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TOPSIS based Renewable-Energy-Source-Selection using Moderator Intuitionistic Fuzzy Set

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Abstract
Many criteria must be taken into account while selecting the best renewable energy source (RES), which necessitates a sophisticated multi-criteria decision-making (MCDM) procedure. Conflicting norms, as well as insufficient and inaccurate information, make this endeavour challenging. The theory of moderator intuitionistic fuzzy set (MIFS), a generalization of intuitionistic fuzzy sets (IFSs) has been developed to handle these uncertainties. The MIFS also helps to get a higher degree of precision in the uncertain behaviours due to the moderator parameter. In this paper, first some distance measures are presented for MIFSs, and then, on the basis of the proposed distances, we suggest a TOPSIS technique for choosing the best RES inside MIFS architecture. The efficacy of the proposed MIFS-based TOPSIS technique is put to the test by comparing different wind generating systems in a case study. The findings of the study are then compared in order to demonstrate that the suggested method is superior to the existing ones.

Keywords- Renewable energy (RE), Renewable energy source (RES), Intuitionistic fuzzy set (IFS), Moderator IFS (MIFS), TOPSIS, MCDM.

List of Abbreviations
MCDM – Multi-criteria decision-making.
FS- Fuzzy set.
IFS - Intuitionistic fuzzy set.
MIFS - Moderator intuitionistic fuzzy set.
TOPSIS - Technique for Order of Preference by Similarity to Ideal Solution.
RES - Renewable energy source.
WGS - Wind generation systems.

1. Introduction
Energy is an essential component of our lives. Now it is turning out to be a crucial component for the continued and healthy development of any nation today. As a result of urbanisation and population growth, the worldwide demand for energy has increased exponentially. Current conventional energy sources are insufficient to meet the global energy demand for the next 30–40 years. Emissions of "greenhouse gases" (GHGs) into the atmosphere, as well as environmental issues including "polluted air" and "global warming,"

are speedily escalating in tandem with energy consumption. The shortage of conventional energy sources and their detrimental effects on the environment are driving up demand for "RESs." RE produces fewer greenhouse gas emissions and, over time, refills itself without diminishing the Earth's resources. Several nations have increased their focus on RES in order to address ecological problems and the energy crisis and meet their sustainable development objectives. RES are now a considerable constituent of economic development in a number of nations, with the aim of preventing greenhouse gas production and encouraging clean and secure development. The choice of the optimal RES can be viewed as a "multi-criteria decision-making (MCDM)" challenge due to the existence of multiple evaluation criteria that are in conflict. MCDM is the process of finding the best element from a finite set on the basis of some criteria and limitations. MCDM methods allow us to evaluate candidates and select the best ones. Several aspects, like partial ignorance, insufficient data, or erroneous decision-related information, typically result in RES selection decisions being made under uncertain circumstances. In addition, human evaluation of characteristics that are qualitative in nature is frequently vague and prejudiced. The decisions that were made are difficult to model using simple numbers. In its place, the use of linguistic factors is applied to explain how individuals come to conclusions that are imprecise, confusing, and biassed. An examination of the best course of action with regard to renewable energy based on fuzzy information was provided in Karatop et al. (2021), while an interval-rough-number-based RES method was given in Ecer et al. (2021). The Fermatean fuzzy RES assessment model was discussed in Mishra et al. (2022). The RES method based on the TOPSIS approach (Rani et al., 2020) and sustainability/maintainability-based (Fetanat and Tayebi, 2023) were recently presented. A hybrid RES Selection assessment model based on MCDM for Optimal Performance is studied (Ali et al., 2023). A combined AHP and fuzzy TOPSIS strategy is demonstrated in Solangi et al. (2021) and a combined TOPSIS-Z MCDM method for the selection of optimal renewable energy is provided (Rathore et al., 2021).

Mathematically, Zadeh was the first person to propose the idea of fuzzy sets (FSs) to deal with vague information (Zadeh, 1965). The conception of intuitionistic FSs (IFSs) by incorporating the hesitancy index in the membership index and non-membership index was introduced (Atanassov, 1986). This extended concept of FSs is a more appropriate technique to handle vagueness in many engineering applications, and since its existence, it has gained much more attention from practitioners. As a result of the IFSs theory's handling properties with uncertainty, it has found widespread application in areas such as MCDM, medical diagnosis, data analysis, artificial intelligence, and other related fields. To deal with MCDM problems, one very important step is to combine information or data associated with alternatives on the basis of criteria, and thus the aggregation or combining operators play an essential role during the data fusion. The work published in 1986 (Atanassov, 1986), 1989 (Atanassov, 1989), 1994 (Atanassov, 1994), 2000 (De et al., 2000), 2002 (Xu and Da, 2002), 2005 (Xu, 2005), 2007 (Xu, 2007), and 2006 (Xu and Yager, 2006) was related to the introduction of various important aggregation operators to the fusion of information. These ground-breaking works attracted the attention of many researchers who were interested in tackling MCDM problems. The ability of FSs to handle problems has led to their application in vast areas such as forecasting problems, pattern recognition, medical diagnosis, MCDM problems, etc.

