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# Multi-Polar Interval-Valued Neutrosophic Hypersoft Set with Multi-criteria decision making of Cost-Effective Hydrogen Generation Technology Evaluation

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**Abstract:** The complex process of decision-making is addressed in this study, especially when dealing with diverse factors and input from several specialists. In the context of m-polar interval-valued neutrosophic hypersoft sets (m-PIVNHSSs), the paper proposes innovative adaptations of the correlation coefficient (CC) and weighted correlation coefficient (WCC), drawing on correlation analysis in statistics and engineering. The goal is to improve decision-making processes in scenarios with complicated features and input from several specialists. Through defined theorems and claims, the study offers a solid mathematical framework and presents methods based on CC and WCC to address decision-making complexity. These strategies show promise for enhancing decision accuracy in circumstances involving a wide range of features and expert inputs. AHP, TOPSIS, and other strategies that are now used might also be extended, according to the research. AHP, TOPSIS, and VIKOR are three possible methodologies that might be used to the m-PIVNHSSs environment, according to the research, opening opportunities for additional breakthroughs in the decision-making sector.

**Keywords:** Aggregate operators, Correlation Coefficient (CC), Neutrosophic Hypersoft Sets (NHSSs), Weighted Correlation Coefficients (WCC), Multi-Polar Neutrosophic Hypersoft Sets (m-PNHSSs).

## 1. Introduction

The importance of hydrogen is due to its capacity to transport clean energy and serve as a flexible remedy for pressing global problems. Hydrogen is a clean fuel that enables emissions-free energy production in fuel cells, making it essential for moving away from fossil fuels and reducing global warming. Its capacity to store energy helps manage the oscillations of renewable energy, and its potential to decarbonize industrial sectors like steel and transportation demonstrates the breadth of its effects on emissions reduction. Hydrogen is also a major facilitator of a sustainable and low-carbon future since it drives technical innovation, encourages international cooperation, and spurs economic growth. Numerous research studies have investigated the use of hydrogen in Multi-Criteria Decision Making (MCDM) and its relevance in ambiguous situations. The adaptability of hydrogen as an energy carrier is especially beneficial in ambiguous situations. By storing surplus energy and releasing it when needed, it can help with renewable energy supply variations and provide grid stability in ambiguous energy situations [1]. Energy security in areas susceptible to supply outages can be improved by hydrogen's capacity for decentralized generation and delivery [2].

Hydrogen technology evaluation for MCDM sometimes entails considering several factors, including price, effectiveness, environmental impact, and scalability. This was demonstrated in research by [3], where a fuzzy MCDM technique was used to evaluate several hydrogen generation technologies considering economic, environmental, and technological issues. Furthermore, Qie, X. et al. [4] used an MCDM framework to assess hydrogen storage systems while taking economic, efficient, and safety considerations into account.

In MCDM applications, the flexibility of hydrogen to various situations is further demonstrated. Fayyazi et al.'s [5] analysis of its influence on transportation choices, for instance, considers the adoption of hydrogen fuel cell cars under ambiguous market conditions. Lu, Z., & Li, Y. applied fuzzy in MCDM approaches are used to evaluate various hydrogen generation processes while taking economic and environmental aspects into account.

A new theory was urgently needed to address inconsistencies. To deal with uncertain and inconsistent environments, Smarandache developed a new idea in 1998 [9]. This theory is referred to neutrosophic set (NS) with the addition of indeterminacy value along with membership and non-membership values (T, I, F) (all these values are independent of each other). Based on the numbers (T, I, and F) assigned by the decision-maker (DM) in the form of neutrosophic numbers, this concept of NS was further expanded. For instance, the single-valued neutrosophic set (SVNS) [10], the multi-valued neutrosophic set (MVNS) [11], the interval-valued neutrosophic set (IVNS) [12], and the multi-valued interval neutrosophic set (MVINS) [13]. The idea behind these statistics can be immediately applied to difficulties referred to as multi-criteria decision-making in real-world situations (MCDM). Numerous scholars have proposed various strategies to address MCDM issues using neutrosophic set based algorithms TOPSIS [14], MULTIMOORA [15], AHP [16], SWOT [17], and many more [18].

Numerous scholars have provided numerous uses for neutrosophic sets and their hybrids while taking into consideration MCDM approaches in daily life issues as an application [19-22]. Using mathematical methods, real-world issues such as human resource selection, gadget selection, shortest path selection, robot selection, security considerations, medical equipment selection, and environmental safety measures can be solved. To address ambiguities and get around the difficulties in the current set architectures, Maji suggested the idea of a soft set (SS) [23]. The SS theory was expanded by Cağman et al. [24] to include the features of the fuzzy soft set (FSS). Maji et al. [25] developed the idea of an intuitionistic fuzzy soft set (IFSS) and its attributes to address the issues with uncertainty. Like, Maji [26] extended the idea of neutrosophic sets by combining them to the soft set and presented the theory of neutrosophic soft sets (NSS) to overcome indeterminacy. Interval-

Valued Neutrosophic Soft Set (IVNSS) was introduced by Deli [27] with several fundamental concepts, operations, and decision-making techniques.

Hypersoft set (HSS) is a new set structure that Smarandache [28] proposed in 2018. In essence, this set is the mapping from the product of attributes (which are further divided) to the power set of the universal set and desire set of attributes. The concepts of fuzzy hypersoft sets, intuitionistic hypersoft sets, and neutrosophic hypersoft sets were also put out [28] to address truthiness, uncertainty, and indeterminacy. The definition of the neutrosophic hypersoft set (NHSSs) [29], aggregate operators, similarity measures, distance measures, and the concepts of single-valued neutrosophic hypersoft sets (SVNHSSs), multi-valued neutrosophic hypersoft sets (m-PNHSSs) [30], interval-valued neutrosophic hypersoft sets (IVNHSSs), and multi-valued interval neutrosophic hypersoft sets (m-PVINHSSs) were proposed by [31], along with matrix notations and using these definitions the applications, the algorithms with case studies has been presented by [32-33]. All these situations demonstrate how well hydrogen works in ambiguous situations and how well it works with MCDM [36] techniques for making decisions. Its adaptability and ability to consider a range of criteria and aspects highlight its value as a dynamic solution in both ambiguous situations and difficult decision-making processes. Novel approaches have been demonstrated by recent studies that have advanced a variety of sectors. Paul, Jana, and Pal [37] extended decision-making utilizing Pythagorean fuzzy Hamacher aggregation operators, Du, Wang, and Lu [38] maximized wireless power transmission with an improved approach, and Haq and Saqlain used machine learning for attendance tracking in a pandemic [39]. Convolutional neural networks were employed by Zulqarnain and Saqlain [40] to evaluate text readability in higher education, while Saqlain et al. [41] presented a multi-polar interval-valued neutrosophic hypersoft set for uncertainty and decision-making. These projects demonstrate a dedication to creativity and cross-domain problem-solving [42-46].

