Renewable Energy 240 (2025) 122175

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

A molecular fuzzy decision-making model for optimizing renewable energy investments towards carbon neutrality

Yedan Shen [a], Wei Liu [b,*], Serhat Yüksel [c,d], Hasan Dinçer [c,d,**]

[a] School of Mathematics and Statistics, Guangdong University of Technology, Guangzhou, 510006, China
[b] School of Economics, Guangdong University of Technology, Guangzhou, 510006, China
[c] The School of Business, Istanbul Medipol University, Istanbul, Turkey
[d] Clinic of Economics, Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan

ARTICLE INFO

Keywords:
Carbon neutrality
Renewable energy integration
Molecular fuzzy
Artificial intelligence

ABSTRACT

Identifying the most important factors is necessary to determine which areas should be given priority in the energy transition. In this way, it is possible to increase the efficiency of investments by using resources effectively. However, there are limited studies in the literature focusing on this issue. Hence, a new study is needed to determine the most important factors affecting the success of renewable energy integration. Accordingly, the purpose of this study is to find the most critical renewable energy investment strategies to implement effective carbon neutrality policies. A new model is generated to reach this objective. Firstly, to define expert prioritization, an evaluation is conducted by artificial intelligence. Secondly, selected indicators are weighted via molecular fuzzy cognitive maps. Thirdly, alternative strategies of carbon neutrality policies are ranked by fuzzy molecular ranking. The main contribution of this study is that effective investment policies related to renewable energy integration can be determined for successful carbon neutrality policies by created a novel model. The most significant superiority of this model is that fuzzy decision-making methodology is integrated with molecular geometry science. In this process, by computing the degrees with different geometrical shapes, uncertainties in the evaluation process can be handled more effectively. The findings denote that technological infrastructure is the most critical performance indicator of renewable energy integration projects. Similarly, economic feasibility is found as the second most essential determinant of this situation. On the other hand, setting the long-term contracts with renewable producers is the most essential investment alternative to implement effective carbon neutrality policies.

1. Introduction

Carbon neutral policies aim to reduce greenhouse gas emissions. These policies play a key role in combating a problem that threatens the entire world, such as global warming. For this reason, these policies are implemented by many countries. The implementation of carbon neutral policies provides many advantages. First, thanks to the implementation of these policies, it is possible to combat climate change more effectively. These policies encourage the use of renewable energy [1]. Hence, it is aimed to significantly reduce the use of fossil fuels. This contributes to the significant reduction of the carbon emission problem. On the other hand, carbon neutral policies also contribute significantly to the protection of biodiversity. Thanks to these policies, the possibility of extinction of living species is reduced. In addition to them, it is possible to achieve energy independence with effective carbon neutral policies. Thanks to these policies, dependence on fossil fuels in energy use can be reduced. Thus, countries can more easily ensure energy supply security. In summary, carbon neutral policies allow long-term sustainability goals to be achieved.

Renewable energy integration plays a critical role in the success of carbon neutral policies. These energy sources are one of the most important alternatives for reducing the use of fossil fuels. Renewable energy integration enables the development of technological innovations in the energy sector. This situation also significantly supports

* Corresponding author.
** Corresponding author. The School of Business, Istanbul Medipol University, Istanbul, Turkey.
E-mail addresses: yedan90s@gdut.edu.cn (Y. Shen), alex.w.liu@gdut.edu.cn (W. Liu), serhatyuksel@medipol.edu.tr (S. Yüksel), hdincer@medipol.edu.tr (H. Dinçer).

https://doi.org/10.1016/j.renene.2024.122175
Received 20 August 2024; Received in revised form 28 November 2024; Accepted 14 December 2024
Available online 15 December 2024

the increase in energy efficiency. For clean energy integration to be successfully achieved, improvements must be made to several factors. An effective regulatory framework is extremely important for the success of renewable energy integration. This is necessary for fair and transparent market access. This condition will facilitate the integration of renewable energy. Economic feasibility is another important factor in this process. For the performance of renewable energy projects to be increased, they must also be financially successful. This situation increases the interest of investors in the project. Technological infrastructure also ensures efficient and safe integration into the energy system [2]. Thanks to the use of advanced technologies, the possibility of energy losses in projects decreases. Social acceptance is also necessary for the success of renewable energy integration. Involving the community in the project helps to make projects more suitable for local needs [3].

For renewable energy integration to be successful, it is necessary to determine the most important factors. This is important primarily for the efficient use of resources. Identifying the most important factors is necessary to determine which areas should be given priority in the energy transition [4]. Thus, it is possible to increase the efficiency of investments by using resources effectively [5]. On the other hand, there are limited studies in the literature focusing on this issue. Instead, researchers have generally emphasized the importance of these factors. This situation is also a significant deficiency in the literature. Therefore, a new study is needed to determine the most important factors affecting the success of renewable energy integration. Accordingly, this study tries to find the most critical renewable energy investment strategies to implement effective carbon neutrality policies. The research question is to understand which criteria are the most important for these policies and which strategies should be implemented priorly to provide successful renewable energy integration. A new model is constructed to answer these questions. First, to define expert prioritization, an evaluation is conducted by artificial intelligence (AI). Secondly, selected indicators are weighted via molecular fuzzy cognitive maps. Thirdly, alternative strategies of carbon neutrality policies are ranked by fuzzy molecular ranking (MORAN).

The main motivation of this study is the need for a detailed examination to identify the most essential renewable energy integration strategies to implement successful carbon neutrality policies. To achieve this objective, a priority analysis should be conducted to define the most important performance indicators and investment alternatives. This priority analysis can give an opportunity to take necessary actions without having high costs. Decision-making models can be considered in the analysis process for this subject. These models can be very helpful to make a priority evaluation for selected criteria and alternatives. In this framework, criticisms related to the existing models should be taken into consideration to have more reliable results. The most critical criticisms for these models are the failure to overcome uncertainties effectively and considering equally weighted expert assessments.

The main contribution of this study is that effective investment policies related to renewable energy integration can be determined for successful carbon neutrality policies by created a novel model. Regarding the theoretical contribution, the most essential performance indicators can be identified. This situation provides an opportunity to select the best strategies of carbon neutrality policies. With the help of this analysis, appropriate policies can be implemented without having high operation costs. In other words, efficiency in the operational procedures can be provided in this process. On the other side, there are also significant superiorities of this proposed model. The details of these issues are detailed below.

(1) Fuzzy decision-making methodology is integrated with molecular geometry science. Different geometric shapes are taken into consideration in the use of molecular geometry. In this integration process, these shapes are used in the calculation of membership, non-membership and hesitancy degrees. This is an important step in solving the problem of high uncertainty, which is the biggest criticism of current models. In addition, it is possible to obtain normalized data more accurately with the molecular geometry technique. This also supports the proposed model to produce more coherent results. Molecular fuzzy sets have some advantages over traditional fuzzy set types in reducing uncertainty. For example, triangular fuzzy sets generally offer limited sensitivity in cases where uncertainty is high [6]. Similarly, trapezoidal sets may be insufficient in determining boundary values [7]. Molecular fuzzy sets use geometric structures. With the help of this issue, they can evaluate in more dimensions. This contributes to the more successful modeling of complex problems. In addition to them, Fermatean fuzzy sets handle uncertainty flexibly by offering a wider acceptance and rejection area Büyüközkan et al., 2024. Molecular fuzzy sets can offer more sensitivity than Fermatean sets because they allow for more detailed analysis.

(2) The development of a new ranking technique called MORAN is also one of the most important novelties of the proposed model. There are some criticisms about the calculation processes of frequently used ranking approaches in the literature. A new technique is being developed to minimize these criticisms. In the MORAN approach, both the importance order of the alternatives can be determined and the causality relationship between these alternatives can be determined. This situation provides a very important advantage to the MORAN model compared to other ranking techniques. Alternative strategies of carbon neutrality policies by using renewable energy sources can have a strong causality relationship. Therefore, it is important to consider this cause-and-effect relationship to determine the most critical strategies. In summary, the use of the MORAN technique in this model allows more accurate ranking results to be obtained. The MORAN technique provides some advantages over traditional ranking techniques. For instance, the multi objective optimization on the basis of ratio analysis (MOORA) technique only considers weighting and ratio analysis [8]. This is limited in solving complex relationships [9]. MORAN can model uncertainties in more detail with molecular geometry. In this context, it analyzes the relationships between criteria in a three-dimensional manner. This allows more reliable analyses to be obtained. Furthermore, the additive ratio assessment (ARAS) method uses additive ratio analysis in the evaluation of alternatives according to the determined criteria [10]. This application may be inadequate in managing high uncertainties Pamucar et al., 2024. MORAN technique reduces uncertainty by integrating with molecular fuzzy sets. With the help of this issue, more precise rankings can be made.