IFSs make it possible for an observer to include a reluctance value in the degree of membership function. The hesitancy value results from a variety of reasons, including the observer's history, fundamental knowledge, previous experiences, and the absence of standard terminology. This results in uncertainty being involved in the membership degree under IFSs. To improve the accuracy of uncertain systems, a moderator parameter is introduced to incorporate the uncertainty in the choice of membership grade made by the observer (Joshi and Kharayat, 2016). The concept of moderator intuitionistic fuzzy (MIF) set (MIFS), which is a generalization of IFSs, is presented in Joshi (2018), Joshi and Kharayat (2016). In addition, the MIF weighted averaging (MIFWA) operator and the MIF weighted geometric (MIFWG) operator are going to be put together MIF numbers (MIFNs). These operators not only take into consideration the evaluation information that was provided by decision-makers but also strive to improve the evaluation information by giving a moderator parameter to eliminate ambiguity. In other words, they do more than just take into consideration the evaluative information provided by those in charge of making decisions.

Literature provides the MIFWA and MIFWG operators with the information integration process while addressing MCDM problems. However, MIFSs are not included in other MCDM methods, such as the TOSIS method. Initially, Hwang and Yoon (1981) presented the TOPSIS method as one of the most effective MCDM techniques. The TOPSIS method is used to rank alternatives from best to worst. Among the alternatives on the ranked list, the optimal solution is the one that is closest to the positive-ideal solution. Consequently, the objective and novelty of this manuscript are to investigate new MCDM techniques based on the theory of TOPSIS, thereby establishing the TOPSIS method within the MIFS environment. The MIFSs-TOPSIS approaches have a number of benefits, some of which include the following: simplicity, rationality, comprehensibility, excellent computing efficiency, and the capacity to quantify the relative performance of each choice in a straightforward mathematical format. Under the MIFNs environment, it is simple to describe human preferences and enables explicit trade-offs between numerous criteria at the same time. One of the shortcomings of TOPSIS is that it has the potential to bring about a phenomenon known as rank reversal. As a result of this phenomenon, the order of preference for the options shifts whenever one of the alternatives is added to or removed from the choice issue.

This study is mainly concerned with providing the conception of MIFSs-TOPSIS and a RES-selection method in the MIFSs environment. The manuscript is organized as follows: Section 1, Introduction," provides background information and relevant research on the topic, including studies on finding the research gap. The objective and originality of the study are also included in this part. The preliminaries, consisting of some important definitions, are presented under Section 2. The distance measures of MIFSs are outlined under Section 3. Section 4 provides a TOPSIS approach for RES selection based on proposed MIFS distances. The efficacy of the proposed MIFS-based TOPSIS technique is put to the test by comparing different wind-generating systems considered in this study. The findings of the study are then compared in order to demonstrate that the suggested method is superior to the existing ones. Finally, key findings of this study are compiled along with future directions in Section 5. The entire organization of the manuscript is also clearly depicted in Figure 1.

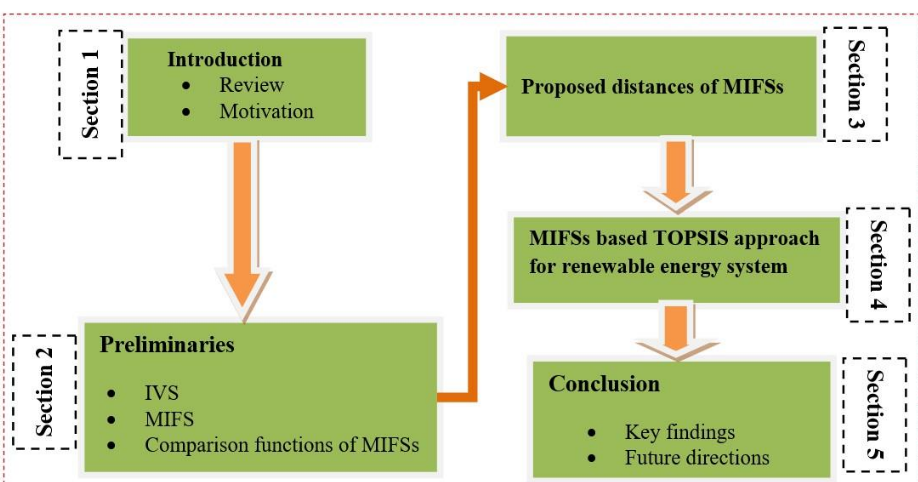

Figure 1. The organization of presented approach.

2. Preliminaries

This section presents condensed definitions that are necessary to present the developed approach for RES selection.

