overline{Sd_{ij}} | i = 1,2,\dots,m\} \tag{25}$$

Step 11. Define the positive and negative ideal based on the third root of the probability interval in order to select a sustainable, positive and negative ideal energy plan with respect to the defined matrix.

$$\overline{Crs}^* = \left[\left(Crs_j^*\right)^L, \left(Crs_j^*\right)^U\right] = \{\overline{Crs}_1^*, \overline{Crs}_2^*, \dots, \overline{Crs}_n^*\} = \{min_i\, \overline{Crs_{ij}} | i = 1,2,\dots,m\} \tag{26}$$

$$\overline{Crs}^{-} = \left[\left(Crs_j^{-}\right)^L, \left(Crs_j^{-}\right)^U\right] = \{\overline{Crs}_1^{-}, \overline{Crs}_2^{-}, \dots, \overline{Crs}_n^{-}\} = \{max_i\ \overline{Crs_{ij}} | i = 1,2, \dots, m\} \tag{27}$$

Step 12. Calculate the weighted distance values for each of the statistical concepts, including mean, standard deviation, and third root of skewness from their corresponding positive ideals displayed in equations (22), (24) and (26) with the symbols $\bar{M}^*$, $\overline{SD}^*$ and $\overline{Crs}^*$, respectively.

$$D_i\left(\bar{m}_{ij}, \bar{M}_j^*\right) = \sqrt{\left(W(M)_j^L \left(\left(m_j^*\right)^L - m_{ij}^L\right)^2 + W(M)_j^U \left(\left(m_j^*\right)^U - m_{ij}^U\right)^2\right)} \tag{28}$$

$$D_i\left(\overline{Sd}_{ij}, \overline{Sd}_j^*\right) = \sqrt{\left(W(Sd)_j^L \left(\left(Sd_j^*\right)^L - Sd_{ij}^L\right)^2 + W(Sd)_j^U \left(\left(Sd_j^*\right)^U - Sd_{ij}^U\right)^2\right)} \tag{29}$$

$$D_i\left(\overline{Crs}_{ij}, \overline{Crs}_j^*\right) = \sqrt{\left(W(Crs)_j^L \left(\left(Crs_j^*\right)^L - Crs_{ij}^L\right)^2 + W(Crs)_j^U \left(\left(Crs_j^*\right)^U - Crs_{ij}^U\right)^2\right)} \tag{30}$$

Step 13. Calculate the weighted distance values for each of the statistical concepts, including mean, standard deviation, and third root of skewness from their corresponding negative ideals displayed in equations (23), (25) and (27) with the symbols $\bar{M}^-$, $\overline{SD}^-$ and $\overline{Crs}^-$ respectively.

$$D_i\left(\bar{m}_{ij}, \bar{M}_j^-\right) = \sqrt{\left(W(M)_j^L \left(\left(m_j^-\right)^L - m_{ij}^L\right)^2 + W(M)_j^U \left(\left(m_j^-\right)^U - m_{ij}^U\right)^2\right)} \tag{31}$$

$$D_i\left(\overline{Sd}_{ij}, \overline{Sd}_j^-\right) = \sqrt{\left(W(Sd)_j^L \left(\left(Sd_j^-\right)^L - Sd_{ij}^L\right)^2 + W(Sd)_j^U \left(\left(Sd_j^-\right)^U - Sd_{ij}^U\right)^2\right)} \tag{32}$$

$$D_i\left(\overline{Crs}_{ij}, \overline{Crs}_j^-\right) = \sqrt{\left(W(Crs)_j^L \left(\left(Crs_j^-\right)^L - Crs_{ij}^L\right)^2 + W(Crs)_j^U \left(\left(Crs_j^-\right)^U - Crs_{ij}^U\right)^2\right)} \tag{33}$$

Step 14. Determine new proposed index for ranking process based on reference points system concept.

