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Comparative and Sensitivity analysis for selection process of onshore wind turbine model

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Abstract Wind energy has emerged as a leading contender to revolutionize the global energy landscape, offering a sustainable alternative to traditional fossil fuels. With mounting concerns over climate change and the urgent need to transition towards cleaner energy sources, countries heavily reliant on fossil fuels are increasingly turning to renewable options like wind power. In this paper, we introduce an innovative method that employs hesitant bipolar intuitionistic fuzzy sets (HBIFs) within the realm of MCDM. Our methodology involves enhancing the HBIF framework with a normalized Euclidean distance measure, which facilitates the selection of the most suitable onshore wind turbine across all life cycle stages. By leveraging the MULTIMOORA ranking method, we aim to streamline the process of designing efficient wind turbine projects, thus aiding the worldwide endeavor to tackle climate change and advance ecological sustainability through the adoption of affordable and clean energy solutions.

1 Introduction

Wind power is distinguished among renewable energy sources for its potential to provide clean, affordable, and abundant energy, making it crucial for sustainable development. Its rapid growth in recent years has made it a prominent choice for electricity generation, garnering attention from both business and environmental perspectives. Researchers have explored various extensions of fuzzy set theory to address decision-making challenges. For instance, Torra [13] introduced hesitant fuzzy sets, which have since evolved into hesitant bipolar fuzzy sets and other variants like hesitant bipolar-valued neutrosophic sets (HBVNS) by Al-Quran et al. [2]. These extensions have been instrumental in handling uncertainties in multiple attribute decision-making scenarios. Additionally, methods like Dombi prioritized aggregation, as proposed by Aydemir et al. [3], have enhanced decision-making processes, particularly in the MULTIMOORA method. Buyukozkan and Guler [4] further refined evaluation techniques with efficient supply chain analytics (SCA) tools, incorporating concepts from Analytic Hierarchy Process (AHP) and MULTIMOORA techniques. Moreover, research efforts have delved into novel approaches such as hesitant fuzzy linguistic term sets (Liao et al., [6]) and hesitant bipolar value ambiguous packages (Mandal et al., [7]) to address decision complexities in various domains. These extensions, including hesitant bipolar intuitionistic fuzzy sets, offer robust mathematical frameworks to handle uncertainties and aid decision-makers in navigating complex decision landscapes effectively.

In this paper, we introduce a novel concept termed as HBIFS, which adeptly encapsulates both membership and non-membership aspects along with positive and negative sentiments. Our study focuses on leveraging multi-criteria decision-making processes to facilitate optimal decision-making. Specifically, we propose the application of the HBIFS-Normalized Euclidean distance measure and the HBIFS MULTIMOORA method. The Normalized Euclidean distance measure stands out as a highly effective method for determining distances in MCDM scenarios, while the MULTIMOORA method excels in ranking alternatives. By integrating these methodologies, we aim to enhance the decision-making process. Notably, our research introduces a novel application of these techniques in evaluating and selecting the most suitable onshore wind turbine model. This application represents a significant advancement in the field, offering a fresh perspective on addressing complex decision-making challenges in the renewable energy sector.

2 Preliminaries

Definition 2.1. An intuitionistic fuzzy set $\mathcal{I}$ in U. The Intuitionistic Fuzzy Set is represented by [1]

$$\mathcal{I} = \{\langle u, \tilde{p}(u), \tilde{p}'(u)\rangle / u \in U\} \tag{2.1}$$

Here, $\tilde{p}(u), \tilde{p}'(u)$ represent the membership value and non-membership value. Basically intuitionistic fuzzy set having both membership and non-membership function. Each membership and non-membership value belongs to $[0, 1]$. It is represented as, $\tilde{p} : U \to [0, 1]$ and $\tilde{p}' : U \to [0, 1]$. The intuitionistic fuzzy set which satisfies one condition that is $0 \leq \tilde{p}(u) + \tilde{p}'(u) \leq 1$, for every $u \in U$. The numbers of membership and non-membership $\tilde{p}(u), \tilde{p}'(u) \in [0, 1]$

Definition 2.2. A bipolar intuitionistic fuzzy set $\mathcal{I}_{B*}$ on U. Basically intuitionistic fuzzy set having both membership and non-membership degree values. The bipolar intuitionistic fuzzy set is represented as, [5]

$$\mathcal{I}_{B*} = \left\{ \langle u, \tilde{p}(u), \tilde{q}(u), \tilde{p}'(u), \tilde{q}'(u)\rangle / u \in U\right\} \tag{2.2}$$

In the above equation, $\tilde{p}(u)$ and $\tilde{q}(u)$ represent the positive and negative membership degree. Each element of $\tilde{p} : U \to [0, 1]$ and $\tilde{q} : U \to [-1, 0]$. Then, $\tilde{p}'(u)$ and $\tilde{q}'(u)$ is representing the positive and negative non-membership degree. Each element of $\tilde{p}' : U \to [0, 1]$ and $\tilde{q}' : U \to [-1, 0]$.

The bipolar intuitionistic fuzzy set satisfies the following condition, $0 \leq \tilde{p}(u) + \tilde{p}'(u) \leq 1$ and $-1 \leq \tilde{q}(u) + \tilde{q}'(u) \leq 0$. Mainly, we consider, the positive non-membership degree $\tilde{p}'$, where $\tilde{p}'(u) = 1 - \tilde{p}(u)$ and negative non-membership degree $\tilde{q}'$, where $\tilde{q}'(u) = 1 - \tilde{q}(u)$.

Definition 2.3. Let us consider any two bipolar intuitionistic fuzzy set, [5]

$$C = \{\langle u, \tilde{p}_1(u), \tilde{q}_1(u), \tilde{p}_1'(u), \tilde{q}_1'(u)\rangle / u \in U\} \quad and \tag{2.3}$$

$$D = \{\langle u, \tilde{p}_2(u), \tilde{q}_2(u), \tilde{p}_2'(u), \tilde{q}_2'(u)\rangle / u \in U\} \tag{2.4}$$

The operation of intersection and union are defined as,

$$(\mathrm{C} \cap D)(u) = \left\{\tilde{p}_1(u) \wedge \tilde{p}_2(u), \tilde{q}_1(u) \vee \tilde{q}_2(u), \tilde{p}_1'(u) \vee \tilde{p}_2'(u), \tilde{q}_1'(u) \wedge \tilde{q}_2'(u) \right\} \tag{2.5}$$

$$(C \cup D)(u) = \left\{\tilde{p}_1(u) \vee \tilde{p}_2(u), \tilde{q}_1(u) \wedge \tilde{q}_2(u), \tilde{p}_1'(u) \wedge \tilde{p}_2'(u), \tilde{q}_1'(u) \vee \tilde{q}_2'(u) \right\} \tag{2.6}$$

