Intelligent Automation & Soft Computing
DOI: 10.32604/iasc.2023.029419
Article

Strategic Renewable Energy Resource Selection Using a Fuzzy Decision-Making Method

Anas Quteishat[1,2,*] and M. A. A. Younis[2]

[1]Electrical Engineering Department, Faculty of Engineering Technology, Al-Balqa Applied University, Al-Salt, Jordan
[2]Department of Electrical and Computer Engineering, Sohar University, Sultanate of Oman
*Corresponding Author: Anas Quteishat. Email: anas.quteishat@bau.edu.jo
Received: 03 March 2022; Accepted: 11 April 2022

Abstract: Renewable energy is created by renewable natural resources such as geothermal heat, sunlight, tides, rain, and wind. Energy resources are vital for all countries in terms of their economies and politics. As a result, selecting the optimal option for any country is critical in terms of energy investments. Every country is nowadays planning to increase the share of renewable energy in their universal energy sources as a result of global warming. In the present work, the authors suggest fuzzy multi-characteristic decision-making approaches for renewable energy source selection, and fuzzy set theory is a valuable methodology for dealing with uncertainty in the presence of incomplete or ambiguous data. This study employed a hybrid method for order of preference by resemblance to an ideal solution based on fuzzy analytical network process-technique, which agrees with professional assessment scores to be linguistic phrases, fuzzy numbers, or crisp numbers. The hybrid methodology is based on fuzzy set ideologies, which calculate alternatives in accordance with professional functional requirements using objective or subjective characteristics. The best-suited renewable energy alternative is discovered using the approach presented.

Keywords: Multi characteristic decision making framework; fuzzy sets; fuzzy theory; renewable energy; energy resource selection

1 Introduction

In today's industrial civilization, energy is a necessary commodity. It provides energy to our homes, offices, transportation, and communication networks. It is a problem that affects everyone, yet it is frequently misunderstood until an energy crisis occurs. Every country in the world is definitely in the middle of an energy crisis. That problem does not appear to be solved anytime soon [1,2]. Fuel prices and oil depletion are causing unprecedented alarm. In addition, global warming issues are creating concern as well. A lot of people are worried about these things and want to fix the indicators right away. However, only a few people understand the root causes of the problems and don't realise that major social and technological reorganisations are needed to solve them [3,4]. Because of these issues, many countries are attempting to replace conventional power plants with sources of renewable energy.

Renewable energy is a sustainable source of energy that will never run out. Dry rocks, lava, hot springs, and even firewood, animal excrement, crop remnants, and garbage can all be found. Biomass energy, solar energy, hydro energy, geothermal energy, and wind energy are the most common renewable energy sources [5].

Many densely populated countries, particularly energy-importing developing countries, rely substantially on petroleum imports now. Increases in international petroleum prices have had a negative impact on the economy and will continue to do so unless dependency on imported petroleum is reduced by switching to other resources [4,5]. Many countries with an oil-based economy, on the other hand, are considering alternatives to enhance their economies until 2050 [3–5]. In the long run, there are many different sorts of renewable energy that may be employed to make the planet a better place to live.

The decision of which options for renewable energy are best is a multi-characteristic problem with numerous competing characteristics. As a result, the decision-making process for multi-characteristic problems should be employed to tackle this problem. Some decision-making processes for multi-characteristic problems have been employed in the various literatures for making energy investment decisions, including the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), the removal and select transforming actuality and favourite position organisation technique for improvement assessment, multiple objective linear programming, and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) [6,7].

When dealing with the imprecise or unclear nature of the linguistic estimation for selecting the challenges of renewable energy systems, the decision-making process alone for the multi-characteristic problems listed above is less effective. The values of any qualitative or linguistic characteristic are frequently imprecisely specified for decision-makers in numerous scenarios. Linguistic variables with values that aren't numbers but words or sentences in a natural or artificial language offer crisp data in the form and accuracy that is suited for the problem. When making a decision, some information can't be looked at exactly in a quantitative way but must be looked at qualitatively, which means using a linguistic method.

The fuzzy-based hybrid strategy is a multi-characteristic method that uses both linguistic variables and crisp definitions to capture this imprecise or hazy nature, as well as a flexible aggregation operator. Furthermore, for issues with interactive characteristics under fuzziness, the fuzzy-based hybrid technique of the ANP-TOPSIS is an outstanding multi-characteristic tool. The best renewable energy option is determined in this paper by considering interactions among characteristics [8–10]. The major goal of this research is to look at how the defined characteristics interact by employing a fuzzy-based hybrid technique of ANP-TOPSIS. The remainder of the present work is structured as follows. A literature overview on energy issues is offered in Section 2. Section 3 explains the criteria for evaluating renewable energy solutions. The combined methodology is presented in Section 4. A genuine application for the case study is carried out in Section 5. Finally, in Section 6, there are some closing observations.

According to the foregoing, the paper's contribution is as follows:

- In this study, two well-known MCDM approaches (ANP and TOPSIS) are combined with fuzzy set theory to rank the options for renewable energy sources in order.
- Using both environmental and conventional criteria to evaluate a variety of renewable energy options.
- A consistency analysis was performed to assess the consistency of the expert's opinion.
- There is no difference in the results of the normalisation process no matter what kind of normalisation function is used.
- TOPSIS is used to look at how alternatives affect the quality used in estimation. Further, ANP is used to look at how important each attribute is.

2 Literature Review

It is vital to determine the best course of action to take while dealing with challenges that include several characteristics, objectives, and actors. Çolak et al. [1] employed four multi-characteristic decision-making models for ranking renewable energy sources, which are: Élimination ET Choix Traduisant La Realité (ELECTRE), TOPSIS, and Viekriterijumsko Kompromisno Rangiranje (VIKOR). According to the findings of this study, hydropower is the best renewable energy alternative in Taiwan. It can also be a good source of information for people who make decisions about how to use energy, as well as a good source of information about how other countries use power.

Barros et al. [2] reviewed the scientific literature using a decision-making process for multi-characteristic problems for renewable energies. They also calculated the advantages and disadvantages of these methods for household systems. Karatop et al. [3] used type-2 fuzzy sets and hesitant fuzzy TOPSIS methods to estimate renewable energy sources from Turkey's perspective. In their study, Sarpong et al. [4] employed Decision Making Trial and Evaluation Laboratory (DEMATEL), ANP, and TOPSIS methodologies to analyse hesitant fuzzy linguistic term sets in order to properly calculate green supply chain management problems quantitatively.