(3) Calculating the weights of experts with the help of AI also increases the advantages of the proposed model. In decision-making models, an expert team consisting of 3–6 people is generally formed. On the other hand, in most of the existing models, the opinions of these people are taken into consideration with the same importance weight. This situation is criticized by many researchers Otay et al., 2024. The main reason for this situation is that these people have different work experiences. To minimize these criticisms, the importance weights of experts are calculated by using the AI technique in this study. In some models in the literature, the weights of experts are usually determined by fixed scales or subjective evaluations Jafari et al., 2024. In this model, a more objective and precise analysis can be performed by taking into consideration demographic characteristics and expertise levels. This situation contributes significantly to increasing the reliability of the analysis results. On the other hand, calculating expert weights using artificial intelligence also makes the model more dynamic and adaptive. Thus, the model can be updated according to changes in the expert group. With

the help of this condition, the model can be adapted to possible changes much more easily. Furthermore, traditional methods can create uncertainty in the process of weighting the importance of a large expert group. As a result of this issue, the effectiveness of the results obtained from the model can be increased.

This study consists of six different sections. Section 2 reviews previous studies related to the subject of renewable energy integration in the literature. As a result, the main literature gap can be understood. To satisfy this missing part, a new model is constructed. The main steps of this proposed model are explained in Section 3. On the other side, Section 4 includes the main results of this model. These results are compared with the findings of similar studies in Section 5. Policy recommendations, the main conclusions and future research directions are highlighted in Section 6.

2. Literature review

An effective regulatory framework is extremely important for the successful integration of renewable energy. In this context, the necessary policies and regulations ensure that renewable energy projects are easily integrated into the system Zakariazadeh et al., 2024. In an effective regulatory framework, there are financial incentives that provide cost efficiency to these projects. In this context, incentives such as providing low-interest loans and tax reductions allow the operational costs of projects to be reduced [11]. The fairness and transparency of energy markets increases investors' confidence in these projects. According to Toghyani and Saadat [12], thanks to effective regulations, it is possible to regulate energy markets more successfully. Battaglia and Vanoli [13] stated that this situation facilitates the entry of energy producers into the energy market. Reddy et al. [14] defined that establishing the necessary regulations also allows for the reduction of bureaucratic obstacles. This application also shortens the time for implementing projects. Investors are more willing to invest in these projects.

For renewable energy integration to be successful, an economic feasibility assessment must be conducted. Economic feasibility studies allow the financial risks of these projects to be determined more clearly. This helps to take the necessary precautions against these risks in a timely manner [15]. Financial risks can be minimized quickly, which reduces the possibility of financial losses. Economic feasibility studies play a critical role in providing financing for renewable energy projects [16]. Financial institutions that will provide funds for these projects pay significant attention to the results of the feasibility study. On the other hand, Alam et al. [17] determined that thanks to economic feasibility studies, it is possible to perform more successful cost control. It is easier to implement the necessary strategies to ensure cost effectiveness. In addition to them, Feio et al. [18] and Sattar et al. [19] concluded that these studies also help to determine the long-term growth potential of the projects. Owing to this situation, more accurate investment decisions can be made regarding these issues.

The technological infrastructure must be developed for renewable energy integration to be successful. In this context, the use of smart grids provides advantages in many ways. Smart grids play a critical role in balancing energy supply and demand [20]. This situation contributes significantly to minimizing energy losses. Thus, it is possible to increase grid profitability. Thanks to the development of the technological infrastructure, the efficiency of energy storage systems can also be increased Geng et al., 2024. Bovesecchi et al. [21] stated that renewable energy projects are also negatively affected by climate conditions. By increasing the performance of storage processes, these negativities can be combated much more successfully. This situation supports projects to produce more uninterrupted electricity. According to Hao et al. [22], one of the most important disadvantages of these projects is that they are generally established in places far from the city center. Migliari et al. [23] mentioned that the distribution infrastructure must be strong to transmit this produced energy to the consumption points in the city center. The development of the technological infrastructure also allows this goal to be achieved more easily.

Social acceptance must be achieved to have more successful renewable energy integration. Social acceptance is very critical for the dissemination of renewable energy sources Niu et al., 2024. The support of the society for the project makes it easier to obtain local permits. This helps the projects to be designed more quickly [24]. In cases where social acceptance is insufficient, groups opposing these projects may organize protests. This situation leads to a delay in the implementation process of the project Hasanien et al., 2024. As a result, the operational costs of the enterprises increase significantly. Ragosa et al. [25] demonstrated that it is very critical to include the society in the project and get their opinions. Projects can be made more suitable for local needs. On the other hand, Khan et al. [26] denoted that renewable energy projects can increase social acceptance by contributing to local economic development. Therefore, social awareness campaigns should be organized on renewable energy Stambouli et al., 2024. This situation also contributes to the increase in the support of the local people for the projects.

The literature review helps to reach some important results. Carbon neutral policies play a crucial role to overcome global warming problem. Renewable energy integration should be provided for the success of carbon neutral policies. It is necessary to determine the most important factors to increase the performance of this integration. It is possible to increase the efficiency of investments by using resources effectively. Prioritizing important factors contributes to reducing unnecessary expenses. However, there are limited studies in the literature focusing on this issue. This situation can be accepted as a critical missing part for this subject. This situation gives information that there is a strong need for a new study to determine the most important factors affecting the success of renewable energy integration. In this study, a novel model is generated to make a priority evaluation so that this missing part can be satisfied.

3. Model

A new model is constructed to find the most critical strategies to implement effective carbon neutrality policies. The methods used in this model are defined in this section.

3.1. Molecular fuzzy sets

Molecular geometry is considered with fuzzy logic in this model. With the help of this integration, the concept of molecular fuzzy sets can be generated. In this process, the shapes under the science of molecular geometry are considered to compute the degrees in the calculation steps. Owing to this condition, uncertainties can be overcome in a more effective manner Gentili, 2024. Equation (1) gives information about the condition that should be satisfied.

$$\mu_U(u) + \nu_U(u) + \xi_U(u) = 1 \tag{1}$$

In this equation, U refers to the molecular fuzzy sets, X defines the universe, μ_i, ν_i and ξ_i denote the membership, non-membership and hesitancy degrees. The calculation process of these degrees is indicated in Equations (2)–(4).

$$\mu_U(u) = f(\theta_u) = 1 - \frac{\theta_u}{\theta_{max}} \tag{2}$$

$$\nu_U(u) = \frac{\theta_u}{\theta_{max}} \tag{3}$$

$$\xi_U(u) = 1 - \left(\left(1 - \frac{\theta_u}{\theta_{max}}\right) + \frac{\theta_u}{\theta_{max}}\right) \tag{4}$$

In this scope, θ_u identifies normalized angle and θ_{max} shows the maximum normalized angle value. The details of the calculations of molecular fuzzy sets are demonstrated in Equations (5)–(12).

$$A \subseteq B \text{ if } \mu_A(u) \le \mu_B(u) \text{ and } \nu_A(u) \le \nu_B(u) \text{ and } \xi_A(u) \ge \xi_B(u), \forall u \in U \tag{5}$$

$$A = B \text{ if } A \subseteq B \text{ and } B \subseteq A \tag{6}$$

$$A \cup B = \{(u, \max(\mu_A(u), \mu_B(u)), \min(\nu_A(u), \nu_B(u)), \min(\xi_A(u), \xi_B(u))) | u \in U\} \tag{7}$$

$$A \cap B = \{(u, \min(\mu_A(u), \mu_B(u)), \max(\nu_A(u), \nu_B(u)), \max(\xi_A(u), \xi_B(u))) | u \in U\} \tag{8}$$

$$A \cdot B = \{(u, \mu_A(u) \cdot \mu_B(u), \nu_A(u) \cdot \nu_B(u), \xi_A(u) \cdot \xi_B(u)) | u \in U\} \tag{9}$$

$$\lambda A = \{(u, \min(\lambda \cdot \mu_A(u), 1), \max(1 - \lambda(1 - \nu_A(u)), 0), \max(1 - \lambda(1 - \xi_A(u)), 0)) | u \in U\} \tag{10}$$

$$A\lambda = \left\{ \left(u, (\mu_A(u))^{\lambda}, 1 - (1 - \nu_A(u))^{\lambda} 1 - (1 - \xi_A(u))^{\lambda}\right) | u \in U \right\} \tag{11}$$

$$A^{-} = \{(u, \nu_A(u), \xi_A(u), \mu_A(u)) | u \in U\} \tag{12}$$

3.2. Molecular fuzzy cognitive maps

Cognitive map methodology is considered to compute the criteria weights. This technique is extended with molecular fuzzy sets in this model. First, assessments are collected from the experts. Second, molecular fuzzy relation matrix is constructed via Equation (13) [27].