Definition 2.4. Let U denote a fixed set, where the hesitant bipolar intuitionistic fuzzy set on U is formally defined as follows:[9]

$$\mathcal{H}_{B^*} = \left\{\left\langle u, h_{B^*}(u), h_{B^*}^{'}(u)\right\rangle / u \in U\right\} \tag{2.7}$$

The hesitant bipolar intuitionistic fuzzy set adheres to certain conditions, specifically ensuring that $0 \leq \tilde{p}(u) + \tilde{p}'(u) \leq 1$ and $-1 \leq \tilde{q}(u) + \tilde{q}'(u) \leq 0$. Notably, we define the positive non-membership degree as $\tilde{p}'(u) = 1 - \tilde{p}(u)$ and the negative non-membership degree as $\tilde{q}'(u) = 1 - \tilde{q}(u)$.

This formalization of hesitant bipolar intuitionistic fuzzy sets enables a comprehensive representation of uncertainty, accommodating both positive and negative perspectives in the assessment of membership and non-membership degrees.

Theorem 3.1:

Let us examine the case where the Euclidean distance measure $B_E^*(\alpha, \beta)$ between two hesitant bipolar intuitionistic fuzzy sets (HBIFs) $\alpha = (\tilde{p}, \tilde{q})$ and $\beta = (\tilde{p}', \tilde{q}')$ is equal to zero. Each HBIF comprises five parameters in both its membership and non-membership functions, denoted as $\eta_\alpha, \vartheta_\alpha, \gamma_\alpha, \phi_\alpha, \theta_\alpha$ and $\eta_\beta, \vartheta_\beta, \gamma_\beta, \phi_\beta, \theta_\beta$ respectively.

Proof. According to theorem, [9], the squared deviations between corresponding parameters must all be zero for $B_E^*(\alpha, \beta)$ to equal zero. Explicitly, we have $(\eta_\alpha^2 - \eta_\beta^2)^2 = 0$, $(\vartheta_\alpha^2 - \vartheta_\beta^2)^2 = 0$, $(\gamma_\alpha^2 - \gamma_\beta^2)^2 = 0$, $(\phi_\alpha - \phi_\beta)^2 = 0$, and $(\sin(\theta_\alpha) - \sin(\theta_\beta))^2 = 0$. Consequently, we can infer that $\eta_\alpha = \eta_\beta$, $\vartheta_\alpha = \vartheta_\beta$, $\gamma_\alpha = \gamma_\beta$, $\phi_\alpha = \phi_\beta$, and $\theta_\alpha = \theta_\beta$. This leads to the conclusion that α and β must be equal sets for their Euclidean distance to be zero. □

This proof establishes the equivalence relationship between the hesitant bipolar intuitionistic fuzzy sets α and β under the condition that their Euclidean distance measure B_E^* equals zero. This relationship is crucial for understanding the behavior and properties of HBIFs within the context of fuzzy set theory.

3 Problem Formulation

3.1 Algorithm: The Hesitant Bipolar Intuitionistic Fuzzy PIPRECIA Approach (HBIF-PIPRECIA)

In this section, we presented the novel hesitant bipolar intuitionistic fuzzy PIPRECIA Method within the realm of MCDM, offering an extended perspective on hesitant bipolar intuitionistic fuzzy sets.
Following is a summary of the steps involved in for any two hesitant bipolar intuitionistic fuzzy sets (HBIFs), denoted as $\alpha = (\tilde{p}, \tilde{q})$ and $\beta = (\tilde{p}', \tilde{q}')$, each comprising a set of five parameters in both membership and non-membership functions, namely $\eta_\alpha, \vartheta_\alpha, \gamma_\alpha, \phi_\alpha, \theta_\alpha$ for membership, and $\eta_\beta, \vartheta_\beta, \gamma_\beta, \phi_\beta, \theta_\beta$ for non-membership, it is proven that $B_E^*(\alpha, \beta) = 0$ if and only if $\alpha = \beta$.

Proof. Let us consider each squared deviation in Theorem 3.1, which is greater than or equal to 0. If $B_E^*(\alpha, \beta) = 0$, then each squared deviation will be equal to 0. Namely, $((\eta_\alpha)^2 - (\eta_\beta)^2)^2 = 0$, $((\vartheta_\alpha)^2 - (\vartheta_\beta)^2)^2 = 0$, $((\gamma_\alpha)^2 - (\gamma_\beta)^2)^2 = 0$, $(\phi_\alpha - \phi_\beta)^2 = 0$, $(\sin(\theta_\alpha) - \sin(\theta_\beta))^2 = 0$. Thus, it follows that $\eta_\alpha = \eta_\beta$, $\vartheta_\alpha = \vartheta_\beta$, $\gamma_\alpha = \gamma_\beta$, $\phi_\alpha = \phi_\beta$, and $\theta_\alpha = \theta_\beta$. Consequently, we obtain the result that $\alpha = \beta$. □

This relationship is crucial for understanding the behavior and properties of HBIFs within the context of fuzzy set theory. The PIPRECIA method to determine criteria weights (Stanujkic et al. 2017 [11]):
Step 1: Determine the pertinent evaluation criteria and arrange them in decreasing order according to the predicted significance of each.
Step 2: Determine the relative significance of $\hat{S}_j$ starting with the second criterion as follows:

$$\hat{S}_j = \left\{ \begin{array}{ll} > 1 & when\ C_j > C_{j-1} \\ 1 & when\ C_j = C_{j-1} \\ < 1 & when\ C_j < C_{j-1} \end{array} \right\} \tag{3.1}$$

Step 3: Calculate the comparable coefficient $(\tilde{k}_j)$ by using,

$$\tilde{k}_j = \left\{ \begin{array}{ll} 1 & j = 1 \\ 2 - \hat{S}_j & j > 1 \end{array} \right\} \tag{3.2}$$

where the score value has a similar importance of $\hat{S}_j$
Step 4: Estimate the recalculated weight $\tilde{P}_j$ by using,

$$\tilde{P}_j = \left\{ \begin{array}{ll} 1 & j = 1 \\ \frac{\tilde{k}_{j-1}}{\tilde{k}_j} & j > 1 \end{array} \right\} \tag{3.3}$$

Step 5: Utilize the following formula to determine the weights of each criterion.

$$\tilde{w}_j = \frac{\tilde{P}_j}{\sum_{j=1}^{n} \tilde{P}_j} \tag{3.4}$$

3.2 Proposed Method-The MULTIMOORA Method Utilizing Hesitant Bipolar Intuitionistic Fuzzy Sets

In this section, we introduce a novel approach termed the HBIF MULTIMOORA method, which incorporates HBIF normalized euclidean distance measure-based weights for addressing MCDM problems.