Shamaki et al. [5] employed AHP and a Sequential Interactive Model for Urban Sustainability (SIMUS) to calculate each alternative source in terms of renewable energy. Authors suggested the use of SIMUS for estimation because it considers quantitative and qualitative assessment at a single time. Medjoudj et al. [6] employed a fuzzy model of decision-making procedure for multi-characteristic problems to measure four different renewable energy sources: solar, geothermal, hydropower, and renewable energy. For ranking the four possibilities in their study, the authors employed a fuzzy analytic hierarchy approach and a fuzzy technique to arrange performance by resemblance to an ideal answer.

Lee et al. [7] employed fuzzy preference programming and an ANP to create a model for determining renewable energy unit determination. Following the analysis, it was determined that the 2.5 W renewable energy unit would provide the best estimation value, which is consistent with the expanding market share of permanent magnet direct-drive renewable energies. Furthermore, Butkiene et al. [8] examined a variety of decision-making procedures for multi-characteristic problems for renewable energy applications, including decision-making that is multi-objective, multi-characteristic, or a mix of the two.

Pang et al. [9] employed multi-characteristic decision-making approaches and a geographic information system to analyse the feasibility of renewable energy farm locations. Their findings can be used to expand policies on renewable energy and assess the feasibility of projects that have already been planned. Kumar et al. [10] describe hybrid decision-making procedures for multi-characteristic problems that use VIKOR, distance from the average solution, and additive ratio assessment methods to rank renewable energy projects in a fuzzy environment. These methods are used to rank renewable energy projects in a fuzzy environment.

Saraswat et al. [11] enhanced fuzzy two-stage decision-making frameworks for offshore renewable energy project location selection. Ramezanzade et al. [12] proved the feasibility of applying multi-objective evolutionary algorithms to renewable energy selection challenges in their research. Wu et al. [13] investigated the use of decision-making procedures for multi-characteristic problem applications for the selection of renewable energy production sites. When it came to site selection, the authors concentrated on two types of conditions and techniques throughout the process's five phases. The findings reveal that hybrid geographic information systems and decision-making procedures for multi-characteristic problems are the most frequently employed technologies in this field. To analyse the viability of renewable power sources, Shao et al. [14] suggested a fuzzy decision-making procedure for multi-characteristic problems based on cumulative prospects. By giving public risk-takers alternative options, this study provided significant findings for determining the most acceptable renewable power source under ambiguous conditions.

As this literature review demonstrates, the decision-making process of multi-characteristic problems is a modest variation from operational research in that it deals with determining optimal solutions in complex scenarios involving many indices, opposing aims, and different characteristics. This widely employed tool in the field of energy planning is gaining popularity due to the freedom it offers decision makers in making judgments while taking into account all factors [15,16]. However, just a few studies have employed decision-making procedures based on fuzzy sets to create a support system of decisions for projects of renewable energy that may assist project managers in analysing and selecting the best options [13–17]. In this study, the authors propose a fuzzy-based decision-making procedure for selecting renewable energy suppliers that involves a multi-characteristic problem.

3 Estimation of Characteristics for Selection Process

To analyse an accomplishment strategy for the dissemination of technology related to renewable energy at a regional scale, authors Widianta et al. [18] employed elimination and choice to interpret reality. To rank the projects, Pourmehdi et al. [19] looked into the energy planning process. The characteristics were taken into consideration [20]. Aryanfar et al. [21] were interested in a multi-characteristic decision-making estimation of energy resources that allowed for the selection of an appropriate power-producing alternative. They looked at several energy options in terms of their political, environmental, physical, economic, and other uncontrollable characteristics. The primary characteristics and sub-characteristics that are derived from the above works are presented in this study. The authors of the present work are currently weighing renewable energy options such as solar, ethanol, biodiesel, etc. It's also shown in Fig. 1 how this paper chose the best renewable energy option through the hierarchy.

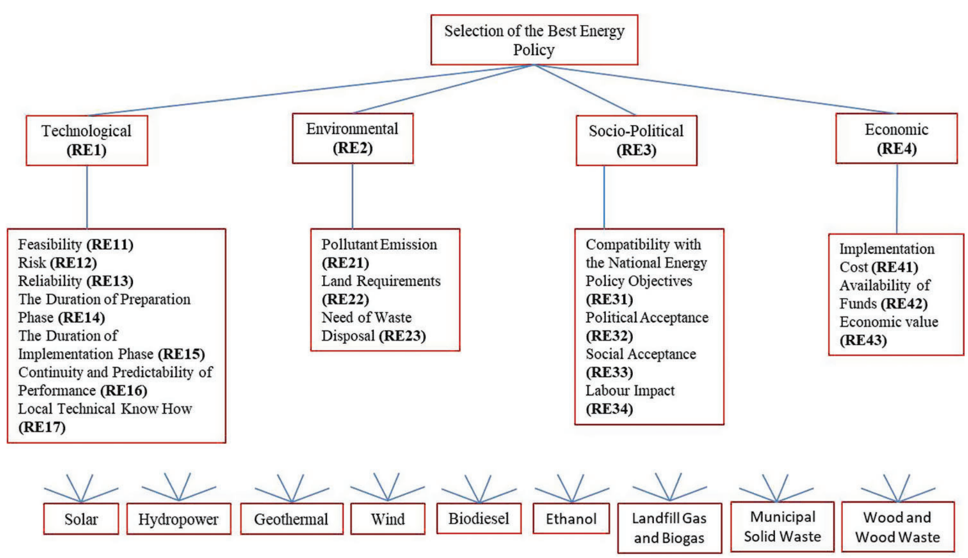

Figure 1: Renewable energy characteristics and alternatives

The next section gives a quick overview of the characteristics that will be used to figure out how to use renewable energy alternatives [19–21]:

- *Feasibility:* This principle assesses the certainty with which renewable energy can be implemented. The number of times a product has worked out could be used to make a decision.