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{13}$$

Next, the aggregated values ς are calculated by Equation (14).

$$\varsigma = \left(\bigcup_{i=1}^{k} \varsigma_i \right) = \left\{ \left(u, \frac{1}{k} \sum_{i=1}^{k} \mu_{\varsigma_i}(u), \frac{1}{k} \sum_{i=1}^{k} \nu_{\varsigma_i}(u), \frac{1}{k} \sum_{i=1}^{k} \xi_{\varsigma_i}(u) \right) \middle| u \in U \right\} \tag{14}$$

Later, fuzzy vectors are computed by using Equation (15).

$$u_i = [(\mu_{i1}, \nu_{i1}, \xi_{i1}), (\mu_{i2}, \nu_{i2}, \xi_{i2}), \dots (\mu_{i(n-1)}, \nu_{i(n-1)}, \xi_{i(n-1)})] \tag{15}$$

The dot product is computed with Equation (16).

$$(u_i . u_j) = \sum_{t=1}^{n-1} \left(\mu_{i,t} \cdot \mu_{j,t} + \nu_{i,t} \cdot \nu_{j,t} + \xi_{i,t} \cdot \xi_{j,t} \right) \tag{16}$$

In the following step, Equation (17) is taken into consideration to define the cosine of the angle cos (θ_{u_i,u_j}).

$$\cos\left(\theta_{u_i,u_j}\right) = \frac{(u_i . u_j)}{\left(\sum_{t=1}^{n-1} \left(\mu_{i,t}^2 + \nu_{i,t}^2 + \xi_{i,t}^2\right)\right) \cdot \left(\sum_{t=1}^{n-1} \left(\mu_{j,t}^2 + \nu_{j,t}^2 + \xi_{j,t}^2\right)\right)} \tag{17}$$

The angle value θ_{u_i,u_j} is calculated for each cosine of angle value as in Equation (18).

$$\theta_{u_i,u_j} = cos^{-1}\left(\cos\left(\theta_{u_i,u_j}\right)\right) \tag{18}$$

In this context, cos^{-1} states the values of the angle in radians. Normalized angle values $norm(\theta_{u_i,u_j})$ are determined via Equations (19)–(24).

$$norm\left(\theta_{u_i,u_j}\right)_{general} = \frac{\theta_{u_i,u_j}}{\theta_{max}} \tag{19}$$

$$norm\left(\theta_{u_i,u_j}\right)_{linear} = \frac{\theta_{u_i,u_j}}{\pi} \tag{20}$$

$$norm\left(\theta_{u_i,u_j}\right)_{trigonal_{planar}} = \frac{\theta_{u_i,u_j}}{\frac{2\pi}{3}} \tag{21}$$

$$norm\left(\theta_{u_i,u_j}\right)_{tetrahedral} = \frac{\theta_{u_i,u_j}}{\frac{\pi}{2}} \tag{22}$$

$$norm\left(\theta_{u_i,u_j}\right)_{trigonal_{bipyramidal}} = \frac{\theta_{u_i,u_j}}{\frac{2\pi}{5}} \tag{23}$$

$$norm\left(\theta_{u_i,u_j}\right)_{octahedral} = \frac{\theta_{u_i,u_j}}{\frac{\pi}{3}} \tag{24}$$

The reciprocal values $recip\left(\theta_{u_i,u_j}\right)$ and normalized matrix N_{ij} are defined by Equations (25)–(27).

$$recip\left(\theta_{u_i,u_j}\right) = \frac{1}{norm\left(\theta_{u_i,u_j}\right)} \tag{25}$$

$$NR = \begin{bmatrix} 0 & N_{12} & \cdots & \cdots & N_{1n} \\ N_{21} & 0 & \cdots & \cdots & N_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ N_{n1} & N_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{26}$$

$$N_{ij} = \frac{recip\left(\theta_{u_i,u_j}\right)}{\sum_{j=1}^{n} recip\left(\theta_{u_i,u_j}\right)} \tag{27}$$

State vectors are identified with Equation (28).

$$A(t) = [a_1(t), a_2(t), \dots, a_n(t)] \tag{28}$$

The updates are performed via Equations (29) and (30).

$$A(t+1) = f(A(t) \cdot NR) \tag{29}$$

$$f(x) = \frac{1}{1 + e^{-x}} \tag{30}$$

In these equations, $f(x)$ shows the sigmoid function. Equation (31) is considered to compute the criteria weights.

$$W_j = \frac{fA(s)_j}{\sum_{j=1}^{n} fA(s)_j} \tag{31}$$

3.3. Fuzzy molecular ranking (MORAN)

MORAN is a new ranking technique that is created based on molecular geometry perspectives [28]. Decision matrix is constructed by using the assessments of the experts with the help of Equation (32).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{32}$$

The weighted values B_{ij} are computed via Equation (33).

$$B_{ij} = \left(w_j . \mu_{ij}, w_j . \nu_{ij}, w_j . \xi_{ij}\right) \tag{33}$$

Fuzzy vectors are calculated in Equation (34).

$$y_i = [(\mu_{i1}, \nu_{i1}, \xi_{i1}), (\mu_{i2}, \nu_{i2}, \xi_{i2}), \dots (\mu_{im}, \nu_{im}, \xi_{im})] \tag{34}$$

The dot product is identified by Equation (35).

$$\left(y_i . y_j\right) = \sum_{t=1}^{n} \left(\mu_{i,t} \cdot \mu_{j,t} + \nu_{i,t} \cdot \nu_{j,t} + \xi_{i,t} \cdot \xi_{j,t}\right) \tag{35}$$

The cosine of the angle $\cos\left(\theta_{y_i y_j}\right)$ and angle values $\theta_{y_i y_j}$ are given in Equations (36) and (37).

$$\cos\left(\theta_{y_i y_j}\right) = \frac{\left(y_i . y_j\right)}{\left(\sum_{t=1}^{m}\left(\mu_{i,t}^2 + \nu_{i,t}^2 + \xi_{i,t}^2\right)\right) . \left(\sum_{t=1}^{m}\left(\mu_{j,t}^2 + \nu_{j,t}^2 + \xi_{j,t}^2\right)\right)} \tag{36}$$

$$\theta_{y_i y_j} = cos^{-1}\left(\cos\left(\theta_{y_i y_j}\right)\right) \tag{37}$$

Equations (38)–(43) are taken into consideration for normalization process.

$$norm\left(\theta_{y_i y_j}\right)_{general} = \frac{\theta_{y_i y_j}}{\theta_{y\_max}} \tag{38}$$

$$norm\left(\theta_{y_i y_j}\right)_{linear} = \frac{\theta_{y_i y_j}}{\pi} \tag{39}$$

$$norm\left(\theta_{y_i y_j}\right)_{trigonal_{planar}} = \frac{\theta_{y_i y_j}}{\frac{2\pi}{3}} \tag{40}$$

$$norm\left(\theta_{y_i y_j}\right)_{tetrahedral} = \frac{\theta_{y_i y_j}}{\frac{\pi}{2}} \tag{41}$$

$$norm\left(\theta_{y_i y_j}\right)_{trigonal_{bipyramidal}} = \frac{\theta_{y_i y_j}}{\frac{2\pi}{5}} \tag{42}$$

$$norm\left(\theta_{y_i y_j}\right)_{octahedral} = \frac{\theta_{y_i y_j}}{\frac{\pi}{3}} \tag{43}$$

The reciprocal values $recip\left(\theta_{y_i y_j}\right)$, final decision matrix f_{ij} and aggregated values of the matrix $Agg(f_i)$ are constructed via Equations (44)–(46). These values are used to rank the alternatives.

$$recip\left(\theta_{y_i y_j}\right) = \frac{1}{norm\left(\theta_{y_i y_j}\right)} \tag{44}$$

$$f_{ij} = \frac{recip\left(\theta_{y_i y_j}\right)}{\sum_{j=1}^{n} recip\left(\theta_{y_i y_j}\right)} \tag{45}$$

$$Agg(f_i) = \sum_{j \neq i} f_{ij} \tag{46}$$

3.4. AI-oriented expert prioritization

The proposed model provides an opportunity to compute the weights of the decision makers. In this process, the perspectives of AI methodology are taken into consideration. In the first step, the within-cluster sum of squares (WCSS) is calculated as in Equation (47) Dinçer et al., 2024.

$$WCSS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d\left(x_i, c_j\right)^2 \tag{47}$$

In this context, k defines cluster numbers, C_j shows data points, x_i refers to a data point, and $d\left(x_i, c_j\right)$ states the Euclidean distance. The next step includes the definition of elbow. Equation (48) is used to compute the distance.

$$d\left(x_i, x_j\right) = \sqrt{\sum_{l=1}^{n}\left(x_{il} - x_{jl}\right)^2} \tag{48}$$

Cluster centers are updated via Equation (49).

$$c_j = \frac{1}{\left|C_j\right|} \sum_{x_i \in C_j} x_i \tag{49}$$

Equations (50)–(52) are used for mean standard deviation.

$$s_j = \frac{1}{n} \sum_{l=1}^{n} \sigma_{jl} \tag{50}$$

$$\sigma_{jl} = \sqrt{\frac{1}{\left|C_j\right|} \sum_{x_i \in C_j}\left(x_{il} - x_{jl}\right)^2} \tag{51}$$

$$x_{jl} = \frac{1}{\left|C_j\right|} \sum_{x_i \in C_j} x_{il} \tag{52}$$

The cluster weights w_j and expert weights w_{tj} are computed via Equations (53) and (54).

$$w_j = \left|C_j\right| \times s_j \tag{53}$$

$$w_{tj} = \frac{1}{\left|C_j\right|} \frac{w_j}{\sum_{w_j \in C_j} w_j} \tag{54}$$

4. Analysis results

There are three different stages in this model. The results are explained with the subtitles based on these stages.