Definition* 1. *IFS (Atanassov, 1986): Let Ʊ be a set that is not empty and is referred to as the universe of discourse. An IFS ʃ in Ʊ is defined as ʃ = {< Ɲ, $ƚ_{ʃ}$(Ɲ), $Ⱡ_{ʃ}$(Ɲ) > : Ɲ ∈ Ʊ}, here the functions $ƚ_{ʃ}$: Ʊ→[0, 1] and $Ⱡ_{ʃ}$: Ʊ→[0, 1] define the "degree of membership" and the "degree of non-membership" of the element Ɲ ϵ Ʊ respectively, and for every element Ɲ of Ʊ, 0 ≤ $ƚ_{ʃ}$(Ɲ) + $Ⱡ_{ʃ}$(Ɲ) ≤ 1.

The main motivation behind the introduction of the concept of MIFS is to address the indeterminacy that is present when an observer chooses a membership degree under IFSs. This indeterminacy needed to be further improved by an additional parameter (referred to as the moderator parameter), which is a kind of assessment value for the information provided by the observer. Through the combination of second information with original information, the MIFS enhances the degree of membership function. By including the moderator parameter in the knowledge representation systems with just original information, the potential for overall uncertainty can be eliminated. As a result, the MIFS idea offers a considerably more realistic representation of the membership grade's uncertainty environment than the IFS theory can. The MIFS is presented as follows:

Definition* 2. *MIFS (Joshi and Kharayat, 2016; Joshi, 2018): Let Δ be a non-empty set called a universe of discourse. A MIFS M in Δ is an object that conforms to the form, as its definition: $M = \left\{\left\langle (\Diamond, t_A(\Diamond), f_A(\Diamond)), (t_M(\Diamond), f_M(\Diamond)) \right\rangle : \Diamond \in \Delta \right\}$, where the functions $t_A, f_A, t_M, t_M, : \Delta \to [0,1]$, define the "degree of membership", the "degree of non-membership" and the "truth degree of moderator parameter", the "falsity degree of moderator parameter" of the element $\Diamond \in \Delta$ respectively. For every element $\Diamond \in \Delta$, $0 \le t_A(\Diamond) + f_A(\Diamond) \le 1$ and $0 \le t_M(\Diamond) + f_M(\Diamond) \le 1$. Using the equality and containment property of MIFSs, for any two MIFNs $a = \{(t_a, f_a), (\mu_a, \nu_a)\}$ and $b = \{(t_b, f_b), (\mu_b, \nu_b)\}$, $a = b$ if and only if $t_a = t_b$, $f_a = f_b$ and $\mu_a = \mu_b$, $\nu_a = \nu_b$, and $a \le b$ if and only if $t_a \le t_b$, $f_a \le f_b$ and $\mu_a \le \mu_b$, $\nu_a \le \nu_b$.

***Definition* 3.** (Joshi, 2018) Let $a = \langle (\alpha_a, \beta_a), (\gamma_a, \delta_a) \rangle$ and $b = \langle (\alpha_b, \beta_b), (\gamma_b, \delta_b) \rangle$ be two moderator intuitionistic fuzzy numbers (MIFNs), then $S(a) = \alpha_a + \beta_a - \gamma_a - \delta_a$, $S(b) = \alpha_b + \beta_b - \gamma_b - \delta_b$ are the score functions and $H(a) = \alpha_a + \beta_a + \gamma_a + \delta_a$, $H(b) = \alpha_b + \beta_b + \gamma_b + \delta_b$ are the accuracy functions of a and b. If $S(a) < S(b)$ then a is smaller than b, denoted by $a < b$. If $S(a) = S(b)$, then find $H(a)$ and $H(b)$: If $H(a) < H(b)$ therefore, a is less than b, as shown by the fact $a < b$, and if $H(a) = H(b)$ then a and b portray the identical information, as shown by the fact $a = b$.

***Definition* 4.** (Joshi, 2018) Let $a = \langle (\alpha_a, \beta_a), (\gamma_a, \delta_a) \rangle$ and $b = \langle (\alpha_b, \beta_b), (\gamma_b, \delta_b) \rangle$ be two MIFNs and for $\lambda > 0$, then,

(i) $$\lambda a = \left\langle (1-(1-\alpha_a)^{\lambda}, \beta_a^{\lambda}), (1-(1-\gamma_a)^{\lambda}, \delta_a^{\lambda}) \right\rangle \tag{1}$$

(ii) $$a^{\lambda} = \left\langle (\alpha_a^{\lambda}, 1-(1-\beta_a)^{\lambda}), (\gamma_a^{\lambda}, 1-(1-\delta_a)^{\lambda}) \right\rangle \tag{2}$$

3. Proposed Distances for MIFSs

We run into problems when trying to compare fuzzy sets in a wide variety of theoretical and practical contexts. When we have two fuzzy sets existing in the same universe, we want to determine the difference between them, which will be represented by a distance. Moving forward, we will broaden the definitions of distances for MIFSs. In order to be more consistent with the concept of normalisation that is found in mathematics, the following distances for two MIFS A and B in the universal set X are proposed.

