Assessing Renewable Energy Alternatives with Multi-Criteria Decision-Making Techniques Based on Q-Rung Orthopair Fuzzy Sets

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Assessing Renewable Energy Alternatives with Multi-Criteria Decision-Making Techniques Based on Q-Rung Orthopair Fuzzy Sets

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Abstract

In recent years, countries have prioritized the selection of viable renewable energy alternatives, driven by the urgent need for a transition to sustainable energy. Selecting appropriate energy sources requires careful consideration of social, political, economic, and technological factors. This study proposes a comprehensive framework for evaluating renewable energy alternatives using a combination of the CRITIC (Criteria Importance Through Intercriteria Correlation) and MABAC (Multi-Attributive Border Approximation area Comparison) methods, enhanced by quantum-Rung Fuzzy Sets. A detailed evaluation is performed using 22 sub-criteria, grouped into environmental, technological, economic, and socio-political dimensions, to assess renewable sources such as wind, solar, geothermal, biomass, wave, hydraulic, and hydrogen. Expert input and literature guide the criteria selection. The model is applied in a case study of the Turkish energy sector, revealing hydrogen as the most promising alternative. Sensitivity analysis confirms the robustness of the results, showing no significant changes in the ranking of energy alternatives. This framework provides valuable insights to policymakers, energy planners, and decision-makers, offering a reliable tool for navigating the complexities of renewable energy selection.

Keywords Renewable Energy, Energy Sources, Fuzzy Sets, Q-Rung Orthopair, Multi-Criteria Decision-Making.

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1. Introduction

Energy is a fundamental necessity in various aspects of living. Economic advancements and global population expansion suggest that energy demand will persistently increase (Dincer, 2001). The energy crisis has given rise to environmental issues that present a significant challenge in the adoption of clean energy solutions. Particularly, the extremes of the global climate underscore the critical need of addressing the climate catastrophe with greater attention and in a timely manner. Therefore, it is necessary to include cleaner, renewable, and sustainable alternative resources in energy production (International Energy Agency, 2023).

Fossil fuels constitute 81% of the energy resource distribution used in the energy sector around the world (EU Commission, 2003; Çelikbilek and Tüysüz, 2016). In contrast to fossil fuels, the environmental friendliness and absence of harmful gas emissions exhibited by renewable energy sources are substantial factors contributing to their desirability (Shahzad, 2012). Increasing the share of renewable energy in the total energy mix has the potential to significantly enhance environmental sustainability and overall ecological well-being. Moreover, renewable energy sources have the capacity to mitigate the worldwide greenhouse gas impact (International Renewable Energy Agency, 2020). In modern times, renewable energy production primarily relies on biomass, solar, geothermal, wind, hydroelectric, and tidal energy sources (Shahzad, 2012).

Türkiye possesses hydraulic, wind, solar, biomass, and geothermal potential for renewable energy (Yılmaz, 2012). Enhancing the renewable energy supply in Türkiye will have a beneficial impact on economic growth, conservation of biodiversity, energy security, and national sovereignty. Türkiye's energy policy prioritises expanding the utilisation of domestic resources, effectively using resources in accordance with geopolitical opportunities, and monitoring global changes (TUBA, 2022). There will be a growing inclination towards renewable energy sources in the coming years. This prediction is further corroborated by the "Türkiye's National Energy Plan 2022" (Ministry of Energy and Natural Resources, 2022). Between 2020 and 2035, primary energy consumption will increase by 2.2%, as shown in Figure 1 and 2. In parallel, primary energy consumption increased by an average of 3.1 percent per year between 2000 and 2020. By 2035, a greater proportion of primary energy consumption will be derived from renewable sources, up from 16.7 percent in 2020. Similarly, nuclear energy is projected to attain a 5.9 percent market share by the year 2035. The proportion attributed to fossil resources is projected to decline from 83.3 percent in 2020 to 70.4 percent in 2035.

In a similar fashion, by 2035, 65.8% of electricity generation will be derived from renewable sources, up from 42.4% in 2020. Hydropower, which is approaching its maximum installed capacity and generation potential, will account for 17.3 percent of total installed capacity in 2035, up from its current highest share.

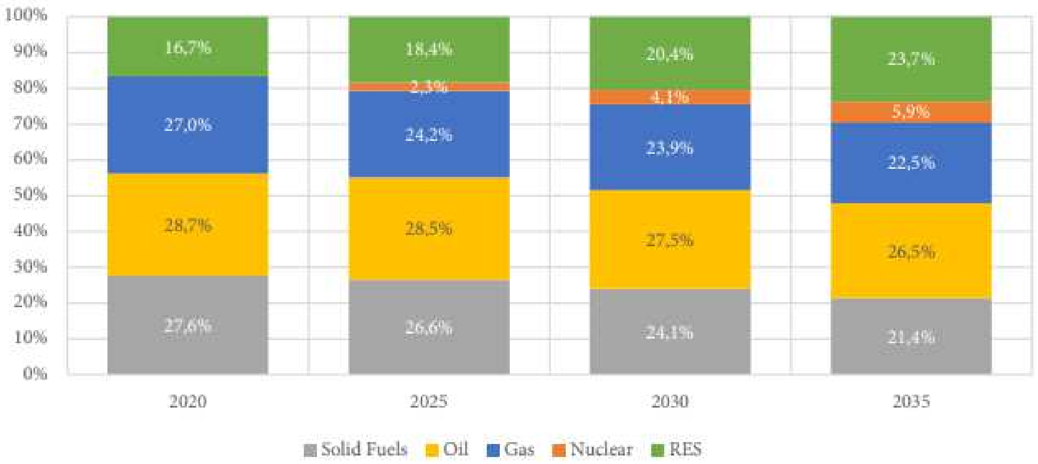


Figure 1. Distribution of primary energy consumption by source (Ministry of Energy and Natural Resources, 2022)

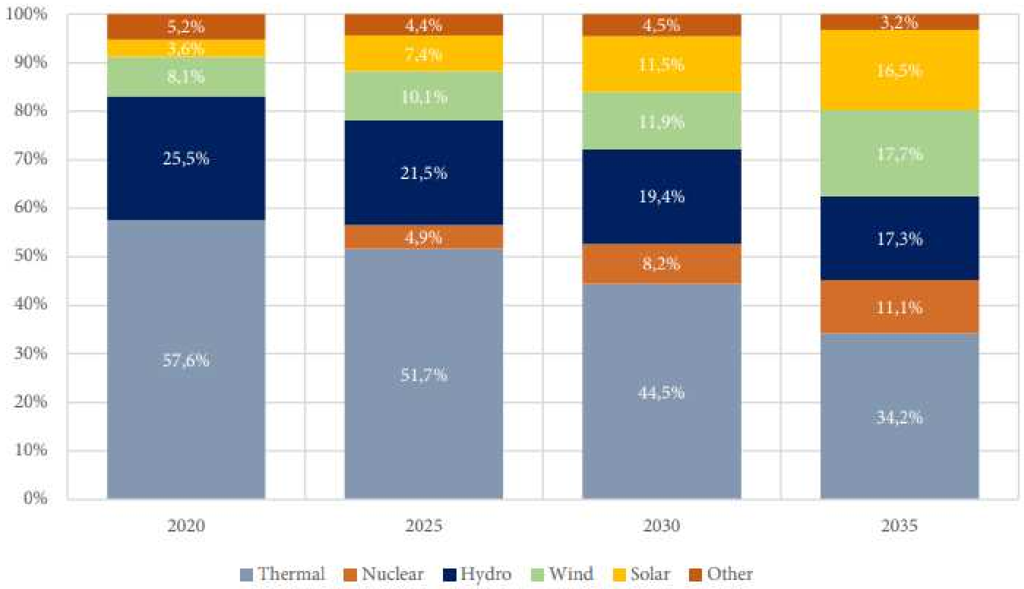


Figure 2. Distribution of electricity generation by source (Ministry of Energy and Natural Resources, 2022)

This study proposes a structured framework to identify key criteria for selecting the most suitable renewable energy source to support sustainable energy solutions for Türkiye. Acknowledging the complexity of these decisions, the research incorporates expert insights to assign weights to these criteria. The study leverages q-Rung Orthopair Fuzzy Sets (q-ROFS), chosen for their enhanced flexibility and superior ability to handle uncertainty compared to Intuitionistic Fuzzy Sets (IFS) and Neutrosophic Sets (NS). The q-parameter in q-ROFS allows these sets to handle more ambiguity and hesitation in data, making them especially useful in scenarios where traditional models may fall short. Moreover, q-ROFS generalizes both Pythagorean Fuzzy Set (PFS) and IFS, offering a precise and adaptable framework, which is vital for complex, real-world decision-making problems. This is achieved through the utilization of advanced MCDM techniques, including q-Rung, fuzzy CRITIC, and MABAC. With such advantages, we aim to conduct a thorough and unbiased assessment of the various factors that impact the choice of a renewable energy source.

The main contributions of this study are as follows; To the best of authors' knowledge, it is the first study that hybridized CRITIC and MABAC methods on q-ROFS domain, to address renewable energy source selection problem. The combination of q-ROFS with CRITIC and MABAC improves decision accuracy by leveraging their strengths to manage uncertainties, establish objective criteria weights, and deliver consistent rankings. This makes the model a crucial approach for renewable energy selection, which augments the decision-making process with a comprehensive and well-informed viewpoint. The study's novel approach of using q-ROFS for handling uncertainty and subjective data enhances decision accuracy, which is critical for complex scenarios like energy planning where conventional models might fall short. Thus, it provides a comprehensive framework for selecting renewable energy sources in Türkiye, which aids decision-makers, including policymakers and energy planners, in making informed, well-structured choices about renewable energy investments. This research can act as a framework for guiding Türkiye's shift toward a more sustainable energy system. The findings offer valuable contributions to enhancing energy resilience, minimizing ecological damage, and fostering economic progress through renewable energy initiatives. These insights can play a pivotal role in shaping long-term national energy policies and advancing sustainable development goals. The paper is organized as follows: Section 2 offers a literature review on renewable energy selection, while Section 3 details the methodology used in the study. Section 4 applies the proposed model through a case study. Section 5 includes a discussion along with managerial implications, and Section 6 concludes by suggesting directions for future research.

2. Literature review

This section initially summarises global studies on the selection of renewable energy sources, followed by a summary of similar studies undertaken in Türkiye.

2.1 Assessment of Renewable Energy Alternatives

Ahmad and Tahar (2014) employed the Analytic Hierarchy Process (AHP) method to rank renewable energy alternatives, focusing on long-term sustainability for electricity generation in Malaysia. Similarly, Kumar and Samuel (2017) applied AHP for weighting criteria and the VIKOR method to select the best renewable energy source for a university campus in India. Ishfaq et al. (2018) explored the optimal renewable energy source for Pakistan using AHP, VIKOR, and TOPSIS methods. Lee and Chang (2018) compared renewable energy alternatives in Taiwan using WSM, VIKOR, TOPSIS, and ELECTRE, with criteria weighted by Shannon entropy.

Fuzzy and grey variants of MCDM methods have also been utilized extensively. Xu et al. (2019) proposed a two-stage MCDM framework for hydrogen production in Pakistan, employing fuzzy AHP for criterion weighting and DEA for alternative ranking. Wang et al. (2020) evaluated biomass, wind and solar options for electricity in Sindh and Baluchistan, using fuzzy AHP. Chen et al. (2020) applied PROMETHEE II to assess renewable energy in northern China. Rani et al. (2020) introduced a fuzzy TOPSIS-based divergence measure to rank renewable energy sources, highlighting its effectiveness under data uncertainty Wang et al. (2021) investigated renewable energy selection in Vietnam by employing the grey AHP approach alongside the weighted aggregate sum product assessment to determine the optimal choice. Similarly, Quteishat and Younis (2023) applied fuzzy ANP and fuzzy TOPSIS for renewable energy evaluation, while Ding et al. (2023) integrated the DEMATEL technique with interval regret theory to evaluate renewable energy investment opportunities in Fujian, China.

Recent studies have integrated novel MCDM methods to tackle this issue. Yazdani et al. (2020) employed Shannon entropy and EDAS in a Saudi Arabian case study. Rani et al. (2021) proposed a SWARA-CoCoSo hybrid based on single-valued neutrosophic sets for India. Sarkodie et al. (2022) utilized CRITIC for weighting and MOORA, TOPSIS, and COPRAS to rank Ghana’s energy alternatives. Krishankumar et al. (2022) adopted hesitant fuzzy linguistic information (HLFI) and variance approaches for India's sustainable energy plans. Al-Barakati et al. (2022) used interval-valued Pythagorean fuzzy WASPAS for the weighting of the criteria.

Ghose et al. (2022) focused on cost-related fuzzy TOPSIS rankings in Gujarat, India. Almutairi et al. (2022) combined SWARA and Gray ARAS for Iran's renewable energy strategies, while Long et al. (2022) introduced cognitive fuzzy SPAN and empathetic preferences for group decision-making in residential energy production.

2.1.1 Renewable Energy Resources Evaluation Studies in Türkiye

The second decade of the Millennium marks a significant transformation in Türkiye's renewable energy capacity. The rise in research pertaining to Türkiye in this domain further substantiates this.

