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Integer Code Series Enhanced IT2 Fuzzy Decision Support System With Alpha Cuts for the Innovation Adoption Life Cycle Pattern Recognition of Renewable Energy Alternatives

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ABSTRACT This study aims to evaluate the innovation adoption performance of the renewable energy alternatives. Within this context, a new model is created that consists of two different stages. Firstly, the decision combinations of innovation adoption life cycle patterns are identified by considering integer code series. On the other side, in the second stage, the innovation adoption life cycle performance of the renewable energy alternatives is ranked. In this framework, interval type-2 (IT2) fuzzy technique for order preference by similarity to ideal solution (TOPSIS) methodology is taken into consideration based on alpha cut levels. Moreover, a comparative evaluation is also conducted by considering IT2 fuzzy VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). It is identified that the analysis results are quite coherent and reliable. The findings demonstrate that solar energy is the most appropriate renewable energy type to make innovation. Additionally, wind and geothermal energies are also other significant renewable energy types that have a great innovation potential. However, it is also concluded that biomass and hydroelectric energy have lower importance in comparison with the others. Another important point is that the ranking results are quite similar for different alpha cuts. This condition indicates that the analysis results are coherent and reliable. It is obvious that making investment to solar energy alternatives provides opportunity to adopt technologic innovation more easily. Therefore, it is recommended that investors should give priority to solar energy projects so that it can be more possible to increase the efficiency and the profitability of the investments.

INDEX TERMS Renewable energy, innovation potential, integer code series, IT2 fuzzy sets, alpha cuts, TOPSIS, VIKOR.

I. INTRODUCTION

In this section, firstly, the theoretical background is given. After that, necessary information is given regarding the innovation in renewable energy projects. Later, the usage of fuzzy MCDM methods in these projects is identified. Finally, the purpose and motivations of this study are defined.

A. THEORETICAL BACKGROUND

There are some social and economic advantages of renewable energy investments to the country. First, thanks to these projects, countries can produce their own energy which reduces the dependence of countries on other countries in terms of energy. Moreover, countries' import payments are also decreasing, as the energy is not purchased from abroad. This situation has a positive influence on the reduction of the current account deficit problem [1]. Furthermore, the carbon emission problem can be reduced owing to the use of renewable energy [2]. In this way, there will be less air pollution in the country. However, it is also possible to mention some disadvantages in renewable energy projects. For instance, the initial cost in renewable energy projects is quite high [3]. On the other hand, most of the renewable energy projects can be affected by seasonal differences. For example, the efficiency of solar energy obtained in winter is very low compared to summer [4].

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It is obvious that necessary actions should be taken to reduce the costs of the renewable energy projects. In many different countries, governments provide some subsidy to the renewable energy investors, such as low-interest loans and tax reduction [5]. These issues have a positive impact to decrease high-cost problem of these projects. However, continuity of such practices is not possible. In other words, it is not easy to keep private investments afloat with constant state support. In this framework, some applications should be made that can reduce the costs specific to these investments [6]. In this context, it may become more efficient to generate electricity from renewable energy types thanks to technological innovations. This stated situation will help to reduce the costs of these projects. Therefore, renewable energy projects will be able to attract the attention of investors, without the need for government support [7].

B. RENEWABLE ENERGY INNOVATION

The most important reason for increasing innovations in renewable energy is cost-based factors. The most important disadvantage of these projects is the very high initial cost. This stated situation is an important obstacle in the development of renewable energy projects [8]. Investors are reluctant to take these projects, as the high initial cost will increase uncertainty. Therefore, lowering the costs of these projects is an important requirement. This situation leads countries and companies to innovate in renewable energy [9]. Thanks to innovations in this field, electricity generation from renewable energy projects can be achieved at a much lower cost. He *et al.* [10] aimed to identify the factors that influence renewable energy technological innovation in China. They reached a conclusion that to reduce the cost of renewable energy projects, the companies should give priority to the technological innovation. Additionally, Bayer *et al.* [11] also focused on the renewable energy policies of 74 different countries for the period between 1990–2009. They identified that high cost is the most significant barrier for the development of the renewable energy investments. Because of this situation, innovations should be increased regarding the renewable energy alternatives.

Another way to increase innovation for renewable energy alternatives is to achieve political stability in the country. Renewable energy investments are long-term projects. On the other hand, the costs of these projects are also quite high. In this framework, every stage of renewable energy project should be considered. In this context, very serious attention should be paid to feasibility analysis [12]. For this purpose, economic, technical, and financial research should be done at the stage of starting a renewable energy innovation project. In this way, it will be revealed whether these investments are profitable or not. It is very important to have political stability in the country in order to carry out these processes effectively. The existence of political stability in a country can minimize the concerns of investors and uncertainties in the market [13]. In this way, it will be possible to increase innovation towards renewable energy projects. Liang and Fiorino [14] tried to understand the implications of policy stability for renewable energy innovation in the United States. They highlighted the importance of the political stability for the improvement of the technological innovation for the renewable energy investment projects. Moreover, Nesta *et al.* [15] focused on the OECD countries regarding renewable energy policies with the help of generalized method of moment (GMM) methodology. It is also concluded that political stability has an important role to increase innovation for these projects.

Another important issue for increasing the performance of the innovations to be made for renewable energy projects is the technological competence of countries and companies. Research and development studies are very important to increase the performance of renewable energy projects [16]. However, many different factors need to be considered to increase these studies. First, countries and companies need to allocate a substantial budget for research work. However, allocating a budget alone is not enough to maintain an effective research activity [17]. In this context, the technological infrastructure in the country is also of vital importance [18]. Countries with better technology can be much more successful in this process than others [19]. In other words, countries must have sufficient technological competence for innovations for renewable energy projects to be successful. Rogge and Schleich [20] made an analysis for the renewable energy innovation in Germany and determined that technological improvement is a necessity for the improvement of these innovations. Similarly, Pitelis *et al.* [21], Cui *et al.* [22] and Cheng and Yao [23] identified that the companies should have sufficient technological background to be successful in renewable energy innovation.

C. FUZZY MCDM METHODS IN RENEWABLE ENERGY INVESTMENT PROJECTS

In the literature, there are also some studies which evaluated renewable energy investments in different country groups with the help of fuzzy MCDM models. For instance, Wang *et al.* [24] aimed to select the renewable energy resources for Pakistan. In the analysis process, fuzzy analytic hierarchy process (AHP) is taken into consideration. Additionally, Alkan and Albayrak [25] made a similar study for Turkey with the help of fuzzy MULTIMOORA methodology. On the other side, Rani *et al.* [26] generated a novel model to evaluate renewable energy technologies in India by considering VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) approach with Pythagorean fuzzy sets. Moreover, Li *et al.* [27] aimed to identify the innovation strategies for renewable energy alternatives using IT2 fuzzy MCDM models. Furthermore, Dinçer and Yüksel [28] made an evaluation to understand the appropriate renewable energy alternative for the investment decision. For this purpose, fuzzy DEMATEL and fuzzy TOPSIS approaches are taken into consideration. In addition to these studies, Zhong *et al.* [29] determined appropriate innovative strategies for the renewable energy investments by considering DEMATEL-based analytic network process (DANP) model with IT2 fuzzy sets.