(i) The Hamming distance:

$$\Theta_{Hamm}^{MIFS}(A,B)=\frac{1}{2}\sum_{i=1}^{n}\begin{pmatrix}|\alpha_A(x_i)-\alpha_B(x_i)|+|\beta_A(x_i)-\beta_B(x_i)| \\ +|\gamma_A(x_i)-\gamma_B(x_i)|+|\delta_A(x_i)-\delta_B(x_i)|\end{pmatrix} \tag{3}$$

(ii) The Euclidean distance:

$$\Theta_{Eucl}^{MIFS}(A,B)=\sqrt{\frac{1}{2}\sum_{i=1}^{n}\begin{pmatrix}(\alpha_A(x_i)-\alpha_B(x_i))^2+(\beta_A(x_i)-\beta_B(x_i))^2 \\ +(\gamma_A(x_i)-\gamma_B(x_i))^2+(\delta_A(x_i)-\delta_B(x_i))^2\end{pmatrix}} \tag{4}$$

(iii) The normalized Hamming distance:

$$\Theta_{N\_Hamm}^{MIFS}(A,B)=\frac{1}{2n}\sum_{i=1}^{n}\begin{pmatrix}|\alpha_A(x_i)-\alpha_B(x_i)|+|\beta_A(x_i)-\beta_B(x_i)| \\ +|\gamma_A(x_i)-\gamma_B(x_i)|+|\delta_A(x_i)-\delta_B(x_i)|\end{pmatrix} \tag{5}$$

(iv) The normalized Euclidean distance:

$$\Theta_{N\_Eucl}^{MIFS}(A,B)=\sqrt{\frac{1}{2n}\sum_{i=1}^{n}\begin{pmatrix}(\alpha_A(x_i)-\alpha_B(x_i))^2+(\beta_A(x_i)-\beta_B(x_i))^2 \\ +(\gamma_A(x_i)-\gamma_B(x_i))^2+(\delta_A(x_i)-\delta_B(x_i))^2\end{pmatrix}} \tag{6}$$

Clearly, these distances are accurate enough to fulfil the requirements of the metric system like non-negative, symmetric and triangular properties

4. RES-Selection Approach based on the Proposed Distances of MIFSs

Too much use and development of fossil fuels have caused problems with the environment and ecology that affect us every day. If we keep using fossil fuels, global warming could happen faster, which would be terrible. Global problems with the environment will have a big effect on how people all over the world use energy in the coming decades. Efforts to cut down on carbon emissions in the future are likely to change how different types of energy affect the total amount of carbon emissions. Because the air is so dirty, some developing countries are starting to worry more and more about the environment. In this way, clean and renewable energy sources are becoming more appealing as a way to make energy more sustainable and cut pollution.

In this section, a renewable energy system (RES) having multiple wind generation systems (WGSs) is considered to compare WGSs on the basis of several criteria. The entire process is illustrated in Figure 2. The adopted steps are presented below:

Step 1. Let the RES process is having ρ WGSs i.e., alternatives $\{\rho_1,\rho_2,...,\rho_\rho\}$ that are to be evaluated on the basis of o criteria $\{o_1,o_2,...,o_o\}$ with weight vector is $\omega=(\omega_1,\omega_2,...,\omega_o)^T$ satisfying

$\omega_i > 0, i = 1,2,.., n$ and $\sum_{o=1}^{o} \omega_o = 1$.

Step 2. Let an expert committee provide their preferences of alternative ρ_ρ against the criterion o_o in the form MIFNs. On the basis of provided preferences, obtain the MIFNs preference table as below:

$(\tilde{q}^{MI}{}_{ij})_{\rho\times o} = \left\langle (\alpha^{MI}{}_{ij}, \beta^{MI}{}_{ij}), (\gamma^{MI}{}_{ij}, \delta^{MI}{}_{ij}) \right\rangle_{\rho\times o}$ $(i = 1,2,..., \rho;\ j = 1,2,...., o)$ by using the MIFNs information of the alternative $\rho_\rho(\rho = 1,2,..., \rho)$ against criteria $o_o(o = 1,2,..., o)$.