4.1. Prioritizing the experts

AI-based expert prioritization ensures that decision makers who are more representative of a diverse cluster contribute more significantly to the prioritization. Accordingly, we used K-means clustering to group decision makers based on demographic factors (education, experience, salary, age, and industry). By employing the elbow method, we determined that the optimal number of clusters was three, as this point minimized the Within-Cluster Sum of Squares (WCSS) and ensured efficient clustering without excess complexity. Based on the K-means results, the decision makers (DMs) were assigned to clusters: DM1, DM4, and DM5 were grouped in Cluster 1, DM2 in Cluster 2, and DM3 in Cluster 3. This segmentation reflects the underlying demographic diversity and similarity among the decision makers, with DM2 and DM3 each forming their own clusters due to distinct demographic attributes that differentiate them from others. Individual weights were calculated based on their cluster weights. Since Clusters 2 and 3 received a weight of zero due to their lack of demographic variability, DM2 and DM3, both belonging to these clusters, also received weights of zero. Thus, only decision makers in Cluster 1 (DM1, DM4, and DM5) retained positive weights in the prioritization as seen in Table A4.

An expert team is generated with 5 different decision makers (DSKR). The specifications of these people are shown in Table 1. It is seen that

Table 1
Specifications of the experts.

Expert	Education	Experience (year)	Salary (USD)	Age	Industry
DSKR 1	3 (PhD)	14	4250	44	3 (Education)
DSKR 2	3 (PhD)	19	4500	48	3 (Education)
DSKR 3	1 (Bachelor)	20	2500	45	1 (Service)
DSKR 4	1 (Bachelor)	14	3750	45	1 (Service)
DSKR 5	2 (Master)	16	4000	46	2 (Production)

two of the experts have doctoral degrees. On the other hand, the fifth expert has a master's degree. The other two experts have bachelor's degrees. Moreover, the experts' work experience is also sufficient. Two experts have 14 years of work experience. On the other hand, the other three experts have more work experience. In addition to them, it is understood that the experts work in different industries. The first two experts work in businesses in the education sector. The other two experts are in the service sector, and the last expert is in senior management in businesses in the production sector.

WCSS values are computed in the next step as detailed in Table A1. Iteration results are calculated in Table A2. Standard deviations are calculated in Table A3. Expert weights are computed in Table A4. It is stated that DSKR1, DSKR4, and DSKR5 has the weights. Because of this issue, in the analysis process, the assessments of these three experts are taken into consideration. On the other side, DSKR2 and DSKR3 have no priorities because they have the lowest significance weights. Due to this situation, the assessments of these two people are not considered in the analysis process.

4.2. Computing criteria weights

According to the results of the literature review, four significant performance indicators of renewable energy integration projects are selected. The criteria are regulatory framework (RGFMWR), technological infrastructure (TGCFUR), economic feasibility (ENMFBY) and social acceptance (SLCCPC). The expert team makes assessment about these items based on the scales in Table A5. The assessments of the criteria are shown in Table A6. Average numbers are computed in Table A7. On the other side, Table A8 indicates the fuzzy vectors. Moreover, dot products are identified in Table A9. In addition to them, Table A10 highlights the cosine of angle values. Furthermore, angle in radians is denoted in Table A11. Normalized angle relation values are presented in Table A12. Additionally, Table A13 defines reciprocal values of the normalized angle matrix. Normalized matrix is explained in Table A14. State vectors are demonstrated in Table A15. In 6th iteration, the function values $f(A(6))$ are same with the values of 5th iteration $f(A(5))$. Because of this issue, the weights are computed for this step. Comparative prioritization results are indicated in Table 2.

Table 2 denotes that technological infrastructure (TGCFUR) is the most critical performance indicator of renewable energy integration projects for all different molecular geometry shapes. Technological infrastructure supports the efficient production and storage of these resources. Similarly, advanced technologies are required for the successful distribution and use of this energy. Therefore, the technological infrastructure needs to be continuously developed and renewed. This condition helps the energy transition to be successful. The development of technological infrastructure is very important in the integration of renewable energy projects into logistics processes. In this context, smart logistics systems and artificial intelligence applications can be taken into consideration. The use of these advanced technologies significantly reduces operational costs. This situation also contributes significantly to increasing the efficiency of the projects. Social recognition and community support can also increase the success of renewable energy technologies. The increase in the public demand for sustainable practices increases the trust and social acceptance of these projects. Projects that are accepted by the public encounter fewer opposing views. This situation also supports the positive development of the image of the projects in the eyes of the public. On the other hand, as renewable energy technologies gain social recognition, the public demands more support from the state for the dissemination of these technologies. This situation allows for the increase of legal regulations that encourage renewable energy. Similarly, socially recognized and accepted renewable energy projects attract more attention from investors. This condition also provides the opportunity for projects to access the funds they need more easily. Owing to this issue, investors tend to invest more in renewable energy. As a result of this issue, this accelerates the development of technologies. Economic feasibility (ENMFBY) is found as the second most essential determinant of this situation. Economic feasibility provides a comprehensive cost and benefit analysis of a project. Thus, it is much more possible to ensure the financial sustainability of projects. A correct economic feasibility makes it easier for projects to find financing. This contributes significantly to increasing the success of projects.

Table 2
Comparative prioritization results of the criteria by the different molecular geometry shapes.

	Linear	Trigonal Planar	Tetrahedral	Trigonal Bipyramidal	Octahedral
RGFMWR	3	3	3	3	3
TGCFUR	1	1	1	1	1
ENMFBY	2	2	2	2	2
SLCCPC	4	4	4	4	4

4.3. Ranking the alternatives

Alternative strategies of carbon neutrality policies by using renewable energy sources are defined based on literature review results. Setting the long-term contracts with renewable producers (STLCRP), determining the specific targets and standards for renewable energy generation (DSTSRG), constructing the transparent trading platforms for efficient renewable market (CTTPER), diversifying the use of renewable energy with community-owned projects (DUREWW), and expanding the industrial use of renewables with several incentives (ETUWSI) are the selected investment alternatives. Table A16 indicates the details of the assessments. Average values are computed in Table A17. Weighted matrix is constructed in Table A18. Furthermore, fuzzy vectors are determined in Table A19. Dot products are computed in Table A20. In addition to them, Table A21 defines the cosine of angle values. On the other side, Table A22 indicates the angle in radians. Normalized values are defined in Table A23. Reciprocal values are computed in Table A24. Final decision matrix is created in Table 3.

Diversifying the use of renewable energy with community-owned projects (DUREWW) is found as the most influencing alternative. The main reason is that it affects other three different alternatives. Another important point is that determining the specific targets and standards for renewable energy generation (DSTSRG) does not have any influence on other factors. Therefore, this alternative can be defined as the most influenced factor. On the other side, there is a mutual relationship between setting the long-term contracts with renewable producers (STLCRP) and expanding the industrial use of renewables with several incentives (ETUWSI). Comparative ranking results of the alternatives are demonstrated in Table 4.

Setting the long-term contracts with renewable producers (STLCRP) is the most essential investment alternative to implement effective carbon neutrality policies. Long-term contracts make financing renewable energy projects more attractive. This makes investors more willing to invest in these projects. On the other hand, long-term contracts reduce the risks arising from fluctuations in energy prices. In addition to this issue, diversifying the use of renewable energy with community-owned projects (DUREWW) is also another important investment alternative for this situation.

5. Discussion

The technological infrastructure is extremely important for the success of renewable energy integration. This plays a key role in ensuring efficiency in the energy production process. It is possible to reduce the cost of energy production by using advanced technologies. Thus, it is easier to increase the profit margin of the projects. On the other hand, thanks to technological developments, it is also possible to use smart grids. These systems provide more efficient distribution of energy.

Table 3
Final decision matrix for linear shape.

	STLCRP	DSTSRG	CTTPER	DUREWW	ETUWSI	Aggregated values	Impact Map
STLCRP		0.068	0.075	0.146	0.160	0.449	STLCRP → DUREWW, ETUWSI
DSTSRG	0.068		0.073	0.072	0.093	0.306	–
CTTPER	0.075	0.073		0.122	0.083	0.353	CTTPER→ DUREWW
DUREWW	0.146	0.072	0.122		0.107	0.448	DUREWW → STLCRP, CTTPER, ETUWSI
ETUWSI	0.160	0.093	0.083	0.107		0.444	ETUWSI → STLCRP, DUREWW

Table 4
Comparative ranking results of the alternatives.

	Linear	Trigonal Planar	Tetrahedral	Trigonal Bipyramidal	Octahedral
STLCRP	1	1	1	1	1
DSTSRG	5	5	5	5	5
CTTPER	4	4	4	4	4
DUREWW	2	2	2	2	2
ETUWSI	3	3	3	3	3

Similarly, according to Barman et al. [29], it is possible to instantly monitor energy production and consumption amounts with these systems. Thus, it is easier to ensure security of energy supply and demand. Thus, both energy losses can be minimized, and customer satisfaction can be ensured. Moreover, Meraj et al. [30] stated that the efficiency of energy storage processes is also increasing thanks to technological innovations. Moreover, Hassan et al. [31] defined that longer-lasting batteries can be developed in new generation energy storage technologies. This issue helps to increase the efficiency and effectiveness of the projects.