$$\eta_i = \max_j D_i\left(\bar{m}_{ij}, \bar{M}_j^*\right) \tag{34}$$

$$\psi_i = \max_j\ D_i\left(\overline{Sd}_{ij}, \overline{Sd}_j^*\right) \tag{35}$$

$$\omega_i = \max_j\ D_i\left(\overline{Crs}_{ij}, \overline{Crs}_j^*\right) \tag{36}$$

$$\xi_i = \min_j\ D_i\left(\bar{m}_{ij}, \bar{M}_j^-\right) \tag{37}$$

$$\varrho_i = \min_j\ D_i\left(\overline{Sd}_{ij}, \overline{Sd}_j^-\right) \tag{38}$$

$$\delta_i = \min_j\ D_i\left(\overline{Crs}_{ij}, \overline{Crs}_j^-\right) \tag{39}$$

Step 15. Calculate the Final Score (Sc_i) for the sustainable energy selection alternatives with respect to the ascending order of preference based on the deviation from reference points.

$$Sc_i = \varphi\left(\frac{\eta_i}{\eta_i + \xi_i}\right) + \mu\left(\frac{\psi_i}{\varrho_i + \psi_i}\right) + \rho\left(\frac{\omega_i}{\delta_i + \omega_i}\right) \tag{40}$$

Knowing that the following conditions $\varphi + \mu + \rho = 1$, $0 \leq \varphi \leq 1$, $0 \leq \mu \leq 1$ and $0 \leq \rho \leq 1$ hold in equation (40).

The next section attempts to determine the appropriate choice of sustainable energy plan by outlining a practical example and applying the proposed new group decision model.

IV. A PRACTICAL EXAMPLE ON SELECTING A SUSTAINABLE ENERGY PLAN

Energy is not only one of the critical indicators of socio-economic development but also plays a vital role in life quality improvement. As fossil fuel energy becomes scarce, countries and their governments will face energy shortages causing increasing energy prices, and energy insecurity within a few decades. Consequently, the development and use of renewable energy sources and technologies are increasingly becoming vital for sustainable economic growth. In this practical example, there are metrics for selecting higher performance programs; those that are superior in terms of sustainability (economic, social, and environmental) are presented below(Kaya and Kahraman 2010).

- Technical
  Technical Efficiency (C_1)
  Energy Efficiency (C_2)
- Economical
  Investment Cost Efficiency (C_3)
  Operation and Maintenance Cost (C_4)
- Environmental
  NO_x emission (C_5)
  CO_2 emission (C_6)
  Land use (C_7)
- Social
  Social Acceptability (C_8)
  Job Creation (C_9)

A. Computational results

Table II. Matrix Evaluation of Expert Opinions on Sustainable Plan Selection with Linguistic Expressions

		EVALUATION CRITERIA								
ALTERNATIVES	**Makers Decision**	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	DM_1	G	F	F	F	MP	MP	G	F	F
	DM_2	MG	F	MG	MG	F	F	MG	MG	MG
	DM_3	G	MG	MG	F	F	MP	G	G	G
A_2	DM_1	MG	VG	G	MG	VG	G	MG	MG	MP
	DM_2	F	MG	MG	F	F	G	MG	MG	F
	DM_3	F	MG	G	G	F	MG	G	VG	VG
A_3	DM_1	G	P	G	G	F	G	G	G	G
	DM_2	MG	MP	G	F	G	VG	VG	G	G
	DM_3	G	MG	MG	MG	G	G	VG	G	G
A_4	DM_1	MG	G	G	G	MP	F	F	F	MG
	DM_2	G	MG	F	MG	F	F	F	MG	G
	DM_3	MG	MG	MG	MP	F	MP	F	MG	G

According to the steps of the proposed model, the evaluation criteria are now set to determine the sustainable energy plan, and then, from the three experts shown using the following symbols, DM_1, DM_2 and DM_3 considered as optimistic, probabilistic and pessimistic respectively. The opinions on applications in the field of sustainable energy including geothermal energy (A_1), solar energy (A_2), wind energy (A_3) and biomass energy (A_4) are obtained using linguistic variables and are evaluated by defining the above criteria which are listed in Table II.

