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An Evidence-Based CoCoSo Framework with Double Hierarchy Linguistic Data for Viable Selection of Hydrogen Storage Methods

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ABSTRACT

Hydrogen is the new age alternative energy source to combat energy demand and climate change. Storage of hydrogen is vital for a nation's growth. Works of literature provide different methods for storing the produced hydrogen, and the rational selection of a viable method is crucial for promoting sustainability and green practices. Typically, hydrogen storage is associated with diverse sustainable and circular economy (SCE) criteria. As a result, the authors consider the situation a multi-criteria decision-making (MCDM) problem. Studies infer that previous models for hydrogen storage method (HSM) selection (i) do not consider preferences in the natural language form; (ii) weights of experts are not methodically determined; (iii) hesitation of experts during criteria weight assessment is not effectively explored; and (iv) three-stage solution of a suitable selection of HSM is unexplored. Driven by these gaps, in this paper, authors put forward a new integrated framework, which considers double hierarchy linguistic information for rating, criteria importance through inter-criteria correlation (CRITIC) for expert weight calculation, evidence-based Bayesian method for criteria weight estimation, and combined compromise solution (CoCoSo) for ranking HSMs. The applicability of the developed framework is testified by using a case example of HSM selection in India. Sensitivity and comparative analysis reveal the merits and limitations of the developed framework.

KEYWORDS

Hydrogen storage methods; double hierarchy hesitant fuzzy linguistic term set; evidence theory; CoCoSo method; sustainability; circular economy

1 Introduction

Developing countries like India have a high energy demand, and to strike a balance between demand and sustainability, countries globally focus on clean and sustainable energy [1]. Hydrogen is one such clean energy source that can effectively balance the demand and sustainability aspects of the nation. India made an ambitious commitment concerning mitigating carbon trace and presented

an updated resolution in the nationally determined contribution (NDC) to reduce emissions by 45% within 2030 (www.bbc.com dated: 13.12.2022). India pledged to adopt 50% of non-fossil fuels for energy generation by 2030. In this line of thought, hydrogen is seen as a potential alternative for energy production.

A recent report from economic-times (www.economictimes.com dated: 13.12.2022) claimed that India is planning a massive move to green hydrogen production to reduce its dependence on fossil fuels and promote green and sustainable habits nationwide. By 2047, New Delhi (India) is estimated to produce 26 million tonnes of hydrogen capacity annually. Besides, in 2020, India launched an initiative called the National Hydrogen Mission that focuses on generating energy via hydrogen to meet the growing demand and maintain sustainability across the nation. Also, the mission aims to make India the world's largest hydrogen hub. Accompanied by the initiative, there is also the focus on active storage of produced hydrogen to effectively meet present and future demand by supporting the economy and ecosystem.

Recently, researchers have concentrated on energy storage to meet the demand of people. Energy storage is the procedure for obtaining and preserving energy in various forms for future purposes. It is crucial because it improves energy security and helps to tame renewable energy sources' fluctuations. A more dependable and sustainable energy system is created by enabling the integration of distributed energy resources and lowering peak demand. Considerable research is being conducted to identify more efficient means of storing renewable energy, such as solar, wind, and geothermal energy, despite the availability of various renewable energy storage methods. Naveenkumar et al. [2] highlighted the potential of phase change materials (PCMs) in various solar energy storage methods and applications due to the sporadic nature of solar radiation. Watil et al. [3] proposed a battery charge controller and energy management algorithm for a standalone wind energy conversion system, which dynamically adapts to available wind power, battery state, and DC load demand to improve the system's efficiency and extend the battery life. Liu et al. [4] proposed an integrated framework for subsurface geothermal energy storage and carbon dioxide (CO_2) sequestration and utilization, where CO_2 is injected into geothermal layers for energy accumulation and then introduced into a target oil reservoir for CO_2 utilization and geothermal energy storage, showing potential for large-scale geothermal energy storage and carbon neutrality.