This paper makes significant contributions to the field of decision-making by addressing the limitations of existing approaches in dealing with m-PIVNHSs. By introducing the m-PIVNHSs model, this research offers a novel solution to the challenges posed by the abstract and context-dependent nature of language. The implementation of the proposed aggregate operators, correlation coefficients (CC) of a practical tool for solving decision-making issues and improving the overall understanding and application of m-PIVNHSs knowledge. This contribution has the potential to

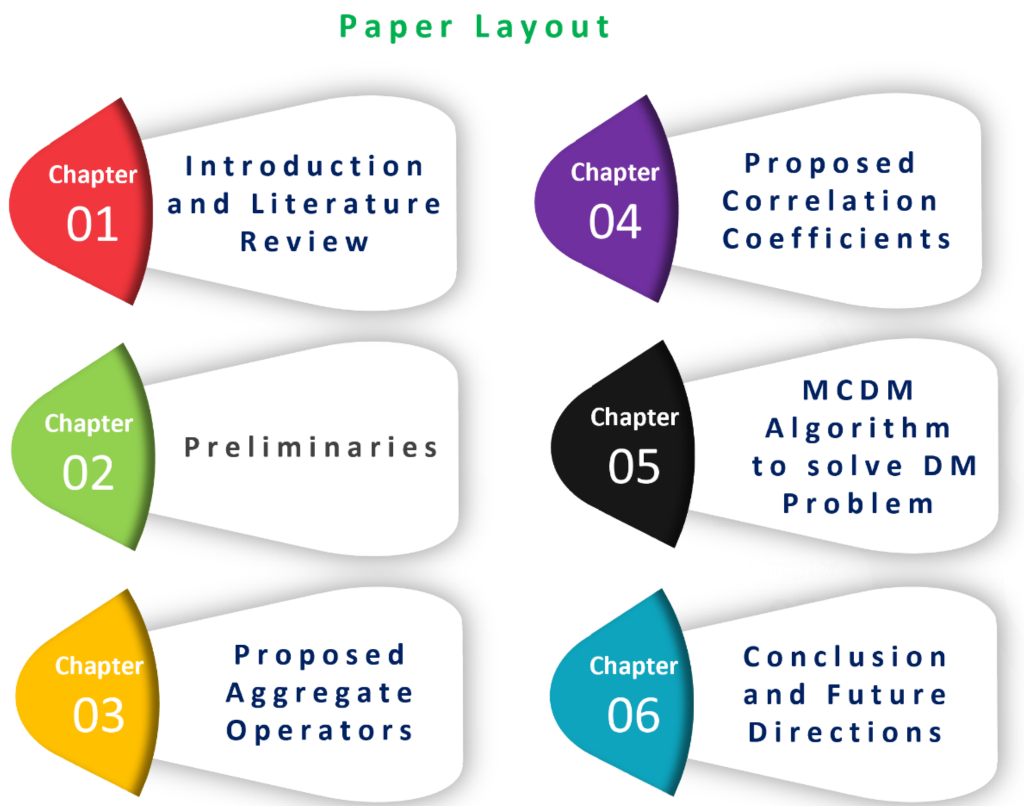


***Figure 1**. Layout of the paper*

benefit various fields that rely on language-based decision-making, such as natural language processing, sentiment analysis, and artificial intelligence, among others. The following shows that, how the work has been organized: The fundamental ideas of m-PIVNHSs are broken down in detail in section 2. In section 3, we present a definition, notions, and examples of m-PIVNHSs with basic properties and operations. The aggregate operators, and correlation coefficients (CC) of m-PIVNHSs have been presented in section 4. In part 5, an MCDM framework is described for the "m-PIVNHSs algorithm to solve MCDM problem" with a case study to demonstrate the benefits of the proposed algorithm. The findings of the study have been summarized, along with their significance, in section 6, and concluded with future directions. The layout of the paper is also presented in figure 1.

## 2. Preliminary section

In this section, we go through some basic definitions that support the construction of the framework of this paper: hypersoft set (HSS), neutrosophic hypersoft set (NHSSs), m-polar neutrosophic hypersoft set (m-PNHSSs), and m-polar interval-valued neutrosophic hypersoft set (m-PIVNHSSs).

**Definition 2.1: Hypersoft Set [28]**

Assume that universal and power set of universal set is given that $\mu$ $and$ $P(\mu)$ . Considering $(i^1, i^2, i^3, \dots, i^n)$ when $n \geq 1$, and suppose $n$ be a well-defined attributives, whose corresponded attributive elements are sequentially, the set $(£^1, £^2, £^3, \dots, £^n)$ with $£^i \cap £^j = \emptyset$, where $i \neq j$ and $i, j \epsilon \{1,2,3 \dots n\}$, then $(\xi, £)$ is called a hypersoft set;

$$\xi: (£ = £^1 \times £^2 \times £^3 \times \dots \times £^n) \rightarrow P(\mu) \qquad (1)$$

**Definition 2.2: Single-Valued Neutrosophic Hypersoft Set [29]**

In equation (1), if we assign the values to each attribute in the form of truthiness, indeterminacy, and falseness $< \mathrm{t}, \mathrm{i}, \mathrm{f} >$ where $\mathrm{t}, \mathrm{i}, \mathrm{f}: \mu \rightarrow [0,1]$ also $0 \leq \mathrm{t}(\xi(\varkappa)) + \mathrm{i}(\xi(\varkappa)) + \mathrm{f}(\xi(\varkappa)) \leq 3$. then the pair then $(\xi, £)$ is called a single-valued neutrosophic hypersoft set.

**Definition 2.3: m-Polar Neutrosophic Hypersoft Set [30]**

In equation (1) if we assign the values to each attribute in the form of

$$\boldsymbol{\xi}: ((£ = £^1 \times £^2 \times £^3 \times \dots \times £^n) \rightarrow \boldsymbol{P}(\boldsymbol{\mu})) = \left\{ \begin{matrix} < \varkappa, . \boldsymbol{T}^i(\xi(\varkappa)) + \boldsymbol{I}^j(\xi(\varkappa)) + \boldsymbol{F}^k(\xi(\varkappa)) > . \varkappa \in \boldsymbol{\mu}, \\ \boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k}. = \mathbf{1}, \mathbf{2}, \mathbf{3}, \dots, \boldsymbol{n} \end{matrix} \right\} \text{ Also}$$

$$\mathbf{0} \leq \sum_{i=1}^{a} \boldsymbol{T}^i(\xi(\varkappa)) \leq \mathbf{1}, \qquad \mathbf{0} \leq \sum_{j=1}^{b} \boldsymbol{I}^j(\xi(\varkappa)) \leq \mathbf{1}, \qquad \mathbf{0} \leq \sum_{k=1}^{c} \boldsymbol{F}^k(\xi(\varkappa)) \leq \mathbf{1}$$

Where $\boldsymbol{T}^i(\xi(\varkappa)), \boldsymbol{I}^j(\xi(\varkappa)), \boldsymbol{F}^k(\xi(\varkappa)) \subseteq [\mathbf{0}, \mathbf{1}]$ are the fuzzy numbers and

$$\mathbf{0} \leq \sum_{i=1}^{a} \boldsymbol{T}^i(\xi(\varkappa)) + \sum_{j=1}^{b} \boldsymbol{I}^j(\xi(\varkappa)) + \sum_{k=1}^{c} \boldsymbol{F}^k(\xi(\varkappa)) \leq \mathbf{3} \qquad (2)$$

then the pair then $(\xi, £)$ is called a m-Polar neutrosophic hypersoft set (m-PNHSSs).

**Definition 2.4: m-Polar Interval-Valued Neutrosophic Hypersoft Set [31]**

In equation (2) if we assign the values to each attribute in the form of

$$T^i(\xi(\varkappa)) = \left[\left(T^i(\xi(\varkappa))\right)^-, \left(T^i(\xi(\varkappa))\right)^+\right] \subseteq [0,1]$$

$$I^j(\xi(\varkappa)) = \left[\left(I^j(\xi(\varkappa))\right)^-, (I^j(\xi(\varkappa))^+\right] \subseteq [0,1]$$

$$F^k(\xi(\varkappa)) = \left[\left(F^k(\xi(\varkappa))\right)^-, \left(F^k(\xi(\varkappa))\right)^+\right] \subseteq [0,1]$$

Also

$$0 \leq \sum_{i=1}^{a} Sup \ \{T^i(\xi(\varkappa)) \leq 1, \qquad 0 \leq \sum_{j=1}^{b} Sup\{I^j(\xi(\varkappa))\} \leq 1, \qquad 0 \leq \sum_{k=1}^{c} \{F^k(\xi(\varkappa))\} \leq 1$$

And,

$$\mathbf{0} \leq \sum_{i=1}^{a} \boldsymbol{T}^i(\xi(\varkappa)) + \sum_{j=1}^{b} \boldsymbol{I}^j(\xi(\varkappa)) + \sum_{k=1}^{c} \boldsymbol{F}^k(\xi(\varkappa)) \leq \mathbf{3} \qquad (\mathbf{3})$$

then the pair then $(\xi, £)$ is called a m-polar interval-valued neutrosophic hypersoft set (m-PIVNHSSs).