The objective of the study conducted by Kahraman et al. (2010) was to evaluate and rank renewable energy sources for Turkey. The Choquet integral method was employed. Çelikbilek and Tüysüz (2016) employed a grey-based integrated DEMATEL, ANP, and VIKOR MCDM methodology for the evaluation of renewable energy resources. In a further contribution to this field, Büyüközkan and Güleryüz (2016) investigated the most suitable renewable energy resource selection problem in Turkey from the perspective of investors. The researchers employed an integrated DEMATEL and ANP MCDM approach. This study represents the inaugural application of the DEMATEL and ANP integrated method in the context of Turkey. Mousavi et al. (2017) put forward a novel soft computing strategy, modified ELECTRE, in a hesitant fuzzy setting, with the objective of overcoming uncertainty in the domain of renewable energy policy selection. The weights of the criteria were determined by a developed maximisation of deviation method, which was subsequently applied to case studies in Turkey and Iran. Toklu and Taşkın (2018) proposed a decision model to evaluate renewable energy sources in Turkey. They determined four criteria, which were further broken down into twelve subcriteria for the study. They used fuzzy AHP to determine criteria weights. Afterward, renewable energy alternatives were ranked using fuzzy TOPSIS. Büyüközkan et al. (2018) proposed an integrated approach to AHP and COPRAS methods in a hesitant fuzzy linguistic environment on a case study from Türkiye. A numerical model is presented in the focus of Sustainable Development Goals. Alkan and Albayrak (2020) determined the criteria weights in their study with the fuzzy entrophy method. Fuzzy COPRAS and fuzzy MULTIMOORA are used to rank alternatives by region for potential energy investment. The study is a guide for renewable energy investment. Ecer et al. (2021) applied a case study in Türkiye for the renewable energy source selection. They used the level based weight assessment (LBWA) model and the CODAS method based on the interval rough number extension. Yürek et al. (2021) ranked renewable energy sources. Model criteria were created based on the sustainability index. Based on Pythagorean fuzzy sets, AHP and TOPSIS methods are integrated. Bilgili et al. (2022) carried out a study that took into account the sustainable growth constraint of Türkiye and came to the forefront with an evaluation in terms of investment. Within this constraint and certain criteria, the best alternative was determined by the Intuitionistic fuzzy-TOPSIS method. In another academic study conducted in Türkiye, Alkan (2024) evaluated renewable energy alternatives focusing on sustainable development. The CRITIC and SWARA methods determined the weights of the criteria, and CODAS ranked the alternatives with using interval-valued picture fuzzy sets.

2. 2 Research Gap

In the literature, MCDM methods are widely used in research focusing on renewable energy source assessment. The proposed approach guides the decision-making process in a more realistic framework in terms of participation, flexibility, and feasibility.

3. Research Methodology

This study addresses the sustainable renewable energy source selection problem with a hybridized framework, q-Rung Orthopair Fuzzy CRITIC & MABAC. To enhance the text's readability, we include the preliminaries on q-ROFS in Section 3.1. Relevant works can also be consulted by interested readers (Krishankumar et.al, 2021; Aytekin et.al, 2023; Turan & Boran, 2022; Yager, 2016; Liu & Wang, 2018; Ali, 2018; Shaheen et.al, 2021; Hussain et.al, 2019).

In this study, we use q-ROFS because they offer a greater degree of flexibility. and are capable of modelling higher levels of uncertainty in comparison to IFS. In IFS, the sum of the membership and non-membership must not exceed the specified limit. 1, $\mu(x) + \nu(x) \leq 1$, while in q-ROFS, the constraint is generalized to $\mu q(x) + \nu q(x) \leq 1$, where q may represent any positive integer. The q-parameter in q-ROFS provides the ability to handle higher levels of uncertainty. As q increases, q-ROFS can accommodate more vagueness and hesitation in the data. This makes q-ROFS especially useful in complex decision-making scenarios, where traditional models might fail to capture the full range of uncertainty (Kumar, P. S.,2024; Peng et al.,2021; Riaz et al., 2020; Kumar, P. S.,2020).

Moreover, q-ROFS generalize both Pythagorean fuzzy sets and IFS, making them suitable for applications requiring a high degree of precision and adaptability. This generalization allows q-ROFS to handle more complex uncertainties while maintaining computational efficiency, which is especially important in MCDM filed (Riaz et al., 2020; Seikh et al., 2022).

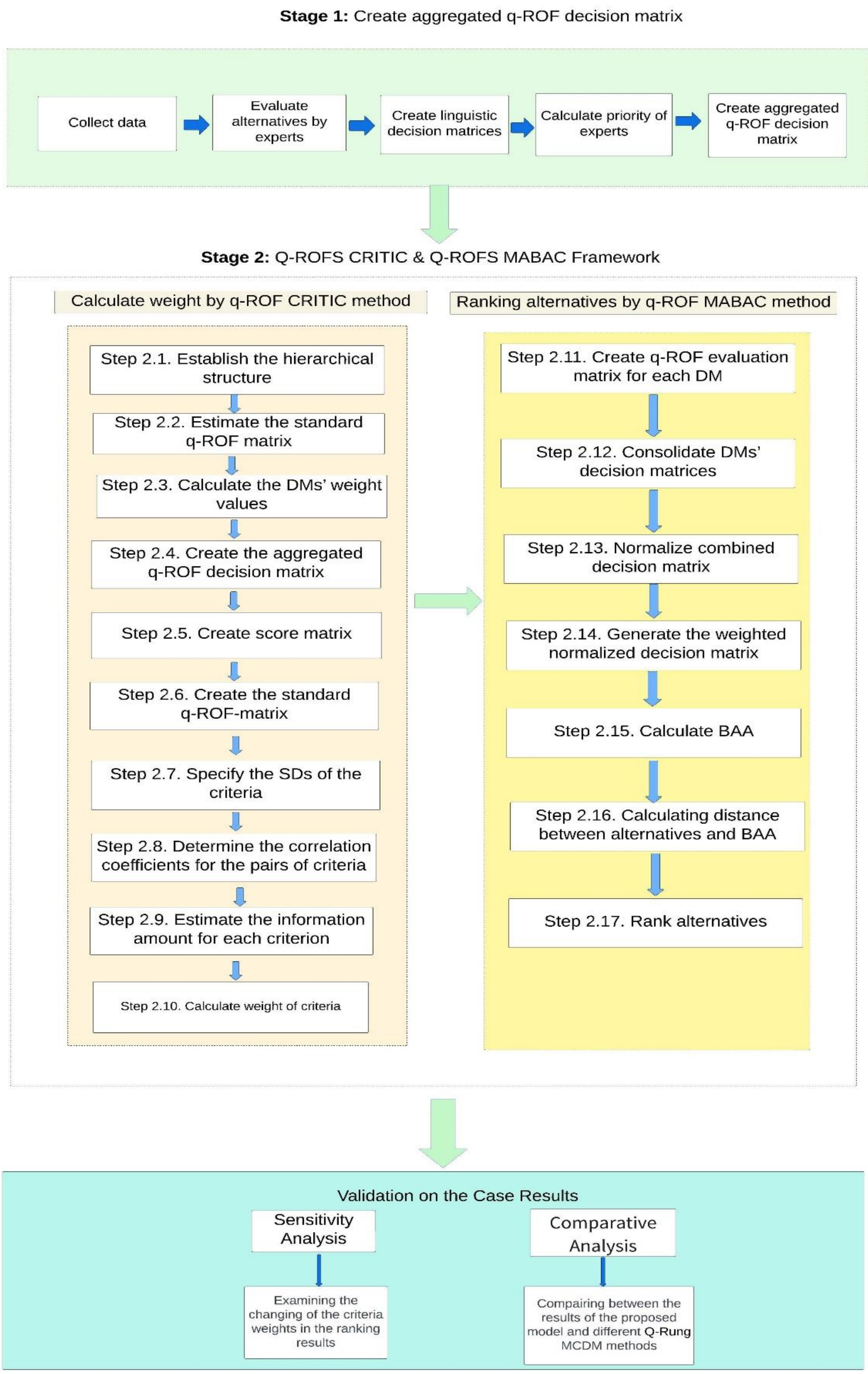


Figure 3. Framework of the developed methodology

The CRITIC method enhances the objectivity in weighting criteria by focusing on the most informative and uncorrelated factors, crucial in energy planning where economic, environmental, and social factors are at play. MABAC further ensures robust and systematic ranking of alternatives, even with incomplete data. The hybridization of q-ROFS with CRITIC and MABAC enhances decision accuracy, combining their strengths to handle uncertainties, determine objective criteria importance, and provide reliable rankings, making it essential for renewable energy decision-making.

Figure 3 depicts the research framework that includes three main stages and six substages. After data collection and preparation stage, the criterion weights are determined by employing combinative weighting method with q-ROFS CRITIC. q-ROFS MABAC method deploys to rank maintenance strategy selection. Thirdly, to validate the presented framework, sensitivity analyses and comparative analyses are conducted. In sensitivity analysis, one hundred supplementary scenarios were simulated by reducing the significance of the paramount criterion (criterion C) by 1% and adjusting the significance of the other two criteria. The criteria weights in the comparative analysis section were computed independently using q-ROF Grey Relational Analysis (q-ROF GRA) and q-ROF CODAS techniques. Spearman correlation analysis was implemented to assess the efficacy of the evaluation methodology in light of the updated rankings.

3.1. Q-Rung Orthopair Fuzzy Sets

Yager (2016) initially proposed the q-rung orthopair fuzzy set (q-ROFS) in order to create a preference framework that is more adaptable., enhancing the capacity for expert information evaluation. In this approach, Yager introduced a regulation parameter qqq, expanding the preference space through the condition $\mu^q + v^q \leq 1$, where (μ) denotes the membership degree and (v) the non-membership degree. For $q = 1$, the q-ROFS model reduces to intuitionistic fuzzy sets (IFS), while $q = 2$ yields Pythagorean fuzzy sets (PFS) (Gündoğdu et al., 2023; Aytekin et al., 2023; Krishankumar et al., 2021).

A q-ROFS B in a finite discourse universe $X = \{x_1, x_2, \ldots\ldots x_m\}$ is given by

$$B = \{ \langle x_i, (\mu_B(x_i), v_B(x_i)) \rangle | x_i \in X \}, \tag{1}$$

where $\mu_B(x_i) \in [0,1]$ stands for the belongingness degree and $v_B(x_i) \in [0,1]$ stands for the degree of non-belongingness of element $x_i \in X$ to set B given that $0 \leq (\mu_B(x_i)^q + v_B(x_i)^q) \leq 1$ where $q \geq 1$. In addition, the degree of indeterminacy is calculated as follows,

$\pi_B(x_i) = (1 - (\mu_B(x_i))^q + (v_B(x_i))^q)^{1/q}$. The q-ROFS B is reduced to $B = (\mu B(x), vB(x))$ which is called q-Rung Orthopair Fuzzy Number if the fixed set $X = \{x_1, x_2, \cdots, x_n\}$ has a single element $X = \{x\}$, Assume that $a = (\mu_a, v_a)$ and $b = (\mu_b, v_b)$ are two q-ROFNs. The operations are as follows (Aytekin et.al 2023: Gündoğdu et al. 2023; Ali 2018)

$$a \vee b = (max(\mu_a, \mu_b), min(v_a, v_b)),$$

$$a \wedge b = (min(\mu_a, \mu_b), max(v_a, v_b)),$$

$$a \oplus b = (\sqrt[q]{(\mu_a)^{q} + (\mu_b)^{q} - (\mu_a)^{q} (\mu_b)^{q}} , v_a v_b),$$

$$a \otimes b = (\mu_a, \mu_b, \sqrt[q]{(v_a)^{q} + (v_b)^{q} - (v_a)^{q} (v_b)^{q}}$$

$$ma = (\sqrt[q]{1 - (1 - (\mu_a)^q)^m}, (v_a)^{m}); \; m \geq 0,$$

$$a^{\lambda} = ((\mu_a)^{\lambda}, \sqrt[q]{1 - (1 - (v_a)^{q})^{\lambda}}; \lambda \geq 0$$

$(a)^{c} = (v_a, \mu_a),$

Consider $a = (\mu_{a,}, v_a)$ as a q-ROFN. The score $S(a)$ and accuracy $H(a)$ functions of a are calculated as follows (Wei et al. 2018):

$$S(a) = \frac{1}{2}(1 + (\mu_a)^{q} - (v_a)^{q}); \; S(a) \in [0, 1] \tag{2}$$

$$H(a) = (\mu_a)^{q} + (v_a)^{q} \; ; \; H(a) \in [0, 1] \tag{3}$$

Note that q-ROFNs depend directly on $S(a)$ and $H(a)$.

If $a = (\mu_{a,}, v_a)$ and $b = (\mu_{b,}, v_b)$ be two q-ROFNs, and $S(a)$ and $S(b)$and $H(a)$ and $H(b)$ are the score and accuracy functions of a and b, then we have (Wang et al. 2019):

(i) if $S(a) > S(b) \rightarrow a > b,$

(ii) if $S(a) = S(b) \; and \; H(a) > H(b) \rightarrow a > b,$

(iii) if $S(a) = S(b) \; and \; H(a) = H(b) \rightarrow a = b.$

The hamming distance, $hd(a, b)$, is a distance measure between two q-ROFNs, $a = (\mu_{a,}, v_a)$ and $b = (\mu_{b,}, v_b)$, which is calculated by Eq. (4):

$$hd(a,b) = \frac{1}{2}(|(\mu_a)^{q} - (\mu_b)^{q}| + |(v_a)^{q} - (v_b)^{q}| + |(\pi_a)^{q} - (\pi_b)^{q}|) \tag{4}$$

3.2 q-ROFS CRITIC Method

The CRITIC method was developed to objectively assign weights to criteria by factoring in the correlation coefficient and standard deviation (SD) (Diakoulaki et al., 1995). Yang et al. (2022) present a succinct explanation of the implementation of the q-ROF CRITIC methodology.