Let us denote the alternatives as $A_i = \{A_1, A_2, ..., A_m\}$ and the criteria as $C_j = \{C_1, C_2, ..., C_n\}$, representing the set of all m alternatives and n criteria. The performance of alternatives, denoted as $A_i(i = 1, 2, ..., m)$, and criteria performance, denoted as $C_j(j = 1, 2, ..., n)$, are assessed using hesitant bipolar intuitionistic fuzzy elements.

Here, each HBIF element is represented as:

$$\mathcal{H}_B^* = \left\{\left\langle u, h_{B^*}(u), h'_{B^*}(u)\right\rangle / u \in U\right\} \tag{3.5}$$

$$= \left\{\langle u, \left(\tilde{p}_{B^*}(u), \tilde{q}_{B^*}(u)\right), \left(\tilde{p}'_{B^*}(u), \tilde{q}'_{B^*}(u)\right)\rangle / h_{B^*}(u), h'_{B^*}(u) \in \mathcal{H}_B^*\right\} \tag{3.6}$$

The main results are outlined as follows:

Main Result I:

Cost criteria and beneficial are distinguished within HBI fuzzy elements. Then, score value is calculated by using the following equation as:

$$R\left(\oplus_{j\in C_1,C_2,...,C_s}\mathcal{H}_{B^*}(u)\right) = \sum_{j=1}^{s} w_j\mathcal{H}_{B^*}(u) \Rightarrow \frac{1}{l}\sum_{j=1}^{s}\left\{\{1-(1-h_{B^*_{ij}})^{w_j}\} - \{(h'_{B^*_{ij}})^{w_j}\}\right\} \tag{3.7}$$

$$R\left(\oplus_{j\in C_{s+1},C_{s+2},...,C_n}\mathcal{H}_{B^*}(u)\right) = \sum_{j=s+1}^{n} w_j\mathcal{H}_{B^*}(u) \Rightarrow \frac{1}{l}\sum_{j=s+1}^{n}\left\{\{1-(1-h_{B^*_{ij}})^{w_j}\} - \{(h'_{B^*_{ij}})^{w_j}\}\right\} \tag{3.8}$$

$$Z_i = R\left(\oplus_{j\in C_1,C_2,...,C_s}\mathcal{H}_B^*(u)\right) - R\left(\oplus_{j\in C_{s+1},C_{s+2},...,C_n}\mathcal{H}_B^*(u)\right) \tag{3.9}$$

The alternatives are then ranked based on these scores.

Main Result II:

The reference values for the benefit criteria are determined by leveraging the highest and lowest values found within the hesitant bipolar intuitionistic fuzzy elements. The same process is applied to determine the cost criteria reference point values. The calculation of the maximum deviation from the reference point involves utilizing a normalized Euclidean distance measure applied to the data points. The optimal alternative is selected based on this deviation.

$$\tilde{G}_{ij} = w_{ij} * G_{ij} \tag{3.10}$$

The benefit and cost criteria reference point values are calculated by the following equation

$$Z_j = \left\{max\{h_{B^*_{ij}}\}, min\{h'_{B^*_{ij}}\}/h_{B^*_{ij}}, h'_{B^*_{ij}} \in \mathcal{H}_{B*}\right\} \tag{3.11}$$

$$Z_j = \left\{min\{h_{B^*_{ij}}\}, max\{h'_{B^*_{ij}}\}/h_{B^*_{ij}}, h'_{B^*_{ij}} \in \mathcal{H}_{B*}\right\} \tag{3.12}$$

The maximum deviation $d\left[(w_j * Z_j), (w_j * \mathcal{H}_{B*})\right]$ from the reference point are calculated by using the normalized euclidean distance measure formula as,

$$d = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(h_{B_1^*}(u_{ij}) - h_{B_2^*}(u_{ij})\right)^2 + \left(h'_{B_1^*}(u_{ij}) - h'_{B_2^*}(u_{ij})\right)^2} \tag{3.13}$$

The preferred choice according to this methodology is:

$$B^*_{HBIFRP} = \{D_i | min_i D_i\} \tag{3.14}$$

where

$$D_i = max \;\; d\left[(w_j * Z_j), (w_j * \mathcal{H}_{B*})\right]$$

The alternatives are ranked by ascending the values of the overall reference points.
Main Result III:
The HBIF weighted multiplicative form is applied to evaluate the overall utility of alternatives. The best option is determined based on the full multiplicative form. Alternatives are ranked accordingly.

$$R\left(\oplus_{j \in C_1, C_2, \ldots, C_s} \mathcal{H}_{B*}(u)\right) = \sum_{j=1}^{s} (\mathcal{H}_{B*}(u))^{w_j} \Rightarrow \frac{1}{l} \sum_{j=1}^{s} \left\{ \{h^{w_j}_{B^*_{ij}}\} - \{1 - (1 - h'_{B^*_{ij}})^{w_j}\} \right\} \tag{3.15}$$

$$R\left(\oplus_{j \in C_{s+1}, C_{s+2}, \ldots, C_n} \mathcal{H}_{B*}(u)\right) = \sum_{j=s+1}^{n} (\mathcal{H}_{B*}(u))^{w_j} \Rightarrow \frac{1}{l} \sum_{j=s+1}^{n} \left\{ \{h^{w_j}_{B^*_{ij}}\} - \{1 - (1 - h'_{B^*_{ij}})^{w_j}\} \right\} \tag{3.16}$$

$$V_i = R\left(\oplus_{j \in C_1, C_2, \ldots, C_s} \mathcal{H}_{B*}(u)\right) \oslash R\left(\oplus_{j \in C_{s+1}, C_{s+2}, \ldots, C_n} \mathcal{H}_{B*}(u)\right) \tag{3.17}$$

In this scenario, the hesitant bipolar intuitionistic fuzzy elements are combined through multiplication for the benefit criteria and division for the cost criteria.
By using the full multiplicative form, the best option is,

$$B^*_{HBIFMF} = \{V_i | max_i V_i\} \tag{3.18}$$

In summary, the proposed HBIF MULTIMOORA method offers a comprehensive approach to decision-making under uncertainty, integrating multiple criteria and preferences effectively. The dominance theory is employed to combine the three ranks and derive an overall ranking for the alternatives. This method provides decision-makers with a robust framework for decision-making in complex scenarios, aiding in informed and optimal choices.