## 3. Calculations

In this section, we propose informational energy along with some necessary theorems and propositions. Informational energy and correlation coefficients are integral components of effective decision-making. Informational energy signifies the value and significance of available information, influencing decision quality, risk assessment, and resource allocation. Correlation coefficients facilitate the identification of relationships, predictive power, risk management, and decision optimization by quantifying the strength between variables. By leveraging high-energy information and understanding correlations, decision-makers can decide more precise and accurate.

**Definition 3.1 Informational Energy of m-PIVNHSSs**

Consider $(\psi, \alpha)$ and $((\psi, \beta))$ be two m-polar IVNHSSs; $(\psi, \alpha) =$

$$\{(v_i, [t_{\psi(d^-_k)}(v_i)^{i-}, t_{\psi(d^-_k)}(v_i)^{i+}], [i_{\psi(d^-_k)}(v_i)^{j-}, i_{\psi(d^-_k)}(v_i)^{j+}], ([f_{\psi(d^-_k)}(v_i)^{k-}, f_{\psi(d^-_k)}(v_i)^{k+}]) \mid v_i \in u\} \quad and\ (\phi, \beta)$$
$$= \{([v_i, t_{\phi(d^-_k)}(v_i)^{i-}, v_i, t_{\phi(d^-_k)}(v_i)^{i+}], [i_{\phi(d^-_k)}(v_i)^{j-}, i_{\phi(d^-_k)}(v_i)^{j+}], [f^-{}_{\phi(d^-_k)}(v_i)^{k-}, f^-{}_{\phi(d^-_k)}(v_i)^{k+}]) \mid v_i \in u\}$$

Then, their informational energies can be defined as;

$$S_{m-PIVNHSSs}(\psi, \alpha)$$
$$= \sum_{k=1}^{-} \sum_{i=1}^{+} (\sum_{i=1}^{p} \left(t^{i-}_{\psi(d^-_k)t}(v_i)\right)^2 + \sum_{i=1}^{p} \left(t^{i+}_{\psi(d^-_k)t}(v_i)\right)^2 + \sum_{j=1}^{q} \left(i^{j-}_{p(a_k)j}(v_i)\right)^2$$
$$+ \sum_{j=1}^{q} \left(i^{j+}_{p(a_k)j}(v_i)\right)^2 + \sum_{k=1}^{r} \left(\left(f^{k-}_{\psi}(d^-_k)k(v_i)\right)^2\right) + \sum_{k=1}^{r} \left(\left(f^{k+}_{\psi}(d^-_k)k(v_i)\right)^2\right)$$

$$S_{m-PIVNHSSs}(\phi, \beta)$$
$$= \sum_{k=1}^{-} \sum_{i=1}^{+} (\sum_{i=1}^{p} \left(t^{i-}_{\phi(d^-_k)i}(v_i)\right)^2 + \sum_{i=1}^{p} \left(t^{i+}_{\phi(d^-_k)i}(v_i)\right)^2 + \sum_{j=1}^{q} \left(i^{j-}_{\phi(d^-_k)j}(v_i)\right)^2$$
$$+ \sum_{j=1}^{q} \left(i^{j+}_{\phi(d^-_k)j}(v_i)\right)^2 + \sum_{k=1}^{r} \left(\tilde{f}^{k-}_{\phi(d^-_k)k}(v_i)\right)^2 + \sum_{k=1}^{r} \left(\tilde{f}^{k+}_{\phi(d^-_k)k}(v_i)\right)^2)$$

**Definition 3.2 Correlation of two m-PIVNHSSs**

Consider $(\psi, \ddot{\alpha})$ and $((\psi, \dddot{\beta}))$ be two m-PIVNHSSs; $(\psi, \ddot{\alpha}) =$

$$\{(v_i, [t_{\psi(d^-_k)}(v_i)^{i-}, t_{\psi(d^-_k)}(v_i)^{i+}], [i_{\psi(d^-_k)}(v_i)^{j-}, i_{\psi(d^-_k)}(v_i)^{j+}], ([f_{\psi(d^-_k)}(v_i)^{k-}, f_{\psi(d^-_k)}(v_i)^{k+}]) \mid v_i \in u\} \quad and\ (\phi, \ddot{\beta})$$
$$= \{([v_i, t_{\phi(d^-_k)}(v_i)^{i-}, v_i, t_{\phi(d^-_k)}(v_i)^{i+}], [i_{\phi(d^-_k)}(v_i)^{j-}, i_{\phi(d^-_k)}(v_i)^{j+}], [f^-{}_{\phi(d^-_k)}(v_i)^{k-}, f^-{}_{\phi(d^-_k)}(v_i)^{k+}]) \mid v_i \in u\}$$

Then, their correlation can be defined as;

$$\hat{C}_{m-PIVNHSSs}((\psi,\alpha^{\cdot\cdot}),(\psi,\beta^{\cdot\cdot}))$$
$$= \sum_{k=1}^{-}\sum_{i=1}^{+}(\sum_{i=1}^{p}\left(t_{\psi(d^{-}_{k})}(v_i)^{i-} * v_i, t_{\phi(d^{-}_{k})}(v_i)^{i-}\right)$$
$$+ (\sum_{i=1}^{p}\left(t_{\psi(d^{-}_{k})}(v_i)^{i+} * v_i, t_{\phi(d^{-}_{k})}(v_i)^{i+}\right) + \sum_{j=1}^{q}\left(i_{\psi(d^{-}_{k})}(v_i)^{j-} * i_{\phi(d^{-}_{k})}(v_i)^{j-}\right)$$
$$+ \sum_{j=1}^{q}\left(i_{\psi(d^{-}_{k})}(v_i)^{j+} * i_{\phi(d^{-}_{k})}(v_i)^{j+}\right) + \sum_{k=1}^{r}\left(f_{\psi(d^{-}_{k})}(v_i)^{k-} * f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k-}\right)$$
$$+ \sum_{k=1}^{r}\left(f_{\psi(d^{-}_{k})}(v_i)^{k+} * f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k+}\right)$$

And using equation (4) one can calculate the correlation coefficient.

$$C_{\beta^{\cdot\cdot}}^{\alpha^{\cdot\cdot}} = \frac{c_{m-PIVNHSSs}\left((\psi,\alpha^{\cdot\cdot}),(\phi,\beta^{\cdot\cdot})\right)}{\sqrt{S_{m-PIVNHSSs}((\psi,\alpha^{\cdot\cdot})} * \sqrt{S_{m-PIVNHSSs}((\phi,\beta^{\cdot\cdot})}} \quad (4)$$