D. THE PURPOSE AND MOTIVATIONS OF THE STUDY

In this study, it is aimed to examine the innovation adoption performance of the renewable energy alternatives. For this purpose, a novel model is created that includes two different stages. In the first stage, the decision combinations of innovation adoption life cycle patterns with integer code series are identified. On the other hand, the second stage includes the ranking the innovation adoption life cycle performance of the renewable energy alternatives. Within this context, an evaluation has been performed by using technique for order preference by similarity to ideal solution (TOPSIS) methodology based on interval type-2 (IT2) fuzzy sets and alpha cuts. As a result, it can be possible to identify the appropriate renewable energy type for making innovation. Moreover, a comparative evaluation has also been conducted with IT2 fuzzy VIKOR methodology.

The main contribution of this study is to identify the appropriate renewable energy type for making innovation with the help of a novel methodology. Hence, the findings can pave the way for both academicians and renewable energy investors. Additionally, this proposed model has some novelties. Firstly, integer pattern recognition methodology is considered to define the decision combinations of innovation adoption life cycle patterns. The main superiority of this approach in comparison with other pattern recognition techniques is that the appropriateness of the experts' evaluations to the patterns can be tested [30]–[32]. On the other side, considering IT2 fuzzy sets can be helpful to handle the uncertainty in decision making process more effectively [33]–[35].

Furthermore, using alpha cuts provides an opportunity to make evaluations for different conditions. With the help of this situation, it is possible to check coherency of the analysis results [36], [37]. In addition to them, the main advantage of TOPSIS approach is using the distances to both positive and negative ideal solutions. However, in some other MCDM methods, only the distance to the negative ideal solution is taken into consideration. Therefore, it is obvious that more appropriate results can be achieved with TOPSIS method [38]–[40]. Another important novelty of this study is making a comparative evaluation is implemented by using IT2 fuzzy VIKOR approach. This situation provides an opportunity to check the consistency and coherency of the analysis results [41]–[43].

The rest of the paper is organized as follows. The second part of the study includes the methodology. In the third section, analysis results are shared. Moreover, the fourth part explains the conclusion of this study. In the final part, limitations and implications are highlighted.

II. METHODOLOGY

In this section, theoretical information is given regarding integer code series, IT2 fuzzy sets, alpha level cuts, TOPSIS and VIKOR methodology. Finally, the details of the proposed model are explained.

A. INTEGER CODE SERIES AND GEOMETRICAL PATTERN RECOGNITION

Integer alphabet is demonstrated by I and $\delta > 0$ *and* $\varepsilon > 0$ indicate the spacings of a spacetime lattice (δ, ε). This process is detailed by equation (1) [30].

$$I_n = \{s = s_1 \ldots s_n, s_i \in I, i = 1, \ldots, n\} \tag{1}$$

Additionally, the piecewise constant functions are given as $W_{\delta\varepsilon}([t_m, t_{m+n}])$. Furthermore, f shows the constant term which can take value of $(t_{i-1}, t_i]$. The equations (2)-(6) illustrate this situation. Within this framework, s_i, $i = 1, \ldots, n$ indicate real numbers and m states an integer [31].

$$f : [t_m, t_{m+n}] \to \Re^1 \tag{2}$$
$$i = m + 1, \ldots, m + n \tag{3}$$
$$f(t_m) = s_1\delta \tag{4}$$
$$f(t) = s_i\delta \tag{5}$$
$$t \in (t_{i-1}, t_i] \text{ and } t_i = i\varepsilon \tag{6}$$

In addition, the kth integral of a function is demonstrated as $f^{[k]}$. On the other side, the kth integral of a function and the kth derivative equals f and $f^{[0]} = f$. The equations (7) and (8) indicate the details of this process [32].

$$f \in W_{\delta\varepsilon}([t_m, t_{m+n}]) \tag{7}$$
$$f^{[k]}(t_m) = 0 \tag{8}$$

In addition to this issue, the code $c(f) = s_1 \ldots s_n$ and the powers of integers can also be used in this context. The equations (9)-(11) includes the details of this process [32].

$$f^{[k]}(t_{m+l+1}) = \sum_{i=0}^{k-1} \alpha_{kmi} \Big((m + l + 1)^i s_1 + \ldots + (m+1)^i s_{l+1} \Big) \delta\varepsilon^k + \sum_{i=0}^{k} \beta_{k,l+1,i} f^{[i]}(t_m)\varepsilon^{k-i} \tag{9}$$

$$\alpha_{kmi} = \frac{\binom{k}{i}\left((-1)^{k-i-1}(m+1)^{k-i} + (-1)^{k-i} m^{k-i}\right)}{k!} \tag{10}$$

$$\beta_{k,l+1,i} = \frac{(l+1)^{k-i}}{(k-i)!}, \quad i = 1, \ldots, k \tag{11}$$

Additionally, the hierarchical forms of geometrical patterns are shown in Figure 1.

The geometrical patterns for 4 different levels are indicated in Figure 1. In this context, the functions of $f^{[k]}(t)$, $t_0 \le t \le t_{16}$ and $k = 1, 2, 3$ are integrated. The piecewise constant function at the level 0 is demonstrated in the equation (12).

$$f^{[0]}(t), \quad t_{j-1} \le t \le t_j \quad t_j = j\varepsilon, \; \text{j} = 1, 2, \ldots, 16 \tag{12}$$