Although the importance of technological infrastructure in energy transition projects has been emphasized in previous studies, in this study, different strategies are determined by comparing them with very comprehensive uncertainty analyses. With the help of this action, this manuscript significantly differentiates itself from other studies in the literature. The innovation offered by the proposed model provides higher accuracy in uncertainty management processes. Thanks to this approach, not only short-term economic effects but also long-term strategic effects are taken into consideration. In this direction, focusing only on state support for the development of renewable energy technologies is a short-term solution. Previous studies in the literature also emphasize the importance of this issue. On the other hand, increasing renewable energy technologies only with state support such as tax reductions is not very sustainable in the long term. To solve this issue in the long term, research and development studies should be carried out effectively. In this context, comprehensive collaborations should be established between industrial producers and universities. Thanks to these collaborations, universities can continue their research activities in line with the demands of industrial producers. This situation offers a long-term solution for the development of renewable energy projects.

The economic feasibility of renewable energy projects is of great importance to investors. Thanks to the feasibility study, the risk, benefit and cost analysis of the projects can be done comprehensively. Investors show more interest in the projects when they have clear information about them. One of the biggest disadvantages of these projects is that their costs are very high. Therefore, both the initial cost and the variable costs encountered during the production process must be clearly understood. By performing a correct feasibility analysis, it is possible to determine these issues clearly. It is possible to determine the most appropriate strategies for cash management. Gudlaugsson et al. [32] identified that economic feasibility results provide information about how the benefits of a project compare to the costs. Therefore, in case of a negative expectation regarding the long-term profitability of the projects, it is possible to take the necessary measures in a timely manner. Similarly, Farghali et al. [33] concluded that economic feasibility allows the financial risks of the projects to be managed more successfully. Imam et al. [34] discussed that the details of the measures to be taken regarding important issues such as exchange rate risk can be determined more clearly. The importance of economic feasibility is emphasized in a significant part of the studies. The biggest difference of this study from the others is that the economic feasibility analysis is not considered as a one-dimensional evaluation. In this process, an analysis is carried out using many variables. In other words, this study does not only emphasize the importance of economic feasibility, but also emphasizes that it is much more important than many different variables. Therefore, the results obtained from this study show that businesses should primarily focus on economic feasibility. This situation supports more effective decisions specific to projects. Owing to this issue, it may be possible for investors to use their resources more effectively.

It is very important to make long-term contracts with renewable energy producers. Thanks to these contracts, it becomes easier to access the funds that projects need. Investors are more willing to invest in projects in this case. The most basic reason for this is that a certain cash flow is guaranteed in long-term projects. In addition to them, long-term contracts reduce the risks caused by fluctuations in energy prices. Thus, it is possible to ensure the stability of energy prices in the market. Moreover, Mesa-Jiménez et al. [35] indicated that long-term contracts are usually made at fixed prices. This provides businesses with a significant cost advantage. Another important advantage of these contracts is that they allow for long-term planning. This allows for projects to be more successful. Similarly, Liu et al. [36] underlined that governments can provide more support for renewable energy investments through long-term contracts. Another important advantage of these contracts is that they allow for long-term planning. This makes projects more likely to be successful. Also, Kamani and Ardehali [37] showed that governments can provide more support for renewable energy investments through long-term contracts. Furthermore, another benefit of these contracts is that they provide longer-term employment opportunities for people living in the region. This issue helps to significantly improve the local economy.

6. Conclusion

Concluding remarks and policy implications are highlighted in this section.

6.1. Concluding remarks

This study tries to identify the prior renewable energy investment strategies to implement effective carbon neutrality policies. It is determined that technological infrastructure is the most effective performance indicator. Economic feasibility is another important determinant for these projects. On the other side, setting the long-term contracts with renewable producers and diversifying the use of renewable energy with community-owned projects are the most essential investment alternatives. The main limitation of this study is that a specific country analysis is not performed. Thus, in the following studies, developing economies can be taken into consideration. With the help of this situation, effective investment strategies can be presented specifically for these countries. The main limitation of this proposed model is that limited variables are considered to compute the weights of the experts. In the next studies, more variables can be used in this process so that the weights can be computed more sensitively. On the other hand, this model may be limited in very complex or dynamic situations. To overcome this problem, dynamic or adaptive modeling techniques can be used in future studies. The use of Bayesian networks contributes significantly to the model being more dynamic.

6.2. Policy implications

For the integration of renewable energy to be successful, it is important to develop the technological infrastructure. To achieve this goal, it is possible to present some policy applications. First, support should be provided to increase research and development studies. This situation accelerates the emergence of new technologies. Similarly, thanks to these supports, it is possible to increase the efficiency of currently implemented technologies. On the other hand, funding support should be provided for innovation projects carried out by the private sector and universities. This situation contributes significantly to the development of renewable energy technologies. Furthermore, investments in smart grid technologies should be increased. It is possible to follow energy production and consumption figures instantly. More accurate analyses can be made, and appropriate investment strategies can be developed. In addition, tax deductions should be offered for investments made for the development of these technologies. With the help of this action, it is more possible to develop investments. National and international standards regarding technological infrastructure should be determined. These standards have a guiding nature for the processes related to investments to be carried out more effectively. On the other hand, there are some policy recommendations to improve the economic feasibility of renewable energy integration. Facilitating access to finance is an important application that can be implemented in this process. In this context, the development of innovative financial products such as microfinance and crowdfunding should be ensured. Similarly, it is possible to provide large-scale financing for these projects through public-private partnerships. Improving the legal framework also allows for the acceleration of bureaucratic processes. This allows investors to focus more on these projects. There are several policy practices that can be implemented to increase long-term contracts for renewable energy investments. Governments should provide long-term purchase guarantees for renewable energy projects. This situation significantly supports investors to focus on these projects. In addition, standard contract formats should be developed for long-term contracts. This situation contributes to the acceleration of contract processes. On the other hand, the development of green bonds is also an important policy practice to increase the effectiveness of these contracts. The state should provide some support for the development of these bonds.

CRediT authorship contribution statement

Yedan Shen: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Wei Liu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Serhat Yüksel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hasan Dinçer:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was sponsored by the Research Project of Humanities and Social Sciences of the Ministry of Education (Grant No.24YJC630142), GuangDong Basic and Applied Basic Research Foundation (Grant No.2023A1515110596)

Appendix

Table A1
WCSS values

K = 1		K = 2		K = 3		K = 4		K = 5	
CCC 1	WCSS	CCC 1	WCSS	CCC 1	WCSS	CCC 1	WCSS	CCC 1	WCSS
DSKR1	202511.32	DSKR1	62502.25	DSKR1	0	DSKR1	0	DSKR1	0
DSKR2	490013.52	DSKR4	62502.25	CCC 2	WCSS	CCC 2	WCSS	CCC 2	WCSS
DSKR3	1690013.92	CCC 2	WCSS	DSKR2	140635.50	DSKR2	0	DSKR2	0
DSKR4	2509.12	DSKR2	694449.67	DSKR4	140635.50	CCC 3	WCSS	CCC 3	WCSS
DSKR5	40000.52	DSKR3	1361117.67	CCC 3	WCSS	DSKR3	562504.75	DSKR3	0
		DSKR5	111116.67	DSKR3	562504.75	DSKR5	562504.75	CCC 4	WCSS
				DSKR5	562504.75	CCC 4	WCSS	DSKR4	0
						DSKR4	0	CCC 5	WCSS
								DSKR5	0
Total	2425048.40		2291688.50		1406280.50		1125009.50		0

Cluster: CCC.

Table A2
Iteration results

Iteration (DSKR1 is in CCC 1; DSKR2 is in CCC 2; DSKR3 is in CCC 3)				
Initial				
Expert	**DCE-CCC1**	**DCE-CCC2**	**DCE-CCC3**	**CCC**
DSKR 1	0.00	250.08	1750.01	1
DSKR 2	250.08	0.00	2000.00	2
DSKR 3	1750.01	2000.00	0.00	3
DSKR 4	500.01	750.028	1250.014	1
DSKR 5	250.02	500.01	1500.01	1
Average				
Expert	**DCE-CCC1**	**DCE-CCC2**	**DCE-CCC3**	**CCC**
DSKR 1	250.01	250.08	1750.01	1
DSKR 2	500.03	0.00	2000.00	2
DSKR 3	1500.01	2000.00	0.00	3
DSKR 4	250.00	750.03	1250.01	1
DSKR 5	1.67	500.01	1500.01	1

Cluster: CCC; distance to: DCE.