- *Risk:* The risk principle looks at how likely it is that a renewable energy system will be employed by counting how many failures there are in a case study.
- *Reliability:* This category assesses renewable energy technologies. In the lab or in a pilot plant, technology may have been tried out, or it may still be being worked on. It could be a combination of technologies.
- *Preparation Phase Duration:* This principle assesses the availability of renewable energy alternatives in order to reduce financial assets and achieve the lowest cost. The planning stage entails making a decision based on years or months.
- *The Duration of the Implementation Phase:* This principle assesses the alternative's suitability for achieving the lowest cost. The cost of the implementation segment is calculated based on the number of years or months it will take to complete.
- *Performance Continuity and Predictability:* This principle assesses the technology's operation and performance as a renewable energy option. It's crucial to determine if the technology works reliably and continually.
- *Local Technical Know How:* Qualitative comparisons must be made for this characteristic. They must look at how difficult a technology is, as well as how well local actors can help with the maintenance and installation of renewable energy technology.
- *Pollutant Emission:* This principle calculates the Carbon Dioxide (CO_2) equivalent emissions, air emissions from the combustion process, liquid wastes from fumes treated with solid wastes, and process water. The principle is assessed based on the type and quantity of emissions as well as the cost of waste treatment. Electromagnetic interference, bad smells, and changes in the microclimate for energy investment are also taken into account when this principle is looked at.
- *Land Requirements:* One of the most important variables in energy investment is the availability of land. The economic losses can also be determined by the high demand for land.
- *Waste Disposal Need:* This principle assesses the impact on environmental quality from the perspective of renewable energy. Taking this into account, the use of renewable energy could be calculated to lessen the destruction of quality of life and make the world a better place.
- *National Energy Strategy Compatibility:* This principle assesses the degree to which the national energy policy and the suggested alternative of renewable energy are aligned with one another. It calculates the degree to which the government's strategy and the proposed strategy have aims that are similar to each other. In addition, the principle takes into account how well the government is on your side, how institutional players act, and the public information policy that the government has in place, among other things.
- *Political Acceptance:* This principle looks to see if there is agreement among leaders on the suggested renewable energy source. It also talks about how to keep politicians from reacting and how to solve problems between political leaders.
- *Social Acceptance:* This principle helps social partners come to an agreement. It also talks about how to keep special-interest groups from being angry about renewable energy options.
- *Labor Impact:* Alternatives to renewable energy are looked at in terms of how many jobs they create, both directly and indirectly, as well as how many new professionals they could help to make.
- *Cost of Implementation:* This principle looks at how much energy it will take to be fully operational, and how much it will cost.
- *Funds Availability:* This factor assesses national and international funding sources as well as government economic support.

- *Economic Value:* This principle uses one of the engineering economics methods, such as current worth, internal rate of return, benefit and cost analysis, payback period, or payback time, to figure out how much money the suggested renewable energy alternative is worth in terms of money.

4 Research Methodologies

In this study, there are two key processes for measuring the performance level of each designated place. The weight of each principle for the fuzzy ANP approach is computed in the first stage of the method of fuzzy TOPSIS. The relationships between the characteristics are explored in this manner to offer more realistic weights. The fuzzy TOPSIS approach is employed to calculate the performance of the collection centres in terms of environmental, social, and economic aspects, as well as the risk related to their presentation, after measuring the vital weights of these characteristics. All of the aforementioned methodologies require the input of renewable energy sector specialists for their processes. The specialists are chosen based on pre-set characteristics: they must have at least five years of professional experience in renewable energy source selection, management, and conceptual understanding. The following is a step-by-step breakdown of the suggested integrated methodology:

4.1 Fuzzy Analytic Network Process

Thomas Saaty [16] offered the ANP, which is an addition to the AHP. It enhances the capability of dealing with interplay and reliance between characteristics and sub-characteristics, which can have an impact on their weights. Despite numerous endeavours to alter the AHP to make it deal with imprecise human assessments, the ANP is quite limited to clear comparison ratios. The fundamental intention behind this is that the AHP's aggregation approach is quite modest and it can be conducted on intervals or fuzzy local priorities. However, the ANP's supermatrix priority derivation process needs sophisticated real-number matrix operations. On the other hand, all known interval and fuzzy prioritisation algorithms produce interval or fuzzy local priorities, which cannot be employed in the ANP matrix calculations. The fuzzy ANP was developed in order to deal with the uncertainty related to the preferences of professionals in a Pairwise Comparison Matrix (PWCM). The following are the steps in the fuzzy ANP technique that will be used to figure out the weights of the characteristics:

Step 1: Constructing the problem network by describing the relationships between its various pieces

Step 2: The second step is in which the comparison matrices are created by comparing different connected characteristics of the network pair-wise using Triangular Fuzzy Numbers (TFN) based on the scale proposed by Saaty [16]. Adoption of the linguistic phrase for comparison has been done in this work, as has the TFN allocated to it [17].

Step 3: Creating the supermatrix.

The weight of each characteristic and sub-characteristic should be determined to build the supermatrix. Due to the triangular fuzzy structure of each comparison matrix's characteristics, the weights are generated using Zadeh's ("s extent analysis method,") [17] which includes the following steps.

Step 3.1: The next step is to figure out the value of the fuzzy artificial extent for each of the following things:

Assuming that Pw is a PWCM matrixin (Eqs. (1)-(5)):

$$Pw = [Q_{ij}]_{r \times s}, Q_{ij} = (l_{ij}, m_{ij}, u_{ij}) \qquad i = 1, 2 \ldots\ldots r \qquad j = 1, \ \ldots\ldots s \tag{1}$$

$$S_i = \sum_{j=1}^{s} Q_{ij} \times \left[\sum_{i=1}^{r} \sum_{j=1}^{s} Q_{ij} \right]^{-1} \tag{2}$$

where

$$\sum_{j=1}^{s} Q_{ij} = \left(\sum_{j=1}^{s} l_j, \ \sum_{j=1}^{s} r_j, \ \sum_{j=1}^{s} u_j \right) \forall i, \tag{3}$$

$$\sum_{i=1}^{r} \sum_{j=1}^{s} Q_{ij} = \left(\sum_{i=1}^{r} \sum_{j=1}^{s} l_{ij}, \ \sum_{i=1}^{r} \sum_{j=1}^{s} m_{ij}, \ \sum_{i=1}^{r} \sum_{j=1}^{s} u_{ij} \right), \text{ and} \tag{4}$$

$$\left[\sum_{i=1}^{r} \sum_{j=1}^{s} Q_{ij} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{r} \sum_{j=1}^{s} u_{ij}}, \frac{1}{\sum_{i=1}^{r} \sum_{j=1}^{s} m_{ij}}, \frac{1}{\sum_{i=1}^{r} \sum_{j=1}^{s} l_{ij}} \right) \tag{5}$$