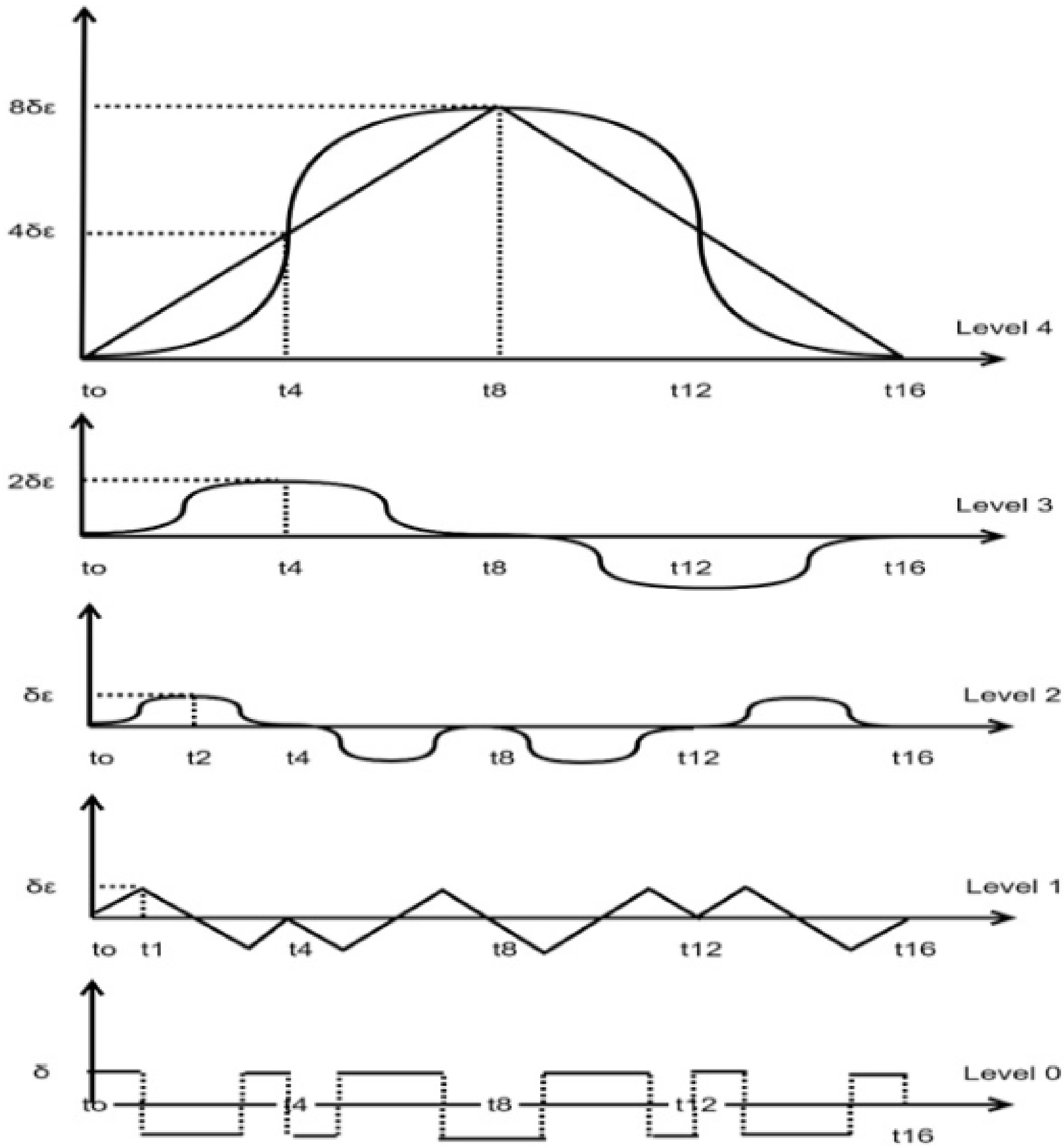

FIGURE 1. Hierarchical forms of the patterns.

B. INTERVAL TYPE-2 FUZZY SETS

Interval type-2 (IT2) fuzzy sets are defined based on trapezoidal membership function. With the help of this situation, it is aimed to handle uncertainties more effectively. In this scope, $\tilde{A}$ represents the set and the membership function is donated by $\mu_{\tilde{A}(x,u)}$. In addition, $\int\int$ indicates the union over all admissible x and u. The equation (13) shows the details of this process [33].

$$\tilde{A} = \left\{ \left((x, u), \mu_{\tilde{A}(x,u)} \right) \mid \forall_x \in X, \forall_u \in J_x \subseteq [0, 1] \right\}, \text{ or}$$
$$\tilde{A} = \int_{x\in X} \int_{u\in J_x} \mu_{\tilde{A}} (x, u) / (x, u) J_x \subseteq [0, 1] \quad (13)$$

On the other side, $\int$ can be replaced by Σ as in the equation (14).

$$\tilde{A} = \int_{x\in X} \int_{u\in J_x} 1/ (x, u) J_x \subseteq [0, 1] \quad (14)$$

Moreover, Figure 2 illustrates the limits of membership functions.

Within this framework, $\tilde{A}_i^U$ and $\tilde{A}_i^L$ represent the upper and lower trapezoidal functions. Also, a_{ij}^U indicates the reference values. Furthermore, $H_j\left(\tilde{A}_i^U\right)$ and $H_j\left(\tilde{A}_i^L\right)$ demonstrate the membership values of upper and lower trapezoidal membership functions. This process is detailed on equation (15) [34].

$$\tilde{A}_i = \left(\tilde{A}_i^U, \tilde{A}_i^L\right) = \begin{pmatrix} \left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1\left(\tilde{A}_i^U\right), H_2\left(\tilde{A}_i^U\right)\right), \\ \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1\left(\tilde{A}_i^L\right), H_2\left(\tilde{A}_i^L\right)\right) \end{pmatrix} \quad (15)$$

Additionally, the equations (16)-(20), as shown at the bottom of the next page, give information about the operational details of the IT2 fuzzy sets [35].

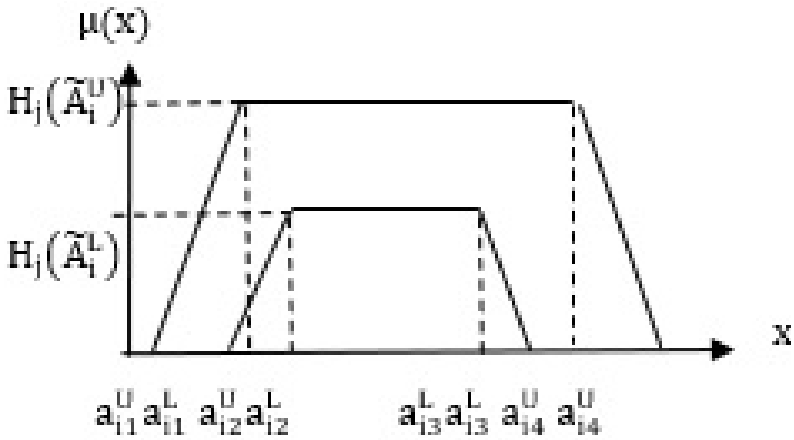

FIGURE 2. Membership functions.

C. ALPHA LEVEL SETS

An alpha level set is demonstrated as α and $X(\boldsymbol{\alpha})$ gives information about the cut of type 1 fuzzy sets. On the other side, $\tilde{X}(\boldsymbol{\alpha})$ denotes the cut of type 2 fuzzy sets. The details of these factors are given on equations (21)-(23) [36].

$$X(\alpha) = \{x \mid \mu_X(x) \geq \alpha\} = [a(\alpha), b(\alpha)] \tag{21}$$

$$\tilde{X}(\alpha) = \{x \mid \mu_{\tilde{X}}(x) \geq \alpha,\ \bar{\mu}_{\tilde{X}}(x) \geq \alpha\} = [a(\alpha), b(\alpha)] \tag{22}$$

$$a(\alpha) \in [a_l(\alpha), a_r(\alpha)],\ b(\alpha) \in [b_l(\alpha), b_r(\alpha)] \tag{23}$$

On the other side, Figure 3 gives information about the alpha cut of the IT2 fuzzy set.

$$\tilde{A}_1 \oplus \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \oplus \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\begin{array}{l} \left(\begin{array}{l} a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \\ \min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), \min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right) \end{array}\right), \\ \left(\begin{array}{l} a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \\ \min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), \min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right) \end{array}\right) \end{array}\right) \tag{16}$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \ominus \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\begin{array}{l} \left(\begin{array}{l} a_{11}^U - a_{24}^U, a_{12}^U - a_{23}^U, a_{13}^U - a_{22}^U, a_{14}^U - a_{21}^U; \\ \min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), \min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right) \end{array}\right), \\ \left(\begin{array}{l} a_{11}^L - a_{24}^L, a_{12}^L - a_{23}^L, a_{13}^L - a_{22}^L, a_{14}^L - a_{21}^L; \\ \min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), \min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right) \end{array}\right) \end{array}\right) \tag{17}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right) \otimes \left(\tilde{A}_2^U, \tilde{A}_2^L\right) = \left(\begin{array}{l} \left(\begin{array}{l} a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; \\ \min\left(H_1\left(\tilde{A}_1^U\right), H_1\left(\tilde{A}_2^U\right)\right), \min\left(H_2\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_2^U\right)\right) \end{array}\right), \\ \left(\begin{array}{l} a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \\ \min\left(H_1\left(\tilde{A}_1^L\right), H_1\left(\tilde{A}_2^L\right)\right), \min\left(H_2\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_2^L\right)\right) \end{array}\right) \end{array}\right) \tag{18}$$

$$k\tilde{A}_1 = \left(k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \times \left(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \tag{19}$$

$$\frac{\tilde{A}_1}{k} = \left(\frac{1}{k} \times a_{11}^U, \frac{1}{k} \times a_{12}^U, \frac{1}{k} \times a_{13}^U, \frac{1}{k} \times a_{14}^U; H_1\left(\tilde{A}_1^U\right), H_2\left(\tilde{A}_1^U\right)\right), \times \left(\frac{1}{k} \times a_{11}^L, \frac{1}{k} \times a_{12}^L, \frac{1}{k} \times a_{13}^L, \frac{1}{k} \times a_{14}^L; H_1\left(\tilde{A}_1^L\right), H_2\left(\tilde{A}_1^L\right)\right) \tag{20}$$