**Example 3.3**

$$\psi_{\alpha^{\cdot\cdot}} = \left(\begin{matrix} e_1,\left\{\begin{matrix}(u_1,([0.4,0.9],[0.3,0.4],[0.3,0.3]),([0.4,0.4],[0.4,0.3],[0.3,0.5]),([0.5,0.6],[0.6,0.3],[0.7,2])) \\ (u_2,([0.4,0.5],[0.1,0.3],[0.7,0.4]),([0.8,0.2],[0.3,0.5],[0.7,0.4]),([0.7,2],[0.4,0.6],[0.5,0.3]))\end{matrix}\right\} \\ e_2,\left\{\begin{matrix}(u_1,([0.4,0.5],[0.3,0.7],[0.4,0.3]),([0.1,0.3],[0.2,0.9],[0.2,04]),([0.4,0.8],[0.2,0.6],[0.7,0.2])) \\ (u_2,([0.3,0.6],[0.1,0.5],[0.6,0.5]),([0.4,0.6],[0.2,0.7],[0.3,0.3]),([0.5,0.8],[0.3,0.6],[0.3,0.4]))\end{matrix}\right\}\end{matrix}\right)$$

$$\psi_{\beta^{\cdot\cdot}} = \left(\begin{matrix} e_1,\left\{\begin{matrix}(u_1,([0.6,0.1],[0.4,0.9],[0.1,0.5]),([0.5,0.6],[0.2,0.7],[0.3,0.1]),([0.9,0.3],[0.5,0.4],[0.2,0.4])) \\ (u_2,([0.4,0.5],[0.3,0.8],[0.3,0.1]),([0.5,0.7],[0.1,0.4],[0.3,0.6]),([0.4,0.9],[0.2,0.4],[0.3,0.5]))\end{matrix}\right\} \\ e_2,\left\{\begin{matrix}(u_1,([0.1,0.9],[0.5,0.4],[0.3,0.4]),([0.2,0.7],[0.7,0.3],[0.5,0.1]),([0.4,0.8],[0.3,0.5],[0.7,0.2])) \\ (u_2,([0.3,0.4],[0.4,0.6],[0.3,0.8]),([0.5,0.2],[0.4,0.5],[0.5,0.3]),([0.6,0.9],[0.1,0.4],[0.3,0.5]))\end{matrix}\right\}\end{matrix}\right)$$

**Proposition 3.4** Consider two m-PIVNHSSs;

$(\psi,\alpha^{\cdot\cdot}) =$
$\{(v_i,\left[t_{\psi(d^{-}_{k})}(v_i)^{i-}, t_{\psi(d^{-}_{k})}(v_i)^{i+}\right],\left[i_{\psi(d^{-}_{k})}(v_i)^{j-}, i_{\psi(d^{-}_{k})}(v_i)^{j+}\right],\left(\left[f_{\psi(d^{-}_{k})}(v_i)^{k-}, f_{\psi(d^{-}_{k})}(v_i)^{k+}\right]\right) \mid v_i \in u\}$

*and*

$(\phi,\beta^{\cdot\cdot}) =$
$\{(\left[v_i, t_{\phi(d^{-}_{k})}(v_i)^{i-}, v_i, t_{\phi(d^{-}_{k})}(v_i)^{i+}\right],\left[i_{\phi(d^{-}_{k})}(v_i)^{j-}, i_{\phi(d^{-}_{k})}(v_i)^{j+}\right],\left[f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k-}, f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k+}\right]) \mid v_i \in u\}$

and $C_{m-PIVNHSSs}\left((\psi,A^{\cdot\cdot\cdot}),(\phi,\beta^{\cdot\cdot\cdot})\right)$ correlation between them.

It satisfies the following properties:

1. $\hat{C}_{m-p_{IVNHSSs}}(\psi,\alpha^{\cdot\cdot}),(\psi,\alpha^{\cdot\cdot}) = \delta_{m-\ PIVNHSSs}\,(\psi,\alpha^{\cdot\cdot})$
2. $C_{m-\ PIVNHSSs}\,(\phi,\beta^{\cdot\cdot}),(\phi,\beta^{\cdot\cdot}) = \delta_{m-\ PIVNHSSs}\,(\phi,\beta^{\cdot\cdot})''$

**Theorem 3.5** Let $(\psi,\alpha) =$

$\{(v_i,\left[t_{\psi(d^{-}_{k})}(v_i)^{i-}, t_{\psi(d^{-}_{k})}(v_i)^{i+}\right],\left[i_{\psi(d^{-}_{k})}(v_i)^{j-}, i_{\psi(d^{-}_{k})}(v_i)^{j+}\right],\left(\left[f_{\psi(d^{-}_{k})}(v_i)^{k-}, f_{\psi(d^{-}_{k})}(v_i)^{k+}\right]\right) \mid v_i \in u\}$ *and* $(\phi,\beta) =$
$\{(\left[v_i, t_{\phi(d^{-}_{k})}(v_i)^{i-}, v_i, t_{\phi(d^{-}_{k})}(v_i)^{i+}\right],\left[i_{\phi(d^{-}_{k})}(v_i)^{j-}, i_{\phi(d^{-}_{k})}(v_i)^{j+}\right],\left[f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k-}, f^{-}{}_{\phi(d^{-}_{k})}(v_i)^{k+}\right]) \mid v_i \in u\}$ be two m-PIVNHSSs, the following characteristics are satisfied by CC between them:

**1.** $0 \leq \delta_{m-PIVNHSSs}((\psi,\alpha),(\phi,\beta)) \leq 1$
**2.** $\delta_{m-PIVNHSSs}((\psi,\alpha),(\phi,\beta))$=$\delta_{m-PIVNHSSs}((\psi,\alpha),(\phi,\beta))$ *iff* $((\psi,\alpha) = (\phi,\beta))$

**3.** $T_{\psi(d_k)}(v_i)^i = T_{\phi(d_k)}(v_i)^i, I_{\psi(d_k)}(v_i)^j = I_{\phi(d_k)}(v_i)^j$ and $\hat{C}_{\psi(d_k)}(v_i)^k = \hat{C}_{\phi(d_k)}(v_i)^k$
then $\delta_{m-p_{IVNHSSs}}((\psi,\alpha),(\phi,\beta)) = 1$

## 4. Notion of Weighted Correlation Coefficients (WCC) under m-PIVNHSSs

When experts assign different weights to each option, the choice may be different. Therefore, it is essential to map the expert weights before putting together a conclusion. Assume that the experts' relative weights may be stated as $\Omega = \{\Omega_1,\Omega_2,\Omega_3,\dots,\Omega_m\}^T$, where $\Omega_k > 0, \sum \Omega_{k}{}_{k=1}^{m} = 1$. Assume the weights for the sub-attributes to be as follows. $= \{\gamma_1,\gamma_2,\gamma_3,\dots,\gamma_n\}^T$, where $\gamma_i > 0, \sum \gamma_{i}{}_{i=1}^{n} = 1$

**Definition 4.1 Weighted correlation coefficient (WCC)**

Let,

$$(\psi,\ddot{\alpha}) = \{(v_i,[t_{\psi(d^{-}_k)}(v_i)^{i-}, t_{\psi(d^{-}_k)}(v_i)^{i+}],[i_{\psi(d^{-}_k)}(v_i)^{j-}, i_{\psi(d^{-}_k)}(v_i)^{j+}],([f_{\psi(d^{-}_k)}(v_i)^{k-}, f_{\psi(d^{-}_k)}(v_i)^{k+}]) \mid v_i \in u\} \quad and$$

$$(\phi,\ddot{\beta}) = \{([v_i, t_{\phi(d^{-}_k)}(v_i)^{i-}, v_i, t_{\phi(d^{-}_k)}(v_i)^{i+}],[i_{\phi(d^{-}_k)}(v_i)^{j-}, i_{\phi(d^{-}_k)}(v_i)^{j+}],[f^{-}{}_{\phi(d^{-}_k)}(v_i)^{k-}, f^{-}{}_{\phi(d^{-}_k)}(v_i)^{k+}]) \mid v_i \in u\}$$

be two m-PIVNHSSs, then WCC can be presented as;

$$\rho_{m-PIVNHSSs}((\psi,\dddot{\alpha}),(\phi,\dddot{\beta})) = \frac{\hat{C}_{m-PIVNHSSs}((\psi,\dddot{\alpha})),(\phi,\dddot{\beta})))}{max((S_{m-PIVNHSSs}(\psi,\alpha'')),(S_{m-PIVNHSSs}(\phi,\dddot{\beta}))))} \quad \textbf{(5)}$$