Researchers have developed novel approaches for hydrogen storage, such as material-based storage, cryogenic tank-based storage, cylinder-based storage, chemical bond-based storage, oxidation-based storage, and so on [5]. It can be observed that these methods have trade-offs among criteria, and as a result, the selection of a viable hydrogen storage method (HSM) is crucial and complex. Researchers adopted multi-criteria decision-making (MCDM) models to support the remedy for the issue. Here, we review relevant and recent literature on HSM evaluation using decision models. Hydrogen is an interesting form of energy that can satisfy countries' demands and promote sustainability and green practices globally. It is a clean form of energy with minimum emission of greenhouse gases and reduced harm to the ecosystem. With this view, hydrogen storage is essential for better usage and distribution. Some authors reviewed different hydrogen storage methods and concluded a promising future for hydrogen as a clean energy based on their well-planned storage. Niaz et al. [6] reviewed various hydrogen-producing and storing methods for creating a hydrogen economy, highlighting the latest advancements in hydrogen-storing materials and technologies and their classification based on storage mechanisms, advantages, and disadvantages. Pang et al. [7] discussed the importance of analyzing hydrogenation and dehydrogenation behaviors using kinetic models to understand the kinetic mechanism for hydrogen storage materials, highlighting the challenges and presenting a summary of existing models and analysis methods, introducing some recently proposed ones. Usman [8]

reviewed hydrogen storage strategies and recent developments in the field, highlighting the challenges presented by hydrogen's lightweight and gaseous nature and the advantages and disadvantages of various physical and chemical storage techniques.

From these reviews, it is clear that there is a high scope for hydrogen shortly, and countries are working on strategies and mechanisms to store hydrogen in a feasible way to serve the needs better. Owing to the diversity in the criteria/factors associated with hydrogen storage and multiple options for storing hydrogen, researchers view the problem as an MCDM problem. In this line, some extant models for selecting a suitable hydrogen storage method are presented here. Wu et al. [9] determined the performance of hydrogen storage projects from the sustainability aspect by considering interval-type 2 AHP and TOPSIS ("technique for order preference by similarity to ideal solution") methods. Wu et al. [10] developed an intuitionistic fuzzy-based model for evaluating the investment in projects concerning photovoltaic coupled hydrogen storage by adopting mixed approaches. Yi et al. [11] adopted a cloud-based hesitant fuzzy linguistic model for determining suitable storage methods for hydrogen. Çolak et al. [12] extended the VIKOR ("VIsekriterijumska Optimizcija I Kompromisno Resenje") method under a hesitant fuzzy context for grading storage methods for hydrogen. Karatas [13] developed an axiomatic design-based fuzzy decision model with AHP for selecting rational hydrogen storage methods. Pamucar et al. [14] extended the MAIRCA ("multi-attribute ideal real comparative analysis") approach to neutrosophic numbers for ranking methods for hydrogen storage. Recently, Guo et al. [15] adopted fuzzy and linguistic versions for data collection along with entropy, DEMATEL ("decision-making trial and evaluation laboratory"), and PROMETHEE ("preference ranking organization method for enrichment evaluation") approaches for evaluating the investment in hydrogen storage projects coupled with wind-photovoltaic contexts. Dhumras et al. [16] extended TOPSIS and VIKOR methods under bi-parametric picture fuzzy numbers for ranking hydrogen fuel cell schemes.

From the review provided above, there is an urge to use MCDM approaches to assess HSMs, and there is scope for proposing novel MCDM models to select methods for the storage of hydrogen appropriately. Researchers have focused on site selection for storage with MCDM [17–19], but selecting suitable methods/technology for hydrogen storage with MCDM needs exploration. This claim motivates the authors to propose a novel integrated model in the present study. Extant models put forward by researchers, indicate the following research gaps such as (i) experts cannot flexibly provide her/his opinions in the natural language form but are directed to follow pre-defined qualitative scales; (ii) experts' reliability values are not calculated methodically, causing inaccuracies and biases in the decision process; (iii) hesitation, interrelationship of experts and variability in the distribution of preferences are not effectively captured during experts/criteria weight assessment, and (iv) ranking based on different compromise solution driven operations is not adequately explored in the extant HSM selection models.

To resolve these gaps, authors gain motivations, and some contributions are presented:

- "Double hierarchy hesitant fuzzy linguistic term set (DHHFLTS)" is considered for rating so that experts can effectively provide her/his views in natural language form, which could be modeled as complex linguistic expressions by using the two hierarchies. The second hierarchy is the concrete supplement of the first hierarchy.
- Criteria importance through inter-criteria correlation (CRITIC) scheme is put forward with DHHFLTS for calculating experts' weights methodically, which would not only reduce subjectivity and biases but also capture the hesitation of experts.

- The weighted evidence-based Bayesian method (EBM) is put forward under DHHFLTS for criteria weight calculation, which can effectively consider the hesitation of experts during choice elicitation along with variability within the distribution of preferences.
- The three-stage rank algorithm is developed to effectively rank HSMs from different compromise strategies and comprehensively determine order based on analyzing the criteria weight component.