Table A3
Standard Deviations

CCC	Size	Education	Experience	Income	Age	Sector	Mean SD	Weight
CCC1	3	0.82	0.94	204.12	0.82	0.82	41.50	124.51
CCC2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CCC3	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A4
Expert Weights

Expert	Weights
DSKR1	0.333
DSKR2	0.000
DSKR3	0.000
DSKR4	0.333
DSKR5	0.333

Table A5
Assessment Set and Fuzzy Numbers

Linguistic Scales	Fuzzy Numbers $(\boldsymbol{\mu_i}, \boldsymbol{\nu_i}, \boldsymbol{\xi_i})$
Negligible	(0.20, 0.70, 0.10)
Little	(0.40, 0.50, 0.10)
Moderate	(0.60, 0.30, 0.10)
Significant	(0.80, 0.15, 0.05)
Perfect	(0.95, 0.05, 0.00)

Table A6
Criteria Assessments

DSKR1	RGFMWR	TGCFUR	ENMFBY	SLCCPC
RGFMWR		S	S	S
TGCFUR	S		M	S
ENMFBY	M	S		H
SLCCPC	M	M	S	
DSKR4	**RGFMWR**	**TGCFUR**	**ENMFBY**	**SLCCPC**
RGFMWR		S	S	S
TGCFUR	S		M	S
ENMFBY	M	S		H
SLCCPC	M	M	S	
DSKR5	**RGFMWR**	**TGCFUR**	**ENMFBY**	**SLCCPC**
RGFMWR		H	H	H
TGCFUR	H		M	S
ENMFBY	H	S		H
SLCCPC	M	M	S	

Table A7
Averaged Fuzzy Numbers

	RGFMWR	TGCFUR	ENMFBY	SLCCPC
RGFMWR		(0.85, 0.12, 0.03)	(0.85, 0.12, 0.03)	(0.72, 0.23, 0.05)
TGCFUR	(0.85, 0.12, 0.03)		(0.60, 0.30, 0.10)	(0.80, 0.15, 0.05)
ENMFBY	(0.72, 0.22, 0.07)	(0.80, 0.15, 0.05)		(0.95, 0.05, 0.00)
SLCCPC	(0.60, 0.30, 0.10)	(0.53, 0.37, 0.10)	(0.80, 0.15, 0.05)	

Table A8
Fuzzy Vectors

Vectors	Fuzzy Vectors (excluding self-connections)
u_1	$[(0.73, 0.20, 0.07), (0.47, 0.43, 0.10), (0.80, 0.15, 0.05)]$
u_2	$[(0.80, 0.15, 0.05), (0.90, 0.08, 0.02), (0.60, 0.32, 0.08)]$
u_3	$[(0.60, 0.32, 0.08), (0.53, 0.37, 0.10), (0.90, 0.08, 0.02)]$
u_4	$[(0.53, 0.38, 0.08), (0.95, 0.05, 0.00), (0.40, 0.50, 0.10)]$

Table A9
Dot Products

	$\boldsymbol{u_1}$	$\boldsymbol{u_2}$	$\boldsymbol{u_3}$	$\boldsymbol{u_4}$
u_1		1.896	2.028	1.659
u_2	1.896		1.934	1.653
u_3	2.028	1.934		1.756
u_4	1.659	1.653	1.756	

Table A10
Cosine of Angle Values

	cos $(\boldsymbol{\theta_{u_1}})$	**cos** $(\boldsymbol{\theta_{u_2}})$	**cos** $(\boldsymbol{\theta_{u_3}})$	**cos** $(\boldsymbol{\theta_{u_4}})$
$\cos(\theta_{u_1})$		0.972	0.971	0.930
$\cos(\theta_{u_2})$	0.972		0.970	0.972
$\cos(\theta_{u_3})$	0.971	0.970		0.964
$\cos(\theta_{u_4})$	0.930	0.972	0.964	

Table A11
Angle in Radians

	$\boldsymbol{\theta_{u_1}}$	$\boldsymbol{\theta_{u_2}}$	$\boldsymbol{\theta_{u_3}}$	$\boldsymbol{\theta_{u_4}}$
θ_{u_1}		0.238	0.243	0.375
θ_{u_2}	0.238		0.245	0.237
θ_{u_3}	0.243	0.245		0.269
θ_{u_4}	0.375	0.237	0.269	

Table A12
Normalized Angle Relation Values

Linear	$\boldsymbol{norm(\theta_{u_1})}$	$\boldsymbol{norm(\theta_{u_2})}$	$\boldsymbol{norm(\theta_{u_3})}$	$\boldsymbol{norm(\theta_{u_4})}$
$norm(\theta_{u_1})$		0.076	0.077	0.119
$norm(\theta_{u_2})$	0.076		0.078	0.076
$norm(\theta_{u_3})$	0.077	0.078		0.086
$norm(\theta_{u_4})$	0.119	0.076	0.086	
Trigonal Planar	$\boldsymbol{norm(\theta_{u_1})}$	$\boldsymbol{norm(\theta_{u_2})}$	$\boldsymbol{norm(\theta_{u_3})}$	$\boldsymbol{norm(\theta_{u_4})}$
$norm(\theta_{u_1})$		0.114	0.116	0.179
$norm(\theta_{u_2})$	0.114		0.117	0.113
$norm(\theta_{u_3})$	0.116	0.117		0.129
$norm(\theta_{u_4})$	0.179	0.113	0.129	
Tetrahedral	$\boldsymbol{norm(\theta_{u_1})}$	$\boldsymbol{norm(\theta_{u_2})}$	$\boldsymbol{norm(\theta_{u_3})}$	$\boldsymbol{norm(\theta_{u_4})}$
$norm(\theta_{u_1})$		0.125	0.127	0.196

(continued on next page)

Table A12 (*continued*)

Linear	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_1})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_2})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_3})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_4})$
$norm(\theta_{u_2})$	0.125		0.129	0.124
$norm(\theta_{u_3})$	0.127	0.129		0.141
$norm(\theta_{u_4})$	0.196	0.124	0.141	
Trigonal Bipyramidal	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_1})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_2})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_3})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_4})$
$norm(\theta_{u_1})$		0.130	0.133	0.205
$norm(\theta_{u_2})$	0.130		0.134	0.130
$norm(\theta_{u_3})$	0.133	0.134		0.147
$norm(\theta_{u_4})$	0.205	0.130	0.147	
Octahedral	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_1})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_2})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_3})$	$\boldsymbol{norm}(\boldsymbol{\theta}_{u_4})$
$norm(\theta_{u_1})$		0.152	0.154	0.239
$norm(\theta_{u_2})$	0.152		0.156	0.151
$norm(\theta_{u_3})$	0.154	0.156		0.171
$norm(\theta_{u_4})$	0.239	0.151	0.171	

Table A13
Reciprocal Values of the Normalized Angles for Linear Shape

	$\frac{1}{norm(\theta_{u_1})}$	$\frac{1}{norm(\theta_{u_2})}$	$\frac{1}{norm(\theta_{u_3})}$	$\frac{1}{norm(\theta_{u_4})}$
$\frac{1}{norm(\theta_{u_1})}$		13.191	12.950	8.373
$\frac{1}{norm(\theta_{u_2})}$	13.191		12.797	13.228
$\frac{1}{norm(\theta_{u_3})}$	12.950	12.797		11.672
$\frac{1}{norm(\theta_{u_4})}$	8.373	13.228	11.672	

Table A14
Normalized Matrix for Linear Shape

	RGFMWR	TGCFUR	ENMFBY	SLCCPC
RGFMWR	0	0.183	0.179	0.116
TGCFUR	0.183	0	0.177	0.183
ENMFBY	0.179	0.177	0	0.162
SLCCPC	0.116	0.183	0.162	0

Table A15
State Vectors

	$\boldsymbol{A}(\boldsymbol{0})$	$\boldsymbol{A}(\boldsymbol{1})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{1}))$	$\boldsymbol{A}(\boldsymbol{2})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{2}))$	$\boldsymbol{A}(\boldsymbol{3})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{3}))$	$\boldsymbol{A}(\boldsymbol{4})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{4}))$	$\boldsymbol{A}(\boldsymbol{5})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{5}))$	$\boldsymbol{A}(\boldsymbol{6})$	$\boldsymbol{f}(\boldsymbol{A}(\boldsymbol{6}))$	Weights
RGFMWR	1.000	0.478	0.617	0.299	0.574	0.277	0.569	0.274	0.568	0.274	0.568	0.274	0.568	0.2487
TGCFUR	1.000	0.543	0.633	0.336	0.583	0.312	0.577	0.309	0.577	0.309	0.577	0.309	0.577	0.2525
ENMFBY	1.000	0.518	0.627	0.322	0.580	0.299	0.574	0.296	0.573	0.296	0.573	0.295	0.573	0.2511
SLCCPC	1.000	0.461	0.613	0.289	0.572	0.267	0.566	0.265	0.566	0.264	0.566	0.264	0.566	0.2477

Table A16
Assessments for Alternatives

DSKR1	RGFMWR	TGCFUR	ENMFBY	SLCCPC
STLCRP	H	H	S	M
DSTSRG	H	M	H	H
CTTPER	M	H	S	H
DUREWW	M	H	M	M
ETUWSI	H	H	H	S
DSKR4	**RGFMWR**	**TGCFUR**	**ENMFBY**	**SLCCPC**
STLCRP	H	H	S	M
DSTSRG	S	M	H	H
CTTPER	M	H	S	H
DUREWW	S	H	S	S
ETUWSI	H	H	H	S

(*continued on next page*)

Table A16 (*continued*)