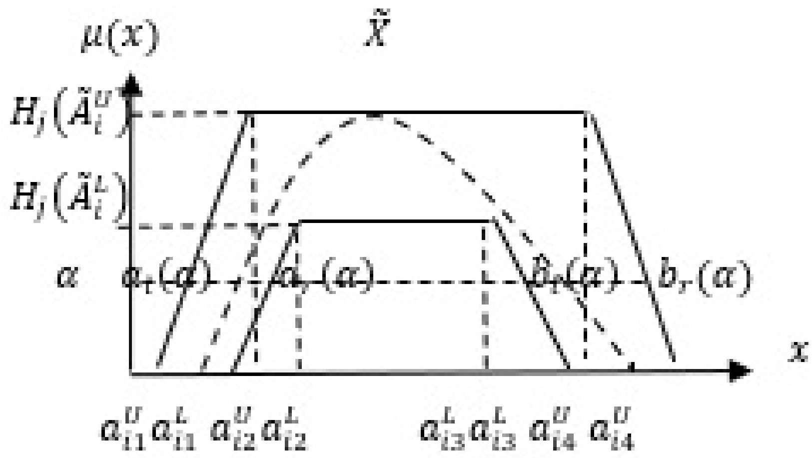

FIGURE 3. Alpha cut of IT2 fuzzy set.

Additionally, equations (24) and (25) state the sub-intervals of $\boldsymbol{a}(\boldsymbol{\alpha})$ and $\boldsymbol{b}(\boldsymbol{\alpha})$ [37].

$$\boldsymbol{a}(\boldsymbol{\alpha}) \in \begin{cases} [a_l(\alpha), a_r(\alpha)], a \in \left[0, H_j\left(\tilde{A}_i^L\right)\right] \\ [a_l(\alpha), b_r(\alpha)], a \in \left[H_j\left(\tilde{A}_i^L\right), 1\right] \end{cases} \tag{24}$$

$$\boldsymbol{b}(\boldsymbol{\alpha}) \in \begin{cases} [b_l(\alpha), b_r(\alpha)], a \in \left[0, H_j\left(\tilde{A}_i^L\right)\right] \\ [a_l(\alpha), b_r(\alpha)], a \in \left[H_j\left(\tilde{A}_i^L\right), 1\right] \end{cases} \tag{25}$$

D. TOPSIS

TOPSIS aims to rank different alternatives according to their significance. Firstly, the normalized values are calculated. For this purpose, equation (26) is taken into consideration [38].

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \quad i = 1, 2, ..m \text{ and } j = 1, 2, ..n \tag{26}$$

In the second step, the values are weighted by considering equation (27).

$$v_{ij} = w_{ij} \times r_{ij} \tag{27}$$

After that, the positive (A^+) and negative (A^-) ideal solutions are computed with the help of equations (28) and (29) [39].

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j} \text{ for } \forall j \in n\} \tag{28}$$

$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min v_{1j} \text{ for } \forall j \in n\} \tag{29}$$

In the following step, the distances to the best (D_i^+) and the worst alternative (D_i^-) are considered by using equations (30) and (31) [40].

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^+\right)^2} \tag{30}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - A_j^-\right)^2} \tag{31}$$

In the final step, the relative closeness to the ideal solution (RC_i) is defined as in equation (32) [44], [45].

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{32}$$

E. VIKOR

VIKOR methodology is preferred to rank different alternatives based on their performance. The first step of this method is similar with TOPSIS. Moreover, the fuzzy best value $\tilde{f}_j^*$ and fuzzy worst value $\tilde{f}_j^-$ are computed with equation (33) [46].

$$\tilde{f}_J^* = \max_i \tilde{x}_{ij}, \quad \text{and } \tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{33}$$

After that, the mean group utility and maximal regret are calculated by considering equations (34) and (35) [47].

$$\tilde{S}_i = \sum_{i=1}^{n} \tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)} \tag{34}$$

$$\tilde{R}_i = max_j \left[\tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)}\right] \tag{35}$$

Within this framework, $\tilde{w}_j$ demonstrates the fuzzy weights. Additionally, $\tilde{S}_i$ is Ai regarding all criteria calculated by the total of the distance for the fuzzy best value. Furthermore, $\tilde{R}_i$ is Ai as for the j-th criterion which can be computed by maximum distance of the fuzzy best value. In the following step, the value of $\tilde{Q}_i$ is calculated with equation (36) [48].

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right) / \left(\tilde{S}^- - \tilde{S}^*\right) + (1 - v)\left(\tilde{R}_i - \tilde{R}^*\right) / \left(\tilde{R}^- - \tilde{R}^*\right) \tag{36}$$

Within this context, v shows the weight of the strategy of maximum group utility which is accepted as 0.5. Moreover, 1 – v represents the weight of the individual regret. Finally,