**Theorem 4.2** Let $(\psi,\ddot{\alpha}) = \{(v_i,[t_{\psi(d^{-}_k)}(v_i)^{i-}, t_{\psi(d^{-}_k)}(v_i)^{i+}],[i_{\psi(d^{-}_k)}(v_i)^{j-}, i_{\psi(d^{-}_k)}(v_i)^{j+}],([f_{\psi(d^{-}_k)}(v_i)^{k-}, f_{\psi(d^{-}_k)}(v_i)^{k+}]) \mid v_i \in u\}$ $and$ $(\phi,\beta) = \{([v_i, t_{\phi(d^{-}_k)}(v_i)^{i-}, v_i, t_{\phi(d^{-}_k)}(v_i)^{i+}],[i_{\phi(d^{-}_k)}(v_i)^{j-}, i_{\phi(d^{-}_k)}(v_i)^{j+}],[f^{-}{}_{\phi(d^{-}_k)}(v_i)^{k-}, f^{-}{}_{\phi(d^{-}_k)}(v_i)^{k+}]) \mid v_i \in u\}$ the WCC between them meets the following qualities:

1. $0 \le \rho_{m-PIVNHSSs}((\psi,\ddot{\alpha})(\phi,\ddot{\beta})) \le 1$
2. $\rho_{m-PIVNHSSs}((\psi,\ddot{\alpha})(\phi,\ddot{\beta})) = \rho_{m-PIVNHSSs}((\phi,\ddot{\beta}),(\psi,\ddot{\alpha}))$ iff $(\psi,\ddot{\alpha}) = (\phi,\ddot{\beta})$
3. $T_{\psi(d_k)}(v_i)^i = T_{\phi(d_k)}(v_i), I_{\psi(d_k)}(v_i)^j = I_{\phi(d_k)}(v_i)^j$ and $\hat{C}_{\psi(d_k)}(v_i)^k = \hat{C}_{\phi(d_k)}(v_i)^k$
then $\rho_{m-PIVNHSSs}((\psi,\ddot{\alpha}),(\phi,\ddot{\beta})) = 1$

**Definition 4.3 Properties of m-PIVNHSSs**

Let $(\psi,\ddot{\alpha}) = \{(v_i,[t_{\psi(d^{-}_k)}(v_i)^{i-}, t_{\psi(d^{-}_k)}(v_i)^{i+}],[i_{\psi(d^{-}_k)}(v_i)^{j-}, i_{\psi(d^{-}_k)}(v_i)^{j+}],([f_{\psi(d^{-}_k)}(v_i)^{k-}, f_{\psi(d^{-}_k)}(v_i)^{k+}]) \mid v_i \in u\}$

Consider, $\hat{J}_{d_k} = \langle T^{i}_{F(d_{ij})}, I_{F(d_{ij})}{}^{j}, \hat{C}_{F(d_{ij})}{}^{k}\rangle, \hat{J}_{d_{11}} = \langle T_{F(d_{11})}{}^{i}, I_{F(d_{11})}{}^{j}, \hat{C}_{F(d_{11})}{}^{k}\rangle$ and $\hat{J}_{d_{12}} = \langle T_{F(d_{11})}{}^{i}, I_{F(d_{12})}{}^{j}, \hat{C}_{F(d_{12})}{}^{k}\rangle$ be three m-PIVNHSSs and $y$ be the positive real number, by algebraic norms, then;

1. $\hat{\jmath}_{d_{11}}{}^{i} \oplus \hat{\jmath}_{d_{12}}{}^{i} = \langle T_{F(d_{11})}{}^{i} + T_{F(d_{12})}{}^{i} - T_{F(d_{11})}{}^{i} T_{F(d_{12})}{}^{i}, \hat{\jmath}_{F(d_{11})}{}^{j} \hat{\jmath}_{F(d_{12})}{}^{j}, \hat{C}_{F(d_{11})}{}^{k} \hat{C}_{F(d_{12})}{}^{k} \rangle$
2. $\hat{\jmath}_{d_{11}}{}^{i} \otimes \hat{\jmath}_{d_{12}}{}^{i} = \langle T_{F(d_{11})}{}^{i} T_{F(d_{12})}{}^{i}, \hat{\jmath}_{F(d_{11})}{}^{j} + \hat{\jmath}_{F(d_{12})}{}^{j} - \hat{\jmath}_{F(d_{11})}{}^{j} \hat{\jmath}_{F(d_{12})}{}^{j}, \hat{C}_{F(d_{11})}{}^{k} + \hat{C}_{F(d_{12})}{}^{k} - \hat{C}_{F(d_{11})}{}^{k} \hat{C}_{F(d_{12})}{}^{k} \rangle$
3. $y\hat{\jmath}_{d_k} = \langle 1 - \left(1 - T_{d_k}{}^{i}\right)^{y}, \hat{\jmath}_{d_k}{}^{j^y}, \hat{C}_{d_k}{}^{k^y} \rangle$
4. $\hat{\jmath}_{d_k}{}^{i^y} = \langle, 1 - \left(1 - \hat{\jmath}_{d_k}{}^{j}\right)^{y}, 1 - \left(1 - \hat{C}_{d_k}{}^{k}\right)^{y} \rangle$

## 5. MCDM Algorithm (MULTIMOORA).

The Multi-Objective Optimization by Ratio Analysis (MOORA) method was initially developed by Brauers et al. [34]. In 2010, Brauers [35] further enhanced the MOORA technique by introducing the full multiplicative form, resulting in a more efficient and powerful method known as MULTIMOORA. The MULTIMOORA method consists of three stages: the ratio system approach (RSA), the reference point approach (RPA), and the full multiplicative form (FMF). These stages are utilized to rank the alternatives under consideration. The theory of dominance is then applied to determine the final ranking and decision. According to this theory, the alternative with the highest presence at the top position across all three ranking lists is selected as the best-ranked alternative."

**Step 1:** Construction of decision matrix.
**Step 2:** RSA approach.
In this approach, the general standing of the alternative $i$ can be measured as follows:

$$\mathcal{Y}_i = \mathcal{Y}_i^+ - \mathcal{Y}_i^-$$

Where,

$$\mathcal{Y}_i^+ = \sum_{j\in\Omega_{max}} \omega_i\, r_{ij}$$

$$\mathcal{Y}_i^- = \sum_{j\in\Omega_{min}} \omega_i\, r_{ij}$$

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1} x_{ij}}$$

where $\mathcal{Y}_i$ stands for $ith$ position of the alternative on the base of all criteria; $\mathcal{Y}_i^+ and\ \mathcal{Y}_i^-$ denotes the position of the $ith$ alternative according to benefit and cost criteria respectively, $r_{ij}$ represents the normalized $ith$ alternative under $jth$ criteria; $x_{ij}$ denotes the $ith$ alternative related to $jth$ criterion; the sets of benefit criteria are denoted by $max$ and $min$ denotes the cost criteria where $i = 1,2,3, \dots m$ $and$ $j = 1,2,3, \dots, n$. The associated alternatives are positioned depending on $\mathcal{Y}_i$ in descending order so the alternative having the largest value of $\mathcal{Y}_i$ is the best in this approach.

**Step 3:** RPA approach
Using this approach best alternative selection could be done as below:

$$\mathfrak{d}_i^{max} = \max_j(\omega_j |r_j^* - r_{ij}|)$$

Where $\mathfrak{d}_i^{max}$ denotes the extreme distance of the alternative $i$ with respect to the reference point and $r_j^*$ represents the coordinate $j$ of the reference point as follows.

$$r_j^* = \begin{cases} \max_i \ r_{ij} \quad , \quad j \in \Omega_{max} \\ \min_i \ r_{ij} \quad , \quad j \in \Omega_{min} \end{cases}$$

The final ranking in this approach is done by using ascending order of $\mathfrak{d}_i^{max}$ and accordingly the lowest $\mathfrak{d}_i^{max}$ value is the best one.