4 Study on Onshore Wind Turbine Models

Wind energy:

Air is formed by pressure differences between different parts. Areas with strong winds at sufficient times of the year can use wind power profitably for a variety of purposes. The pressure of the moving air is the result of the slope. Globally, this warm, low-density air rises above the ground, which is the primary force that forces surface air to move from the poles toward the equator. The wind blows away from the equator and toward the poles in the high atmosphere close to the equator. The overall phenomenon is the global transport cycle with surface winds in the northern hemisphere moving from north to south. That is why the use of wind is considered a part of solar technology. Local wind occurs in two ways, that is

• The air above the ground is warmer than the air over the ocean because the surface is hotter than the water. Warmer, lighter air rises over the earth, while colder, heavier air rises above the water to take its place. Coastal winds operate in this manner. As the earth cools toward the sky throughout the night, the wind direction flips.

• Mountains and their slopes contribute to local winds. In comparison to air on the plains, the air above slopes warms during the day and cools more quickly at night. During the day, it rises on warm slopes and at night, it flows downward in powerful, comparatively cold gusts.

Onshore wind turbine model:

The chosen alternatives illustrated in Fig. 1 consist of our selected onshore wind turbine models, which are detailed below.

SG 2.6-114

SG 2.9-129

SG 3.4-132

SG 3.4-145

SG 4.7-155

Figure 1. Selected onshore wind turbine model

1. S G 2.6-114 2. S G 2.9-129 3. S G 3.4-132 4. S G 3.4-145
5. S G 4.7-155.

The identified criteria include: **1. Environment, 2. Technical, 3. Customer 4. Operation and maintenance and 5. Economic.** The hierarchical structure of the selected alternatives and criteria shown in Fig.:2. The details of selected criteria are described below,

1. Environment:

The installed capacity and phase capacity of wind power plants at low wind speeds directly depend on the availability of wind resources. These also directly affect the reliability and safety of low speed wind turbines. The average annual wind speed, wind energy density and wind resource availability periods are the major indicators of the amount of wind resources. wind turbines at a low speed. Seasonal variations might also have an impact on wind turbines.

2. Technical:

The primary product on the market today is wind turbines, which are best suited for wind resources. The developing low power wind turbine market is not yet receiving much attention from major wind turbine manufacturers. The technical compatibility between dispersed wind power projects and wind turbines that do not reach the period of low wind speeds. The wind turbine system that scatters at low wind speeds is significantly at danger due to this problem.

3. Customer:

The performance requirements of wind turbines must be adjusted to account for the substation's load distribution and load change behaviour. The load stability properties of the self-service area must also be considered in the case of distributed projects. Electricity demand refers to the quantity of electricity required for regional economic expansion and the erratic daily lives of local residents. This project is built primarily to supply local demand for electricity. Higher electricity demand will result in stronger growth projections, allowing for local absorption of the generated energy. The requirement for social power will, however, alter throughout time and given the current economic situation. When there is a large demand for power, low wind speed wind turbines have a strong absorption capacity and offer a higher return on investment. The return on project investment will be impacted by low electricity demand.

4. Operation and maintains:

There are some risks associated with operating and maintaining the lost wind power in this region. The normal operation of low speed wind turbines can be impacted by equipment components that aggravate and repair changes in terrain characteristics, weather conditions and other factors. Operational problems can result in wind turbine maintenance because maintenance work can result in significant energy loss, which can affect the investment return of the project.

5. Economic:

Since roads and other forms of infrastructure are still in relatively poor shape, wind farm projects in remote locations must suffer substantial investment expenses. Currently, wind turbines cost is low, but the price is still high and the cost of purchasing wind turbines is correspondingly high, which affects the construction cost of the project.

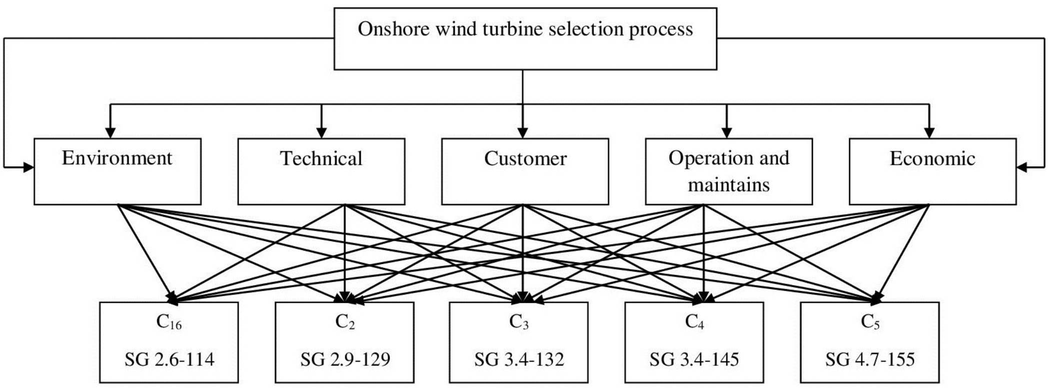

Figure 2. Hierarchical structure of selected alternatives and criteria

5 Application of the Proposed Method for Choosing Onshore Wind Turbine Models

Nowadays wind turbine installation has increased for world development.

In this study, we introduce the HBIF-MULTIMOORA method for selecting onshore wind turbine models based on wind turbine installation characteristics serving as the criteria. The selected alternative and criteria are listed below that is,

Alternatives:

• S G 2.6-114 • S G 2.9-129 • S G 3.4-132 • S G 3.4-145 • S G 4.7-155.