Then by using Table I, it first converts the linguistic variables into an interval-valued fuzzy number and then integrates it according to the experts' opinions shown in equation (8); Which is usually followed by maximum agreements.

Using the normalization ideas and calculating matrices of statistical concepts such as mean, standard deviation, and third-order skewness root in steps 7 and 8, the importance of the identified criteria with entropy procedure is calculated, and the results are presented below.

- $W(M)_j = [W(M)_j^L, W(M)_j^U] = [(0.55,0.75), (0.40,0.50), (0.23,0.41), (0.40,0.58), (0.55,0.70), (0.44,0.48),(0.24,0.29), (0.46,0.62), (0.41,0.62)]$

- $W(SD)_j = [W(Sd)_j^L, W(SD)_j^U] = [(0.02,0.84), (0.03,0.75), (0.04,0.67), (0.07,0.81), (0.06,0.79), (0.04,0.73),(0.05,0.59), (0.01,0.72), (0.00,0.74)]$

- $W(Crs)_j = [W(Crs)_j^L, W(Crs)_j^U] = [(0.37,0.55), (0.37,0.48), (0.26,0.34), (0.19,0.53), (0.21,0.62), (0.27,0.58),(0.33,0.42), (0.44,0.41), (0.42,0.34)]$

In step 14, new proposed indicators for the ranking process based on the concept of reference point system in equations (31) - (36) are presented which are illustrated in Table III.

Table III. Ranking process based on the concept of reference point

	η_i	ψ_i	ω_i	ξ_i	ϱ_i	σ_i
A_1	0.2822	0.10428	0.08069	0.07142	0.00000	0.03413
A_2	0.47767	0.08557	0.07763	0.01283	0.00756	0.03724
A_3	0.54598	0.07554	0.06591	0.00301	0.01358	0.03917
A_4	0.27007	0.09396	0.08867	0.01961	0.00625	0.03413

Table IV. Final ranking of energy plan alternatives along with other studies' rankings

ALTERNATIVES	FINAL SCORE (Sc_i) BASED ON THE PROPOSED MODEL	FINAL RANKING BASED ON THE PROPOSED MODEL	FINAL SCORE BASED ON (KAYA AND KAHRAMAN 2010)	RANKING BASED ON (KAYA AND KAHRAMAN 2010)
A_1	0.8508	4	0.94	4
A_2	0.8299	2	0.29	2
A_3	0.7815	1	0.27	1
A_4	0.8516	3	0.56	3

In Table (IV), the ranking of energy plan alternatives (Sc_i) is based on the deviation from the reference points and by determining the coefficients $\varphi = 0.15, \mu = 0.45, \rho = 0.40$, thus, $A_3 > A_2 > A_4 > A_1$ is obtained, which confirms the results of the model in the literature of the recent issue (Kaya and Kahraman 2010). The computational results show the efficiency and robustness of the proposed entropy weighted group decision model using interval-valued fuzzy sets and possibilistic statistical concepts to select a sustainable energy plan.

B. Sensitivity Analysis

In this subsection, sensitivity analysis is carried out to evaluate the impacts of weights of environmental criteria including (NO_x (C_5), emission, CO_2 (C_6) and land use (C_7)) on the final ranking of sustainable energy plan selection. Fig. (2) shows the results of this analysis. The main idea of this evaluation is to exchange the weight obtained for each environmental measure with the other two criteria. Hence, three combinations of the idea have been obtained, and each one is considered as one of the conditions. In addition, the main state is also taken into account. The results show the role of changes and the importance of environmental criteria in the problem solved. For example, it can be seen in Fig. (2) that with the change of environmental criteria, the third alternative, namely the wind energy program (selected in the previous section), remains unchanged. Still, there are changes to the ranking of other energy alternatives.