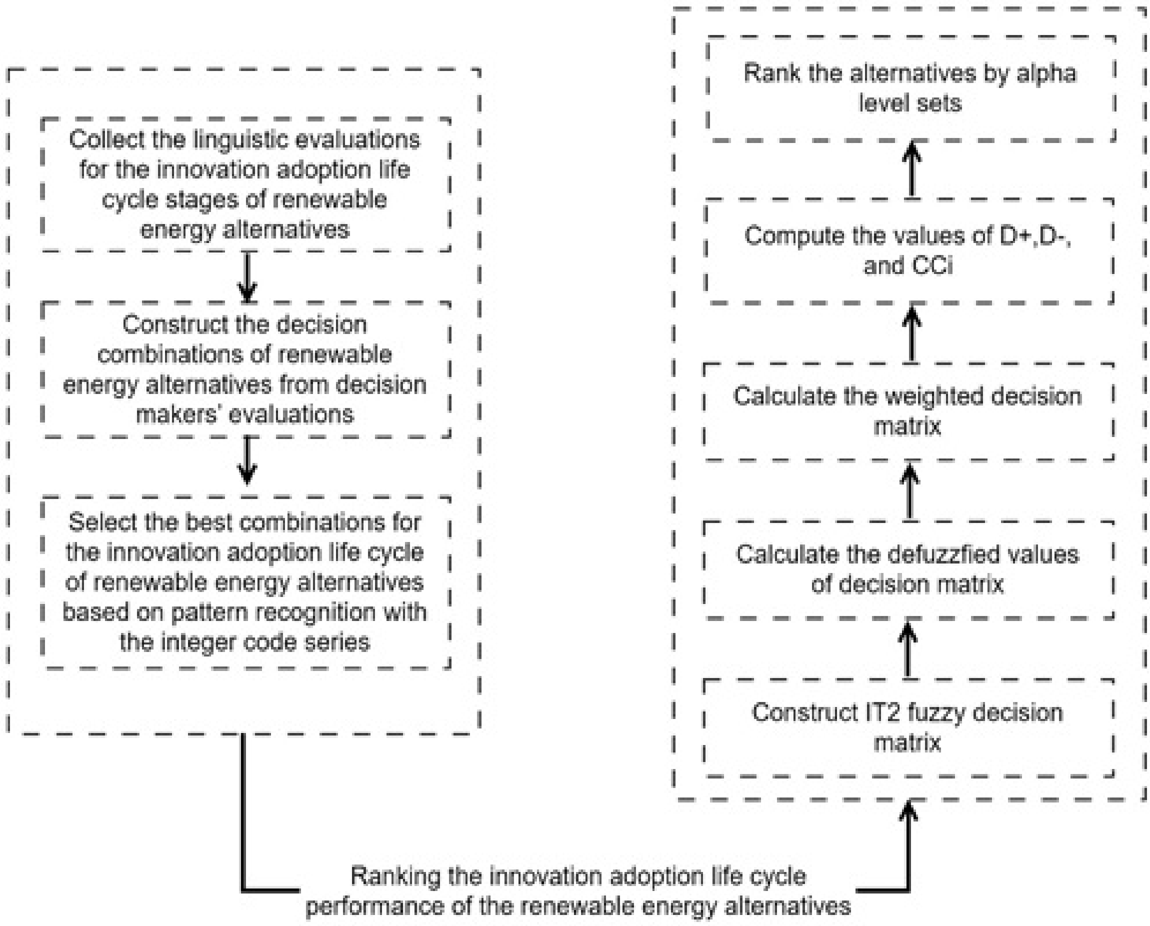

FIGURE 4. **The details of the suggested model.**

the values of S, R, Q are computed. In order to control the reliability of the ranking results, two different conditions must be satisfied. Equation (37) is related to the first condition [46].

$$Q\left(A^{(2)}\right)-Q\left(A^{(1)}\right) \geq \frac{1}{(j-1)} \tag{37}$$

In addition, the second condition includes the acceptable stability in decision making process. If the first condition cannot be satisfied, the alternatives $A^{(1)}, A^{(2)} \ldots, A^{(M)}$ are considered. On the other side, the solution is the combination of the alternatives $A^{(1)}$ and $A^{(2)}$ when the second condition cannot be satisfied [47].

F. PROPOSED MODEL

In this study, a novel model is generated that has two different stages. Figure 4 gives information about the details of this model.

In the first section of this study, the decision combinations of innovation adoption life cycle patterns are determined with integer code series. Within this context, the first step includes the collection of the linguistic evaluations for the innovation adoption life cycle stages of renewable energy alternatives. The second step is related to the construction of the decision combinations of renewable energy alternatives from decision makers' evaluations. In the third step, the best combinations are selected for the innovation adoption life cycle of renewable energy alternatives based on pattern recognition with the integer code series. On the other hand, the innovation adoption life cycle performance of the renewable energy alternatives is ranked in the second stage. For this purpose, firstly, IT2 fuzzy decision matrix is constructed. Secondly, the defuzzified values of decision matrix are calculated. In the third step, the weighted decision matrix is computed. After that, the values of D +, D-, and CCi are computed. With the help of these results, the alternatives are ranked by alpha level sets.

It is possible to mention some novelties of this suggested model. First of all, the integer code series are used for the identification of the decision combinations of innovation adoption life cycle patterns. With the help of this methodology, it will be helpful to control the appropriateness of the evaluations to the patterns [30]–[32]. Moreover, IT2 fuzzy sets provides opportunity to handle the uncertainty in the decision-making process in a better way [33]–[35]. On the other side, owing to the alpha cuts, the results can be calculated for different conditions so that the coherency of the findings can be evaluated [36], [37]. In addition to them, TOPSIS methodology has also some advantages by comparing with other MCDM models. For instance, in the calculation process, the distances to both negative and positive ideal solutions are used [38]–[40]. Due to this issue, it can be possible to reach more appropriate results [44]. Finally, making a comparative evaluation with IT2 fuzzy VIKOR is another important novelty of this proposed model. This situation provides opportunity to check the consistency and reliability of the ranking results [41]–[43].

III. ANALYSIS RESULTS

In this proposed model, there are two different sections. They are detailed below.

A. SECTION 1: DETERMINING THE DECISION COMBINATIONS OF INNOVATION ADOPTION LIFE CYCLE PATTERNS WITH INTEGER CODE SERIES

In this section, firstly, the linguistic evaluations are obtained for the innovation adoption life cycle stages of renewable energy alternatives. Table 1 gives information about the evaluation scales based on IT2 fuzzy numbers and integer alphabet.

TABLE 1. Evaluation scales based on IT2 fuzzy numbers and integer alphabet.

Linguistic Scales	IT2 Fuzzy Numbers	Integer Alphabet
Weakest	((0.00,0.10,0.10,0.30;1.00,1.00), (0.05,0.10,0.10,0.20;0.90,0.90))	-2
Poor	((0.10,0.30,0.30,0.50;1.00,1.00), (0.20,0.30,0.30,0.40;0.90,0.90))	-1
Fair	((0.30,0.50,0.50,0.70;1.00,1.00), (0.40,0.50,0.50,0.60;0.90,0.90))	0
Good	((0.50,0.70,0.70,0.90;1.00,1.00), (0.60,0.70,0.70,0.80;0.90,0.90))	+1
Best	((0.70,0.90,0.90,1.00;1.00,1.00), (0.80,0.90,0.90,0.95;0.90,0.90))	+2

Additionally, the decision makers' evaluations are obtained for the renewable energy alternatives by the stages of innovation adoption life cycle. Within this context, innovators and early adopters, early majority, late majority and laggards are identified as the innovation adoption life cycle stages. On the other side, renewable energy alternatives are listed as solar (alternative 1), wind (alternative 2), biomass solar (alternative 3), geothermal (alternative 4), and hydroelectric energy (alternative 5). The linguistic evaluations are defined in Table 2.

In the second step, the decision combinations of renewable energy alternatives are generated from decision makers' evaluations. Tables 3-7 indicate the decision combinations for 5 different renewable energy alternatives.

In the following step, the best combinations are selected for the innovation adoption life cycle of renewable energy alternatives based on pattern recognition with the integer code series. Regarding the alternative 1, the following calculations are considered for the combinations.

Combination 1:

At the level 1, $f^{[0]}(t_1,t_2) = (2)^0 - (1)^0 = 0, f^{[0]}(t_3,t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5,t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7,t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9,t_{10}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{11},t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13},t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15},t_{16}) = (1)^0 - (1)^0 = 0,$

At the level 2, $f^{[1]}(t_1,t_4) = (2)^1 - (1)^1 + (1)^1 - (1)^1 \neq 0, f^{[1]}(t_5,t_8) = (1)^1 - (2)^1 + (2)^1 - (1)^1 = 0, f^{[1]}(t_9,t_{12}) = (1)^1 - (1)^1 + (1)^1 - (1)^1 = 0, f^{[1]}(t_{13},t_{16}) = (2)^1 - (2)^1 + (1)^1 - (1)^1 = 0$

Other levels of the function are not computed as $f^{[1]}(t_1,t_4) \neq 0$ at the level 2. Similarly, the function results are constructed for the following combinations to figure out the most appropriate geometrical patterns at the different levels.