Step 3.2: Estimating the degree of the possibility for each S_i over others (Eq. (6)).

$$V(S_1 \geq S_2) = \begin{cases} 1 & if \ m_1 \geq m_2 \\ 0 & if \ l_1 \geq u_2 \\ \dfrac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)} & otherwise \end{cases} \tag{6}$$

Step 3.3: Using Eqs. (7)-(8), it's hard to figure out how much each characteristic should be worth in terms of the chance that a convex fuzzy number is bigger than k convex fuzzy numbers.

$$W'_i = V(S_k \geq S_1, S_2, \ \ldots\ldots S_r) = \min_{i=1,2,\ldots.k,..r} (S_k \geq S_i) \tag{7}$$

$$w' = (W'_1, W'_2, \ \ldots.., W'_r) \tag{8}$$

Step 3.4: Calculating the normalized weight vector (Eq. (9)).

$$w = (W_1, W_2, \ \ldots..W_r) \tag{9}$$

After computing the weights of each PWCMmatrix, the super-matrix can be designed as shown in Eq. (10):

$$W' = \begin{matrix} 1 = Goal \\ 2 = Criteria \\ 3 = Sub - criteria \end{matrix} \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \tag{10}$$

Step 4: Calculating the absolute weight vector of each sub-characteristic (Eq. (11)).

$$W = \lim_{x \to \infty} W'^{2k+1} \tag{11}$$

4.2 Fuzzy Technique for Order of Preference by Similarity to Ideal Solution

Widianta et al. [18] was the first to propose the fuzzy strategy for order performance based on resemblance to the ideal solution method, and since then, it has been widely employed for assessing alternatives in a variety of scenarios. This method can be employed to rate options based on how close they are to or how similar they are to an ideal answer. On this page, a detailed description of the stages involved in employing the fuzzy TOPSIS is given [19].

Step 1: Calculating the normalized decision matrix.

Assume that D_{nd} is the normalized fuzzy decision matrix (Eq. (12)):

$$D_{nd} = [d_{ij}]_{r \times s} \quad i = 1, \ldots\ldots. r \quad j = 1, \ldots\ldots, s \tag{12}$$

Each characteristic of decision-making is normalised to the category of each principle, with the exception of decision-making itself. Whether the principle is a benefit or a cost principle, which means that a rise in their magnitude is favourable in the first group and a drop in their size is favourable in the second category, depends on the principle. Each component of the normalised decision-making is calculated using the following equations, which are organised according to their category. (Eq. (13)):

$$d_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right) \tag{13}$$

where u_j^+ is the maximum u_{ij} for benefit characteristic (Eq. (14)).

$$d_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right) \tag{14}$$

where l_j^- is the minimum l_{ij} for cost characteristic.

Step 2: Calculating the weighted normalized decision matrix.

The weight of characteristic i is represented as w_i, and the weighted normalized decision matrix is deliberated as follows (Eq. (15)):

$$V = (v_{ij})_{r \times s} \text{where } v_{ij} = r_{ij} \times w_{ij} \forall j = 1, \ldots\ldots, s, \textit{ and } i = 1, \ldots.., r \tag{15}$$

Step 3: Postulating the fuzzy positive ideal and negative ideal solutions.

$FPI = (v_{1j}^+, \ldots..v_{ij}^+)$ for benefit characteristic, $FPI = (v_{1j}^-, \ldots..v_{ij}^-)$ for cost characteristic.

$FNI = (v_{1j}^-, \ldots..v_{ij}^-)$ for benefit characteristic, $FNI = (v_{1j}^+, \ldots..v_{ij}^+)$ for cost characteristic.

Where v_i^+ is maximum v_{ij}^-, v_{ij}^- is the minimum v_{ij}^+, and i = 1,….., r; j = 1,……, s.

Step 4: Calculating the distance of each alternative from positive ideal and negative ideal solutions (Eqs. (16)-(17)).

$$dia_j^+ = \sum_{j=1}^{n} dia_v(v_{ij}, v_j^+) i = 1, \ldots\ldots, r \tag{16}$$

$$dia_j^- = \sum_{j=1}^{n} dia_v(v_{ij}, v_j^-) i = 1, \ldots\ldots, r \tag{17}$$

The distance between two TFN can be calculated (Eq. (18)):

$$dia(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}\left((l_A - l_B)^2 + (m_A - m_B)^2 + (u_A - u_B)^2\right)} \tag{18}$$

Step 5: Calculating the Closeness Coefficient Factor (CCF) (Eq. (19)).

$$CCF_j = \frac{dia_j^-}{(dia_j^+ + dia_j^-)} \tag{19}$$

Step 6: Prioritizing the alternatives.

Since the formula employed to calculate the closeness coefficient rewards the option with the highest CCFj value, the one with the highest CCFj value comes out on top in the ranking list.

5 Results

Because energy resource selection is first and foremost a qualitative metric, which further quantifies the renewable energy resource selection process, it is a multifaceted and complicated job. Prioritization of quality characteristics throughout the renewable energy resource selection process is critical for any country. This research work offers an approach for the estimation of the impact of renewable energy resources using the FANP-technique for ordering performance by similarity to an ideal solution. According to Fig. 1, the four main factors for evaluating the impact of renewable energy resources are technological (RE1), environmental (RE2), socio-political (RE3), and economic (RE4), in that order: feasibility, risk, and reliability. In that order, when it comes to renewable energy resource selection at level 2, RE1 is at the top of the list. Pollutant emissions, land requirements, and the need for waste disposal are represented as RE21, RE22, and RE23, respectively, in terms of renewable energy resource selection at level 2 with respect to RE2. Compatibility with the national energy policy objectives, political acceptance, social acceptance, and labour impact are represented as RE31, RE32, RE33, and RE34, respectively, in terms of renewable energy resource selection at level 2 with respect to RE3. RE41, RE42, and RE43 are also shown in terms of renewable energy resource selection at level 2 with respect to RE4. These are the costs of implementation, the availability of funds, and the economic value.