Step 3. (PIS and NIS): For each criterion, obtain the +ve ideal-solution (PIS) ρ^+ and the -ve ideal-solution (NIS) ρ^- for the WGSs as follow:

$$\rho^+ = [\{< o_j, (\max_i(\alpha^{MI}{}_{ij}, \alpha^{MI}{}_{ij}), \min_i(\beta^{MI}{}_{ij}, \beta^{MI}{}_{ij})), (\max_i(\gamma^{MI}{}_{ij}, \gamma^{MI}{}_{ij}), \min_i(\delta^{MI}{}_{ij}, \delta^{MI}{}_{ij})) >\}\ \forall j = 1,2,...., o] \quad (7)$$

$$\rho^- = [\{< o_j, (\min_i(\alpha^{I}{}_{ij}, \alpha^{QI}{}_{ij}), \max_i(\beta^{QI}{}_{ij}, \beta^{QI}{}_{ij})), (\min_i(\gamma^{QI}{}_{ij}, \gamma^{QI}{}_{ij}), \max_i(\delta^{QI}{}_{ij}, \delta^{QI}{}_{ij})) >\}\ \forall j = 1,2,...., o] \quad (8)$$

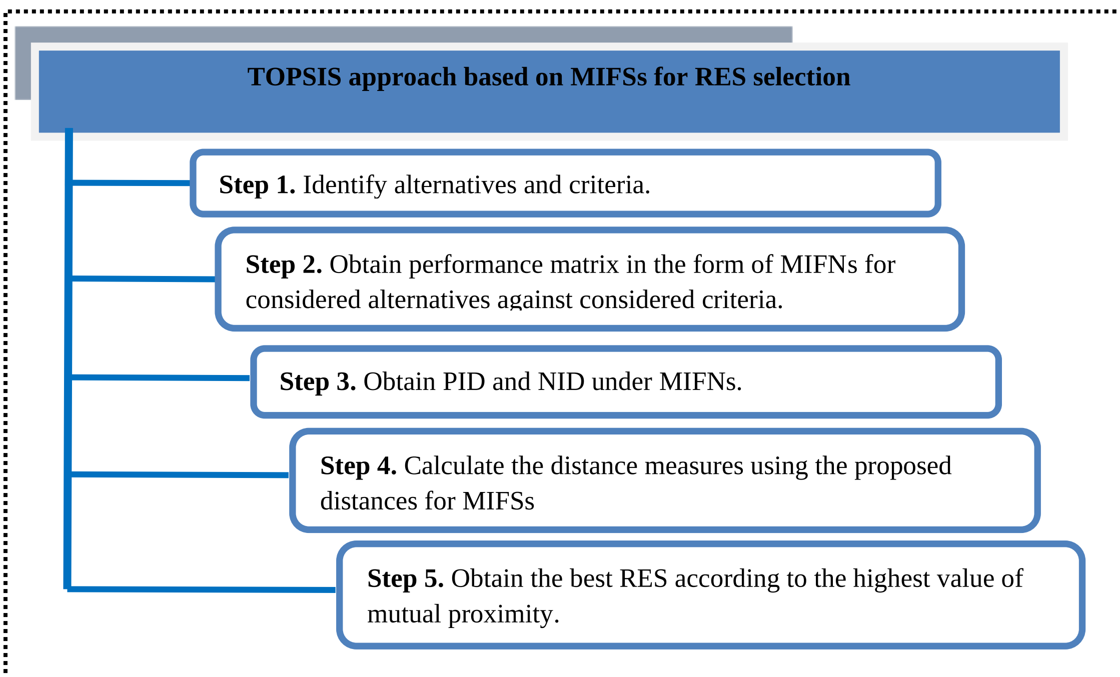

Figure 2. The MIFS-TOPSIS based model for RES selection.

Step 4. Calculate the distance measures of each WGS from these PIS and NIS with the help of proposed distances either the normalized Hamming distance (NHD) or the normalized Euclidean distance (NED), using the following equations:

$$\Delta^{+}{}_{\rho_i} = \frac{1}{2.o}\sum_{j=1}^{o}\begin{pmatrix}\left|\alpha_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \alpha_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| + \left|\beta_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \beta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| \\ +\left|\gamma_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \gamma_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| + \left|\delta_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \delta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right|\end{pmatrix} \tag{9}$$

Or

$$\Delta^{+}{}_{\rho_i} = \sqrt{\frac{1}{2.o}\sum_{j=1}^{o}\begin{pmatrix}\left(\alpha_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \alpha_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 + \left(\beta_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \beta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 \\ +\left(\gamma_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \gamma_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 + \left(\delta_{\rho^+}{}^{\mathrm{MI}}(x_{ij}) - \delta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2\end{pmatrix}} \tag{10}$$

and $\Delta^{-}{}_{\rho_i} = \frac{1}{2.o}\sum_{j=1}^{o}\begin{pmatrix}\left|\alpha_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \alpha_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| + \left|\beta_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \beta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| \\ +\left|\gamma_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \gamma_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right| + \left|\delta_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \delta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right|\end{pmatrix}$ (11)

Or

$$\Delta^{-}{}_{\rho_i} = \sqrt{\frac{1}{2.o}\sum_{j=1}^{o}\begin{pmatrix}\left(\alpha_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \alpha_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 + \left(\beta_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \beta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 \\ +\left(\gamma_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \gamma_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2 + \left(\delta_{\rho^-}{}^{\mathrm{MI}}(x_{ij}) - \delta_{\tilde{q}}{}^{\mathrm{MI}}(x_{ij})\right)^2\end{pmatrix}} \tag{12}$$

Step 5. Compute the mutual proximity of each WGS with respect to the PIS and NIS using the equation that is below:

$$\wp_i = \frac{\Delta^{-}{}_{\rho_i}}{\Delta^{+}{}_{\rho_i} + \Delta^{-}{}_{\rho_i}} \tag{13}$$

The highest value of mutual proximity $\wp_i$ is the best WGS.