Combination 2:

At the level 1, $f^{[0]}(t_1,t_2) = (1)^0 - (1)^0 = 0, f^{[0]}(t_3,t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5,t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7,t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9,t_{10}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{11},t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13},t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15},t_{16}) = (1)^0 - (1)^0 = 0,$

At the level 2, $f^{[1]}(t_1,t_4) = (1)^1 - (1)^1 + (1)^1 - (1)^1 = 0, f^{[1]}(t_5,t_8) = (1)^1 - (2)^1 + (2)^1 - (1)^1 = 0, f^{[1]}(t_9,t_{12}) = (1)^1 - (1)^1 + (1)^1 - (1)^1 = 0, f^{[1]}(t_{13},t_{16}) = (2)^1 - (2)^1 + (1)^1 - (1)^1 = 0$

At the level 3, $f^{[2]}(t_1,t_8) = (1)^2 - (1)^2 + (1)^2 - (1)^2 + (1)^2 - (2)^2 + (2)^2 - (1)^2 = 0, f^{[2]}(t_9,t_{16}) = (1)^2 - (1)^2 + (1)^2 - (1)^2 + (2)^2 - (2)^2 + (1)^2 - (1)^2 = 0$

At the level 4, $f^{[3]}(t_1,t_{16}) = (1)^3 - (1)^3 + (1)^3 - (1)^3 + (1)^3 - (2)^3 + (2)^3 - (1)^3 + (1)^3 - (1)^3 + (1)^3 - (1)^3 + (2)^3 - (2)^3 + (1)^3 - (1)^3 = 0$

Combination 2 satisfies the hierarchical forms of geometrical patterns for alternative 1 at all levels.

Combination 3:

At the level 1, $f^{[0]}(t_1,t_2) = (1)^0 - (0)^0 \neq 0, f^{[0]}(t_3,t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5,t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7,t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9,t_{10}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{11},t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13},t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15},t_{16}) = (1)^0 - (1)^0 = 0,$

Combination 3 is not consistent at the level 1 as $f^{[0]}(t_1,t_2) = (1)^0 - (0)^0 \neq 0$

Combination 4:

At the level 1, $f^{[0]}(t_1,t_2) = (2)^0 - (0)^0 \neq 0, f^{[0]}(t_3,t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5,t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7,t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9,t_{10}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{11},t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13},t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15},t_{16}) = (1)^0 - (1)^0 = 0,$

$f^{[0]}(t_1,t_2) = (2)^0 - (0)^0 \neq 0$. Therefore, the other hierarchical forms of geometrical patterns are not calculated for combination 4.

Combination 5:

At the level 1, $f^{[0]}(t_1,t_2) = (1)^0 - (1)^0 = 0, f^{[0]}(t_3,t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5,t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7,t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9,t_{10}) = (0)^0 - (1)^0 \neq 0, f^{[0]}(t_{11},t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13},t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15},t_{16}) = (1)^0 - (1)^0 = 0,$

TABLE 2. Decision makers' linguistic evaluations for the renewable energy alternatives by the stages of innovation adoption life cycle.

Time/Alternatives			Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
Groups	Stages	Time	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
Innovators and Early Adopters	Stage 1	T1	G	G	B	B	B	B	G	G	G	G	G	B	G	G	G
	Stage 2	T2	P	F	F	W	W	W	W	F	F	W	W	W	W	W	W
	Stage 3	T3	G	G	G	G	G	G	B	B	B	B	B	B	G	B	G
	Stage 4	T4	P	P	P	W	P	W	P	P	P	W	W	W	P	F	F
Early Majority	Stage 1	T5	G	G	G	B	B	B	F	G	G	B	B	B	B	B	B
	Stage 2	T6	W	W	W	W	W	W	P	P	P	W	W	W	P	P	P
	Stage 3	T7	B	B	B	B	B	B	G	G	G	G	G	G	G	G	G
	Stage 4	T8	P	P	P	W	F	F	P	P	P	P	P	P	W	W	W
Late Majority	Stage 1	T9	F	G	G	G	G	G	B	B	B	G	G	G	G	B	B
	Stage 2	T10	P	P	P	P	P	P	W	W	W	P	F	F	W	W	W
	Stage 3	T11	G	G	G	G	G	G	G	G	G	G	G	G	G	B	B
	Stage 4	T12	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Laggards	Stage 1	T13	B	B	B	G	G	G	F	G	F	G	G	G	G	G	G
	Stage 2	T14	W	W	W	P	P	P	P	P	P	P	P	P	P	P	P
	Stage 3	T15	G	G	G	G	G	G	B	B	B	G	G	G	B	B	B
	Stage 4	T16	P	P	P	P	F	P	W	W	W	P	P	P	W	W	W

TABLE 3. Decision combinations for renewable energy alternative 1.

Alternative 1	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Combination 1	B	P	G	P	G	W	B	P	G	P	G	P	B	W	G	P
Combination 2	G	P	G	P	G	W	B	P	G	P	G	P	B	W	G	P
Combination 3	G	F	G	P	G	W	B	P	G	P	G	P	B	W	G	P
Combination 4	B	F	G	P	G	W	B	P	G	P	G	P	B	W	G	P
Combination 5	G	P	G	P	G	W	B	P	F	P	G	P	B	W	G	P
Combination 6	B	P	G	P	G	W	B	P	F	P	G	P	B	W	G	P
Combination 7	G	F	G	P	G	W	B	P	F	P	G	P	B	W	G	P
Combination 8	B	F	G	P	G	W	B	P	F	P	G	P	B	W	G	P

TABLE 4. Decision combinations for renewable energy alternative 2.

Alternative 2	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Combination 1	B	W	G	P	B	W	B	W	G	P	G	P	G	P	G	F
Combination 2	B	W	G	W	B	W	B	W	G	P	G	P	G	P	G	F
Combination 3	B	W	G	P	B	W	B	F	G	P	G	P	G	P	G	F
Combination 4	B	W	G	W	B	W	B	F	G	P	G	P	G	P	G	F
Combination 5	B	W	G	P	B	W	B	W	G	P	G	P	G	P	G	P
Combination 6	B	W	G	W	B	W	B	W	G	P	G	P	G	P	G	P
Combination 7	B	W	G	P	B	W	B	F	G	P	G	P	G	P	G	P
Combination 8	B	W	G	W	B	W	B	F	G	P	G	P	G	P	G	P

TABLE 5. Decision combinations for renewable energy alternative 3.

Alternative 3	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Combination 1	G	W	B	P	F	P	G	P	B	W	G	P	F	P	B	W
Combination 2	G	W	B	P	G	P	G	P	B	W	G	P	G	P	B	W
Combination 3	G	W	B	P	F	P	G	P	B	W	G	P	G	P	B	W
Combination 4	G	W	B	P	G	P	G	P	B	W	G	P	F	P	B	W

TABLE 6. Decision combinations for renewable energy alternative 4.

Alternative 4	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Combination 1	B	W	B	W	B	W	G	P	G	P	G	P	G	P	G	P
Combination 2	G	W	B	W	B	W	G	P	G	P	G	P	G	P	G	P
Combination 3	B	W	B	W	B	W	G	P	G	F	G	P	G	P	G	P
Combination 4	G	W	B	W	B	W	G	P	G	F	G	P	G	P	G	P

$f^{[0]}(t_9, t_{10}) = (0)^0 - (1)^0 \neq 0$ for combination 5. For this reason, it is impossible to go ahead with the computation of other levels.