Step 1. Establish the hierarchical structure.

Step 2. Develop the decision matrix. Formulate the problem.

Let $O = \{O_1, O_2, ..., O_m\}$ signify a set of options and $C = \{C_1, C_2, ... C_m\}$ represent a set of criteria. The set of DMs , $\{D_1, D_2, ..., D_1\}$, offer their judgements on all choices O_i over the criteria C_j as "linguistic variables (LVs)". The decision matrix for the k^{th} decision maker (DM) in q-ROF context can be expressed as; $N = \left(\xi_{ij}^{(k)}\right)$, where $i = 1, \cdots, m, j = 1, \cdots, n$ and $k = 1, \cdots, l$.

Step 3. Calculation of the weight of DMs'.

The DMs' evaluations of the decision problem are assigned weights. The linguistic scale is given in Table 1. Assume that, $l_k = (\mu_k, v_k)$ stands for the rating of k^{th} DM defined with q-ROFN, then the weight of the k^{th} DM, λ_k will be calculated using Eq. (5):

$$\lambda_k = \frac{\frac{1}{2}\left((\mu_k^q - v_k^q)+1\right)}{\sum_{k=1}^{l}\left(\frac{1}{2}((\mu_k^q - v_k^q)+1\right)} \tag{5}$$

$\lambda_k \geq 0$ and $\sum_{k=1}^{1} \lambda_k = 1$.

Table 1. Linguistic scale for q-ROFNs for criteria (Alkan and Kahraman 2021).

Linguistic Terms	(μ, v)
Certainly high importance (CHI)	(0.99,0.11)
Very high importance (VHI)	(0.88,0.22)
High importance (HI)	(0.77,0.33)
Above average importance (AAI)	(0.66,0.44)
Average importance (AI)	(0.55,0.55)
Under average importance (UAI)	(0.44,0.66)
Low importance (LI)	(0.33,0.77)
Very low importance (VLI)	(0.22,0.88)
Certainly low importance (CLI)	(0.11,0.99)

Step 4. The aggregated q-ROF decision matrix is obtained.

$$\xi_{ij} = (\mu_{ij}, v_{ij}) = q - ROFWA_\lambda\left(\xi_{ij}^{(1)}, \xi_{ij}^{(2)}, \ldots\ldots. \xi_{ij}^{(l)}\right)$$

$$= \left(\sqrt[q]{1 - \prod_{k=1}^{l} (1 - (\mu_k^q)^{\lambda_k}} , \ \prod_{k=1}^{l} (v_k)^{\lambda_k} \right) \tag{6}$$

Step 5. Create score matrix $S = (x_{ij})_{mxn}$ with Eq. (7)

$$x_{ij} = \frac{1}{2}\left(\left(\mu_{ij}^q - v_{ij}^q\right) + 1\right) \tag{7}$$

Step 6. Determine the standard q-ROF-matrix $\tilde{S} = (\tilde{x}_{ij})_{mxn}$ where

$$\tilde{x}_{\overline{ij}} = \begin{cases} \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, \ j \in C_b \\ \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}, \ j \in C_n \end{cases} \tag{8}$$

Here, $x_j^+ = \underset{i}{max}\, x_{ij}$ and $x_j^- = \underset{i}{min}\, x_{ij}$.

Step 7. Specify the SDs of the criteria with Eq. (9)

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m} (\tilde{x}_{ij} - \bar{x}_j)^2}{m}}, \text{ where } \bar{x}_j = \sum_{i=1}^{m} \ \tilde{x}_{ij}/m \tag{9}$$

Step 8. Determine correlation coefficients for the pairs of criteria.

$$r_{jt} = \frac{\sum_{i=1}^{m} (\tilde{x}_{ij} - \bar{x}_j)(\tilde{x}_{it} - \bar{x}_t)}{\sqrt{\sum_{i=1}^{m} (\tilde{x}_{ij} - \bar{x}_j)^2 \ \sum_{i=1}^{m} (\tilde{x}_{it} - \bar{x}_t)^2}} \tag{10}$$

Step 9. Estimate the information amount for each criterion with Eq. (11)

$$c_j = \sigma_j \ \sum_{i=1}^{n} \left(1 - r_{jt}\right) \tag{11}$$

Step 10. Find the criteria weights using Eq. (12)

$$w_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \tag{12}$$

3.3. q-ROFS MABAC Method

The MABAC model was defined and introduced to the literature by Pamučar and Ćirović (Pamučar & Ćirović, 2015). In the MABAC, the first step is to establish the criterion functions for each decision alternative and the distances of these functions to the Border Approximation Area (BAA). Subsequently, the choice alternatives are prioritized, and the optimal alternative is chosen. (Pamučar & Ćirović, 2015). The MABAC model has many advantages such as consistency, and simplicity. Additionally, it considers the hidden values of losses and gains, and it can be integrated with other views. Therefore, the MABAC method is a good tool for obtaining acceptable decisions (Turan & Boran, 2022). The steps for the q-ROF MABAC method are as follows:

Step 1. Create q-ROF evaluation matrix for each DM.

$$R^k = \left[A_{ij}{}^k\right]_{mxn} = R^k = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{pmatrix} (\mu_{11}^k, v_{11,}^k) & \cdots & \mu_{1n}^k, v_{1n,}^k \\ \vdots & \ddots & \vdots \\ (\mu_{m1}^k, v_{m1,}^k) & \cdots & \mu_{mn}^k, v_{mn,}^k \end{pmatrix} \tag{13}$$

where $A_{ij}{}^k = (\mu_{ij}^k ; v_{ij,}^k)$ defines the q-ROF knowledge of alternative on criteria $C_j{}^k$ by DM k.

Step 2. Consolidate DMs' decision matrices.

DM's evaluation matrices are integrated using q-ROFWA (q-ROF Weighted Average) or q-ROFWG (g-ROF Weighted Geometric) aggregating operators using with Eq. (14).

$$r = \left[A_{ij}\right]_{mxn} = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{pmatrix} (\mu_{11}^k, v_{11,}^k) & \cdots & \mu_{1n}^k, v_{1n,}^k \\ \vdots & \ddots & \vdots \\ (\mu_{m1}^k, v_{m1,}^k) & \cdots & \mu_{mn}^k, v_{mn,}^k \end{pmatrix} \tag{14}$$

Step 3. Normalize the combined decision matrix with Eq. (15) and Eq. (16).

For benefit criteria; $N_{ij} = A_{ij} = (\mu_{ij} ; v_{ij})$ (15)

For cost criteria; $N_{ij} = (A_{ij})^{cost} = (v_{ij} ; \mu_{ij})$ (16)

Step 4. Generate the weighted normal decision matrix. Consider the normalised matrix N_{ij} and criteria weights vector w_j, the weighted normalized matrix WN_{ij}=(μ'_{ij} ; v'_{ij}) can be found with Eq. (17).

$$WN_{ij} = w_j \otimes N_{ij} = \left(\sqrt[q]{1-(1-\mu_{ij}^q)^{w_j}} ; v_{ij}^{w_j}\right) \tag{17}$$

Step 5. Estimate the values of BAA and the BAA matrix $G = \left[g_j\right]_{lxn}$

$$g_j = \left(\prod_{i=1}^m WN_{ij}\right)^{1/m} = \left\{\left(\prod_{i=1}^m (\mu'_{ij}\right)^{1/m} ; \sqrt[q]{1-\prod_{j=1}^n (1-v_{ij}^q)^{1/m}}\right\} \tag{18}$$

Step 6. Determine the distance $D = \left[d_{ij}\right]_{mxn}$ between alternatives and BAA by using Eq. (19).

$$d_{ij} = \begin{cases} d\,(WN_{ij}, g_j) & if \;\; WN_{ij} > g_j \\ 0, & WN_{ij} = g_j \\ -\,d\,(WN_{ij}, g_j) & if \;\; WN_{ij} < g_j \end{cases} \tag{19}$$

where d(WN_{ij}, g_j) is the distance from WN_{ij} to g_j. $d_{q-ROFNHD_{WN_{ij},g_j}}$, is calculated with q-Rung Orthopair fuzzy normalized Hamming distance measure. The formula is given in Eq. (20).

$$d_{q-ROFNHD_{WN_{ij},g_j}} = \frac{1}{2}\left\{\left|(\mu_{WN_{ij}})^q - (\mu_{g_j})^q\right| + \left|(v_{WN_{ij}})^q - (v_{g_j})^q\right| + \left|(\gamma_{WN_{ij}})^q - (\gamma_{g_j})^q\right|\right\} \quad (20)$$

Next, the indeterminacy degree γ_p (x) can be derived by Eq. (21).

$$\gamma_p (x) = \sqrt[q]{1 - ((\mu_p (x))^q + (v_p (x))^q)} \quad (21)$$

Step 7. Lastly, find the sum of distance values of alternatives, d_{ij}. As a result, the bigger the score, the better the choice.

$$S_i = \sum_{j=1}^{n} d_{ij} \quad (22)$$

4. Sustainable Renewable Energy Source Assessment in Türkiye

4.1 Application of q-ROFS CRITIC Method

The evaluation criteria were established by a comprehensive literature review. Upon reviewing the criteria with the decision-makers, the evaluation criteria list was finalized. The experts contacted in this study mostly consist of senior managers and academics with extensive experience in the energy sector. Table A1 presents a detailed enumeration of criteria, together with their definitions and citations.

Step 1. To build the decision frame, we define the hierarchical structure that consists of four main criteria and 22 sub-criteria (see Figure 4).

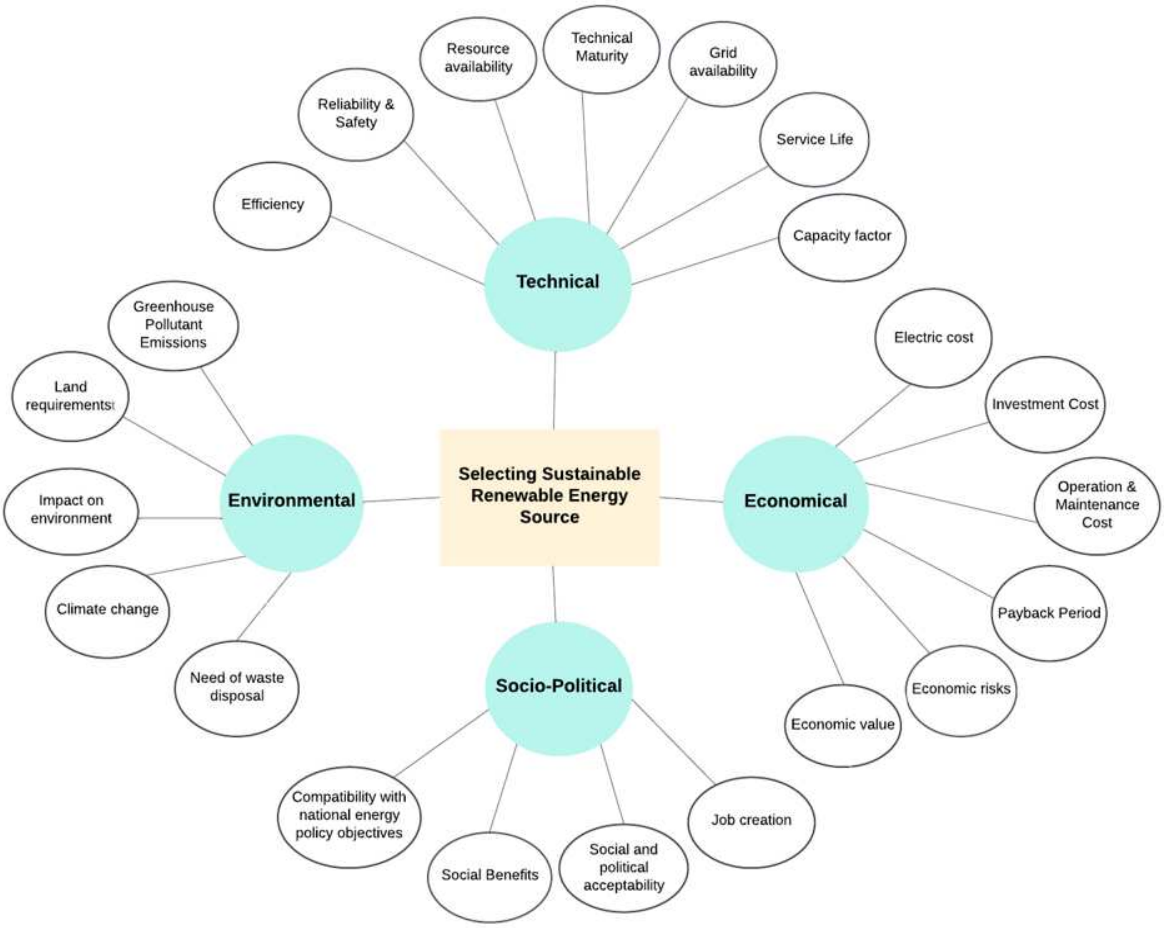


Figure 4. Suggested hierarchy for selecting sustainable renewable energy

Step 2-3. The decision matrix $N = \left(\xi_{ij}^{(k)}\right),\ k = 1, .., 5$ of q-ROFNs is defined by each DM, $DM_1, DM_2, \dots, DM_5$, as in Appendix Table A2.