Criteria:

• Environment • Technical • Customer • Operation and maintenance • Economic

Initially, we aim to establish the score function for the hesitant bipolar intuitionistic fuzzy set, following the methodology outlined in the paper by Wei et al. (2017)[**?**]. The score functions for membership and non-membership are computed using the following equation:

$$S(h_{B^*_{ij}}) = \frac{1}{\#h_{B^*_{ij}}} \sum_{i=1}^{\#h_{B^*_{ij}}} \frac{1+\tilde{p}_i+\tilde{q}_i}{2} \tag{5.1}$$

$$S(h'_{B^*_{ij}}) = \frac{1}{\#h'_{B^*_{ij}}} \sum_{i=1}^{\#h'_{B^*_{ij}}} \frac{1+\tilde{p}'_i+\tilde{q}'_i}{2} \tag{5.2}$$

Table 1. The hesitant bipolar intuitionistic fuzzy decision matrix

	Criteria				
Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	{(0.5,0.6,0.7), (-0.35, -0.3, -0.2) (0.2,0.3,0.3), (-0.5,-0.6,-0.65)}	{(0.3,0.4,0.4), (-0.2,-0.3,-0.4), (0.4,0.5,0.6), (-0.1,-0.2,-0.3)}	{(0.4,0.3,0.4), (-0.1,-0.2,-0.3), (0.3,0.4,0.6), (-0.7,-0.4,-0.3)}	{(0.8,0.8,0.7), (-0.4,-0.5,-0.6), (0.2,0.1,0.2), (-0.1,-0.2,-0.4)}	{(0.3,0.6,0.9), (-0.6,-0.9,-0.8), (0.1,0.05,0.05), (-0.05,-0.1,-0.1)}
A_2	{(0.1,0.3,0.5), (-0.6,-0.7,-0.75), (0.1,0.16,0.25), (-0.25,-0.2,-0.1)}	{(0.2,0.7,0.8), (-0.25,-0.65,-0.75), (0.1,0.15,0.2), (-0.2,-0.05,-0.1)}	{(0.2,0.5,0.6), (-0.4,-0.5,-0.6), (0.3,0.4,0.2), (-0.2,-0.4,-0.3)}	{(0.6,0.7,0.7), (-0.1,-0.1,-0.4), (0.3,0.3,0.2), (-0.4,-0.5,-0.5)}	{(0.5,0.6,0.8), (-0.2,-0.1,-0.2), (0.1,0.15,0.2), (-0.7,-0.8,-0.8)}
A_3	{(0.5,0.7,0.8), (-0.5,-0.6,-0.65), (0.1,0.15,0.2), (-0.1,-0.3,-0.35)}	{(0.9,0.8,0.7), (-0.8,-0.6,-0.5), (0.1,0.05,0.07), (-0.2,-0.4,-0.3)}	{(0.15,0.2,0.25), (-0.1,-0.2,-0.05), (0.73,0.75,0.7), (-0.8,-0.8,-0.4)}	{(0.5,0.6,0.5), (-0.41,-0.49,-0.57), (0.357,0.4,0.3), (-0.42,-0.45,-0.5)}	{(0.2,0.4,0.6), (-0.2,-0.3,-0.6), (0.35,0.4,0.3), (-0.4,-0.4,-0.2)}
A_4	{(0.275,0.675,0.6), (-0.1,-0.4,-0.5), (0.325,0.3,0.25), (-0.375,-0.275,-0.4)}	{(0.5,0.8,0.9), (-0.7,-0.6,-0.9), (0.1,0.1,0.05), (-0.05,-0.05,-0.1)}	{(0.7,0.7,0.8), (-0.165,-0.5,-0.78), (0.2,0.2,0.1), (-0.175,-0.2,-0.22)}	{(0.3,0.4,0.5), (-0.295,-0.375,-0.425) (0.5,0.4,0.5), (-0.125,-0.58,-0.37)}	{(0.4,0.6,0.8), (-0.9,-0.91,-0.83), (0.2,0.1,0.2), (-0.07,-0.05,-0.1)}
A_5	{(0.8,0.85,0.665), (-0.6,-0.7,-0.5), (0.125,0.2,0.1), (-0.3,-0.2,-0.1)}	{(0.3,0.7,0.7), (-0.225,-0.375,-0.495), (0.3,0.2,0.27), (-0.61,-0.535,-0.4)}	{(0.2,0.33,0.44), (-0.11,-0.22,-0.33), (0.56,0.4,0.5), (-0.66,-0.55,-0.5)}	{(0.21,0.43,0.66), (-0.12,-0.8,-0.85), (0.3,0.35,0.2), (-0.15,-0.1,-0.05)}	{(0.7,0.7,0.8), (-0.5,-0.7,-0.55), (0.2,0.2,0.1), (-0.3,-0.45,-0.4)}

Using equation (5.1) & (5.2) the HBIF score matrix is calculated. The values of the score functions for membership and non-membership are displayed as,

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \end{array} \\ \begin{pmatrix} \{0.658, 0.34\} & \{0.53, 0.65\} & \{0.58, 0.48\} & \{0.63, 0.46\} & \{0.42, 0.49\} \\ \{0.31, 0.49\} & \{0.51, 0.52\} & \{0.46, 0.5\} & \{0.73, 0.4\} & \{0.73, 0.19\} \\ \{0.54, 0.45\} & \{0.58, 0.38\} & \{0.54, 0.53\} & \{0.52, 0.48\} & \{0.52, 0.5\} \\ \{0.59, 0.47\} & \{0.5, 0.51\} & \{0.63, 0.48\} & \{0.52, 0.55\} & \{0.36, 0.55\} \\ \{0.58, 0.47\} & \{0.6, 0.37\} & \{0.55, 0.45\} & \{0.42, 0.59\} & \{0.57, 0.39\} \end{pmatrix} \end{array}$$

In this context, the criteria are divided into two categories: benefit criteria and cost criteria. The MULTIMOORA method involves the utilization of both beneficial and non-beneficial criteria to evaluate the alternatives. Environmental and Economic are in the list of benefits. Technical, Customer, Operation and maintenance are on the list of cost-related criteria. Benefit criteria and cost criteria have separate calculations.

Every MCDM method has unique procedure and advantages.In multi-criteria decision-making (MCDM) methods, the process is typically divided into two main stages: weight determination and ranking. The initial phase of MCDM involves determining weights, which is accomplished using various techniques designed for this purpose. Here, we use PIPRECIA method for determining criteria weights.

Table 2. Hesitant bipolar intuitionistic fuzzy score value

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	0.32	-0.12	0.1	0.17	-0.07
A_2	-0.18	-0.01	-0.04	0.33	0.54
A_3	0.09	0.2	0.01	0.04	0.02
A_4	0.12	-0.01	0.15	-0.03	-0.19
A_5	0.11	0.23	0.09	-0.17	0.18

Equation (3.3) is utilized to determine the recalculated weight values. Equation (3.4) is used to determine the degree of significance of the criteria weights. Table 3 lists the values for the criteria weight and the recalculated weight. The total of the weighted criterion values is one.

Table 3. Hesitant bipolar intuitionistic fuzzy criteria weight values

Avg value	$\tilde{k}_j$	$\tilde{P}_j$	$\tilde{W}_j$
0.096	1	1	0.32
0.092	1.908	1.1013	0.35
0.068	1.932	0.57	0.18
0.062	1.938	0.294	0.09
0.058	1.942	0.1515	0.05

The weight values are $W_1 = 0.35$, $W_2 = 0.05$, $W_3 = 0.09$, $W_4 = 0.18$ and $W_5 = 0.32$. The weight vector is denoted as $(W_j = W_1, W_2, W_3, W_4, W_5)$.