The authors used a unified method of fuzzy ANP and fuzzy TOPSIS to determine how much renewable energy resources would have an impact on the environment. Present work got the numbers from linguistic values and then accumulated TFN using the standard Saaty scale and Eqs. (1)–(5). Further, Eqs. (6)-(8) were utilised to convert the crisp numerical values into fuzzy TFN. The PWCM matrixes for level-1 characteristics are then generated and displayed in Tabs. 1–5, respectively. After that, Eq. (9) was employed to derive the consistency index and random index. The random index of this PWCM matrix is less than 0.1, indicating that it is consistent. They can also be used for things like adding, multiplying, defuzzing, and normalising fuzzy numbers in the middle.

Table 1: The PWCM of dimensions with respect to renewable energy dimension

	RE1	RE2	RE3	RE4	Fuzzified weights	Defuzzified and normalized weights
Technological (RE1)	1.000, 1.000, 1.000	0.500, 0.600, 0.890	0.470, 0.580, 0.740	0.680, 0.860, 1.260	0.141, 0.455, 0.696	0.391
Environmental (RE2)	1.120, 1.550, 1.940	1.000, 1.000, 1.000	0.202, 0.233, 0.282	0.296, 0.357, 0.437	0.035, 0.085, 0.215	0.169
Socio-Political (RE3)	1.360, 1.730, 2.120	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.332, 0.410, 0.474	0.149, 0.176, 0.257	0.200
Economic (RE4)	1.120, 1.550, 1.940	1.360, 1.730, 2.120	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.035, 0.076, 0.128	0.240

Table 2: The PWCM of dimensions with respect to technological dimension

	RE1	RE2	RE3	RE4	RE15	RE16	RE17	Fuzzified weights	Defuzzified and normalized weights
Feasibility (RE11)	1.000, 1.000, 1.000	0.500, 0.600, 0.890	0.470, 0.580, 0.740	0.680, 0.860, 1.260	0.470, 0.580, 0.740	0.680, 0.860, 1.260	0.470, 0.580, 0.740	0.079, 0.135, 0.256	0.123
Risk (RE12)	1.120, 1.550, 1.940	1.000, 1.000, 1.000	0.202, 0.233, 0.282	0.296, 0.357, 0.437	0.202, 0.233, 0.282	0.296, 0.357, 0.437	0.202, 0.233, 0.282	0.035, 0.075, 0.115	0.103
Reliability (RE13)	1.360, 1.730, 2.120	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.332, 0.410, 0.474	0.470, 0.580, 0.740	0.680, 0.860, 1.260	0.470, 0.580, 0.740	0.049, 0.076, 0.157	0.127
The duration of preparation phase (RE14)	1.120, 1.550, 1.940	1.360, 1.730, 2.120	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.202, 0.233, 0.282	0.296, 0.357, 0.437	0.202, 0.233, 0.282	0.074, 0.134, 0.257	0.141
The duration of implementation phase (RE15)	1.120, 1.550, 1.940	1.000, 1.000, 1.000	0.470, 0.580, 0.740	1.360, 1.730, 2.120	1.000, 1.000, 1.000	0.470, 0.580, 0.740	0.680, 0.860, 1.260	0.035, 0.076, 0.118	0.173
Continuity and predictability of performance (RE16)	1.360, 1.730, 2.120	1.120, 1.550, 1.940	1.000, 1.000, 1.000	1.120, 1.550, 1.940	0.470, 0.580, 0.740	1.000, 1.000, 1.000	0.296, 0.357, 0.437	0.074, 0.134, 0.247	0.076
Local technical know how (RE17)	0.470, 0.580, 0.740	1.360, 1.730, 2.120	0.790, 1.160, 1.470	0.470, 0.580, 0.740	0.470, 0.580, 0.740	0.470, 0.580, 0.740	0.470, 0.580, 0.740	0.035, 0.076, 0.118	0.257

Table 3: The PWCMof dimensions in perspective of the environmental dimension

	RE21	RE22	RE23	Fuzzified weights	Defuzzified and normalized weights
Pollutant emission (RE21)	1.000, 1.000, 1.000	1.120, 1.550, 1.940	0.470, 0.580, 0.740	0.079, 0.135, 0.256	0.178
Land requirements (RE22)	1.120, 1.550, 1.940	1.000, 1.000, 1.000	0.680, 0.860, 1.260	0.035, 0.075, 0.115	0.316
Need of waste disposal (RE23)	1.360, 1.730, 2.120	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.049, 0.076, 0.157	0.506

Table 4: The PWCMof dimensions with respect to socio-political dimension

	RE31	RE32	RE33	RE34	Fuzzified weights	Defuzzified and normalized weights
Compatibility with the national energy policy objectives (RE31)	1.000, 1.000, 1.000	0.202, 0.233, 0.282	0.296, 0.357, 0.437	0.202, 0.233, 0.282	0.078, 0.132, 0.255	0.103
Political acceptance (RE32)	1.120, 1.550, 1.940	1.000, 1.000, 1.000	0.500, 0.600, 0.890	0.202, 0.233, 0.282	0.035, 0.075, 0.115	0.516
Social acceptance (RE33)	1.120, 1.550, 1.940	0.470, 0.580, 0.740	1.000, 1.000, 1.000	0.296, 0.357, 0.437	0.049, 0.075, 0.155	0.306
Labour impact (RE34)	1.360, 1.730, 2.120	0.296, 0.357, 0.437	0.470, 0.580, 0.740	1.000, 1.000, 1.000	0.075, 0.145, 0.325	0.075

Table 5: The PWCMof dimensions with respect to economic dimension

	RE41	RE42	RE43	Fuzzified weights	Defuzzified and normalized weights
Implementation cost (RE41)	1.000, 1.000, 1.000	0.500, 0.600, 0.890	0.470, 0.580, 0.740	0.078, 0.132, 0.255	0.118
Availability of funds (RE42)	0.790, 1.160, 1.470	1.000, 1.000, 1.000	0.470, 0.580, 0.740	0.035, 0.075, 0.115	0.306
Economic value (RE43)	0.470, 0.580, 0.740	0.202, 0.233, 0.282	1.000, 1.000, 1.000	0.049, 0.075, 0.155	0.576

The significance acquired from the numerous PWCMs is employed to create an un-weighted super-matrix. In addition, Eqs. (10)–(11) are employed to construct the un-weighted super matrix, and the weighted super matrix is calculated by altering all column sums to unity [18–21]. A weighted super matrix is then employed to compute the limit super-matrix. Universal characteristic weights are also computed, and the outcomes are shown in Tab. 6 with the characteristics ranked.