Step 4. The q-ROF decision matrix is $N = \left(\xi_{ij}\right)_{mxn}$ provided in Table 2 with using Eq. (6) and Table A2. To derive the aggregated q-ROF decision matrix, we set q = 3.

Table 2. q-ROF-decision matrix

Criteria	**(WI)**		**(SE)**		**(GE)**		**(BI)**		**(WA)**		**(HC)**		**(HN)**	
C1	0.43	0.70	0.46	0.67	0.53	0.58	0.71	0.43	0.44	0.67	0.68	0.47	0.59	0.52
C2	0.73	0.40	0.61	0.50	0.55	0.56	0.56	0.59	0.57	0.57	0.65	0.49	0.48	0.63
C3	0.66	0.49	0.53	0.59	0.63	0.49	0.73	0.40	0.57	0.57	0.75	0.37	0.48	0.63
C4	0.63	0.49	0.60	0.54	0.56	0.56	0.59	0.53	0.55	0.56	0.57	0.57	0.53	0.58
C5	0.41	0.72	0.41	0.72	0.61	0.53	0.72	0.39	0.48	0.66	0.61	0.53	0.59	0.53
C6	0.70	0.41	0.68	0.43	0.64	0.47	0.66	0.45	0.75	0.37	0.70	0.41	0.70	0.41
C7	0.70	0.41	0.66	0.45	0.68	0.43	0.70	0.41	0.76	0.36	0.72	0.39	0.70	0.41
C8	0.60	0.50	0.56	0.55	0.58	0.53	0.60	0.50	0.64	0.47	0.64	0.47	0.62	0.50
C9	0.56	0.56	0.56	0.56	0.56	0.56	0.57	0.54	0.62	0.48	0.60	0.52	0.67	0.44
C10	0.60	0.50	0.60	0.50	0.60	0.50	0.61	0.50	0.62	0.48	0.61	0.50	0.66	0.45
C11	0.55	0.58	0.57	0.55	0.56	0.55	0.58	0.53	0.58	0.53	0.60	0.50	0.64	0.47
C12	0.66	0.45	0.67	0.43	0.63	0.49	0.64	0.47	0.66	0.45	0.66	0.45	0.66	0.45
C13	0.60	0.52	0.59	0.52	0.60	0.50	0.63	0.49	0.66	0.45	0.67	0.43	0.69	0.43
C14	0.73	0.40	0.73	0.40	0.68	0.43	0.70	0.41	0.79	0.32	0.71	0.42	0.67	0.46
C15	0.59	0.52	0.64	0.47	0.58	0.53	0.66	0.45	0.68	0.44	0.64	0.47	0.73	0.37
C16	0.63	0.49	0.63	0.49	0.57	0.54	0.63	0.49	0.64	0.47	0.64	0.47	0.64	0.47
C17	0.60	0.50	0.60	0.50	0.58	0.53	0.56	0.55	0.62	0.50	0.66	0.45	0.66	0.45
C18	0.59	0.52	0.60	0.50	0.58	0.53	0.58	0.53	0.60	0.50	0.64	0.47	0.68	0.43
C19	0.61	0.50	0.61	0.50	0.62	0.48	0.67	0.43	0.64	0.47	0.62	0.48	0.70	0.41
C20	0.63	0.49	0.64	0.47	0.66	0.45	0.66	0.45	0.53	0.57	0.59	0.52	0.66	0.52
C21	0.59	0.52	0.61	0.50	0.62	0.48	0.67	0.43	0.55	0.55	0.60	0.50	0.61	0.50
C22	0.56	0.56	0.52	0.61	0.57	0.54	0.64	0.47	0.56	0.55	0.66	0.46	0.51	0.00

Step 5-6. The score matrix and standard decision matrix are calculated with Eq. (7) and Eq. (8).

Step 7-8-9-10. Next, using Eqs. (9)-(11), the standard deviation (σ_j), correlation coefficient (C_j) and amount of information of each criteria are estimated. Using Eq. (12) criteria weights (w_j) are calculated and are shown in Table 3.

Table 3. The standard q-ROF-matrix SD, criteria weights.

	(WI)	**(SE)**	**(GE)**	**(BI)**	**(WA)**	**(HC)**	**(HN)**	σ_j	C_j	w_j
C1	1.0	3.0	4.0	7.0	2.0	6.0	5.0	0.53	10.41	0.04
C2	1.0	6.0	4.0	3.0	5.0	7.0	1.0	0.33	5.94	0.02
C3	1.0	3.0	5.0	6.0	4.0	7.0	2.0	0.42	7.35	0.03
C4	1.0	7.0	4.0	6.0	3.0	5.0	1.0	0.35	6.26	0.03
C5	1.0	2.0	5.0	7.0	3.0	5.0	4.0	0.53	9.96	0.04
C6	1.0	4.0	2.0	3.0	7.0	5.0	5.0	0.60	12.79	0.05
C7	1.0	2.0	3.0	4.0	7.0	6.0	4.0	0.59	11.70	0.05
C8	1.0	2.0	3.0	4.0	6.0	6.0	5.0	0.64	13.23	0.05
C9	1.0	2.0	2.0	4.0	6.0	5.0	7.0	0.66	15.01	0.06
C10	5.0	5.0	5.0	3.0	2.0	3.0	1.0	0.64	13.33	0.05
C11	1.0	3.0	2.0	4.0	4.0	6.0	7.0	0.64	14.35	0.06
C12	2.0	1.0	7.0	6.0	2.0	2.0	2.0	0.48	9.24	0.04
C13	6.0	7.0	5.0	4.0	3.0	2.0	1.0	0.65	13.86	0.06
C14	3.0	2.0	6.0	5.0	1.0	4.0	7.0	0.44	9.88	0.04
C15	6.0	5.0	7.0	3.0	2.0	4.0	1.0	0.60	12.19	0.05
C16	5.0	5.0	7.0	4.0	2.0	1.0	2.0	0.64	13.54	0.05

C17	4.0	4.0	6.0	7.0	3.0	2.0	1.0	0.54	10.39	0.04
C18	5.0	3.0	6.0	6.0	3.0	2.0	1.0	0.55	11.10	0.04
C19	6.0	6.0	4.0	2.0	3.0	4.0	1.0	0.58	12.64	0.05
C20	5.0	3.0	1.0	1.0	7.0	6.0	4.0	0.53	12.47	0.05
C21	6.0	3.0	2.0	1.0	7.0	5.0	3.0	0.47	11.10	0.04
C22	6.0	7.0	4.0	2.0	5.0	1.0	3.0	0.54	12.96	0.05

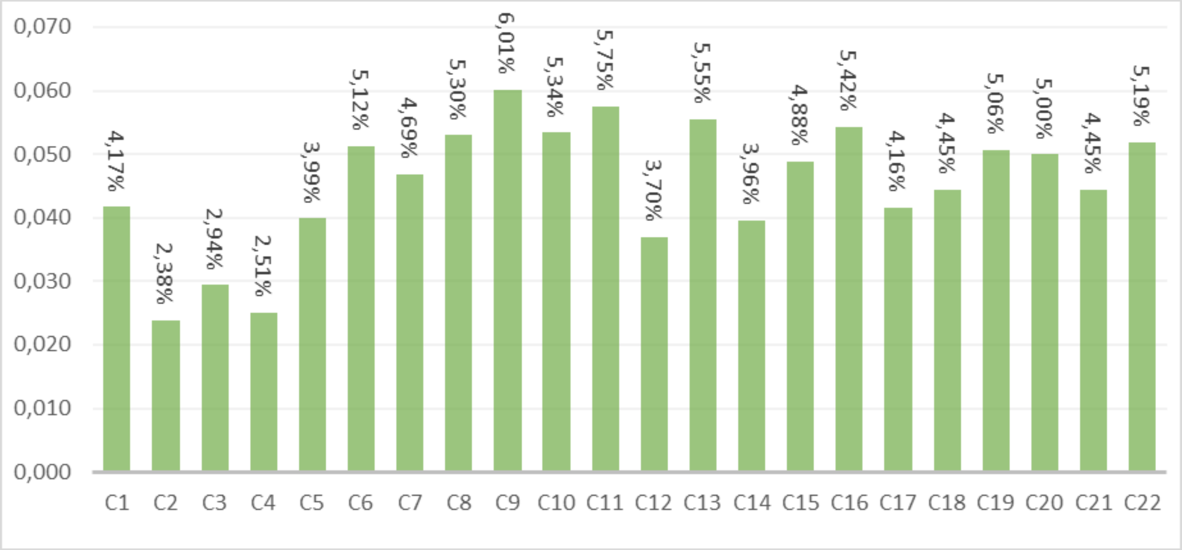


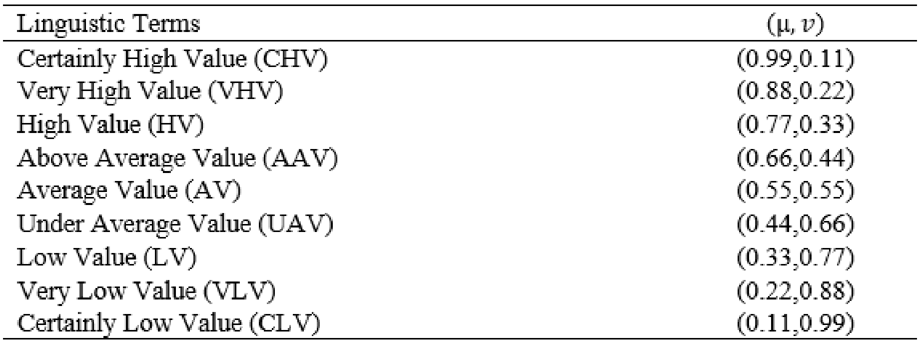
Figure 5. Relative importance of criteria obtained with the CRITIC technique

As illustrated in Table 3 and Figure 5, economic risks (C9) are identified as the most significant factor, with a weight of 0.06. Conversely, land requirements (C2) are considered the least influential factor, Its weight is 0.024. The remaining criteria are ordered as follows: C9≻C11≻C13≻C16≻C10≻C8≻C22≻C6≻C19≻C20≻C15≻C7≻C18≻C21≻C1≻C17≻C5 ≻C14≻C12≻C3≻C4≻C2.

4.2 Application of q-ROFS MABAC Method

Subsequently, the decision-makers evaluate the available alternatives in the context of a real-world case study. Following the determination of the q-ROFS weights during the preceding step, the ranking of the alternatives was conducted using q-ROFS MABACThe individual ratings of five experts were collected in this study. The linguistic scale used is shown in Table 4.

Table 4. Linguistic scale for q-ROFNs for alternatives. (Alkan and Kahraman 2021).



Linguistic Terms	(μ, v)
Certainly High Value (CHV)	(0.99,0.11)
Very High Value (VHV)	(0.88,0.22)
High Value (HV)	(0.77,0.33)
Above Average Value (AAV)	(0.66,0.44)
Average Value (AV)	(0.55,0.55)
Under Average Value (UAV)	(0.44,0.66)
Low Value (LV)	(0.33,0.77)
Very Low Value (VLV)	(0.22,0.88)
Certainly Low Value (CLV)	(0.11,0.99)

Firstly, they were asked to select the most appropriate linguistic for evaluating each alternative based on each criterion. As shown in Table 4, these linguistic terms were mapped to the corresponding q-ROFS.The energy source options are listed as follows: (WI), (SE), (GE), (BI), (WA), (HC), and (HN).

Step 1. Construction of a q-ROF evaluation matrix for each decision maker. Firstly, subjective evaluations of experts on renewable energy alternatives are collected. The linguistic variable scores are converted into q-ROF scores using Table 4 and presented in Table A3.

Step 2. Creation of combined the decision matrix with the opinions of the experts. The combined q-ROF decision matrix in Table 5 is obtained by combining the opinions of five experts with the q-ROFWA operator presented in Eq. (14). This table presents the aggregated opinions of five experts on different renewable energy sources. It shows their evaluations for each criterion, using membership (μ) and non-membership (v) values for each criterion (C1 to C22). The values represent how well each energy alternative meets each of the 22 criteria, where lower v and higher μ are preferable. For example, the entry for Wind (WI) under Criterion C1 is $\mu=0.43$, $v=0.70$, indicating moderate membership and relatively high non-membership in satisfying C1.