**Step 4:** FMF approach

For this form the total efficacy of the alternative could be obtained as follows:

$$u_i = \frac{a_i}{b_i}$$

Where,

$$a_i = \prod_{j \in \Omega_{max}} \omega_i r_{ij}$$

$$b_i = \prod_{j \in \Omega_{min}} \omega_i r_{ij}$$

Here: $u_i$ means the overall efficacy of the $ith$ alternative, a$a_i$ and $b_i$ indicate the product of the weighted performance ratings of the benefit and cost criteria of the $ith$ alternative respectively. Like RSA, the associated alternatives are graded in descending order based on the value of $u_i$ and the best alternative is selected having maximum value of $u_i$.

**Step 5:** The final rank of alternatives established through the MULTIMOORA method.

After the calculating using MULTIMOORA method, three ranking lists are obtained for the alternatives under consideration. According to Brauers [34], dominace theory is used and the alternative having the first positions in all ordered rankings is the best-ranked alternative.

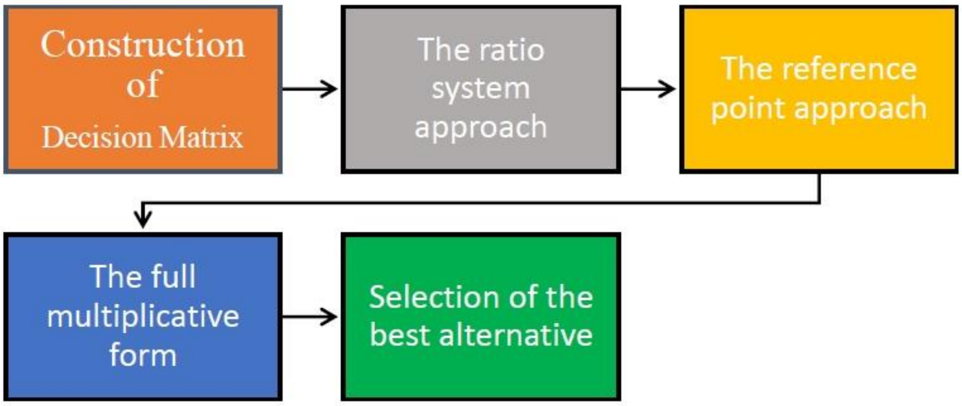


Figure 2. MCDM Algorithm (MULTIMOORA)

### 5.1 *Illustrative Example*

To determine the most efficient and affordable technology for hydrogen production, we conducted a case study. The process involved several steps, including selecting various alternatives, establishing a criteria system, and gathering relevant data. Within this study, we evaluated eight different hydrogen production technologies, focusing on their abstract descriptions. Drawing upon prior research in this field, we identified seven criteria that encompassed both cost and benefit aspects. The data used in this analysis was collected from diverse hydrogen production technologies available in table 1 [34].

***Table 1.*** *Hydrogen production technologies statistics till 2013.*

| *Method* | | *CO2 E.E* | *EE* | *CC* | *FOC* | *VOC* | *FDC* | *EAC* |
|---|---|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ |
| $A_1$ | *SMR* | 0.080 | 77.5 | 172.35 | 06.48 | 135.70 | 128.00 | 156.02 |
| $A_2$ | *CG* | 0.076 | 55.8 | 511.48 | 25.81 | 37.550 | 33.190 | 104.40 |
| $A_3$ | *POX* | 0.136 | 67.5 | 326.60 | 30.99 | 191.97 | 65.320 | 249.17 |
| $A_4$ | *BG* | 0.020 | 42.5 | 262.06 | 16.71 | 69.420 | 44.030 | 107.16 |
| $A_5$ | *PV-EL* | 0.040 | 31.2 | 388.32 | 16.71 | 250.66 | 246.31 | 298.53 |
| $A_6$ | *W-EL* | 0.005 | 33.8 | 388.32 | 16.71 | 117.59 | 112.60 | 165.46 |
| $A_7$ | *H-EL* | 0.010 | 52.0 | 388.32 | 16.71 | 92.840 | 87.970 | 140.71 |
| $A_8$ | *WS-CL* | 0.012 | 21.0 | 857.46 | 131.67 | 12.820 | 11.540 | 213.29 |

The weights are calculated using the entropy method. $w1 = 0.2544$ $w2 = 0.0453$; $w3 = 0.0620$; $w4 = 0.2874$; $w5 = 0.1415$ $w6 = 0.1703$ ; $w7 = 0.0391$

***Solution:***

***Step 1.*** *Construction of decision matrix and it is same as table 1.*

***Step 2.*** RSA approach.

*Applying the method we get,*

$\mathcal{Y}_1 = -\ 0.0027401$

$\mathcal{Y}_2 = +\ 0.0032370$

$\mathcal{Y}_3 = 0.00719220$

$\mathcal{Y}_4 = -0.02882$

$\mathcal{Y}_5 = -0.099813$

$\mathcal{Y}_6 = -0.067408$

$\mathcal{Y}_7 = -0.051607$

$\mathcal{Y}_8 = -0.16064$

$$\mathcal{Y}_3 > \mathcal{Y}_2 > \mathcal{Y}_1 > \mathcal{Y}_4 > \mathcal{Y}_5 > \mathcal{Y}_6 > \mathcal{Y}_7 > \mathcal{Y}_8$$

***Step 3.*** RPA approach.

Using this approach, the alternative orders are.

$\mathfrak{d}_1^{max} = 0{:}0376$

$\mathfrak{d}_2^{max} = 0{:}0403$

$\mathfrak{d}_3^{max} = 0{:}0279$

$\mathfrak{d}_4^{max} = 0{:}0779$

$\mathfrak{d}_5^{max} = 0{:}0645$

$\mathfrak{d}_6^{max} = 0{:}0879$

$\mathfrak{d}_7^{max} = 0{:}0846$

$\mathfrak{d}_8^{max} = 0{:}1375$

$$\mathfrak{d}_3^{max} < \mathfrak{d}_1^{max} < \mathfrak{d}_2^{max} < \mathfrak{d}_5^{max} < \mathfrak{d}_4^{max} < \mathfrak{d}_7^{max} < \mathfrak{d}_6^{max} < \mathfrak{d}_8^{max}$$

***Step 4.*** FMF approach.

Using this approach, the total efficacy of the all the alternatives are obtained.

$u_1 = 8015519.718$

$u_2 = 9907856.161$

$u_3 = 1132088.766$

$u_4 \quad = \quad 2362483.732$

$u_5 \quad = \quad 40864.3973$

$u_6 \quad = \quad 47005.1677$

$u_7 \quad = \quad 273951.5255$

$u_8 \quad = \quad 277721.2461$

$$u_2 > u_i > u_4 > u_3 > u_8 > u_7 > u_6 > u_5$$

***Step 5.*** Selection of best alternative.
The ranking of alternatives using all the approaches has been obtained.

***Table 2.*** *Hydrogen production technologies ranking*

| Method | Alternative Scores ranking |
|---|---|
| *RSA* | $\mathcal{Y}_3 > \mathcal{Y}_2 > \mathcal{Y}_1 > \mathcal{Y}_4 > \mathcal{Y}_5 > \mathcal{Y}_6 > \mathcal{Y}_7 > \mathcal{Y}_8$ |
| *RPA* | $\eth_3^{max} < \eth_1^{max} < \eth_2^{max} < \eth_5^{max} < \eth_4^{max} < \eth_7^{max} < \eth_6^{max} < \eth_8^{max}$ |
| *FMF* | $u_2 > u_i > u_4 > u_3 > u_8 > u_7 > u_6 > u_5$ |

According to [34] dominance theory is used and the alternative having the first positions in all ordered rankings is the best-ranked alternative. Table 2 shows that $\boldsymbol{A_3}$ is the best-ranked alternative. POX (Partial Oxidation) is recognized as another widely employed technique for hydrogen production from fossil fuels. This method involves the conversion of hydrocarbon-based fossil fuels, including natural gas, coal, and heavy oil, into hydrogen. Through the POX process, these fuels undergo partial oxidation, resulting in the production of hydrogen gas. POX is a well-established method utilized to harness the hydrogen potential inherent in fossil fuel resources.