The hesitant decision matrix enables decision-makers to evaluate options while effectively expressing their uncertain or hesitant views and opinions. We have initiated the development of our proposed mathematical model for hesitant bipolar intuitionistic fuzzy sets. The MULTIMOORA method is broadly categorized into three approaches: ratio system, reference point, and full multiplicative form. We are adapting and integrating these categories into our proposed mathematical framework.

• **The Hesitant Bipolar Intuitionistic Fuzzy Ratio System:**

In the case of benefit criteria, the hesitant bipolar intuitionistic fuzzy elements are aggregated (added), whereas for the cost criteria, they are aggregated (subtracted). The respective score values for benefit and cost criteria are documented in Table 4 and visualized in Fig.:3. Equation (3.7)&(3.8) is used to generate the score values for the benefit and cost criteria.

Table 4. Approach for ratio system score value

Alternatives	Benefit criteria score value	Cost criteria score value
A_1	-0.5042	-0.8361
A_2	-0.4514	-0.8187
A_3	-0.5549	-0.8466
A_4	-0.5963	-0.8525
A_5	-0.4883	-0.8618

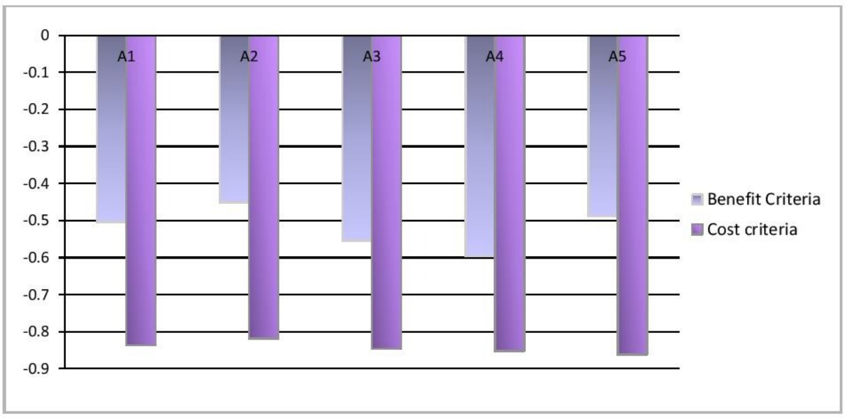

Figure 3. Score value of ratio system

Next, we calculate the ratio of score values for the alternatives using equation (3.9).

$$Z_i = \{0.3319, 0.3673, 0.2917, 0.2563, 0.3735\}$$

The alternatives are ranked in descending order based on their score values.

$$B^*_{HBIFRS} = \{0.3735, 0.3673, 0.3319, 0.2917, 0.2563\}$$

• The Hesitant Bipolar Intuitionistic Fuzzy Reference Point Approach:

In this next section, we introduce a method to select the optimal alternatives using a reference point value approach. This approach helps identify the best option based on a weighted hesitant bipolar intuitionistic fuzzy decision matrix. The weighted matrix is calculated using equation (3.10), where G_{ij} represents the score values for membership and non-membership. The resulting weighted hesitant bipolar intuitionistic fuzzy values are presented below,

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \end{array} \\ \begin{pmatrix} \{0.230, 0.119\} & \{0.026, 0.033\} & \{0.052, 0.043\} & \{0.113, 0.083\} & \{0.134, 0.156\} \\ \{0.108, 0.172\} & \{0.025, 0.026\} & \{0.041, 0.045\} & \{0.131, 0.072\} & \{0.234, 0.061\} \\ \{0.189, 0.157\} & \{0.029, 0.019\} & \{0.048, 0.047\} & \{0.094, 0.086\} & \{0.166, 0.16\} \\ \{0.206, 0.165\} & \{0.025, 0.025\} & \{0.056, 0.043\} & \{0.094, 0.099\} & \{0.115, 0.176\} \\ \{0.203, 0.164\} & \{0.03, 0.018\} & \{0.049, 0.041\} & \{0.075, 0.106\} & \{0.182, 0.125\} \end{pmatrix} \end{array}$$

The reference point values for the benefit criterion are calculated using equation (3.11), and the reference point values for the cost criteria are calculated using equation (3.12).
$d\left[(w_j * Z_j), (w_j * \mathcal{H}_{B*})\right]$ has the maximum deviation. Equation (3.13) gives the method for computing from the reference point value using normalized euclidean distances. Equation (3.14)

provides the optimum alternative based on this method.
The best alternative values are give below,

$$D_1 = \{0.2327\}, D_2 = \{0.2689\}, D_3 = \{0.0857\}, D_4 = \{0.1608\}, D_5 = \{0.1574\}$$

The ranking of selected alternatives is determined by arranging them in ascending order based on their scores.

$$B^*_{HBIFRP} = \{0.0857, 0.1574, 0.1608, 0.2327, 0.2689\}$$

•The Weighted Full Multiplicative Form for Hesitant Bipolar Intuitionistic Fuzzy Sets

In this section, the hesitant bipolar intuitionistic fuzzy elements are divided into two separate categories: benefit criteria and cost criteria. Within this framework, the elements undergo multiplication by the benefit criteria and division by the cost criteria. This process enables a systematic approach to evaluating and prioritizing the elements based on their respective contributions to both benefit and cost considerations.

Table 5. Multiplicative form score value approach

A	BCSV	CCSV
A_1	0.6461	0.8759
A_2	0.6464	0.8866
A_3	0.6147	0.8693
A_4	0.5638	0.8626
A_5	0.6692	0.8510

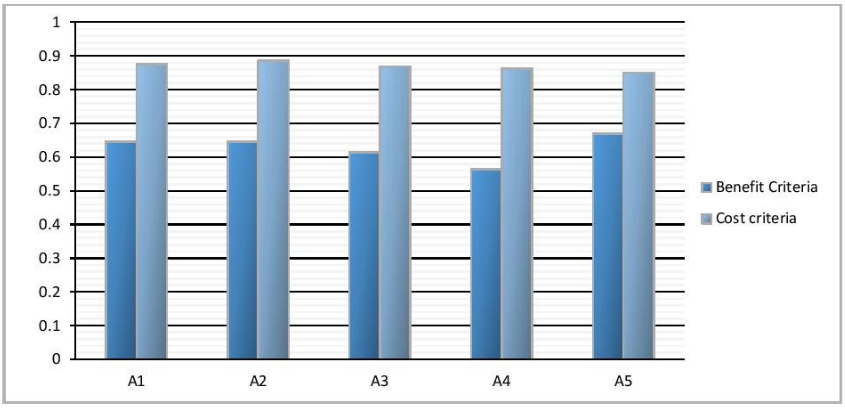

Figure 4. Score value of multiplicative form

The calculation of the multiplicative form for both benefit criteria and cost criteria is outlined through equations (3.15) and (3.16) in our research. These equations define the methodology for determining the multiplicative form score function values corresponding to the benefit and cost criteria. By applying these equations, we establish a quantitative framework for evaluating the efficacy of each criterion within the hesitant bipolar intuitionistic fuzzy set context. This allows for a rigorous analysis of the contributions of both benefit and cost criteria to the decision-making process is determined by the overall utility to i^{th} alternative. calculated using an equation (3.17) the utility of the i^{th} alternative.