Table 5. The Combined q-ROF Decision Matrix (*rij*)

	C1		**C2**		**C3**		**C4**		**C5**		**C6**		**C7**		**C8**	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
WI	0.43	0.70	0.73	0.40	0.66	0.49	0.63	0.49	0.41	0.72	0.70	0.41	0.70	0.41	0.60	0.50
SE	0.46	0.67	0.61	0.50	0.53	0.59	0.60	0.54	0.41	0.72	0.68	0.43	0.66	0.45	0.56	0.55
GE	0.53	0.58	0.55	0.56	0.63	0.49	0.56	0.56	0.61	0.53	0.64	0.47	0.68	0.43	0.58	0.53
BI	0.71	0.43	0.56	0.59	0.73	0.40	0.59	0.53	0.67	0.46	0.66	0.45	0.70	0.41	0.60	0.50
WA	0.44	0.67	0.57	0.57	0.57	0.57	0.55	0.56	0.48	0.66	0.75	0.37	0.76	0.36	0.64	0.47
HC	0.68	0.47	0.65	0.49	0.75	0.37	0.57	0.57	0.61	0.53	0.70	0.41	0.72	0.39	0.64	0.47
HN	0.59	0.52	0.48	0.63	0.48	0.63	0.53	0.58	0.59	0.53	0.70	0.41	0.70	0.41	0.62	0.50
	C9		**C10**		**C11**		**C12**		**C13**		**C14**		**C15**			
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν		
WI	0.56	0.56	0.60	0.50	0.55	0.58	0.66	0.45	0.60	0.52	0.73	0.40	0.61	0.50		
SE	0.56	0.56	0.60	0.50	0.57	0.55	0.67	0.43	0.59	0.52	0.74	0.38	0.64	0.47		

GE	0.56	0.56	0.60	0.50	0.56	0.55	0.63	0.49	0.60	0.50	0.68	0.43	0.60	0.50
BI	0.57	0.54	0.61	0.50	0.58	0.53	0.64	0.47	0.63	0.49	0.70	0.41	0.66	0.45
WA	0.62	0.48	0.62	0.48	0.58	0.53	0.66	0.45	0.66	0.45	0.77	0.34	0.68	0.44
HC	0.60	0.52	0.61	0.50	0.60	0.50	0.66	0.45	0.64	0.46	0.73	0.40	0.64	0.47
HN	0.67	0.44	0.66	0.45	0.64	0.47	0.66	0.45	0.69	0.43	0.70	0.41	0.68	0.44
	C16		**C17**		**C18**		**C19**		**C20**		**C21**		**C22**	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
WI	0.63	0.49	0.60	0.50	0.59	0.52	0.61	0.50	0.63	0.49	0.59	0.52	0.56	0.56
SE	0.63	0.49	0.60	0.50	0.60	0.50	0.61	0.50	0.64	0.47	0.61	0.50	0.52	0.61
GE	0.57	0.54	0.58	0.53	0.58	0.53	0.62	0.48	0.66	0.45	0.62	0.48	0.57	0.54
BI	0.64	0.47	0.56	0.55	0.58	0.53	0.67	0.43	0.66	0.45	0.67	0.43	0.64	0.47
WA	0.70	0.41	0.62	0.50	0.58	0.53	0.60	0.50	0.60	0.52	0.55	0.55	0.56	0.55
HC	0.66	0.45	0.66	0.45	0.64	0.47	0.62	0.48	0.59	0.52	0.60	0.50	0.66	0.46
HN	0.70	0.41	0.66	0.45	0.67	0.45	0.67	0.43	0.66	0.45	0.57	0.54	0.58	0.53

Step 3. The aggregated decision matrix is normalized using the formulas specified in equations (17) and (18), with adjustments made based on the type of each criterion. Table A4 shows the normalized decision matrix.

Step 4: Using the normalized values *Nij* and the criterion weights, w_j, the elements of the weighted normalized matrix, WN_{ij}, are determined as Equation (17). The outcomes are displayed in Table A5.

Step 5. Calculate the BAA. The Border Approximation Area (BAA) represents ideal values for comparison in decision-making. The μ and v values for each criterion (C1 to C22) describe the boundary of the decision-making space. In this context, it provides the reference values against which the alternatives can be compared to determine their proximity to the ideal solution. The corresponding matrix is shown in Table 6.

Table 6. The Border Approximation Area (BAA)

	C1		**C2**		**C3**		**C4**		**C5**		**C6**		**C7**		**C8**	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
g_j	0.30	0.98	0.25	0.99	0.25	0.99	0.26	0.99	0.31	0.98	0.23	0.98	0.22	0.98	0.28	0.97
	C9		**C10**		**C11**		**C12**		**C13**		**C14**		**C15**			
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν		
g_j	0.30	0.97	0.34	0.96	0.30	0.97	0.34	0.97	0.36	0.96	0.39	0.96	0.36	0.96		
	C16		**C17**		**C18**		**C19**		**C20**		**C21**		**C22**			
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν		
g_j	0.36	0.96	0.33	0.97	0.33	0.97	0.35	0.96	0.35	0.96	0.33	0.97	0.33	0.97		

Step 6: The distances between each alternative and the BAA are calculated using Equation (21), with the results detailed in Table 7. This table displays the distance of each energy source alternative from the BAA across all criteria. A larger distance indicates a closer alignment with the ideal solution.

Table 7. Distances to the BAA

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
WI	0.041	0.018	0.004	0.008	0.043	0.002	0.001	0.001	0.012	0.004	0.014
SE	0.034	0.009	0.014	0.004	0.043	0.002	0.007	0.009	0.012	0.004	0.007
GE	0.017	0.011	0.002	0.004	0.024	0.009	0.003	0.006	0.012	0.004	0.009
BI	0.036	0.012	0.012	0.004	0.033	0.006	0.001	0.001	0.009	0.003	0.005
WA	0.036	0.010	0.010	0.005	0.027	0.009	0.007	0.006	0.011	0.004	0.005
HC	0.031	0.011	0.014	0.004	0.024	0.002	0.003	0.006	0.005	0.003	0.009
HN	0.020	0.020	0.022	0.007	0.022	0.002	0.001	0.002	0.019	0.012	0.015

	C12	**C13**	**C14**	**C15**	**C16**	**C17**	**C18**	**C19**	**C20**	**C21**	**C22**
WI	0.001	0.013	0.002	0.012	0.009	0.002	0.005	0.008	0.004	0.005	0.009
SE	0.005	0.015	0.005	0.006	0.009	0.002	0.002	0.008	0.004	0.003	0.018
GE	0.007	0.011	0.009	0.013	0.021	0.006	0.007	0.004	0.008	0.007	0.006
BI	0.002	0.006	0.005	0.008	0.004	0.010	0.007	0.014	0.008	0.018	0.018
WA	0.001	0.012	0.015	0.013	0.020	0.001	0.007	0.009	0.009	0.011	0.007
HC	0.001	0.010	0.002	0.004	0.008	0.010	0.009	0.004	0.011	0.002	0.022
HN	0.001	0.022	0.005	0.013	0.020	0.010	0.016	0.014	0.008	0.008	0.005

Step 7: Finally, the total distance for each alternative is computed using Equation (22). The aggregated results are shown in Table 8, highlighting the overall distance (S_i) of each energy source from the ideal solution by summing distances across all criteria. Among the evaluated options, hydrogen emerges as the top-performing energy alternative, whereas hydraulic scores the lowest.

Table 8. S_i values and Ranking of Decision Alternatives

Alternative	**Si**	**Rank**
Wind (WI)	0.218	5
Solar Energy (SE)	0.224	3
Geothermal (GE)	0.200	6
Biomass (BI)	0.223	4
Wave (WA)	0.237	2
Hydraulic (HC)	0.194	7
Hydrogen (HN)	0.264	1

A nomenclature table is added to the Appendix to increase the readability of mathematical formulations (See Table A6).

4.3. Sensitivity Analysis

This section employs an algorithm developed by Gorcun et al. (2021) that efficiently assesses the impact of adjusting each criterion's weight individually. It considers all possible scenarios related to shifts in ranking results. This approach serves as a robust tool for testing the reliability of the decision-making method. In total, one hundred alternative scenarios were generated by reducing the weight of the most critical criterion (C9) by 1% and adjusting the weights of other criteria accordingly. The updated criterion values for each scenario are calculated using Equations (23) and (24).

$$w_{nv} = w_{pv} - (w_{pv}.\%\alpha_v) \tag{23}$$

$$w'_{nv} = \frac{(1-w_{nv})}{m-1} + w'_{pv} \tag{24}$$

Here, w_{nv} represents the updated weight of the v^{th} factor, while w_{pv} denotes the prior value of the criterion, The percentage adjustment, $\%\alpha_v$ is the modification degree. Additionally, w'_{nv} stands for the adjusted weights of the other factors, where *m* refers to the total number of factors, w'_{pv} is the previous values of the remaining criteria. We determined the respective ranking performances of the alternatives concerning the scenarios in Figure 6.

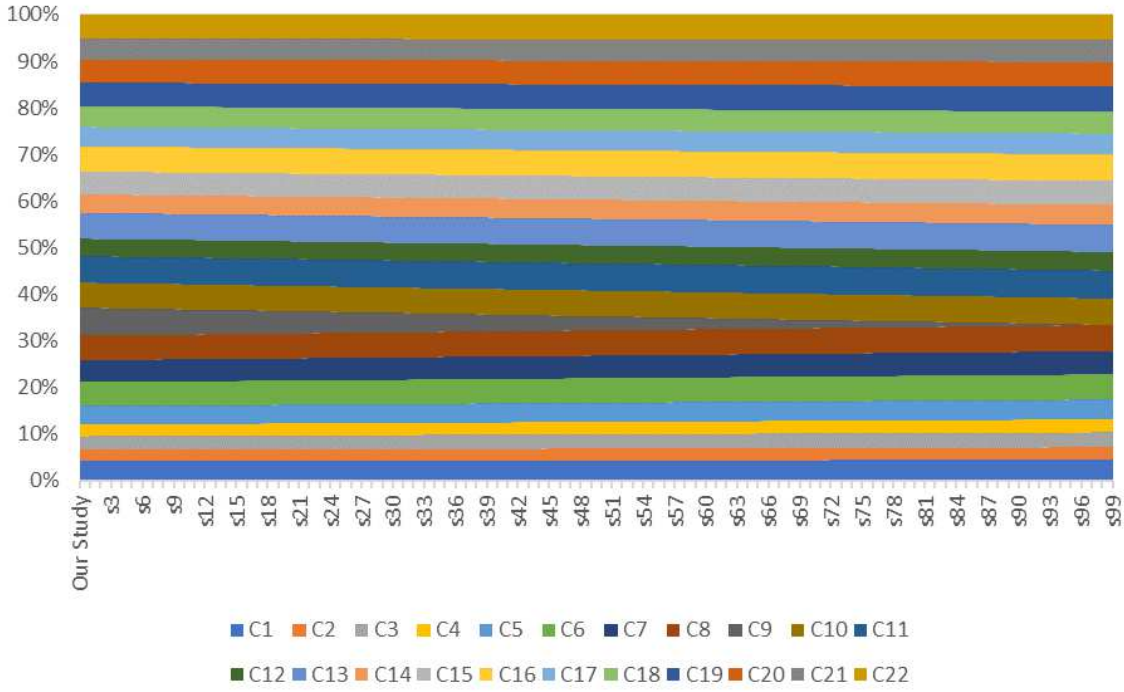


Figure 6. The simulated criteria importance scenarios.

The new ranking results are shown in Figure 7 that confirms hydrogen energy and wave energy are consistently ranked first and second across all scenarios. This result underscores the model's reliability and robustness in handling variations in criteria weightings. Despite changes in the relative importance of different evaluation criteria, the ranking of these two energy sources remains unchanged. This indicates that the q-ROFS CRITIC-MABAC model provides stable and robust results, offering decision-makers confidence in the reliability of the conclusions drawn from the analysis.

The minimal changes in the ranking of other energy sources, such as solar, wind, and biomass, further emphasize the model's resilience to weight fluctuations. The outcomes are not overly sensitive to shifts in criteria importance, meaning that the model delivers consistent recommendations even when different decision-makers or experts prioritize criteria differently. This robustness ensures that the final decisions derived from this model are trustworthy and can withstand the subjective nature of weight assignment in multi-criteria decision-making processes.