Combination 6:

At the level 1, $f^{[0]}(t_1, t_2) = (2)^0 - (1)^0 = 0, f^{[0]}(t_3, t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5, t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7, t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9, t_{10}) = (0)^0 - (1)^0 \neq 0,$ $f^{[0]}(t_{11}, t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13}, t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15}, t_{16}) = (1)^0 - (1)^0 = 0,$

Combination 6 is not equal to zero at the level 1 for $f^{[0]}(t_9, t_{10})$.

Combination 7:

At the level 1, $f^{[0]}(t_1, t_2) = (1)^0 - (0)^0 \neq 0, f^{[0]}(t_3, t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5, t_6) = (1)^0 - (2)^0 = 0,$

TABLE 7. Decision combinations for renewable energy alternative 5.

Alternative 5	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Combination 1	G	W	G	P	B	P	G	W	G	W	G	P	G	P	B	W
Combination 2	G	W	B	P	B	P	G	W	G	W	G	P	G	P	B	W
Combination 3	G	W	G	F	B	P	G	W	G	W	G	P	G	P	B	W
Combination 4	G	W	B	F	B	P	G	W	G	W	G	P	G	P	B	W
Combination 5	G	W	G	P	B	P	G	W	B	W	G	P	G	P	B	W
Combination 6	G	W	B	P	B	P	G	W	B	W	G	P	G	P	B	W
Combination 7	G	W	G	F	B	P	G	W	B	W	G	P	G	P	B	W
Combination 8	G	W	B	F	B	P	G	W	B	W	G	P	G	P	B	W
Combination 9	G	W	G	P	B	P	G	W	G	W	B	P	G	P	B	W
Combination 10	G	W	B	P	B	P	G	W	G	W	B	P	G	P	B	W
Combination 11	G	W	G	F	B	P	G	W	G	W	B	P	G	P	B	W
Combination 12	G	W	B	F	B	P	G	W	G	W	B	P	G	P	B	W
Combination 13	G	W	G	P	B	P	G	W	B	W	B	P	G	P	B	W
Combination 14	G	W	B	P	B	P	G	W	B	W	B	P	G	P	B	W
Combination 15	G	W	G	F	B	P	G	W	B	W	B	P	G	P	B	W
Combination 16	G	W	B	F	B	P	G	W	B	W	B	P	G	P	B	W

TABLE 8. Decision combinations of innovation adoption life cycle patterns for renewable energy alternatives.

Time/ Alternatives	Alternative 1 (Combination 2)	Alternative 2 (Combination 5)	Alternative 3 (Combination 2)	Alternative 4 (Combination 1)	Alternative 5 (Combination 6)
T1	G	B	G	B	G
T2	P	W	W	W	W
T3	G	G	B	B	B
T4	P	P	P	W	P
T5	G	B	G	B	B
T6	W	W	P	W	P
T7	B	B	G	G	G
T8	P	W	P	P	W
T9	G	G	B	G	B
T10	P	P	W	P	W
T11	G	G	G	G	G
T12	P	P	P	P	P
T13	B	G	G	G	G
T14	W	P	P	P	P
T15	G	G	B	G	B
T16	P	P	W	P	W

$f^{[0]}(t_7, t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9, t_{10}) = (0)^0 - (1)^0 \neq 0, f^{[0]}(t_{11}, t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13}, t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15}, t_{16}) = (1)^0 - (1)^0 = 0,$

$f^{[0]}(t_1, t_2) = (1)^0 - (0)^0 \neq 0$. Due to this situation, it is identified that combination 7 cannot be illustrated for the level 2,3, and 4.

Combination 8:

At the level 1, $f^{[0]}(t_1, t_2) = (2)^0 - (0)^0 \neq 0, f^{[0]}(t_3, t_4) = (1)^0 - (1)^0 = 0, f^{[0]}(t_5, t_6) = (1)^0 - (2)^0 = 0, f^{[0]}(t_7, t_8) = (2)^0 - (1)^0 = 0, f^{[0]}(t_9, t_{10}) = (0)^0 - (1)^0 \neq 0, f^{[0]}(t_{11}, t_{12}) = (1)^0 - (1)^0 = 0, f^{[0]}(t_{13}, t_{14}) = (2)^0 - (2)^0 = 0, f^{[0]}(t_{15}, t_{16}) = (1)^0 - (1)^0 = 0,$

$f^{[0]}(t_1, t_2) = (2)^0 - (0)^0 \neq 0$ and combination 8 is not appropriate for the hierarchical forms of geometrical patterns at all levels. Similar procedure is also applied for the combinations of other alternatives and the combinations are selected that are consistent for the innovation adoption life cycle patterns at all levels. The results are presented in Table 8.

B. SECTION 2: RANKING THE INNOVATION ADOPTION LIFE CYCLE PERFORMANCE OF THE RENEWABLE ENERGY ALTERNATIVES

The first step of this section includes the construction of IT2 fuzzy decision matrix. Table 9 gives information about the details of this matrix.

In the next step, the defuzzfied values of decision matrix are calculated. Table 10 demonstrates this matrix for the fact that alpha-level set is equal to zero.

The following step is related to the calculation of the weighted decision matrix. Groups weighs of innovation adoption life cycle are given in theory as 16% for innovators and early Adopters; 34% for early majority; 34% for late majority; 16% for laggards. For this study, each group is divided into 4 stages to be able to define the hierarchical forms of geometrical patterns with integer code series. Accordingly, the weights are normalized by considering 16 different time spans. The time weights are calculated as 4% for time 1-4; 8.5% for time 5-12; 4% for time 13-16. The

TABLE 9. IT2 fuzzy decision matrix.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
T1	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))
T2	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))
T3	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))
T4	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))
T5	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))
T6	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))
T7	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))
T8	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))
T9	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))
T10	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))
T11	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))
T12	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))
T13	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))
T14	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))
T15	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))	((0.5,0.7,0.7,0.9;1,1),(0.6,0.7,0.7,0.8;0.9,0.9))	((0,0.1,0.1,0.3;1,1),(0.05,0.1,0.1,0.2;0.9,0.9))
T16	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.1,0.3,0.3,0.5;1,1),(0.2,0.3,0.3,0.4;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))	((0.3,0.5,0.5,0.7;1,1),(0.4,0.5,0.5,0.6;0.9,0.9))	((0.7,0.9,0.9,1;1,1),(0.8,0.9,0.9,0.95;0.9,0.9))

TABLE 10. Defuzzified decision matrix (alpha-level set: 0).

	A1	A2	A3	A4	A5
T1	0.70	0.86	0.70	0.86	0.70
T2	0.30	0.14	0.14	0.14	0.14
T3	0.70	0.70	0.86	0.14	0.86
T4	0.30	0.30	0.30	0.86	0.30
T5	0.70	0.86	0.50	0.86	0.86
T6	0.14	0.14	0.30	0.14	0.30
T7	0.86	0.86	0.70	0.50	0.70
T8	0.30	0.14	0.50	0.50	0.14
T9	0.70	0.70	0.86	0.70	0.86
T10	0.70	0.30	0.14	0.30	0.14
T11	0.30	0.70	0.50	0.70	0.70
T12	0.30	0.30	0.50	0.30	0.30
T13	0.86	0.70	0.70	0.50	0.70
T14	0.14	0.30	0.30	0.30	0.30
T15	0.50	0.70	0.14	0.70	0.14
T16	0.50	0.30	0.86	0.50	0.86

TABLE 11. Weighted decision matrix (alpha-level set: 0).