### 5.2 *Result Discussion and Comparison*

We have been able to identify complicated linkages inside complex systems by using correlation coefficients. We have discovered possible connections that would have otherwise remained buried inside the complexity of the system by analyzing the interaction between several factors involved in hydrogen creation. This understanding is particularly useful since it provides a greater grasp of the fundamental mechanisms at work by illuminating how many elements interact and affect one another. Additionally, the MULTIMOORA a MCDM technique's inclusion of the multipolar analysis improves our capacity to negotiate this complexity.

We successfully combined the novel idea of multipolar analysis with correlation coefficients using the MULTIMOORA a MCDM method. The evaluation of efficient methods for producing hydrogen was the focus of our work. Our thorough investigation and implementation of these approaches produced insightful findings about the complex dynamics of the hydrogen generating environment. The development of a solid decision-making framework was made possible in large part by the identification of probable links and dependencies among various characteristics using the correlation coefficients. The multipolar method using MULTIMOORA was then used to provide a full evaluation of the many criteria associated with the hydrogen-generating systems. Using this method, we were able to weigh other important aspects in addition to cost efficiency. Consequently, we were able to rank and prioritize the various hydrogen generating processes efficiently, considering a wide range of factors. The effective use of correlation coefficients and the cutting-edge multipolar analysis using MULTIMOORA is an example of the power of this integrated strategy in tackling challenging real-world issues like the production of sustainable energy. Our findings indicate how this technique may be used in a variety of decision-making contexts, as well as providing contributions to the field of hydrogen generation.

## 6. Conclusion

The correlation coefficient (CC) and weighted correlation coefficient (WCC) for the m-polar interval-valued neutrosophic hypersoft set (m-PIVNHSSs) are presented in this paper, and their fundamental features are examined within the context of m-PIVNHSSs. This ground-breaking method has enormous promise for addressing difficult decision-making issues in a variety of fields, including education, healthcare, engineering, economics, and more. Additionally, the combination of the m-polar hypersoft set with other cutting-edge soft computing methods, such as bipolar fuzzy, Pythagorean set, and hybrid structures, holds the key to creating extraordinarily intelligent systems with improved machine intelligence (IQ). Such connections open new avenues for intelligent problem-solving and knowledge representation, offering interesting opportunities for applications in image processing, expert systems, and cognitive mapping.

Our study provides a thorough comparison of the recently suggested cost-effective hydrogen generating approaches versus current technologies by integrating correlation coefficients using the MULTIMOORA methodology. The correlation coefficients make possible trade-offs and synergies between factors visible, allowing for a more thorough review. The multipolar analysis then considers several factors, offering a comprehensive evaluation of each technique's performance in terms of economic viability, environmental effect, and technical maturity. This integrated methodology enables decision-makers to choose the most appropriate hydrogen generation technique while considering both novel solutions and tried-and-true methods, eventually directing sustainable energy choices and guiding future research paths.

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## References

[1] Rengel, A., Téllez, A. A., Ortiz, L., & Ruiz, M. (2023). Optimal Insertion of Energy Storage Systems Considering the Economic Dispatch and the Minimization of Energy Not Supplied. Energies, 16(6), 2593. http://dx.doi.org/10.3390/en16062593

[2] Ramchandra, B., Ronak, R. S., (2021). Hydrogen as energy carrier: Techno-economic assessment of decentralized hydrogen production in Germany, Renewable Energy, 177, 915-931. https://doi.org/10.1016/j.renene.2021.05.149

[3] Pao-Long C., Chiung-Wen H., Po-Chien C. (2011). Fuzzy Delphi method for evaluating hydrogen production technologies, International Journal of Hydrogen Energy, 36 (21), 14172-14179. Doi: 10.1016/j.ijhydene.2011.05.045

[4] Qie, X., Zhang, R., Hu, Y., Sun, X., & Chen, X. (2021). A Multi-Criteria Decision-Making Approach for Energy Storage Technology Selection Based on Demand. Energies, 14(20), 6592. http://dx.doi.org/10.3390/en14206592

[5] Fayyazi, M., Sardar, P., Thomas, S. I., Daghigh, R., Jamali, A., Esch, T., Kemper, H. (2023). Artificial Intelligence/Machine Learning in Energy Management Systems, Control, and Optimization of Hydrogen Fuel Cell Vehicles. Sustainability, 15(6), 5249. http://dx.doi.org/10.3390/su15065249

[6] Lu, Z., & Li, Y. (2023). A Multi-Criteria Framework for Sustainability Evaluation of Hydrogen-Based Multi-Microgrid Systems under Triangular Intuitionistic Fuzzy Environment. Sustainability, 15(4), 3708. http://dx.doi.org/10.3390/su15043708

[7] Zadeh A L. (1965). Fuzzy sets. Information and control, 8, 353-388.

[8] Atanassov, K. (1986). Intuitionistic Fuzzy Sets. Fuzzy Sets and Systems, 20, 87-96. doi: 10.1016/S0165-0114(86)80034-3

[9] Smarandache, F. (1998). Neutrosophy: neutrosophic probability, set, and logic: analytic synthesis and synthetic analysis, (October).

[10] H. Wang, Y. Zhang, and R. Sunderraman. (2010). Single-Valued Neutrosophic Sets, Multispace and Multistructure, Neutrosophic Transdisciplinarity, 100 Collected Papers of Sciences, Vol. IV, 410-419. North-European Scientific Publishers Hanko, Finland 2010. ISBN: 978-952-67349-2-7

[11] Peng, J., Wang, J., Xiaohui, Wu., Wang, J., and Chen, X. (2014). Multi-valued Neutrosophic Sets and Power Aggregation Operators with Their Applications in Multi-criteria Group Decision-making Problems. International Journal of Computational Intelligence Systems, 8., 345-363. Doi: 10.1080/18756891.2015.1001957

[12] Aiwu, Z., Jianguo, Du., and Hongjun, G. (2015). Interval Valued Neutrosophic Sets and Multi-attribute Decision-making Based on Generalized Weighted Aggregation Operator. Journal of Intelligent and Fuzzy Systems, 29(6), 2697-2706. doi: 10.13195/j.kzyjc.2014.0467.

[13] Yang, W., & Pang, Y. (2018). New Multiple Attribute Decision Making Method Based on DEMATEL and TOPSIS for Multi-Valued Interval Neutrosophic Sets. Symmetry, 10(4), 115. MDPI AG. Retrieved from http://dx.doi.org/10.3390/sym10040115

[14] Abdel-Basset, M., Manogaran, G., Gamal, A., and Smarandache, F. (2019). A group decision-making framework based on neutrosophic TOPSIS approach for smart medical device selection. Journal of Medical Systems, 43(2), 38. DOI: 10.1007/s10916-019-1156-1

[15] Adalı, E. A., and Işık, A. T. (2017). The multi-objective decision making methods based on MULTIMOORA and MOOSRA for the laptop selection problem. Journal of Industrial Engineering International, 13, 229–237.

[16] Abdel-Basset, M., Mohamed, M., and Sangaiah, A. K. (2017). Neutrosophic AHP-Delphi group decision making model based on trapezoidal neutrosophic numbers. Journal of Ambient Intelligence and Humanized Computing, 1–17. https://doi.org/10.1007/s12652-017-0548-7.

[17] Basset, M. A., Mohamed, M., Sangaiah, A. K., and Jain, V. (2018). An integrated neutrosophic AHP and SWOT method for strategic planning methodology selection. Benchmarking: An International Journal 25(7), 2546–2564.