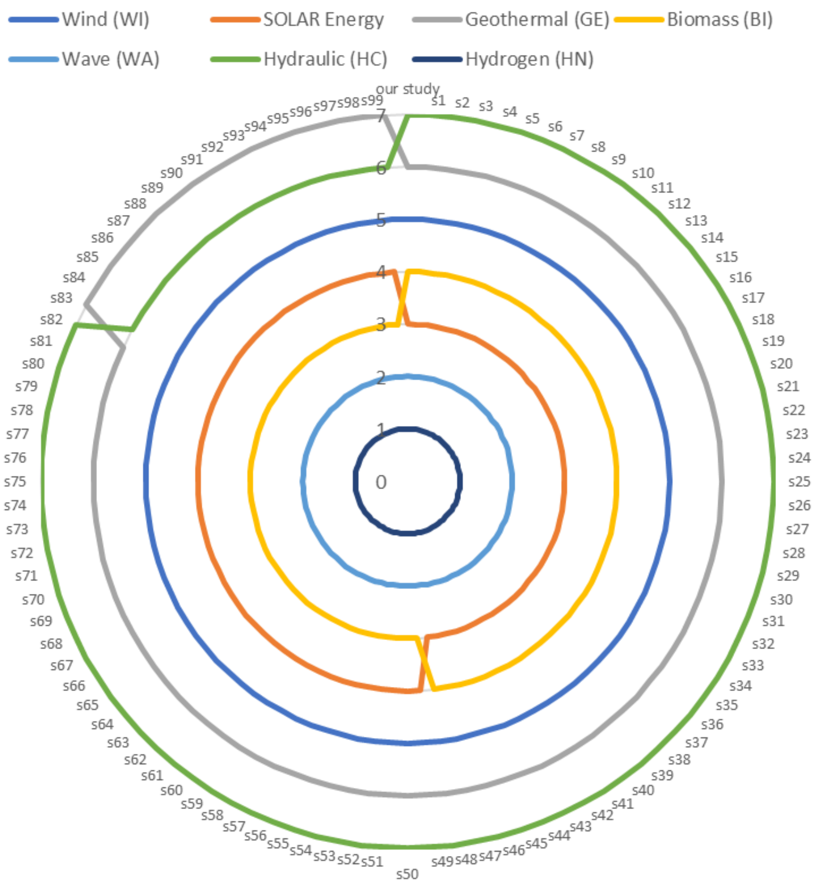


Figure 7. The result of the sensitivity analysis

4.4. Comparative Analysis

In this section, a comparative evaluation is carried out to assess the validity, efficiency and robustness of the proposed q-Rung Orthopair Fuzzy CRITIC & MABAC framework. To this end, we applied the q-ROF Grey Relational Analysis (q-ROF GRA) and q-ROF CODAS. All these approaches were implemented on the same decision problemAs can be seen in Table 9, the rankings obtained by these three methods are slightly different. Using the presented q-Rung

Orthopair Fuzzy CRITIC & MABAC, q-Rung Orthopair Fuzzy CRITIC & GRA, q-Rung Orthopair Fuzzy CRITIC &CODAS methods. The same result is visualised in Figure 8.

Table 9. Rankings with different ranking methods

	q-Rung Orthopair Fuzzy CRITIC & MABAC	q-Rung Orthopair Fuzzy CRITIC & GRA	q-Rung Orthopair Fuzzy CRITIC & CODAS
Alternatives	Rank	Rank	Rank
(WI)	5	4	2
(SE)	3	2	4
(GE)	6	6	5
(BI)	4	5	6
(WA)	2	3	3
(HC)	7	7	7
(HN)	1	1	1

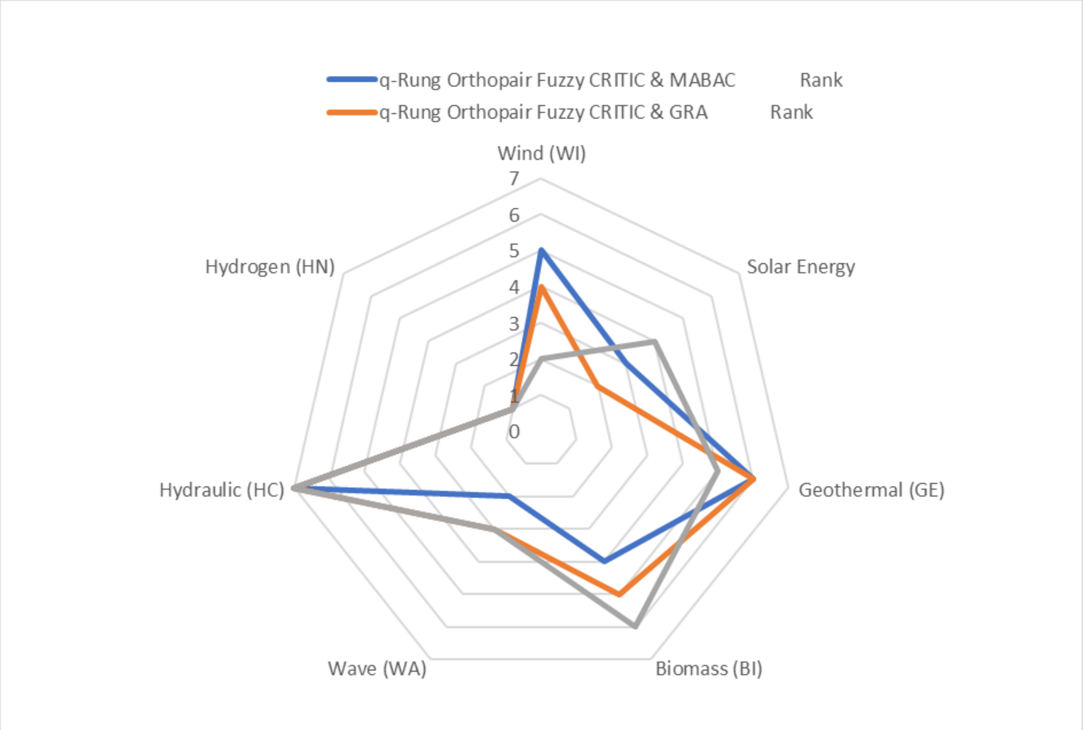


Figure 8. The graphical depiction of the comparative analysis

We also calculated Spearman's correlation coefficients between the rankings obtained using the different methods. Figure 9 is generated with Python and demonstrates the heat map of Spearman's rank correlation coefficients.

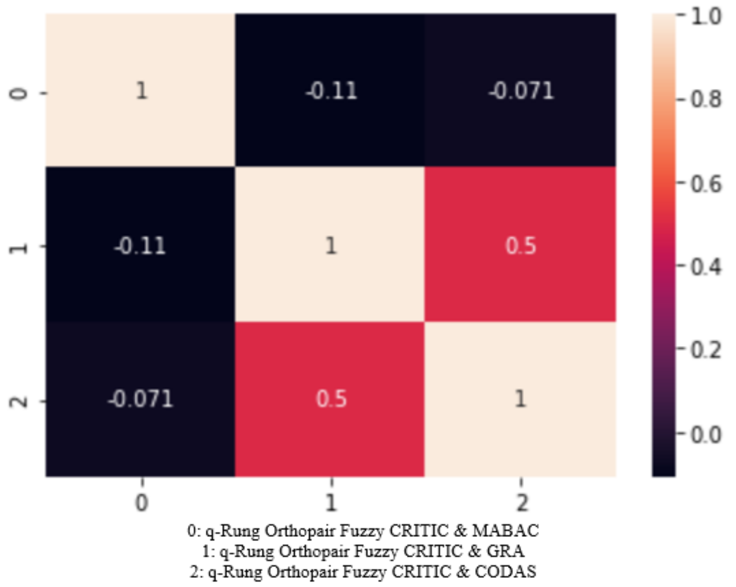


Figure 9. The Spearman correlation coefficients between different methods

5. Discussion and Managerial Implications

With its strategic geographic location and varied energy requirements, Türkiye faces a critical decision in selecting optimal energy resources to address its increasing demand while minimizing greenhouse gas emissions. However, the selection process is multifaceted. To make an informed decision, policymakers and stakeholders should draw on comprehensive feasibility studies, technological assessments, and energy modelling. A holistic approach, considering factors such as energy security, environmental impacts, and economic viability, will be essential in shaping Türkiye's energy future. Diversifying energy sources is crucial for reaching these aims. Our study also found evidence supporting diversity, with renewable energy options like hydrogen, wave, biomass, and solar gaining prominence.

The Ministry of Energy and Natural Resources of the Republic of Türkiye has published the Turkish national energy plan for the year 2022. The plan proposed "The Türkiye Energy Model" outlining the country's energy needs until 2035 and providing the composition of alternative energy sources to meet these needs (Ministry of Energy and Natural Resources, 2022).

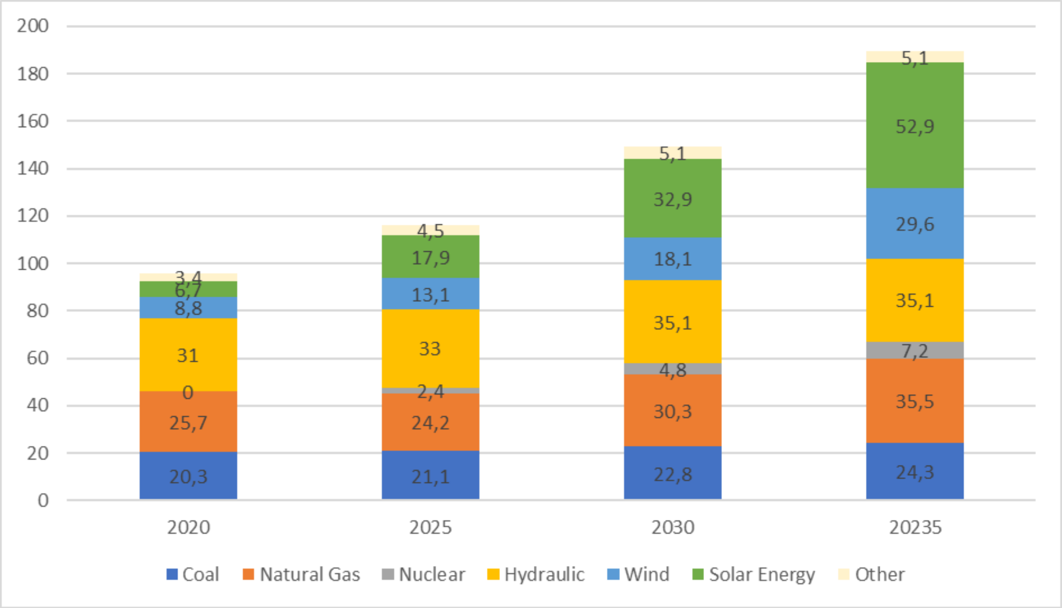


Figure 10. Estimate of the installed power according to Türkiye's energy resources (GW)

Upon detailed examination of Figure 10, it can be observed that solar, wind, and nuclear energy will replace coal and natural gas. Similarly, a decrease is expected in the hydraulic energy source. Evaluating these figures reveals that Türkiye's energy supply is expected to increasingly shift towards environmentally friendly sources like wind and solar. However, a major drawback of these resources is their vulnerability to seasonal changes and abrupt fluctuations in energy production (Karayel et al., 2022). This situation poses a serious obstacle to the establishment of a stable energy policy. Another significant issue here is the challenge of storing energy produced by wind and solar power on a large scale (Karayel et al., 2022).

Hydrogen is one of the most promising options for producing electrical energy directly and with higher efficiency using fuel cells without combustion (Uysal et al., 2021). Although hydrogen is primarily used in industrial sectors currently, it might also serve as a significant alternative for energy storage and transportation. "For this reason, the use of large areas and abundant solar energy can be a compensation for this lack of energy production (Karayel et al., 2022).The hydrogen injection into natural gas pipelines is a cost-effective solution for long-distance transmission due to the existing infrastructure and lower transportation costs compared to other methods (Karayel et al., 2022). Similarly, there are studies focusing on utilising surplus energy generated by wind turbines for hydrogen production (Li et al., 2019).

Studies have shown that Türkiye offers attractive opportunities for hydrogen production in terms of its solar energy potential. The cities of Van, Konya, Erzurum, Sivas and were determined as the most suitable provinces in this regard (Karayel et al., 2022).

The study advocates for hydrogen energy as the most appropriate renewable resource due to its benefits, including geographical flexibility, storability, enhanced energy security, and environmental sustainability.Unlike other studies, hydrogen energy stands out as a strategic option for uninterrupted energy supply, zero emission targets and future technology investment. Hydrogen is a perfect solution for meeting future energy demand, because hydrogen is easily stored and transported, it reduces foreign dependency through local energy production and it has a minimal environmental impact. The growing interest in hydrogen in Turkey is aligned with global trends. Hydrogen is a promising option for sustainable energy, particularly as a balance to the intermittent production of renewable energy sources such as wind and solar. While hydrogen has not been a dominant feature of renewable energy debates elsewhere, its potential role in energy storage, transport and industrial applications is being increasingly recognised. Recent studies focusing on the integration of hydrogen into natural gas pipelines or its use in fuel cells are particularly indicative of this trend. While solar and wind energy are often prioritised in the broader literature, the Türkiye study positions hydrogen as a leading option. This is in line with both national energy needs and evolving global trends. This suggests a forward-looking approach to integrating hydrogen into Turkey's renewable energy strategy.

6. Conclusions

In the quest for a sustainable and low carbon energy future, the assessment of renewable energy resources is of paramount importance. This study focused on the issue of selecting sustainable energy sources for Türkiye. The study introduced an innovative model that integrates q-ROFS CRITIC and q-ROFS MABAC. The study's key originality is in the approach that combines the q-ROFS versions of CRITIC and MABAC to include the subjectivity inherent in the rating process. The model's effectiveness was shown through a case study on Türkiye's energy sector. Analysed by academics, managers, and engineers with a wealth of expertise, seven energy sources in the country were analysed. Findings showed that hydrogen energy was most suitable as an alternative energy source, followed by wave, solar and wind energy. We have carried out a sensitivity analysis and a comparison study to assess the robustness of the decision to the model parameters and the reliability of the results. As a result, this work is one of the few attempts to develop a decision support tool using q-ROFS. In addition, the proposed model will provide a practical framework for use in the energy sector. In this way, the study can serve as a reference for companies, researchers and decision-makers in the field, helping them to make more informed decisions. This will enhance the efficiency of renewable energy investments and help saving expenses.