	A1	A2	A3	A4	A5
T1	0.03	0.03	0.03	0.03	0.03
T2	0.01	0.01	0.01	0.01	0.01
T3	0.03	0.03	0.03	0.01	0.03
T4	0.01	0.01	0.01	0.03	0.01
T5	0.06	0.07	0.04	0.07	0.07
T6	0.01	0.01	0.03	0.01	0.03
T7	0.07	0.07	0.06	0.04	0.06
T8	0.03	0.01	0.04	0.04	0.01
T9	0.06	0.06	0.07	0.06	0.07
T10	0.06	0.03	0.01	0.03	0.01
T11	0.03	0.06	0.04	0.06	0.06
T12	0.03	0.03	0.04	0.03	0.03
T13	0.03	0.03	0.03	0.02	0.03
T14	0.01	0.01	0.01	0.01	0.01
T15	0.02	0.03	0.01	0.03	0.01
T16	0.02	0.01	0.03	0.02	0.03

details of the weighted decision matrix are demonstrated on Table 11.

After that, the values of D+, D−, and CCi are calculated and the details are given in Table 12.

Finally, renewable energy alternatives are ranked for different alpha sets. Table 13 explains the analysis results.

Table 13 indicates that solar (A1) is the best renewable energy alternative for innovation potential. Additionally, it is

TABLE 12. The values of D+, D− and CCi (alpha-level set: 0).

Alternatives	D+	D-	CCi
Alternative 1	0.057	0.069	0.549
Alternative 2	0.063	0.066	0.515
Alternative 3	0.070	0.060	0.464
Alternative 4	0.064	0.066	0.510
Alternative 5	0.070	0.065	0.483

also identified that wind (A2) is also another significant renewable energy type that has a great innovation potential. Moreover, geothermal energy (A4) has the third rank with respect to the innovation potential. On the other side, it is also concluded that biomass (A3) and hydroelectric energy (5) have lower importance in comparison with the others. Furthermore, the ranking results are quite similar for different alpha cuts. This condition demonstrates that the analysis results are coherent and reliable. On the other side, a comparative analysis has also been performed by considering IT2 fuzzy VIKOR methodology. The ranking results are demonstrated on Table 14.

Table 14 indicates that the analysis results of IT2 fuzzy TOPSIS and IT2 fuzzy VIKOR are quite similar. This situation gives information that the ranking results are consistent.

IV. CONCLUSION

The aim of this study is to evaluate the innovation adoption performance of the renewable energy alternatives. For this purpose, a 2-stage model is constructed by considering the integer code series enhanced IT2 fuzzy decision support system with alpha cuts. The first stage includes the identification of the decision combinations of innovation adoption life cycle patterns with integer code series. On the other side, in the second stage, the innovation adoption life cycle performance of the renewable energy alternatives is ranked. In this regard, IT2 fuzzy TOPSIS methodology is taken into consideration with alpha cuts. Moreover, a comparative evaluation is also conducted by considering IT2 fuzzy VIKOR. It is identified that the analysis results are quite coherent and reliable. The findings indicate that solar energy is the most appropriate renewable energy type to make innovation. Hence, it is obvious that making investment to solar energy alternatives provides opportunity to adopt technologic innovation more easily. Moreover, wind is found as another significant renewable energy type that has a great innovation potential. However, biomass and hydroelectricity have lower importance in comparison with others. Additionally, the ranking results are the same for different alpha cuts. Thus, it is obvious that the analysis results are coherent and reliable.

V. LIMITATIONS AND IMPLICATIONS

The very high initial costs are one of the most important obstacles in increasing renewable energy investments. Therefore, this problem should be reduced by focusing on research and development studies. The reason for this is that technological developments for renewable energy alternatives contribute to the reduction of costs. However, this situation stated for each type of renewable energy may not be as important. The results obtained in this study are that the innovation potential of solar energy is very good compared to others. Thanks to technological developments, the capacity of electrical energy obtained from solar energy has increased significantly especially in recent years. Considering this information, it is predicted that technological developments for solar energy will increase even more in the coming years. In this context, it would be appropriate for investors who want to invest in renewable energy alternatives to prioritize

TABLE 13. Ranking results of renewable energy alternatives by alpha level sets with IT2 fuzzy TOPSIS.

Alternatives	Alpha Levels											
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Average
A1	1	1	1	1	1	1	1	1	1	1	1	1
A2	2	2	2	2	2	2	2	2	2	2	2	2
A3	5	5	5	5	5	5	5	5	5	5	5	5
A4	3	3	3	3	3	3	3	3	3	3	3	3
A5	4	4	4	4	4	4	4	4	4	4	4	4

TABLE 14. Ranking results of renewable energy alternatives by alpha level sets with IT2 fuzzy VIKOR.

Alternatives	Alpha Levels											
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Average
A1	1	1	1	1	1	1	1	1	1	1	1	1
A2	2	2	2	2	3	3	2	2	2	2	2	2
A3	5	5	5	5	5	5	5	5	5	5	5	5
A4	3	3	3	3	2	2	3	3	3	3	3	3
A5	4	4	4	4	4	4	4	4	4	4	4	4

solar energy. Thanks to the predicted technological advances, the costs of solar energy investments will be reduced significantly. On the other hand, it is obvious that the efficiency of solar energy investments will be much higher compared to other renewable energy types with the increased capacity. This situation will contribute both to increase the profitability of renewable energy investors and to the achievement of the sustainable development goals of the countries.

There are many studies in the literature indicating that the innovation potential of solar energy investments is high. For example, Saymbetov *et al.* [49], Wong *et al.* [50] and Dahlioui *et al.* [51] stated that important work has been done to increase the efficiency of electrical energy production with solar cells. In this context, with the application of the biaxial photovoltaic system, it is possible to move the system carrying the solar panels to direct them to the sun. In this way, maximum benefit from solar energy can be achieved. This situation also contributes to the increase in the amount of obtained electricity. In addition to these studies, Cheng *et al.* [52] and Li *et al.* [53] conducted an analysis of renewable energy investments. As a result, it is identified that investors should give priority to solar energy projects. Technological developments regarding solar energy investments have been shown as the main reason for this situation. They indicated that solar energy investments will be much more efficient than others. Also, Li *et al.* [54], Ahmed *et al.* [55] and Kabir *et al.* [56] underlined that owing to the technological developments, solar energy investments will be even more effective in the future. In this way, it was stated that solar energy projects will both provide significant profit to investors and contribute to the economic development of the country.

The main contribution of this study is generating a novel model to evaluate the innovation potential of renewable energy alternatives by considering IT2 fuzzy TOPSIS based on the integer code series and alpha cuts. However, focusing on only the innovation potential of the renewable energy investments is a significant limitation of this study. In the future studies, more specific analysis can be conducted, such as technological improvements of these energy types. Additionally, it is also possible to examine renewable energy types separately. On the other side, different methodologies can be considered in the analysis process, such as DEMATEL, and MOORA. In addition to these issues, another significant limitation of this study is that there is no industrial application. Instead of this situation, this study has a leading role for the investors. Hence, in the following studies, an industrial evaluation can be conducted based on the innovation of the renewable energy projects.

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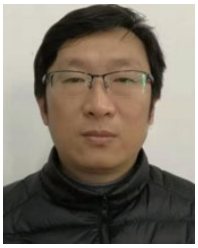

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