Table 6: Final weights

Characteristics	Final weights	Weights in percentage	Ranks
Feasibility (RE11)	0.0481	4.81%	11
Risk (RE12)	0.0403	4.03%	12
Reliability (RE13)	0.0497	4.97%	10
The duration of preparation phase (RE14)	0.0551	5.51%	8

(Continued)

Table 6 (continued)

Characteristics	Final weights	Weights in percentage	Ranks
The duration of implementation phase (RE15)	0.0676	6.76%	6
Continuity and predictability of performance (RE16)	0.0297	2.97%	14
Local technical know how (RE17)	0.1005	10.05%	3
Pollutant emission (RE21)	0.0301	3.01%	13
Land requirements (RE22)	0.0534	5.34%	9
Need of waste disposal (RE23)	0.0855	8.55%	4
Compatibility with the national energy policy objectives (RE31)	0.0206	2.06%	16
Political acceptance (RE32)	0.1032	10.32%	2
Social acceptance (RE33)	0.0612	6.12%	7
Labour impact (RE34)	0.0150	1.50%	17
Implementation cost (RE41)	0.0283	2.83%	15
Availability of funds (RE42)	0.0734	7.34%	5
Economic value (RE43)	0.1382	13.82%	1

A renewable energy source is obtained from renewable resources that are replenished naturally over time, as measured by the human calendar. Examples include waves, tides, rain, wind, sunlight, and geothermal heat, to name a few. According to some estimates, some biomass sources are no longer viable if employed at current rates of production. In addition, the authors gathered information on nine renewable energy sources, including ethanol, solar, biodiesel, wind, geothermal, hydropower, Landfill Gas (LFG), biogas, Municipal Solid Waste (MSW), and wood and wood waste. The following is a description of these resources:

- *Wood and Wood Waste:* Humans have been cooking with wood for thousands of years and heating and lighting their homes with it for even longer. Forestry was the dominant source of energy in the United States and around the world until around 1850, when coal and oil supplanted it.
- *Municipal Solid Waste:* At waste-to-energy plants and landfills in the United States, MSW, often known as rubbish, is used to generate electricity to power the facilities. There are a lot of different types of materials that are called “MSW.”
- *Landfill Gas:* LFG is a natural by-product of organic waste breakdown in landfills. LFG is made up of around half methane (natural gas’s major component), half CO_2, and a minor quantity of non-methane chemical molecules. LFG is a type of biogas produced by anaerobic microorganisms in MSW dumps that can be used to generate electricity. Because methane is a flammable gas, LFG that contains a high concentration of methane can be hazardous to both people and the environment. Methane is a potent greenhouse gas as well.
- *Biogas:* Biogas is a high-energy gas produced by anaerobic decomposition of biomass or thermo-chemical conversion of biomass. Methane and CO_2 are the primary components of biogas. When it comes to raw (untreated) biogas, the methane content can range from 40 to 60 percent, with the rest made up of CO_2 and water vapour. Biogas is produced in MSW landfills and livestock manure holding ponds and can be collected.

- *Ethanol:* Ethanol is classified as a renewable biofuel because it is obtained from biomass. Ethanol is a colourless, pure alcohol that can be produced from a variety of biomass feedstock sources (the raw materials employed to make a product). Feed stocks for ethanol production in the United States are often made from food grains and crops with high starch and sugar content. Examples of such crops are sugar beets, sugar cane, barley, sorghum, and maize.
- *Biodiesel:* Biodiesel and renewable diesel are both biomass-based diesel fuels that are employed in the same way that petroleum distillate fuel oil is employed in transportation (diesel fuel and heating oil). As biomass-based diesel fuels, they're both referred to as such because of their most common use in diesel engines, but they can similarly be employed for heating purposes. In accordance with the American Society for Testing and Components (ASTM) specification ASTM D6751, biodiesel may be blended with petroleum distillate or diesel in any proportion.
- *Hydropower:* Water running through streams and rivers has been employed to generate mechanical energy by humans for thousands of years. Since hydroelectricity was among one of the initial forms of energy to be employed for electricity generation, it has accounted for the vast majority of the total yearly renewable electricity output in the United States, which will continue until 2019 [11].
- *Geothermal Energy:* Geothermal energy that originates deep beneath the earth is referred to as geothermal energy. Geothermal energy is taken from the Greek words geo (earth) and therme (heat). Given that heat is constantly produced within the earth, geothermal energy is considered a renewable energy source. Geothermal heat is employed for a variety of purposes, including bathing, heating homes, and generating electricity. This energy is produced by the slow disintegration of radioactive particles in the earth's core, a process that happens in all rocks and is responsible for the formation of geothermal energy [12].
- *Wind Power:* The wind is caused by the uneven heating of the earth's surface caused by the sun. The earth's surface, which is made up of diverse types of land and water, engages the sun's heat at diverse rates depending on its composition. Nowadays, wind energy is the primary source of electricity generation. The use of windmills to pump water was once widespread across the United States, and some still do so on farms and ranches, mostly to provide water for cattle and other livestock.
- *Solar Energy:* In addition to creating energy for billions of years, the sun also serves as our sole and ultimate source of all modern energy sources and fuels. For thousands of years, people have relied on the sun's beams (solar radiation) to keep warm and preserve grains, fruit, and dry meat in their homes and farms. People devised methods for collecting solar energy for use as heat, with the energy eventually converted to electricity. The solar oven is an example of a solar energy harvesting device that was developed in the early 1900s (a box for collecting and absorbing sunlight).

Renewable energy is employed in a variety of applications, including electricity generation, air and water heating and cooling, transportation, and rural (off-grid) energy services [22,23]. Energy-efficient and cost-effective renewable energy systems are rapidly improving, and their share of total energy consumption is increasing, with renewable energy accounting for the great majority of newly added power capacity around the world. In most countries, photovoltaic solar or onshore wind energy is the most cost-effective new-build electricity source. The data in Tab. 7 reflects the output and consumption of renewable energy in the United States as of January 2022. If current estimates are correct, wood and wood waste (bark, sawdust, and wood chips, as well as wood scrap and paper mill wastes) will account for about 2.3% of the total amount of electricity that the United States uses each year in 2020. There were about 12% of the 292 million metric tonnes of MSW that the United States made in 2018. Waste-to-energy plants and other facilities that looked like them burned about 12% of that waste in 2018.