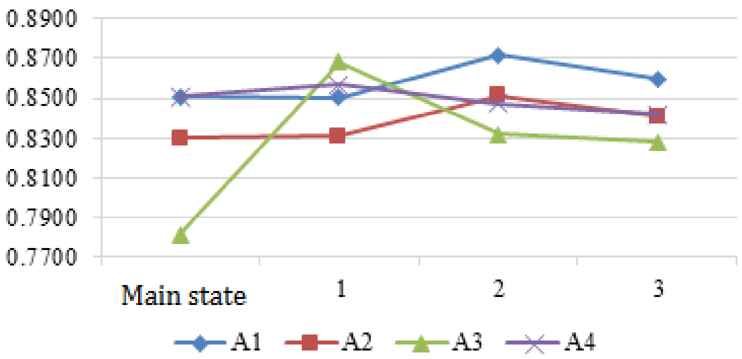

Fig. 2. Impact of the importance of environmental criteria for sustainable energy choice alternatives

C. Comparative analysis

Unlike the previous studies, the comprehensive approach has some advantages that make it more reliable and appropriate for the MCGDM which are presented and discussed below in detail.

- ***Computational accuracy:*** Considering uncertain elements can be presented through a linguistic environment, by implementing interval-valued fuzzy sets, higher degrees of accuracy will be provided in computations. Furthermore, unlike the previous studies, considering possibilistic statistical concepts exhibits some advantages in representing uncertain or imprecise in the evaluation information.

- ***Computational phase:*** The method applies two main phases to assess the weight of evaluation factors and alternatives rating. The two-phase approach provides experts with a better sustainable energy plan selection. Unlike the previous studies, this makes it possible for them to go through the sustainable energy planning process with a better performance vision.

- ***Qualitative analysis:*** The group decision method studies the role of linguistic preferences in sustainable energy planning environment through introducing a new closeness coefficient. The proposed approach, unlike the previous studies, applies uncertain data via interval-valued fuzzy sets and possibilistic statistical concepts in order to address the weights of sustainable energy evaluation criteria.

V. CONCLUSION

In this study, concerning the general approach, the criteria used to determine the energy program within the framework of sustainable development are considered, and a set of expert opinions has been used. Experts in any field of energy can have optimistic, pessimistic, and probabilistic views. In order to accommodate all opinions, an interval-valued fuzzy group decision-making method based on fuzzy statistical concepts and possibility theory has been suggested. This model can improve the traditional way of decision-making, analyzing data obtained from a group of experts more accurate. In this decision-making model not only the new indexes based on the concept of reference point system are used, but also in order to get a better analysis on both of the sustainable system and the uncertainty, the proposed developed Entropy method has been used. In this method, fuzzy statistical concepts, including mean, standard deviation and skewness with interval-valued form, are used to determine the importance of criteria in order to make a comprehensive decision. On the issue of sustainable energy plan determination, three different dimensions have been considered, including environmental, social, and economic, can simultaneously provide a better perspective of the issues raised in the actual context of energy planning. Following is a practical example to illustrate the steps of this proposed model. An evaluation team consisting of three energy experts was formed. The proposed approach was implemented in this practical example, and the results were analyzed. These results indicate that wind energy is the top choice among sustainable energy applications including geothermal, solar, wind and biomass. The proposed model has also been compared with the existing literature in recent years, and the same results have been obtained concerning the ranking of candidates for renewable energy planning. Further researches need to be focused on the multi-criteria analysis of sustainable energy production technologies by employing new developments of fuzzy logic and therefore undertake the uncertainty associated with suchlike assessments. For future study, extending other PROMETHEE and ELECTRE categories is suggested based on the IVFSs. Furthermore, it will be engaging attention to consider the proposed intuitionistic fuzzy methods by a group of the DMs through a decision support system to assist decision-making problems in the engineering and management field under uncertainty.

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