[18] Peng, J., Wang, J., Wang, J., Zhang, H., and Chen, X., Simplified neutrosophic sets and their applications in multi-criteria group decision-making problems. International Journal of Systems Science 47(10):2342–2358, 2015. https://doi.org/10.1080/00207721.2014.994050.

[19] Abdel-Baset, M. Chang, V., and Gamal, A. (2019). Evaluation of the green supply chain management practices: A novel neutrosophic approach. Computers in Industry, 108, 210-220. https://doi.org/10.1016/j.compind.2019.02.013

[20] Abdel-Basset, M., Saleh, M., Gamal, A., and Smarandache, F. (2019). An approach of TOPSIS technique for developing supplier selection with group decision making under type- 2 neutrosophic number. Applied Soft Computing, 77, 438-452. https://doi.org/10.1016/j.asoc.2019.01.035

[21] Abdel-Basset, M., Mohamed, M., Elhoseny, M., Son, L. H., Chiclana, F., & Zaied, A. E. H. (2019). Cosine similarity measures of bipolar neutrosophic set for diagnosis of bipolar disorder diseases. Artificial intelligence in medicine, 101, 101735. https://doi.org/10.1016/j.artmed.2019.101735

[22] M. Abdel-Basset, A. Gamal, G. Manogaran, L. H. Son, and H. V. Long. (2020). A novel group decision-making model based on neutrosophic sets for heart disease diagnosis. Multimedia Tools and Applications, 79(15-16), 9977-10002. doi: 10.1007/s11042-019-07742-7.

[23] Molodtsov, D. (1999). Soft set theory - First results. Computers and mathematics with applications, 37(4-5), 19-31. doi: 10.1016/30898-1221(99)00056-5

[24] Cağman, N., Enginoğlu, S., and Citak, F. (2011). Fuzzy soft set theory and its applications. Iranian Journal of Fuzzy Systems, 8(3), 137-147. doi: 10.22111/1jfs.2011.292

[25] Deli, I., and Çağman, N. (2013). Intuitionistic fuzzy soft set theory and its decision making. Applied Soft Computing, 28. Doi: 10.3233/IFS-2012-0601.

[26] Maji, K P. (2013). Neutrosophic soft set. Annals of Fuzzy Mathematics and Informatics, 5(1), 157-168.

[27] Deli, I. (2017). Interval-valued neutrosophic soft sets and its decision-making. International Journal of Machine Learning and Cybernetics, 8, 665–676. https://doi.org/10.1007/s13042-015-0461-3

[28] Smarandache F. (2018). Extension of Soft Set to Hypersoft Set, and then to Plithogenic Hypersoft Set, Neutrosophic Sets and Systems, 22, 168-170.

[29] Saqlain M., S. Moin, M. N. Jafar, M. Saeed, and F. Smarandache. (2020). Aggregate Operators of Neutrosophic Hypersoft Set, Neutrosophic Sets and Systems, 32,294-306. doi: 10.5281/ zenodo. 3723155.

[30] Saqlain M, Sana M, Jafar N, Saeed. M, Said. B, (2020). Single and Multi-valued Neutrosophic Hypersoft set and Tangent Similarity Measure of Single valued Neutrosophic Hypersoft Sets, Neutrosophic Sets and Systems (NSS), 32, 317-329. doi: 10.5281 zenodo. 3723165.

[31] Saqlain M., and X. L. Xin. (2020). Interval Valued, m-Polar and m-Polar Interval Valued Neutrosophic Hypersoft Sets," Neutrosophic Sets and Systems,36,389-399. doi: 10.5281/ zenodo. 4065475.

[32] Jafar N M., Saeed, M., Saqlain, M., and Yang, S M. (2021). Trigonometric Similarity Measures for Neutrosophic Hypersoft Sets with Application to Renewable Energy Source Selection, IEEE Access,9,129178 129187. doi: 10.1109/ ACCESS. 2021.3112721.

[33] Zulqarnain M R., Xin L X., Ali B., Broumi S., Abdal S., and Ahamad, I M. (2021). Decision-Making Approach Based on Correlation Coefficient with its Properties Under Interval-Valued Neutrosophic Hypersoft Set Environment. Neutrosophic Sets and System, 40, 12-48.

[34] Brauers, Willem Karel M. and Edmundas Kazimieras Zavadskas. (2006). The MOORA method and its application to privatization in a transition economy. *Control and Cybernetics, 35,* 445-469.

[35] Sonal K. Thengane, Andrew Hoadley, Sankar Bhattacharya, Sagar Mitra, Santanu Bandyopadhyay. (2014). Cost-bene.t analysis of different hydrogen production technologies using AHP and Fuzzy AHP. International Journal of Hydrogen Energy, 39, 15293-15306.

[36] Taherdoost H., Madanchian M. (2023). Multi-Criteria Decision Making (MCDM) Methods and Concepts. Encyclopedia, 3(1), 77-87. https://doi.org/10.3390/encyclopedia3010006

[37] Paul, T. K., Jana, C., & Pal, M. (2023). Enhancing Multi-Attribute Decision Making with Pythagorean Fuzzy Hamacher Aggregation Operators, Journal of Industrial Intelligence, 1(1), 30-54. https://doi.org/10.56578/jii010103

[38] Du, Y., Wang, J. L., & Lu, J. G. (2023). Optimization of Magnetically Coupled Resonant Wireless Power Transfer Based on Improved Whale Optimization Algorithm. Journal of Industrial Intelligence, 1(1), 63-74. https://doi.org/10.56578/jii010105

[39] H. B. U. Haq, & M. Saqlain. (2023). Iris Detection for Attendance Monitoring in Educational Institutes Amidst a Pandemic: A Machine Learning Approach, Journal of Industrial Intelligence, 1(3), 136-147. https://doi.org/10.56578/jii010301

[40] M. Zulqarnain, & M. Saqlain. (2023). Text Readability Evaluation in Higher Education Using CNNs, Journal of Industrial Intelligence, 1(3), 184-193. https://doi.org/10.56578/jii010305

[41] M. Saqlain, H. Garg, P. Kumam, W. Kumam. (2023). Uncertainty and decision-making with multi-polar interval-valued neutrosophic hypersoft set: A distance, similarity measure, and machine learning approach, Alexandria Engineering Journal, 84, 323-332. https://doi.org/10.1016/j.aej.2023.11.001

[42] Stević, Ž., Mujaković, N., Goli, A., & Moslem, S. (2023). Selection of Logistics Distribution Channels for Final Product Delivery: FUCOM-MARCOS Model, Journal of Intelligent and Management Decision, 2(4), 172-178. https://doi.org/10.56578/jimd020402

[43] M. Saqlain. (2023). Sustainable Hydrogen Production: A Decision-Making Approach Using VIKOR and Intuitionistic Hypersoft Sets, Journal of Intelligent and Management Decision, 2(3), 130-138. https://doi.org/10.56578/jimd020303

[44] Tešić, D., Božanić, D., Radovanović, M., & Petrovski, A. (2023). Optimising Assault Boat Selection for Military Operations: An Application of the DIBR II-BM-CoCoSo MCDM Model. Journal of Intelligent and Management Decision, 2(4), 160-171. https://doi.org/10.56578/jimd020401

[45] Hicham, N., Nassera, H., & Karim, S. (2023). Strategic Framework for Leveraging Artificial Intelligence in Future Marketing Decision-Making. Journal of Intelligent and Management Decision, 2(3), 139-150. https://doi.org/10.56578/jimd020304

[46] M. Saqlain, P. Kumam, W. Kumam and S. Phiangsungnoen. (2023). Proportional Distribution Based Pythagorean Fuzzy Fairly Aggregation Operators with Multi-Criteria Decision-Making, IEEE Access, 11, 72209-72226. https://doi.org/10.1109/ACCESS.2023.3292273

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