Table 7: Renewable energy production and consumption (in trillion BTU)

Production		Consumption								
Year	Overall production	Year	Hydro-electric Power	Geothermal	Solar	Wind	Wood	Waste	Bio-fuels	Overall consumption
2011	9308	2011	3103	212	112	1168	2213	462	1941	9212
2012	8893	2012	2629	212	159	1340	2151	467	1899	8856
2013	9433	2013	2562	214	225	1601	2338	496	2022	9459
2014	9789	2014	2467	214	337	1728	2401	516	2089	9752
2015	9754	2015	2321	212	427	1777	2312	518	2170	9737
2016	10459	2016	2472	210	570	2096	2226	503	2313	10391
2017	11237	2017	2767	210	777	2343	2185	495	2339	11116
2018	11552	2018	2663	209	915	2482	2261	487	2324	11343
2019	11595	2019	2564	201	1017	2635	2236	442	2341	11436
2020	11667	2020	2503	203	1211	2965	2081	440	2100	11503

To analyse the influence of various solutions on order performance, the fuzzy TOPSIS method makes use of this description and data. This is accomplished through the application of Eq. (12), and a normalised decision-matrix is obtained as shown in Tab. 8. The fuzzy negative-ideal solution and the fuzzy positive-ideal solution are then calculated using Eqs. (13)–(15). Finally, the performance value of each principle was calculated using Eq. (16) through Eq. (19), and the ranking of alternatives was established using the resulting performance score, which is also shown in Tab. 9 and Fig. 2.

Table 8: Individual awareness outcomes

	Solar	Hydropower	Geothermal	Wind	Biodiesel	Ethanol	Landfill gas and biogas	Municipal solid waste	Wood and wood waste
(RE11)	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	4.100, 5.400, 6.600	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6000	3.900, 5.700, 7.400	4.100, 5.400, 6.600
(RE12)	4.100, 5.600, 7.000	5.200, 6.700, 7.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500	2.800, 3.700, 4.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.500, 3.900, 5.500
(RE13)	2.800, 4.100, 5.600	2.900, 4.400, 6.000	4.100, 5.600, 7.000	5.200, 6.700, 7.900	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	4.100, 5.400, 6.600
(RE14)	2.800, 3.900, 5.100	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6000	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500

(Continued)

Table 8 (continued)

	Solar	Hydropower	Geothermal	Wind	Biodiesel	Ethanol	Landfill gas and biogas	Municipal solid waste	Wood and wood waste
(RE15)	3.900, 5.500, 6.900	4.100, 5.600, 7.000	5.200, 6.700, 7.900	2.800, 3.700, 4.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600
(RE16)	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	3.900, 5.700, 7.400	4.100, 5.400, 6.600	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6000
(RE17)	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500	2.800, 3.700, 4.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500
(RE21)	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.600, 7.000	5.200, 6.700, 7.900	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500
(RE22)	4.100, 5.600, 7.000	5.200, 6.700, 7.900	4.100, 5.600, 7.000	5.200, 6.700, 7.900	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6.000	3.900, 5.700, 7.400
(RE23)	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.600, 7.000	5.200, 6.700, 7.900	3.900, 5.700, 7.400	4.100, 5.400, 6.600
(RE31)	5.200, 6.700, 7.900	2.800, 3.700, 4.900	4.100, 5.400, 6.600	4.100, 5.600, 7.000	5.200, 6.700, 7.900	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6000
(RE32)	3.900, 5.700, 7.40000	3.900, 5.700, 7.400	4.100, 5.400, 6.600	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.600, 7.000	5.200, 6.700, 7.900	3.900, 5.700, 7.400	4.100, 5.400, 6.600
(RE33)	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6.000	4.100, 5.600, 7.000	5.200, 6.700, 7.900	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6000
(RE34)	2.800, 3.700, 4.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.500, 3.900, 5.500	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.600, 7.000
(RE41)	3.900, 5.700, 7.400	4.100, 5.400, 6.600	2.500, 3.900, 5.500	3.900, 5.700, 7.400	5.200, 6.700, 7.900	5.200, 6.700, 7.900	4.100, 5.600, 7.000	5.200, 6.700, 7.900	2.500, 3.900, 5.500
(RE42)	3.900, 5.700, 7.400	5.000, 6.600, 7.800	2.900, 4.400, 6.000	3.900, 5.700, 7.400	3.900, 5.700, 7.400	3.900, 5.700, 7.400	5.000, 6.600, 7.800	4.100, 5.400, 6.600	2.500, 3.900, 5.500
(RE43)	2.800, 3.700, 4.900	4.100, 5.400, 6.600	2.500, 3.900, 5.500	4.100, 5.400, 6.600	2.800, 3.700, 4.900	2.800, 3.700, 4.900	4.100, 5.400, 6.600	4.100, 5.600, 7.000	5.200, 6.700, 7.900

Table 9: Closeness coefficients of selected renewable energy sources

Alternatives	Negative distance	Positive distance	Closeness coefficients
Alternative 1 (Solar)	0.225	0.131	0.543
Alternative 2 (Hydropower)	0.245	0.146	0.489
Alternative 3 (Geothermal)	0.229	0.154	0.445
Alternative 4 (Wind)	0.245	0.156	0.452
Alternative 5 (Biodiesel)	0.183	0.182	0.481
Alternative 6 (Ethanol)	0.165	0.191	0.542
Alternative 7 (Landfill Gas and Biogas)	0.247	0.156	0.477
Alternative 8 (Municipal Solid Waste)	0.256	0.187	0.463
Alternative 9 (Wood and Wood Waste)	0.274	0.196	0.474

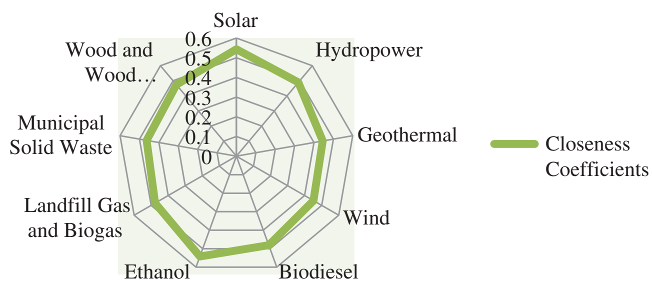

Figure 2: Ranking of renewable energy sources

6 Conclusions

Every country has a substantial renewable energy potential due to the abundance of natural resources such as hydropower, biomass, geothermal, sunlight, and wind. A consequence of this is that governments encourage business investments in the renewable energy sector by releasing new energy companies. For the country's energy options to be as effective as possible, the country's resources must be properly utilised. As an outcome, determining the relative importance of various energy options is crucial. In this study, a fuzzy-based combination methodology was employed to estimate the relative importance of several possibilities. Efficiency is calculated from best to worst for various renewable energy sources, including hydropower, solar, geothermal, biomass, and wind. Further exploration into the usage of an ANP technique to analyse internal and external dependencies among characteristics is proposed. Another way to figure out energy options and their characteristics in language is to use a fuzzy ANP technique in a fuzzy setting.