4.1 Numerical Illustration

To test the effectiveness of the proposed MIFSs-TOPSIS method, a study was done to compare four wind generation systems $\{\rho_1, \rho_2, \rho_3, \rho_4\}$ that use wind turbine, interior permanent magnet (IPM) synchronous generator and two-sided PWM converter. Three criteria: efficiency (o_1), reliability (o_2) and durability (o_3), were identified as evaluation criteria for the machine. The performance rating of each machine was calculated, by using the available data of these machines. All the criteria will be treated as benefit criteria. Let {0.4, 0.35, 0.25} be the criteria weight set. Let an expert committee provide their preferences of alternative ρ_ρ against the criterion o_o in the form MIFNs. On the basis of provided preferences, obtain the following MIFNs preference table (See Table 1).

Using the procedure given in Step 3 above, the PIS ρ^+ and the NIS ρ^- for each of the mentioned criteria are obtained and presented in Table 2.

Calculate the distance measures of each WGS from these PIS and NIS with the help of proposed distances the NHD and the NED (see Table 3).

Table 1. Experts MIFNs preference table.

WGS\ Criteria	o_1	o_2	o_3
ρ_1	$\langle(0.61,0.22),(0.71,0.17)\rangle$	$\langle(0.51,0.34),(0.77,0.24)\rangle$	$\langle(0.57,0.30),(0.71,0.27)\rangle$
ρ_2	$\langle(0.69,0.24),(0.80,0.18)\rangle$	$\langle(0.62,0.33),(0.75,0.22)\rangle$	$\langle(0.56,0.31),(0.77,0.18)\rangle$
ρ_3	$\langle(0.82,0.16),(0.82,0.14)\rangle$	$\langle(0.61,0.33),(0.80,0.18)\rangle$	$\langle(0.60,0.33),(0.81,0.16)\rangle$
ρ_4	$\langle(0.59,0.24),(0.78,0.21)\rangle$	$\langle(0.60,0.22),(0.78,0.19)\rangle$	$\langle(0.66,0.32),(0.80,0.19)\rangle$

Table 2. PIS and NIS table.

	o_1	o_2	o_3
PIS	$\langle(0.82,0.16),(0.82,0.14)\rangle$	$\langle(0.62,0.22),(0.80,0.18)\rangle$	$\langle(0.66,0.30),(0.81,0.16)\rangle$
NIS	$\langle(0.59,0.24),(0.71,0.21)\rangle$	$\langle(0.51,0.34),(0.75,0.24)\rangle$	$\langle(0.56,0.33),(0.71,0.27)\rangle$

Table 3. Distance measures of each WGS.

WGS	Using proposed NHD		Using proposed NED	
	Measures from PIS	Measures from NIS	Measures from PIS	Measures from NIS
ρ_1	0.17167	0.02333	0.14254	0.02517
ρ_2	0.10667	0.08833	0.09452	0.08534
ρ_3	0.03500	0.16000	0.05276	0.13916
ρ_4	0.08833	0.10667	0.10654	0.09609

Finally, obtain the mutual proximity of each WGS (see Table 4) and highest value of mutual proximity (see Figure 3) is corresponding to ρ_3. So, ρ_3 is the best WGS out of considered WGSs.

Table 4. Mutual proximity of each WGS.

WGS	Mutual proximity based on obtained measures using proposed NHD	Mutual proximity based on obtained measures using proposed NED
ρ_1	0.11966	0.15006
ρ_2	0.45299	0.47450
ρ_3	0.82051	0.72511
ρ_4	0.54701	0.47422

Further, the obtained ranking $\rho_3 > \rho_4 > \rho_2 > \rho_1$ of WGSs $\{\rho_1, \rho_2, \rho_3, \rho_4\}$ is compared with some of the existing methods and compiled in Table 5. The fact that we have achieved the same rating using the suggested technique as we have obtained using the other methods under consideration is evidence that our method is legitimate. In addition, the provided method is preferable since it considers the moderator parameter based TOPSIS approaches, which are not currently accessible in the relevant literature.