DSKR1	RGFMWR	TGCFUR	ENMFBY	SLCCPC
DSKR5	**RGFMWR**	**TGCFUR**	**ENMFBY**	**SLCCPC**
STLCRP	S	H	S	S
DSTSRG	S	S	H	S
CTTPER	S	H	S	H
DUREWW	S	S	S	S
ETUWSI	H	H	H	S

Table A17
Averaged Numbers

	RGFMWR	TGCFUR	ENMFBY	SLCCPC
STLCRP	(0.90, 0.08, 0.02)	(0.95, 0.05, 0.00)	(0.80, 0.15, 0.05)	(0.67, 0.25, 0.08)
DSTSRG	(0.85, 0.12, 0.03)	(0.67, 0.25, 0.08)	(0.95, 0.05, 0.00)	(0.90, 0.08, 0.02)
CTTPER	(0.67, 0.25, 0.08)	(0.95, 0.05, 0.00)	(0.80, 0.15, 0.05)	(0.95, 0.05, 0.00)
DUREWW	(0.73, 0.20, 0.07)	(0.90, 0.08, 0.02)	(0.73, 0.20, 0.07)	(0.73, 0.20, 0.07)
ETUWSI	(0.95, 0.05, 0.00)	(0.95, 0.05, 0.00)	(0.95, 0.05, 0.00)	(0.80, 0.15, 0.05)

Table A18
Weighted Matrix

	RGFMWR	TGCFUR	ENMFBY	SLCCPC
STLCRP	(0.22, 0.02, 0.00)	(0.24, 0.01, 0.00)	(0.20, 0.04, 0.01)	(0.17, 0.06, 0.02)
DSTSRG	(0.21, 0.03, 0.01)	(0.17, 0.06, 0.02)	(0.24, 0.01, 0.00)	(0.22, 0.02, 0.00)
CTTPER	(0.17, 0.06, 0.02)	(0.24, 0.01, 0.00)	(0.20, 0.04, 0.01)	(0.24, 0.01, 0.00)
DUREWW	(0.18, 0.05, 0.02)	(0.23, 0.02, 0.00)	(0.18, 0.05, 0.02)	(0.18, 0.05, 0.02)
ETUWSI	(0.24, 0.01, 0.00)	(0.24, 0.01, 0.00)	(0.24, 0.01, 0.00)	(0.20, 0.04, 0.01)

Table A19
Fuzzy Vectors

Vectors	Fuzzy Vectors
y_1	$[(0.22, 0.02, 0.00), (0.24, 0.01, 0.00), (0.20, 0.04, 0.01), (0.17, 0.06, 0.02)]$
y_2	$[(0.21, 0.03, 0.01), (0.17, 0.06, 0.02), (0.24, 0.01, 0.00), (0.22, 0.02, 0.00)]$
y_3	$[(0.17, 0.06, 0.02), (0.24, 0.01, 0.00), (0.20, 0.04, 0.01), (0.24, 0.01, 0.00)]$
y_4	$[(0.18, 0.05, 0.02), (0.23, 0.02, 0.00), (0.18, 0.05, 0.02), (0.18, 0.05, 0.02)]$
y_5	$[(0.24, 0.01, 0.00), (0.24, 0.01, 0.00), (0.24, 0.01, 0.00), (0.20, 0.04, 0.01)]$

Table A20
Dot Products

	$\boldsymbol{y_1}$	$\boldsymbol{y_2}$	$\boldsymbol{y_3}$	$\boldsymbol{y_4}$	$\boldsymbol{y_5}$
y_1		0.176	0.178	0.169	0.195
y_2	0.176		0.179	0.166	0.194
y_3	0.178	0.179		0.171	0.193
y_4	0.169	0.166	0.171		0.181
y_5	0.195	0.194	0.193	0.181	

Table A21
Cosine of Angle Values

	$\cos(\boldsymbol{\theta_{y_1}})$	$\cos(\boldsymbol{\theta_{y_2}})$	$\cos(\boldsymbol{\theta_{y_3}})$	$\cos(\boldsymbol{\theta_{y_4}})$	$\cos(\boldsymbol{\theta_{y_5}})$
$\cos(\theta_{y_1})$		0.957	0.964	0.991	0.992
$\cos(\theta_{y_2})$	0.957		0.963	0.961	0.977
$\cos(\theta_{y_3})$	0.964	0.963		0.986	0.971
$\cos(\theta_{y_4})$	0.991	0.961	0.986		0.983
$\cos(\theta_{y_5})$	0.992	0.977	0.971	0.983	

Table A22
Angle in Radians

	θ_{y_1}	θ_{y_2}	θ_{y_3}	θ_{y_4}	θ_{y_5}
θ_{y_1}		0.295	0.268	0.137	0.126
θ_{y_2}	0.295		0.274	0.279	0.216
θ_{y_3}	0.268	0.274		0.165	0.241
θ_{y_4}	0.137	0.279	0.165		0.187
θ_{y_5}	0.126	0.216	0.241	0.187	

Table A23
Normalized angle decision values using different molecular geometry shapes

Linear	$norm(\theta_{y_1})$	$norm(\theta_{y_2})$	$norm(\theta_{y_3})$	$norm(\theta_{y_4})$	$norm(\theta_{y_5})$
$norm(\theta_{y_1})$	0.000	0.094	0.085	0.044	0.040
$norm(\theta_{y_2})$	0.094	0.000	0.087	0.089	0.069
$norm(\theta_{y_3})$	0.085	0.087	0.000	0.052	0.077
$norm(\theta_{y_4})$	0.044	0.089	0.052	0.000	0.059
$norm(\theta_{y_5})$	0.040	0.069	0.077	0.059	0.000
Trigonal Planar	$norm(\theta_{y_1})$	$norm(\theta_{y_2})$	$norm(\theta_{y_3})$	$norm(\theta_{y_4})$	$norm(\theta_{y_5})$
$norm(\theta_{y_1})$	0.000	0.141	0.128	0.065	0.060
$norm(\theta_{y_2})$	0.141	0.000	0.131	0.133	0.103
$norm(\theta_{y_3})$	0.128	0.131	0.000	0.079	0.115
$norm(\theta_{y_4})$	0.065	0.133	0.079	0.000	0.089
$norm(\theta_{y_5})$	0.060	0.103	0.115	0.089	0.000
Tetrahedral	$norm(\theta_{y_1})$	$norm(\theta_{y_2})$	$norm(\theta_{y_3})$	$norm(\theta_{y_4})$	$norm(\theta_{y_5})$
$norm(\theta_{y_1})$	0.000	0.154	0.140	0.072	0.066
$norm(\theta_{y_2})$	0.154	0.000	0.143	0.146	0.113
$norm(\theta_{y_3})$	0.140	0.143	0.000	0.086	0.126
$norm(\theta_{y_4})$	0.072	0.146	0.086	0.000	0.098
$norm(\theta_{y_5})$	0.066	0.113	0.126	0.098	0.000
Trigonal Bipyramidal	$norm(\theta_{y_1})$	$norm(\theta_{y_2})$	$norm(\theta_{y_3})$	$norm(\theta_{y_4})$	$norm(\theta_{y_5})$
$norm(\theta_{y_1})$	0.000	0.161	0.146	0.075	0.069
$norm(\theta_{y_2})$	0.161	0.000	0.150	0.152	0.118
$norm(\theta_{y_3})$	0.146	0.150	0.000	0.090	0.132
$norm(\theta_{y_4})$	0.075	0.152	0.090	0.000	0.102
$norm(\theta_{y_5})$	0.069	0.118	0.132	0.102	0.000
Octahedral	$norm(\theta_{y_1})$	$norm(\theta_{y_2})$	$norm(\theta_{y_3})$	$norm(\theta_{y_4})$	$norm(\theta_{y_5})$
$norm(\theta_{y_1})$	0.000	0.188	0.170	0.087	0.080
$norm(\theta_{y_2})$	0.188	0.000	0.174	0.177	0.137
$norm(\theta_{y_3})$	0.170	0.174	0.000	0.105	0.153
$norm(\theta_{y_4})$	0.087	0.177	0.105	0.000	0.119
$norm(\theta_{y_5})$	0.080	0.137	0.153	0.119	0.000

Table A24
Reciprocal Values

	$\frac{1}{norm(\theta_{y_1})}$	$\frac{1}{norm(\theta_{y_2})}$	$\frac{1}{norm(\theta_{y_3})}$	$\frac{1}{norm(\theta_{y_4})}$	$\frac{1}{norm(\theta_{y_5})}$
$\frac{1}{norm(\theta_{y_1})}$		10.652	11.735	22.910	25.023
$\frac{1}{norm(\theta_{y_2})}$	10.652		11.469	11.276	14.568
$\frac{1}{norm(\theta_{y_3})}$	11.735	11.469		19.093	13.053
$\frac{1}{norm(\theta_{y_4})}$	22.910	11.276	19.093		16.821
$\frac{1}{norm(\theta_{y_5})}$	25.023	14.568	13.053	16.821	

References

[1] S. Bag, M.S. Rahman, S. Ghai, S.K. Srivastava, R.K. Singh, R. Mishra, Unveiling the impact of carbon-neutral policies on vital resources in Industry 4.0 driven smart manufacturing: a data-driven investigation, Comput. Ind. Eng. 187 (2024) 109798.