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

[1] M. Çolak and I. Kaya, "Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey," *Renewable and Sustainable Energy Reviews*, vol. 80, no. 2, pp. 840–853, 2017.

[2] J. J. C. Barros, M. L. Coira, M. P. D. López and A. D. Gochi, "Assessing the global sustainability of different electricity generation systems," *Energy*, vol. 89, no. 5, pp. 473–489, 2015.

[3] B. Karatop, B. Taşkan, E. Adar and C. Kubat, "Decision analysis related to the renewable energy investments in Turkey based on a fuzzy-AHP-EDAS-fuzzy-FMEA approach," *Computers & Industrial Engineering*, vol. 151, no. 5, pp. 106958–106969, 2021.

[4] S. K. Sarpong, J. Sarkis and X. Wang, "Assessing green supply chain practices in the Ghanaian mining industry: A framework and estimation," *International Journal of Production Economics*, vol. 181, no. 1, pp. 325–341, 2016.

[5] P. B. Shamaki, "Integration of real time optimization with model predictive control applied to a gas-lift system: A comparative study," Universidad de São Paulo, 2021. [Online]. Available: https://www.teses.usp.br/teses/disponiveis/3/3137/tde-05032021-093254/publico/PatienceBelloShamakiCorr21.pdf.

[6] R. Medjoudj, F. Iberraken and D. Aissani, "Combining AHP method with BOCR merits to analyze the outcomes of business electricity sustainability," *Applications and Theory of Analytic Hierarchy Process-Decision Making for Strategic Decisions*, vol. 45, no. 6, pp. 277–295, 2016.

[7] H. C. Lee and C. T. Chang, "Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan," *Renewable and Sustainable Energy Reviews*, vol. 92, no. 5, pp. 883–896, 2018.

[8] I. S. Butkiene, E. K. Zavadskas and D. Streimikiene, "Multi-characteristic decision-making for the assessment of renewable energy technologies in a household: A review," *Energies*, vol. 13, no. 5, pp. 1164–1178, 2020.

[9] N. Pang, Q. Meng and M. Nan, "Multi-characteristic estimation and selection of renewable energy battery energy storage system-A case study of Tibet, China," *IEEE Access*, vol. 9, no. 8, pp. 119857–119870, 2021.

[10] A. Kumar, B. Sah, A. R. Singh, Y. Deng, X. He *et al.,* "A review of multi characteristic decision making towards sustainable renewable energy development," *Renewable and Sustainable Energy Reviews*, vol. 69, no. 4, pp. 596–609, 2017.

[11] S. K. Saraswat, A. K. Digalwar, S. S. Yadav and G. Kumar, "MCDM and GIS based modelling technique for assessment of solar and wind farm locations in India," *Renewable Energy*, vol. 169, no. 6, pp. 865–884, 2021.

[12] M. Ramezanzade, H. Karimi, K. Almutairi, H. A. Xuan, J. Saebi *et al.,* "Implementing MCDM techniques for ranking renewable energy projects under fuzzy environment: A case study," *Sustainability*, vol. 13, no. 22, pp. 12858–12869, 2021.

[13] Y. Wu, T. Zhang, R. Gao and C. Wu, "Portfolio planning of renewable energy with energy storage technologies for different applications from electricity grid," *Applied Energy*, vol. 287, no. 1, pp. 116562–116574, 2021.

[14] M. Shao, Z. Han, J. Sun, C. Xiao, S. Zhang *et al.,* "A review of multi-characteristic decision making applications for renewable energy site selection," *Renewable Energy*, vol. 157, no. 4, pp. 377–403, 2020.

[15] Y. Wu, J. Wang, S. Ji and Z. Song, "Renewable energy investment risk assessment for nations along China's belt & road initiative: An ANP-cloud model method," *Energy*, vol. 190, no. 6, pp. 116381–116398, 2020.

[16] T. L. Saaty, "Decision making-The analytic hierarchy and network processes (AHP/ANP)," *Journal of Systems Science and Systems Engineering*, vol. 13, no. 1, pp. 1–35, 2004.

[17] L. A. Zadeh, "Fuzzy sets," *Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems*, vol. 1, no. 1, pp. 394–432, 1996.

[18] M. M. D. Widianta, T. Rizaldi, D. P. S. Setyohadi and H. Y. Riskiawan, "Comparison of multi-characteristic decision support methods (AHP, TOPSIS, SAW & PROMENTHEE) for employee placement," *Journal of Physics: Conference Series*, vol. 953, no. 1, pp. 12116. 2018.

[19] M. Pourmehdi, M. M. Paydar and E. A. Gangraj, "Reaching sustainability through collection center selection considering risk: Using the integration of fuzzy ANP-TOPSIS and FMEA," *Soft Computing*, vol. 25, no. 16, pp. 10885–10899, 2021.

[20] W. Dong, G. Zhao, S. Yüksel, H. Dinçer and G. G. Ubay, "A novel hybrid decision making approach for the strategic selection of wind energy projects," *Renewable Energy*, vol. 185, no. 5, pp. 321–337, 2022.

[21] A. Aryanfar, A. Gholami, P. Ghorbannezhad, B. Yeganeh, M. Pourgholi *et al.,* "Multi-criteria prioritization of the renewable power plants in Australia using the fuzzy logic in decision-making method," *Clean Energy*, vol. 6, no. 1, pp. 780–798, 2022.

[22] Z. Wang, R. Jiao and H. Jiang, "Emotion recognition using WT-SVM in human-computer interaction," *Journal of New Media*, vol. 2, no. 3, pp. 121–130, 2020.

[23] X. R. Zhang, X. Chen, W. Sun and X. Z. He, "Vehicle re-identification model based on optimized densenet with joint loss," *Computers, Materials & Continua*, vol. 67, no. 3, pp. 3933–3948, 2021.