Limitations of the study are that; there is a lack of standardized guidelines for the application of q-ROFS methods, leading to variability in implementation and interpretation across different studies and applications. The weighting of each decision expert is determined directly within the q-ROFS settings. This may introduce subjective variability. Therefore, deriving the decision expert's weight information poses a significant challenge in the process of MCDM. (Mishra & Rani, 2023). Additionally, challenges associated with the existing regulatory framework, including inconsistent policies and bureaucratic barriers, may hinder the effective selection and integration of renewable energy sources into the Turkish energy sector. Future research could analyze the impact of various policy shifts or reforms on the adoption of renewable energy technologies. This direction could enhance the decision-making process and ensure a more resilient and adaptable energy framework for Türkiye and other countries transitioning towards sustainable energy. Furthermore, the recent geo-political challenges, such wars in Ukraine and Palestine, pose additional risk on energy security and diversity. Subsequent research endeavours may explore these novel problem domains.

Conflict of interest: The authors have no competing interests to declare that are relevant to the content of this article.

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Ethical approval

I testify on behalf of all co-authors that our article submitted to Journal of Soft Computing (SOCO). This research has not been published in whole or in part elsewhere; The manuscript is not currently being considered for publication in another journal; All authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content. This article does not contain any studies with human participants or animals performed by any of the authors

Data availability Enquiries about data availability should be directed to the authors.

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Authors contribution

Berk Ayvaz: Supervision, Conceptualization, Data curation, Formal analysis, Writing – original draft, Visualization. **Emine Elif Nebati:** Methodology, Formal analysis, Resources, Writing – original draft, Visualization. **Ali Osman Kusakci**: Validation, Visualization, Writing – review & editing. **Selin Oral:** Writing – original draft, Resources. **Mehmet Rafet Özdemir**: Data curation

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APPENDIX

Table A1. Evaluation criteria used in the study

Main Criteria	Sub-Criteria	Definition	Reference
Environmental	**Greenhouse Pollutant Emissions (C1)**	It is the amount of emission of gases such as CO2 and Nox etc. that cause global warming to the atmosphere.	Büyüközkan and Güleryüz (2016); Lee and Chang (2018); Alkan and Albayrak (2020).
	Land requirements (C2)	Refers to a appropriate land required for the establishment of a renewable energy plant.	Kahraman et al. (2010); Ahmad and Tahar (2014); Büyüközkan and Güleryüz (2016); Kumar and Samuel (2017); Mousavi et al. (2017); Büyüközkan et al. (2018); Lee and Chang (2018); Toklu and Taşkın (2018); Alkan and Albayrak (2020); Chen et al. (2020); Rani et al. (2020);Wang et al. (2020); Wang et al. (2021); Al-Barakati et al. (2022); Bilgili et al. (2022); Krishankumar et al. (2022); Sarkodie et al. (2022); Quteishat and Younis (2023).
	Impact on environment (C3)	Evaluates the damage of the renewable power plant to the environment and biodiversity.	Ahmad and Tahar (2014); Wang et al. (2020); Almutairi et al. (2022); Ding et al. (2023).
	Climate change (C4)	Indicates climate change caused by greenhouse gas emissions	Büyüközkan et al. (2018).
	Need of waste disposal (C5)	Evaluates the negative effects of the wastes to be left by the renewable energy plant on the environmental quality.	Kahraman et al. (2010); Mousavi et al. (2017); Rani et al. (2021); Al-Barakati et al. (2022); Quteishat and Younis (2023).
Economical	**Investment Cost (C6)**	Expenditures for the establishment and operation of a renewable energy plant (labor, equipment, technological investment and construction works, etc.)	Büyüközkan and Güleryüz (2016); Çelikbilek and Tüysüz (2016); Kumar and Samuel (2017); Mousavi et al. (2017); Büyüközkan et al. (2018); Lee and Chang (2018); Toklu and Taşkın (2018); Rani et al. (2020); Ecer et al. (2021); Al-Barakati et al. (2022).
	Operation & Maintenance Cost (C7)	Refers to the expenditure required for operation and maintenance in the production of renewable energy (employee salaries, operating costs of the system, product and service costs)	Büyüközkan and Güleryüz (2016); Samuel (2017); Büyüközkan et al. (2018); Kumar and Ishfaq et al. (2018); Lee and Chang (2018); Toklu and Taşkın (2018); Rani et al. (2020); Ecer et al. (2021); Bilgili et al. (2022); Sarkodie et al. (2022).
	Payback Period (C8)	Refers to the required period for the investment to become profitable	Alkan and Albayrak (2020); Chen et al. (2020); Bilgili et al. (2022); Ding et al. (2023).
	Economic risks (C9)	States the risk that the investment will be less profitable than expected	Mousavi et al. (2017); Al-Barakati et al. (2022).
	Economic value (C10)	Refers to the financial measurement of the benefit value provided by renewable energy production.	Kahraman et al. (2010); Mousavi et al. (2017); Quteishat and Younis (2023); Alkan, (2024).
	Electric cost (C11)	Includes costs incurred in the electricity generation process (operating costs, fuel costs, depreciation expense, land cost, construction costs, etc.)	Lee and Chang (2018).
Technical	**Efficiency (C12)**	The ratio of energy to be produced to energy used	Ahmad and Tahar (2014); Büyüközkan and Güleryüz (2016); Çelikbilek and Tüysüz (2016); Mousavi et al. (2017); Ishfaq et al. (2018); Lee and Chang

			(2018); Toklu and Taşkın (2018); Chen et al. (2020); Rani et al (2020); Wang et al. (2020); Yazdani et al. (2020); Ecer et al. (2021); Wang et al. (2021); Almutairi et al. (2022); Bilgili et al. (2022); Ghose et al. (2022); Sarkodie et al. (2022).
	Reliability & Safety (C13)	Refers to the capacity of the performance of the renewable energy system. Evaluates the ability of the system to perform its performance under the planned and designed conditions.	Kahraman et al. (2010); Büyüközkan and Güleryüz (2016); Mousavi et al. (2017); Toklu and Taşkın (2018); Ecer et al. (2021); Rani et al. (2021); Wang et al. (2021); Quteishat and Younis (2023).
	Resource availability (C14)	The amount of resources available to be used to produce renewable energy	Yazdani et al. (2020); Bilgili et al. (2022).
	Technical Maturity (C15)	Refers to an improved technology where faults are reduced. Measures the level of commercial reliability	Lee and Chang (2018); Wang et al. (2021).
	Grid availability (C16)	Indicates the renewable energy system has access to the on-grid.	Wang et al. (2020); Wang et al. (2021).
	Service Life (C17)	Refers to the period (years) that the renewable energy plant can serve	Mousavi et al, (2017); Alkan and Albayrak (2020).
	Capacity factor (C18)	It is the ratio of the electricity produced by the power plant in a specific period to the electricity production of the power plant with uninterrupted full power capacity during the same period.	Lee and Chang (2018); Yürek et al. (2021); Sarkodie et al. (2022).
	Compatibility with national energy policy objectives (C19)	A measure of compliance with national energy policy	Kahraman et al. (2010); Büyüközkan and Güleryüz (2016); Mousavi et al. (2017); Quteishat and Younis (2023).
Socio-Political	**Social Benefits (C20)**	Refers to the public benefits to be provided by the renewable energy plant	Büyüközkan and Güleryüz (2016); Chen et al. (2020); Ecer et al. (2021); Wang et al. (2021); Bilgili et al. (2022).
	Social and political acceptability (C21)	Refers to the learning, approval and acceptance of energy resources by stakeholders. The increase in acceptability is positive.	Büyüközkan et al. (2018); Al-Barakati et al. (2022); Sarkodie et al. (2022).
	Job creation (C22)	It means that the renewable power plant creates new job opportunities.	Ahmad and Tahar (2014); Büyüközkan and Güleryüz (2016); Lee and Chang (2018); Toklu and Taşkın (2018); Chen et al. (2020); Wang et al. (2020); Ecer et al. (2021); Rani et al. (2021); Wang et al. (2021); Bilgili et al. (2022); Krishankumar et al. (2022); Ding et al. (2023), Alkan, (2024).

Table A2. Evaluation ratings of alternatives by five experts

		Wind (WI)		Solar Energy (SE)		Geothermal (GE)		Biomass (BI)		Wave (WA)		Hydraulic (HC)		Hydrogen (HN)	
C1	DM1	0.33	0.77	0.33	0.77	0.33	0.77	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66
	DM2	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.44	0.66	0.55	0.55
	DM3	0.44	0.66	0.44	0.66	0.44	0.66	0.77	0.33	0.44	0.66	0.66	0.44	0.66	0.44
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.22	0.88	0.22	0.88	0.66	0.44	0.88	0.22	0.22	0.88	0.88	0.22	0.66	0.44
C2	DM1	0.77	0.33	0.44	0.66	0.55	0.55	0.44	0.66	0.66	0.44	0.77	0.33	0.44	0.66
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.44	0.66	0.44	0.66	0.44	0.66	0.77	0.33	0.44	0.66	0.66	0.44	0.66	0.44
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.22	0.88	0.22	0.88	0.66	0.44	0.88	0.22	0.22	0.88	0.88	0.22	0.66	0.44
C3	DM1	0.55	0.55	0.44	0.66	0.77	0.33	0.66	0.44	0.77	0.33	0.77	0.33	0.44	0.66
	DM2	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66
	DM3	0.44	0.66	0.44	0.66	0.44	0.66	0.77	0.33	0.44	0.66	0.77	0.33	0.55	0.55
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.88	0.22	0.66	0.44	0.66	0.44	0.88	0.22	0.33	0.77	0.88	0.22	0.33	0.77
C4	DM1	0.44	0.66	0.33	0.77	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.44	0.66
	DM2	0.55	0.55	0.33	0.77	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.77	0.33	0.77	0.33	0.33	0.77	0.44	0.66	0.33	0.77	0.11	0.99	0.33	0.77
C5	DM1	0.33	0.77	0.33	0.77	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.44	0.66
	DM2	0.44	0.66	0.44	0.66	0.55	0.55	0.66	0.44	0.33	0.77	0.44	0.66	0.44	0.66
	DM3	0.33	0.77	0.33	0.77	0.33	0.77	0.77	0.33	0.33	0.77	0.33	0.77	0.55	0.55
	DM4	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.22	0.88	0.22	0.88	0.77	0.33	0.77	0.33	0.22	0.88	0.77	0.33	0.77	0.33
C6	DM1	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
	DM3	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33

	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM5	0.77	0.33	0.77	0.33	0.55	0.55	0.55	0.55	0.88	0.22	0.66	0.44	0.66	0.44
C7	DM1	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM5	0.77	0.33	0.66	0.44	0.77	0.33	0.77	0.33	0.88	0.22	0.77	0.33	0.77	0.33
C8	DM1	0.66	0.44	0.44	0.66	0.55	0.55	0.66	0.44	0.77	0.33	0.77	0.33	0.55	0.55
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
C9	DM1	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	DM2	0.44	0.66	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.44	0.66
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM5	0.33	0.77	0.33	0.77	0.33	0.77	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55
C10	DM1	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55
C11	DM1	0.55	0.55	0.66	0.44	0.44	0.66	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM5	0.22	0.88	0.22	0.88	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
C12	DM1	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	DM2	0.55	0.55	0.66	0.44	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44
	DM3	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55
C13	DM1	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.77	0.33

	DM2	0.44	0.66	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.66	0.44	0.66	0.44
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	DM5	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66
C14	DM1	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55
	DM3	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33
	DM4	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44
	DM5	0.88	0.22	0.88	0.22	0.55	0.55	0.66	0.44	0.88	0.22	0.88	0.22	0.66	0.44
C15	DM1	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.66	0.44	0.55	0.55	0.66	0.44
	DM2	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.66	0.44	0.55	0.55	0.66	0.44
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.77	0.33
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.33	0.77	0.44	0.66	0.33	0.77
C16	DM1	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55
	DM2	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55
	DM3	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.66	0.44	0.66	0.44	0.77	0.33
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44
C17	DM1	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.66	0.44	0.66	0.44
	DM2	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.66	0.44	0.66	0.44
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
C18	DM1	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM2	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.77	0.33
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM5	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
C19	DM1	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44
	DM2	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	DM3	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44

	DM5	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.66	0.44	0.55	0.55	0.66	0.44
C20	DM1	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	DM2	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	DM3	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.44	0.66	0.66	0.44
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.44	0.66	0.66	0.44
	DM5	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.77	0.33
C21	DM1	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44
	DM2	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	DM3	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.44	0.66
	DM4	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.44	0.66
	DM5	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.55	0.55	0.66	0.44	0.44	0.66
C22	DM1	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55
	DM2	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	DM3	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55
	DM4	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55
	DM5	0.33	0.77	0.33	0.77	0.66	0.44	0.77	0.33	0.55	0.55	0.77	0.33	0.66	0.44