$$V_1 = \{0.7376\}, V_2 = \{0.7291\}, V_3 = \{0.7071\}, V_4 = \{0.6536\}, V_5 = \{0.7864\}.$$

The multiplicative form in best alternative,

$$B^*_{HBIFMF} = \{0.7864, 0.7376, 0.7291, 0.7071, 0.6536\}$$

Table 6. Ranking the alternatives for onshore wind turbine model

Methods	A_1	A_2	A_3	A_4	A_5	Ranking
Ratio system	0.3319	0.3673	0.2917	0.2562	0.3735	$A_5 > A_2 > A_1 > A_3 > A_4$
Reference point approach	0.2327	0.2689	0.0857	0.1608	0.1574	$A_3 > A_5 > A_4 > A_1 > A_2$
Multiplicative form	0.7375	0.7291	0.7071	0.6536	0.7864	$A_5 > A_1 > A_2 > A_3 > A_4$

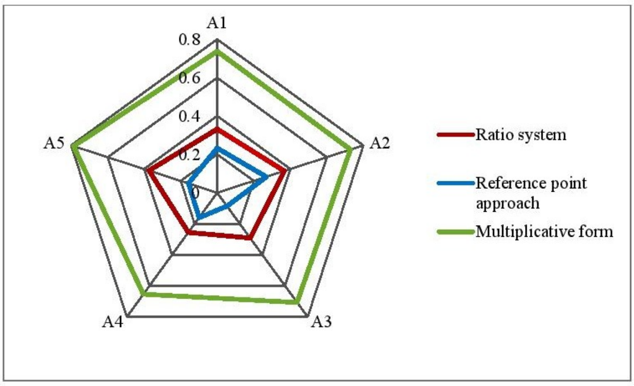

Figure 5. Alternatives for onshore wind turbine model with ranking

The alternatives are listed in decreasing order. The three ranks provided by the different HBIF-MULTIMOORA components were combined into one using the dominance theory.The whole ranking system is illustrated in Table 6, and the outcomes are depicted in Fig.: 5.

From the table result we conclude alternative A_5 is onshore wind turbine best model. Because, the ratio system approach and multiplicative form approach alternative A_5 is the best alternative. Then, by the reference point approach observed that A_5 is in the second position. So maximum ranking possibility is for alternative A_5.

6 Comparison Results:

This study entails a comprehensive comparison between our proposed mathematical method and existing methodologies. Our comparative analysis is thorough, considering the distinctive features of our proposed method, which incorporates three distinct ordering methods: the ratio system, reference point approach, and multiplicative form. These methods are employed for ranking purposes, with dominance theory utilized to amalgamate the three rankings into a singular ranking output.

In selecting the Multi-Criteria Decision Making (MCDM) method for our analysis, we opt for the ARAS (Additive Ratio Assessment) method. The ARAS method is recognized for its incorporation of both positive and negative aspects of membership and non-membership values, addressing both beneficial and non-beneficial criteria comprehensively.

Specifically, our proposed methodology, the hesitant bipolar intuitionistic fuzzy-ARAS method, stands as the focal point of our research. We recognize that both the comparison method and our proposed method possess unique characteristics. However, their core functionalities revolve around the evaluation of benefit and cost criteria, with rankings determined based on the degree of alternative utility.

Table 7. The comparison result of HBIF-MULTIMOORA method and HBIF-ARAS method

Methods	A_1	A_2	A_3	A_4	A_5	Ranking
Ratio system	0.3319	0.3673	0.2917	0.2562	0.3735	$A_5 > A_2 > A_1 > A_3 > A_4$
Reference point approach	0.2327	0.2689	0.0857	0.1608	0.1574	$A_3 > A_5 > A_4 > A_1 > A_2$
Multiplicative form	0.7375	0.7291	0.7071	0.6536	0.7864	$A_5 > A_1 > A_2 > A_3 > A_4$
ARAS Method	0.9136	0.8652	0.9582	0.9464	0.9796	$A_5 > A_3 > A_4 > A_1 > A_2$

Through our investigation, we aim to delineate the efficacy and distinct advantages of the hesitant bipolar intuitionistic fuzzy-ARAS method in facilitating decision-making processes, particularly in scenarios where assessing both positive and negative values of membership and non-membership criteria is essential.
The comparison results are provided in Fig.:6 and Table 7, respectively. The comparison results show that the outcome of our proposed work is nearly identical. The hesitant bipolar intuitionistic fuzzy -MULTIMOORA technique that we propose does not have a single part. The three independent mathematical parts of the approach are then combined into one ranking procedure using dominance theory.