[2] C. He, W. Song, Z. Li, C. Liu, W. Liu, Y. Cheng, Optimisation method of product family supplier selection based on data mining under carbon neutral policy, J. Eng. Des. (2024) 1–27.

[3] G. Xu, Z. Huang, M. Jiang, H.U. Rehman, "Gray" prediction of carbon neutral pathways in the G7 economies by 2050, Appl. Energy 373 (2024) 123924.

[4] J. Ma, L. Yang, D. Wang, Y. Li, Z. Xie, H. Lv, D. Woo, Digitalization in response to carbon neutrality: mechanisms, effects and prospects, Renew. Sustain. Energy Rev. 191 (2024) 114138.

[5] W. Jung, J. Lee, K.S. Ha, Ethylene production processes in a carbon-neutral strategy, Energy Convers. Manag. 311 (2024) 118462.

[6] W. Wang, Y. Chen, Y. Wang, M. Deveci, S. Moslem, D.M. Coffman, Unveiling the implementation barriers to the digital transformation in the energy sector using the Fermatean cubic fuzzy method, Appl. Energy 360 (2024) 122756.

[7] M. Youssef, M.S.E. Mohamed, A.A.S. Balah, Fuzzy model for Libyan construction projects delivery system selection, Int. J. Construct. Manag. 24 (6) (2024) 643–650.

[8] P. Raj, P.L. Biju, B. Deepanraj, N. Senthilkumar, Optimizing the machining conditions in turning hybrid aluminium nanocomposites adopting teaching–learning based optimization and MOORA technique, Int. J. Interact. Des. Manuf. 18 (5) (2024) 3089–3101.

[9] J. Barman, B. Biswas, K.S. Rao, A hybrid integration of analytical hierarchy process (AHP) and the multiobjective optimization on the basis of ratio analysis (MOORA) for landslide susceptibility zonation of Aizawl, India, Nat. Hazards (2024) 1–26.

[10] A.M. Ali, M. Abdel-Basset, M. Abouhawwash, M. Gharib, M. Mohamed, N-type-2-ARAS: an efficient hybrid multi-criteria optimization approach for end-of-life vehicle's recycling facility location: a sustainable approach, Expert Syst. Appl. 250 (2024) 123873.

[11] A. Ur Rehman, S. Iqbal, A. Shafiq, N.F. Alshammari, S.H. Dar, R.T. Iqbal, Multifaceted impacts of widespread renewable energy integration on socio-economic, ecological, and regional development, Sustain. Futures 8 (2024) 100241.

[12] M. Toghyani, A. Saadat, From challenge to opportunity: enhancing oil refinery plants with sustainable hybrid renewable energy integration, Energy Convers. Manag. 305 (2024) 118254.

[13] V. Battaglia, L. Vanoli, Optimizing renewable energy integration in new districts: power-to-X strategies for improved efficiency and sustainability, Energy 305 (2024) 132312.

[14] V.J. Reddy, N.P. Hariram, M.F. Ghazali, S. Kumarasamy, Pathway to sustainability: an overview of renewable energy integration in building systems, Sustain. 16 (2) (2024) 638.

[15] A. Naveed, S. Iqbal, S. Munir, A.U. Rehman, M. Eslami, S. Kamel, Renewable energy integration in healthcare systems: a case study of a hospital in Azad Jammu and Kashmir, IET Renew. Power Gener. 18 (5) (2024) 796–809.

[16] X. Yang, C. Xiong, W. Han, Y. Yang, Analysis of the impacts of carbon neutral policy portfolios on the economy, environment, and residents' welfare based on computable general equilibrium models, J. Clean. Prod. 458 (2024) 142288.

[17] M.S. Alam, M.A. Hossain, M. Shafiullah, A. Islam, M.S.H. Choudhury, M. O. Faruque, M.A. Abido, Renewable energy integration with DC microgrids: challenges and opportunities, Elec. Power Syst. Res. 234 (2024) 110548.

[18] A.D. Feio, F.C. da Silva, M.A. Teixeira, A.C.L. Maria, G.B.S. da Silva, Viability of renewable energy integration in isolated systems in Brazil–A case study at Trindade Island (Espírito Santo, Brazil), Renew. Energy 222 (2024) 119805.

[19] F. Sattar, S. Ghosh, Y.J. Isbeih, M.S. El Moursi, A. Al Durra, T.H. El Fouly, A predictive tool for power system operators to ensure frequency stability for power grids with renewable energy integration, Appl. Energy 353 (2024) 122226.

[20] H. Onodera, R. Delage, T. Nakata, The role of regional renewable energy integration in electricity decarbonization—a case study of Japan, Appl. Energy 363 (2024) 123118.

[21] G. Bovesecchi, M. Pierro, M. Petitta, C. Cornaro, Flexible photovoltaic systems for renewable energy integration in Lazio region, Italy, Energy Rep. 12 (2024) 1221–1234.

[22] F. Hao, A. Mu, Z. Lv, H. Zhou, A comprehensive review of liquid piston compressed air energy storage for sustainable renewable energy integration, J. Energy Storage 98 (2024) 113071.

[23] L. Migliari, D. Micheletto, D. Cocco, A hydrogen-fuelled compressed air energy storage system for flexibility reinforcement and variable renewable energy integration in grids with high generation curtailment, Energy Convers. Manag. 306 (2024) 118308.

[24] X. Zhang, J. Su, F. Jiao, R. Zeng, J. Pan, X. He, H. Li, Performance investigation and operation optimization of an innovative hybrid renewable energy integration system for commercial building complex and hydrogen vehicles, Energy 301 (2024) 131640.

[25] G. Ragosa, J. Watson, M. Grubb, The political economy of electricity system resource adequacy and renewable energy integration: a comparative study of Britain, Italy and California, Energy Res. Social Sci. 107 (2024) 103335.

[26] N.S. Khan, S.A.A. Kazmi, M. Anwar, S.U.R. Mughal, K. Ullah, M.K. Rathi, A. Salal, Enhancing renewable energy integration in developing countries: a policy-oriented analysis of net metering in Pakistan amid economic challenges, Sustain. 16 (14) (2024) 6034.

[27] I. Sarmiento, A. Cockcroft, A. Dion, L. Belaid, H. Silver, K. Pizarro, N. Andersson, Fuzzy cognitive mapping in participatory research and decision making: a practice review, Arch. Publ. Health 82 (1) (2024) 76.

[28] Z.A. Rollins, M.B. Curtis, S.C. George, R. Faller, A computational strategy for the rapid identification and ranking of patient-specific T cell receptors bound to neoantigens, Macromol. Rapid Commun. (2024) 2400225.

[29] P. Barman, L. Dutta, S. Bordoloi, A. Kalita, P. Buragohain, S. Bharali, B. Azzopardi, Renewable energy integration with electric vehicle technology: a review of the existing smart charging approaches, Renew. Sustain. Energy Rev. 183 (2023) 113518.

[30] S.T. Meraj, S.S. Yu, M.S. Rahman, K. Hasan, M.H. Lipu, H. Trinh, Energy management schemes, challenges and impacts of emerging inverter technology for renewable energy integration towards grid decarbonization, J. Clean. Prod. 405 (2023) 137002.

[31] Q. Hassan, P. Viktor, T.J. Al-Musawi, B.M. Ali, S. Algburi, H.M. Alzoubi, M. Jaszczur, The renewable energy role in the global energy Transformations, Renew. Energy Focus 48 (2024) 100545.

[32] B. Gudlaugsson, T.G. Ahmed, H. Dawood, C. Ogwumike, M. Short, N. Dawood, Cost and environmental benefit analysis: an assessment of renewable energy integration and smart solution technologies in the InteGRIDy project, Clean. Energy Syst. 5 (2023) 100071.

[33] M. Farghali, A.I. Osman, Z. Chen, A. Abdelhaleem, I. Ihara, I.M. Mohamed, D. W. Rooney, Social, environmental, and economic consequences of integrating renewable energies in the electricity sector: a review, Environ. Chem. Lett. 21 (3) (2023) 1381–1418.

[34] A.A. Imam, A. Abusorrah, M. Marzband, Potentials and opportunities of solar PV and wind energy sources in Saudi Arabia: land suitability, techno-socio-economic feasibility, and future variability, Result Eng. 21 (2024) 101785.

[35] J.J. Mesa-Jiménez, A.L. Tzianoumis, L. Stokes, Q. Yang, V.N. Livina, Long-term wind and solar energy generation forecasts, and optimisation of Power Purchase Agreements, Energy Rep. 9 (2023) 292–302.

[36] F. Liu, C.W. Su, M. Qin, O.R. Lobonţ, Winner or loser? The bidirectional impact between geopolitical risk and energy transition from the renewable energy perspective, Energy 283 (2023) 129174.

[37] D. Kamani, M.M. Ardehali, Long-term forecast of electrical energy consumption with considerations for solar and wind energy sources, Energy 268 (2023) 126617.