Table A3. Conversion of Subjective Judgements into q- ROF numbers

		C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM1	(WI)	0.33	0.77	0.77	0.33	0.55	0.55	0.44	0.66	0.33	0.77	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55
	(SE)	0.33	0.77	0.44	0.66	0.44	0.66	0.33	0.77	0.33	0.77	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.66	0.44
	(GE)	0.33	0.77	0.55	0.55	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66
	(BI)	0.44	0.66	0.44	0.66	0.66	0.44	0.55	0.55	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
	(WA)	0.44	0.66	0.66	0.44	0.77	0.33	0.55	0.55	0.66	0.44	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55
	(HC)	0.44	0.66	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44
	(HN)	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55
		C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM1	(WI)	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44
	(SE)	0.66	0.44	0.55	0.55	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.44	0.66
	(GE)	0.55	0.55	0.55	0.55	0.77	0.33	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(BI)	0.66	0.44	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(WA)	0.66	0.44	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44
	(HC)	0.66	0.44	0.66	0.44	0.55	0.55	0.77	0.33	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44	0.55	0.55	0.55	0.55	0.77	0.33
	(HN)	0.55	0.55	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55
		C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM2	(WI)	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
	(SE)	0.55	0.55	0.55	0.55	0.44	0.66	0.33	0.77	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
	(GE)	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(BI)	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
	(WA)	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.33	0.77	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(HC)	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
	(HN)	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55
		C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	

		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM2	(WI)	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.44	0.66	0.55	0.55	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55
	(SE)	0.66	0.44	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55
	(GE)	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66
	(BI)	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66	0.44	0.66	0.44	0.66	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(WA)	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(HC)	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.44	0.66	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.44	0.66
	(HN)	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55	0.66	0.44	0.55	0.55
		C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM3	(WI)	0.44	0.66	0.66	0.44	0.44	0.66	0.66	0.44	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(SE)	0.44	0.66	0.66	0.44	0.44	0.66	0.66	0.44	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(GE)	0.44	0.66	0.66	0.44	0.44	0.66	0.66	0.44	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(BI)	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(WA)	0.44	0.66	0.55	0.55	0.44	0.66	0.66	0.44	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(HC)	0.66	0.44	0.77	0.33	0.77	0.33	0.66	0.44	0.33	0.77	0.77	0.33	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55
	(HN)	0.66	0.44	0.44	0.66	0.55	0.55	0.66	0.44	0.55	0.55	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33
		C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM3	(WI)	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(SE)	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(GE)	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44	0.44	0.66	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(BI)	0.77	0.33	0.77	0.33	0.77	0.33	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(WA)	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(HC)	0.77	0.33	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44
	(HN)	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
		C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM4	(WI)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	(SE)	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	(GE)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	(BI)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44

	(WA)	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	(HC)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.55	0.55	0.66	0.44	0.66	0.44	0.66	0.44
	(HN)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.77	0.33	0.66	0.44	0.55	0.55	0.77	0.33	0.66	0.44	0.66	0.44
		C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM4	(WI)	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66
	(SE)	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66
	(GE)	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66
	(BI)	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.66	0.44	0.44	0.66
	(WA)	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.77	0.33	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66
	(HC)	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.55	0.55	0.55	0.55	0.55	0.55	0.44	0.66	0.55	0.55	0.44	0.66
	(HN)	0.66	0.44	0.66	0.44	0.66	0.44	0.66	0.44	0.77	0.33	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.44	0.66	0.55	0.55
		C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
	(WI)	μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM5	(SE)	0.22	0.88	0.88	0.22	0.88	0.22	0.77	0.33	0.22	0.88	0.77	0.33	0.77	0.33	0.55	0.55	0.33	0.77	0.55	0.55	0.22	0.88
	(GE)	0.22	0.88	0.66	0.44	0.66	0.44	0.77	0.33	0.22	0.88	0.77	0.33	0.66	0.44	0.55	0.55	0.33	0.77	0.55	0.55	0.22	0.88
	(BI)	0.66	0.44	0.33	0.77	0.66	0.44	0.33	0.77	0.77	0.33	0.55	0.55	0.77	0.33	0.55	0.55	0.33	0.77	0.55	0.55	0.55	0.55
	(WA)	0.88	0.22	0.22	0.88	0.88	0.22	0.44	0.66	0.77	0.33	0.55	0.55	0.77	0.33	0.55	0.55	0.44	0.66	0.44	0.66	0.55	0.55
	(HC)	0.22	0.88	0.11	0.99	0.33	0.77	0.33	0.77	0.22	0.88	0.88	0.22	0.88	0.22	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	(HN)	0.88	0.22	0.22	0.88	0.88	0.22	0.11	0.99	0.77	0.33	0.66	0.44	0.77	0.33	0.55	0.55	0.44	0.66	0.44	0.66	0.55	0.55
	(WI)	0.66	0.44	0.33	0.77	0.33	0.77	0.33	0.77	0.77	0.33	0.66	0.44	0.77	0.33	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
		C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
		μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
DM5	(WI)	0.55	0.55	0.44	0.66	0.88	0.22	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.33	0.77
	(SE)	0.55	0.55	0.55	0.55	0.88	0.22	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.33	0.77
	(GE)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.66	0.44	0.66	0.44
	(BI)	0.44	0.66	0.44	0.66	0.66	0.44	0.66	0.44	0.77	0.33	0.55	0.55	0.55	0.55	0.77	0.33	0.77	0.33	0.77	0.33	0.77	0.33
	(WA)	0.55	0.55	0.55	0.55	0.88	0.22	0.33	0.77	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.55	0.55	0.55	0.55
	(HC)	0.55	0.55	0.55	0.55	0.88	0.22	0.44	0.66	0.77	0.33	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.44	0.66	0.44	0.77	0.33
	(HN)	0.55	0.55	0.44	0.66	0.66	0.44	0.33	0.77	0.66	0.44	0.55	0.55	0.55	0.55	0.66	0.44	0.77	0.33	0.44	0.66	0.66	0.44

Table A4. Normalized matrix (N_{ij})

	C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
	μ	N	μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
(WI)	0.70	0.43	0.40	0.73	0.49	0.66	0.49	0.63	0.72	0.41	0.41	0.70	0.41	0.70	0.50	0.60	0.56	0.56	0.60	0.50	0.58	0.55
(SE)	0.67	0.46	0.50	0.61	0.59	0.53	0.54	0.60	0.72	0.41	0.43	0.68	0.45	0.66	0.55	0.56	0.56	0.56	0.60	0.50	0.55	0.57
(GE)	0.58	0.53	0.56	0.55	0.49	0.63	0.56	0.56	0.53	0.61	0.47	0.64	0.43	0.68	0.53	0.58	0.56	0.56	0.60	0.50	0.55	0.56
(BI)	0.43	0.71	0.59	0.56	0.40	0.73	0.53	0.59	0.46	0.67	0.45	0.66	0.41	0.70	0.50	0.60	0.54	0.57	0.61	0.50	0.53	0.58
(WA)	0.67	0.44	0.57	0.57	0.57	0.57	0.56	0.55	0.66	0.48	0.37	0.75	0.36	0.76	0.47	0.64	0.48	0.62	0.62	0.48	0.53	0.58
(HC)	0.47	0.68	0.49	0.65	0.37	0.75	0.57	0.57	0.53	0.61	0.41	0.70	0.39	0.72	0.47	0.64	0.52	0.60	0.61	0.50	0.50	0.60
(HN)	0.52	0.59	0.63	0.48	0.63	0.48	0.58	0.53	0.53	0.59	0.41	0.70	0.41	0.70	0.50	0.62	0.44	0.67	0.66	0.45	0.47	0.64

	C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
	μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
(WI)	0.66	0.45	0.60	0.52	0.73	0.40	0.61	0.50	0.63	0.49	0.60	0.50	0.59	0.52	0.61	0.50	0.63	0.49	0.59	0.52	0.56	0.56
(SE)	0.67	0.43	0.59	0.52	0.74	0.38	0.64	0.47	0.63	0.49	0.60	0.50	0.60	0.50	0.61	0.50	0.64	0.47	0.61	0.50	0.52	0.61
(GE)	0.63	0.49	0.60	0.50	0.68	0.43	0.60	0.50	0.57	0.54	0.58	0.53	0.58	0.53	0.62	0.48	0.66	0.45	0.62	0.48	0.57	0.54
(BI)	0.64	0.47	0.63	0.49	0.70	0.41	0.66	0.45	0.64	0.47	0.56	0.55	0.58	0.53	0.67	0.43	0.66	0.45	0.67	0.43	0.64	0.47
(WA)	0.66	0.45	0.66	0.45	0.77	0.34	0.68	0.44	0.70	0.41	0.62	0.50	0.58	0.53	0.60	0.50	0.60	0.52	0.55	0.55	0.56	0.55
(HC)	0.66	0.45	0.64	0.46	0.73	0.40	0.64	0.47	0.66	0.45	0.66	0.45	0.64	0.47	0.62	0.48	0.59	0.52	0.60	0.50	0.66	0.46
(HN)	0.66	0.45	0.69	0.43	0.70	0.41	0.68	0.44	0.70	0.41	0.66	0.45	0.67	0.45	0.67	0.43	0.66	0.45	0.57	0.54	0.58	0.53

Table A5. Weighted normalized decision matrix WN_{ij}

	C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
	μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
(WI)	0.37	0.97	0.19	0.99	0.24	0.99	0.24	0.99	0.38	0.96	0.23	0.98	0.22	0.98	0.28	0.97	0.32	0.97	0.34	0.96	0.33	0.97
(SE)	0.36	0.97	0.24	0.99	0.29	0.98	0.26	0.99	0.38	0.96	0.24	0.98	0.25	0.98	0.30	0.97	0.32	0.97	0.34	0.96	0.31	0.97
(GE)	0.31	0.97	0.27	0.99	0.24	0.99	0.27	0.99	0.28	0.98	0.26	0.98	0.23	0.98	0.29	0.97	0.32	0.97	0.34	0.96	0.31	0.97
(BI)	0.23	0.99	0.28	0.99	0.20	0.99	0.26	0.99	0.24	0.98	0.25	0.98	0.22	0.98	0.28	0.97	0.31	0.97	0.34	0.96	0.30	0.97
(WA)	0.36	0.97	0.27	0.99	0.28	0.98	0.27	0.99	0.35	0.97	0.20	0.99	0.19	0.99	0.26	0.98	0.27	0.97	0.35	0.96	0.30	0.97
(HC)	0.25	0.98	0.23	0.99	0.18	0.99	0.27	0.99	0.28	0.98	0.23	0.98	0.21	0.98	0.26	0.98	0.30	0.97	0.34	0.96	0.28	0.97
(HN)	0.28	0.98	0.30	0.98	0.32	0.98	0.28	0.98	0.28	0.98	0.23	0.98	0.22	0.98	0.28	0.97	0.25	0.98	0.37	0.96	0.27	0.97

	C12		C13		C14		C15		C16		C17		C18		C19		C20		C21		C22	
	μ	N	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
(WI)	0.34	0.97	0.34	0.96	0.39	0.96	0.34	0.97	0.35	0.96	0.32	0.97	0.32	0.97	0.34	0.97	0.35	0.97	0.32	0.97	0.31	0.97
(SE)	0.35	0.97	0.33	0.96	0.40	0.96	0.35	0.96	0.35	0.96	0.32	0.97	0.32	0.97	0.34	0.97	0.36	0.96	0.33	0.97	0.29	0.97
(GE)	0.33	0.97	0.34	0.96	0.36	0.97	0.33	0.97	0.32	0.97	0.31	0.97	0.31	0.97	0.35	0.96	0.36	0.96	0.34	0.97	0.32	0.97
(BI)	0.34	0.97	0.36	0.96	0.37	0.97	0.37	0.96	0.36	0.96	0.30	0.98	0.31	0.97	0.38	0.96	0.36	0.96	0.37	0.96	0.36	0.96
(WA)	0.34	0.97	0.37	0.96	0.42	0.96	0.38	0.96	0.40	0.95	0.33	0.97	0.31	0.97	0.33	0.97	0.33	0.97	0.30	0.97	0.31	0.97
(HC)	0.34	0.97	0.36	0.96	0.39	0.96	0.36	0.96	0.37	0.96	0.35	0.97	0.35	0.97	0.35	0.96	0.32	0.97	0.32	0.97	0.37	0.96
(HN)	0.34	0.97	0.39	0.95	0.37	0.97	0.38	0.96	0.40	0.95	0.35	0.97	0.36	0.96	0.38	0.96	0.36	0.96	0.31	0.97	0.32	0.97

Table A6. Nomenclature

Symbol	Description
q-ROFS	q-Rung Orthopair Fuzzy Set
q	Regulating factor for preference space extension
μ	Belongingness degree
v	Non-belongingness degree
π	Indeterminacy degree
B	A q-ROFS in a finite universe
X	Finite universe of discourse
$a = (\mu_a, v_a)$	q-Rung Orthopair Fuzzy Number (q-ROFN)
$b = (\mu_b, v_b)$	q-Rung Orthopair Fuzzy Number (q-ROFN)
$S(a)$	Score function of a q-ROFN
$H(a)$	Accuracy function of a q-ROFN
$hd(a, b)$	Hamming distance measure between a and b
$O_i = \{O_1, O_2, \ldots, O_m\}$	Set of options
$C_j = \{C_1, C_2, \ldots, C_m\}$	Set of criteria
$D_k = \{D_1, D_2, .., D_l\}$	Decision Maker
λ_k	Weight of the k^{th} DM
$N = \left(\xi_{ij}^{(k)}\right)$	Decision matrix
$S = (x_{ij})_{mxn}$	Score matrix
σ_j	Standard deviation of the criteria
r_{jt}	Correlation coefficient between pairs of criteria
c_j	Information amount for each criterion
w_j	Criteria weight
R^k	q-ROF evaluation matrix for k^{th} DM
WN_{ij}	weighted normalized matrix
BAA	Border Approximation Area