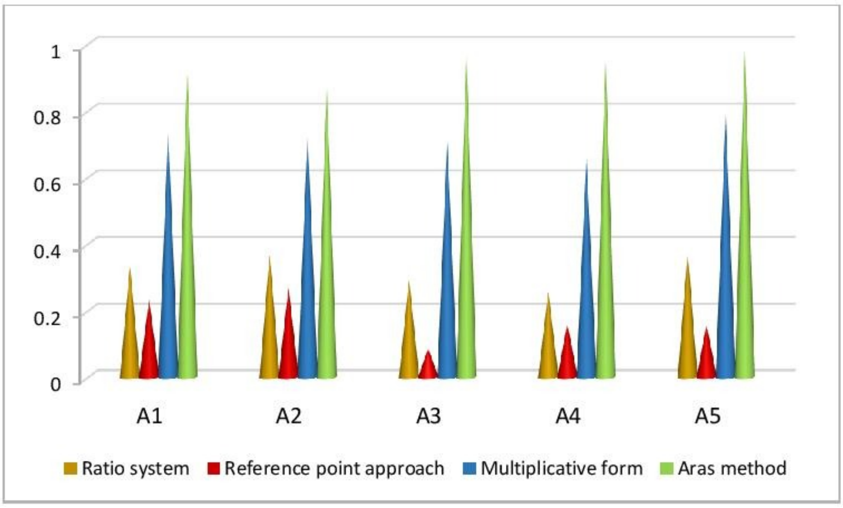

Figure 6. The comparison result of HBIF-MULTIMOORA method and HBIF-ARAS method

7 Sensitivity Analysis

According to the five weights presented in the table and shown graphically in the figure, the section presents the sensitivity analysis of the onshore wind turbine model selection alternative using the proposed methodology. The findings of five cases are compared for the sensitivity analysis of this full multiplicative form technique, and the comparison is represented graphically in Fig.:7. In this instance, **Case 1** represents the study's findings, whereas instances Case 2, 3, 4 and 5 represent additional findings based on other criteria weights. In this chapter, an onshore wind turbine model is chosen based on the following five factors: c_1-environment, c_2-technical, c_3-customer, c_4-technical and maintenance and c_5-economic. Using the enhanced fuzzy HBIF-MULTIMOORA technique, we examine the weights to determine the alternative ranks. In onshore wind turbine selection, the best alternative can be found by not only environmental, economic benefit criteria, but also technical, customer, operation and maintenance cost criteria are considered. Criteria give a good compromise solution when they are significant. It is depicted graphically in Fig.:7 and shown in the Table 8.

Case 2:

Considering equal weights in this case. Accordingly, W_1=0.2, W_2=0.2, W_3=0.2, W_4=0.2 and W_5=0.2 respectively. The ranking order in this scenario is as follows:
$A_5 > A_1 > A_2 > A_3 > A_4$

Case 3:

In this case, we are giving equal weight to the positive and negative attributes that is 50% to the beneficial attribute and 50% to the non-beneficial attribute. Then the weight values are $W_1 =$

0.25, $W_2 = 0.17$, $W_3 = 0.17$, $W_4 = 0.17$, $W_5 = 0.25$. In this instance, the ranking is as follows: $A_5 > A_1 > A_2 > A_3 > A_4$

Case 4:

Here, we are evaluating the weight values of 60% for the beneficial attribute and 40% for the non-beneficial attribute. The weight values are, $W_1 = 0.3$, $W_2 = 0.13$, $W_3 = 0.13$, $W_4 = 0.13$, $W_5 = 0.3$. In this case, the ranking order is,
$A_5 > A_2 > A_1 > A_3 > A_4$

Case 5:

Here, we give 70% of the weight to attributes that are beneficial and 30% of the weight to attributes that are non-beneficial, resulting in weight values of $W_1 = 0.35$, $W_2 = 0.1$, $W_3 = 0.1$, $W_4 = 0.1$, $W_5 = 0.35$. In this case, the ranking order is,
$A_5 > A_2 > A_1 > A_3 > A_4$

Table 8. Sensitivity analysis of ranking values based on criteria weights

Alternatives	$Case1$	$Case2$	$Case3$	$Case4$	$Case5$
A_1	0.7376	1.031	0.9207	0.8090	0.7201
A_2	0.7291	1.016	0.9134	0.8091	0.7258
A_3	0.7071	0.988	0.879	0.7690	0.6799
A_4	0.6536	0.9626	0.8404	0.7203	0.6237
A_5	0.7864	1.054	0.9479	0.8389	0.7523

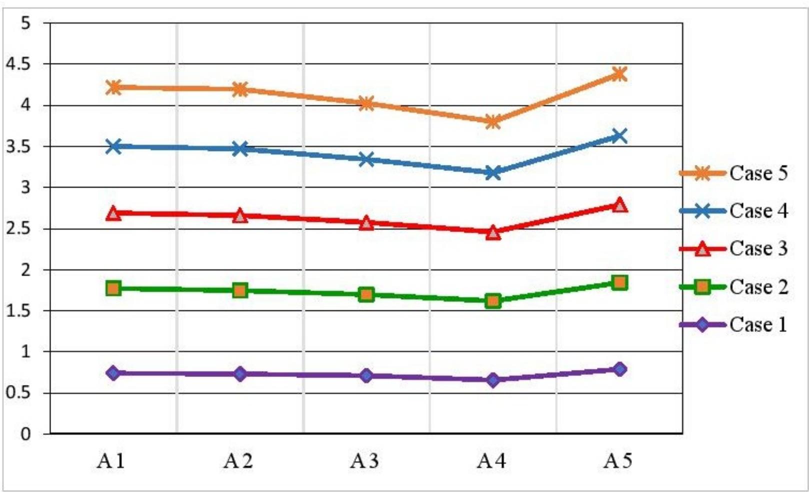

Figure 7. Sensitivity analysis of ranking values

8 Discussion

In general, the foundation of a country's economy often stems from the utilization of the abundant resources present in our natural surroundings. The diverse elements of nature provide a rich backdrop that we harness for our daily necessities and the advancement of our nation. Among the plethora of resources available to us, five primary categories stand out: land, water, knowledge, air, and fire, each offering a unique array of resources and energies crucial for our development. It is imperative that we utilize these resources judiciously to fuel the progress of our country.

In this study, we promote the utilization of onshore wind turbine models to optimize energy production and bolster our renewable energy portfolio. These wind turbine models are selected based on their unique features and performance attributes.

Furthermore, we introduce a novel methodology and extension of hesitant fuzzy set in this chapter. The hesitant bipolar intuitionistic fuzzy set serves as an extension of the hesitant set, incorporating the concept of bipolarity by addressing both positive and negative values within the membership function. This extension builds upon the foundation of intuitionistic fuzzy sets, incorporating both membership and non-membership functions, along with their respective positive and negative values. Our proposed extension, the hesitant bipolar intuitionistic fuzzy set, is tailored to accommodate uncertainties inherent in decision-making processes.

Additionally, we introduce the Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA) method within the framework of hesitant bipolar intuitionistic fuzzy sets. This method encompasses three distinct mathematical components, along with dominance theory, to comprehensively analyze and evaluate alternative options. The versatility of hesitant bipolar intuitionistic fuzzy sets proves instrumental in handling uncertainty, particularly in the context of selecting onshore wind turbine models. Through our proposed methodology, we demonstrate the manifold benefits of leveraging hesitant bipolar intuitionistic fuzzy sets in decision-making processes.

Furthermore, our analysis utilizing the hesitant bipolar intuitionistic fuzzy-MULTIMOORA method identifies alternative A_5 $(SG\,4.7-155)$ as the optimal choice, underscoring the efficacy of our approach in decision-making contexts.

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