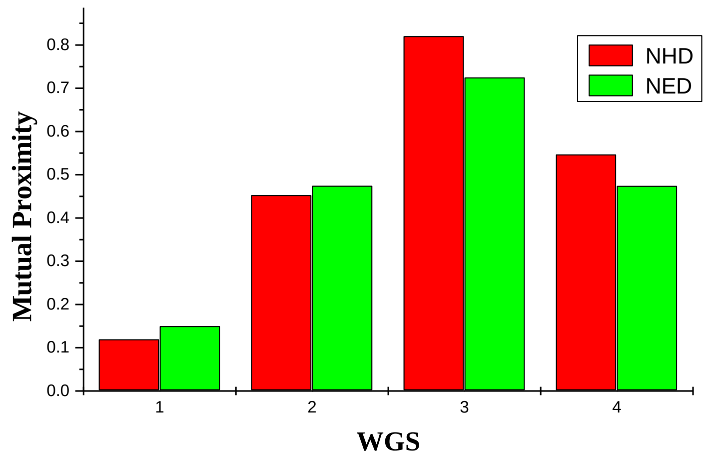

Figure 3. Mutual proximity of WGS.

Table 5. Comparative analysis.

S. No.	Method	Obtained ranking and remarks
1.	Xu and Yager approach (Xu and Yager, 2006)	This technique is not deemed a parameter for the moderator. If the rating is developed without considering the moderator parameter, then the resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
2.	Xu approach (Xu, 2007)	This technique is not deemed a parameter for the moderator. If the rating is developed without considering the moderator parameter, then the resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
3.	Joshi and Kumar approach (Joshi and Kumar, 2014)	This method is based on TOPSIS technique but it is not deemed the moderator parameter. If the rating is developed without considering the moderator parameter, then the resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
4.	Joshi approach (Joshi, 2018)	This method is based on aggregation operator instead of TOPSIS technique. It also considered the moderator parameter. The resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
5.	Joshi and Gegov approach (Joshi and Gegov, 2020)	This technique is not deemed the moderator parameter. If the rating is developed without considering the moderator parameter, then the resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
6.	Mishra et al. approach (Mishra et al., 2022)	This technique is not deemed the moderator parameter. If the rating is developed without considering the moderator parameter, then the resulting ranking is $\rho_3 > \rho_4 > \rho_2 > \rho_1$.
7.	Proposed approach	This technique is deemed with the moderator parameter and we obtained the ranking $\rho_3 > \rho_4 > \rho_2 > \rho_1$, i.e., the same rating as we have obtained using the other methods under consideration. Further, the suggested method is superior because it incorporates moderator parameter-based TOPSIS approaches, which are not currently accessible in the relevant literature. This implies that the suggested method introduces a new perspective that is not commonly discussed or utilized in the field.

5. Conclusions

The indeterminacy that was already present with an observer in the selection of membership degrees under IFSs was further improved by including the moderator parameter, which is a kind of assessment value attached to the information that was provided by the observer. This was done in order to improve the reliability of the unreliable system, which was the primary motivation for the introduction of the concept of MIFS. As a result, the idea of MIFS offers a far more realistic representation of the uncertain environment around the membership grade, which the IFSs theory is unable to take into consideration in more depth. The information provided by MIF has the potential to significantly improve the already established knowledge-based systems, leading to judgements that are more accurate overall. If the moderator parameter is not taken into account, then the original performance will remain uncertified; as a result, the legitimacy of the evaluation objects will be called into question. The aggregation operations for MIFSs may be found in the relevant literature; however, the distance measurements have not yet been presented to this day. Motivated by it, this paper first presents some distance measures for MIFSs then, on the basis of the proposed distances, a TOPSIS technique for choosing the best RES inside MIFS architecture is suggested. Overall, the key findings of this study are as follows:

- For the MIFSs, we provide several distance measures that are in general required to deal with MCDM issues in an uncertain environment.
- Based on the proposed distances, a TOPSIS method under MIFSs is presented to deal with MCDM problems.
- Finally, an approach for the RES-selection problem is included in this study on the basis of proposed distance measures and, TOPSIS method in the environment of MIFSs.
- The efficacy of the proposed MIFS-based TOPSIS technique is put to the test by comparing different wind-generating systems. The findings of the study are then compared in order to demonstrate that the suggested method is superior to the existing ones.
- This TOPSIS method will provide a vast array of applications for addressing technical and environmental concerns under MIFSs.

The work that will be done in the future will consist of establishing new series of operators, similarity measurements inside the MIFNs environment based on various norms and co-norms, and applications for the purpose of solving problems that occur in real life. In addition to this, it is possible to extend it in a way that is analogous to the generalisation of IFSs.

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

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References

Ali, G., Musbah, H.N., Aly, H.H., & Little, T. (2023). Hybrid renewable energy resources selection based on multi criteria decision methods for optimal performance. *IEEE Access*, *11*, 26773-26784. https://doi.org/10.1109/ACCESS.2023.3254532.

Atanassov, K.T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *20*(1), 87-96. https://doi.org/10.1016/S0165-0114(86)80034-3.

Atanassov, K.T. (1989). More on intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *33*(1), 37-45. https://doi.org/10.1016/0165-0114(89)90215.

Atanassov, K.T. (1994). New operations defined over the intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *61*(2), 137-142. https://doi.org/10.1016/0165-0114(94)90229-1.

De, S.K., Biswas, R., & Roy, A.R. (2000). Some operations on intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *114*(3), 477-484. https://doi.org/10.1016/S0165-0114(98)00191-2.

Ecer, F., Pamucar, D., Mardani, A., & Alrasheedi, M. (2021). Assessment of renewable energy resources using new interval rough number extension of the level based weight assessment and combinative distance-based assessment. *Renewable Energy*, *170*, 1156-1177. https://doi.org/10.1016/j.renene.2021.02.004.

Fetanat, A., & Tayebi, M. (2023). Industrial filtration technologies selection for contamination control in natural gas processing plants: A sustainability and maintainability-based decision support system under q-rung orthopair fuzzy set. *Process Safety and Environmental Protection*, *170*, 310-327. https://doi.org/10.1016/j.psep.2022.12.014.

Hwang, C.L., & Yoon, K. (1981). *Methods for multiple attribute decision making* (pp. 58-191). https://doi.org/10.1007/978-3-642-48318-9_3.

Joshi, B.P. (2018). Moderator intuitionistic fuzzy sets with applications in multi-criteria decision-making. *Granular Computing*, *3*, 61-73. https://doi.org/10.1007/s41066-017-0056-3.

Joshi, B.P., & Gegov, A. (2020). Confidence levels q-rung orthopair fuzzy aggregation operators and its applications to MCDM problems. *International Journal of Intelligent Systems*, *35*(1), 125-149. https://doi.org/10.1002/int.22203.

Joshi, B.P., Kharayat, P.S. (2016). Moderator intuitionistic fuzzy sets and application in medical diagnosis. In: Satapathy, S., Raju, K., Mandal, J., Bhateja, V. (eds) *Proceedings of the Second International Conference on Computer and Communication Technologies*. *Advances in Intelligent Systems and Computing* (Vol 380). Springer, New Delhi. https://doi.org/10.1007/978-81-322-2523-2_16.

Joshi, D., & Kumar, S. (2014). Intuitionistic fuzzy entropy and distance measure based TOPSIS method for multi-criteria decision making. *Egyptian Informatics Journal*, *15*(2), 97-104. https://doi.org/10.1016/j.eij.2014.03.002.

Karatop, B., Taşkan, B., Adar, E., & Kubat, C. (2021). Decision analysis related to the renewable energy investments in Turkey based on a Fuzzy AHP-EDAS-Fuzzy FMEA approach. *Computers & Industrial Engineering*, *151*, 106958. https://doi.org/10.1016/j.cie.2020.106958.

Mishra, A.R., Rani, P., Saha, A., Senapati, T., Hezam, I.M., & Yager, R.R. (2022). Fermatean fuzzy copula aggregation operators and similarity measures-based complex proportional assessment approach for renewable energy source selection. *Complex & Intelligent Systems*, *8*(6), 5223-5248. https://doi.org/10.1007/s40747-022-00743-4.

Rani, P., Mishra, A.R., Mardani, A., Cavallaro, F., Alrasheedi, M., & Alrashidi, A. (2020). A novel approach to extended fuzzy TOPSIS based on new divergence measures for renewable energy sources selection. *Journal of Cleaner Production*, *257*, 120352. https://doi.org/10.1016/j.jclepro.2020.120352.

Rathore, N., Debasis, K., Singh, M.P. (2021). Selection of optimal renewable energy resources using TOPSIS-Z methodology. In: Hura, G.S., Singh, A.K., Siong Hoe, L. (eds) *Advances in Communication and Computational Technology*. *ICACCT 2019*. Lecture Notes in Electrical Engineering (Vol 668). Springer, Singapore. https://doi.org/10.1007/978-981-15-5341-7_73.

Solangi, Y.A., Longsheng, C., & Shah, S.A.A. (2021). Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach. *Renewable Energy*, *173*, 209-222. https://doi.org/10.1016/j.renene.2021.03.141.

Xu, Z. (2005). An overview of methods for determining OWA weights. *International Journal of Intelligent Systems*, *20*(8), 843-865. https://doi.org/10.1002/int.20097.

Xu, Z. (2007). Intuitionistic fuzzy aggregation operators. *IEEE Transactions on Fuzzy Systems*, *15*(6), 1179-1187. https://doi.org/10.1109/TFUZZ.2006.890678.

Xu, Z., & Yager, R.R. (2006). Some geometric aggregation operators based on intuitionistic fuzzy sets. *International Journal of General Systems*, *35*(4), 417-433. https://doi.org/10.1080/03081070600574353.

Xu, Z.S., & Da, Q.L. (2002). The ordered weighted geometric averaging operators. *International Journal of Intelligent Systems*, *17*(7), 709-716. https://doi.org/10.1002/int.10045.

Zadeh, L.A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338-353. https://doi.org/10.1016/S0019-9958(65)90241-X.

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