DHHFLTS is a powerful linguistic model that can not only express preferences flexibly but also provide ease to experts for expressing ratings in the natural form modeled as complex linguistic expressions by adopting the double hierarchy structure. Notably, the model offers maximum possible linguistic combinations (PLC) compared to other linguistic models such as the probabilistic linguistic model, 2-tuple linguistic models, hesitant fuzzy linguistic models, etc. Suppose the cardinality of the first hierarchy is q and the cardinality of the second hierarchy is r; then the PLC of DHHFLTS is $q.r$, which is not the case with other linguistic forms [20]. To better understand the structure of DHHFLTS, terms such as 'not so bad' and 'slightly big' cannot be modeled by earlier linguistic models. DHHFLTS offers flexibility to experts to model such natural expressions [21]. The main advantages of DHHLFTS that motivated authors to use the structure in this study are: (i) it can model natural expressions effectively; (ii) provide maximum PLC compared to other linguistic models, which could give experts ease of expression of views and choices; and (iii) allow more than one instance to capture hesitation of experts during the preference articulation process.

The rest of the article is organized as Section 2, which describes the literature studies related to DHHFLTS, CRITIC, EBM, and CoCoSo; Section 3 provides the core implementation part with a methodical description, a case example is explained in Section 4, followed by a comparative study in Section 5 and concluding remarks with future directions in Section 6.

2 Literature Review

2.1 DHHFLTS-Based MCDM Models

Rodriguez et al. [22] put forward a variant of the linguistic term set (LTS) by introducing hesitancy, which attracted many researchers to use the set for MCDM [23]. Handling complex expression was an issue, which was circumvented by Gou et al. [21] with DHHFLTS, which had two hierarchies where the second hierarchy concretely complemented the first hierarchy and attracted by the set; researchers used it for the decision process [24]. The review reveals that DHHFLTS has a wide scope from both the theoretical and application point of view. This section extends the review and briefly describes DHHLFTS models for MCDM.

Researchers have focused on aggregation operators, information measures, ranking methods, and variants of DHHFLTS for promoting the decision process. Ranking methods such as VIKOR ("Viekriterijumsko kompromisno rangiranje") [25] and TODIM ("Interactive multi-criteria decision-making") [26] are put forward for rational selection of an option from the set of options. Theoretical aspects such as quality function deployment [27], weighted distance measure [28], entropy measures [29], evidence measure [30], and similarity measure [31] are presented under the DHHFLTS context for setting a concrete foundation of the set for efficient applicability. Aggregation operators such as the Hamacher operator [32], hybrid operator [20], and generalized power operator [33] are proposed for rational aggregation of double hierarchy information.

Some variants of DHHFLTS are free DHHFLTS [34], probabilistic DHHFLTS [35], and interval-valued DHHFLTS [36]. Applications such as green supplier selection [37], warhead power grading [38],

risk assessment [39], zero-carbon measure [40], medicine evaluation [41], sustainable supplier selection [42], and passenger evaluation [43] are explored with DHHFLTS based frameworks.

From the review above, it is clear that DHHFLTS is a flexible structure that can model natural terms as complex linguistic expressions and use two hierarchies to model. The second hierarchy is the concrete complement of the primary. Besides, flexibility is gained through possible linguistic combination, which accounts for the $a \times b$ factor, where the cardinality of the primary hierarchy is, and b is the cardinality of the second hierarchy. It is also noted that different MCDM problems adopt DHHFLTS for arriving at rational decision-making.

2.2 CRITIC, Evidence, and CoCoSo Methods

Diakoulaki et al. [44] introduced CRITIC (CRiteria Importance Through Intercriteria Correlation), a method for determining objective weights of relative importance in multi-criteria decision-making (MCDM) problems. CRITIC incorporates contrast intensity and conflict in the decision problem structure by analytically investigating the evaluation matrix to extract all relevant information from the evaluation criteria.

Voorbraak [45] discussed the computational complexity of Dempster-Shafer's theory for handling uncertainty in expert systems and proposed the Evidence-based method. (EBM), It is a Bayesian approximation of belief functions that is computationally less involved than combining belief functions, making it a practical alternative in many applications.

The CoCoSo method, developed by Yazdani et al. [46], aims to provide a compromise solution to rank alternatives based on three levels of compromise space: sum, minimum, and maximum. This method aggregates weights of compared alternatives using the multiplication rule and weighted power of distance methods, calculates a ranking index based on the three measures, and provides the final ranking of alternatives.

Predominant authors have utilized the CRITIC, Evidence, and CoCoSo methods in recent times. Table 1 summarizes a few works which have been published using this method.

Table 1: Some applications of the CoCoSo method

Source	Type of fuzzy used	Methodology	Applications
CRITIC method			
Wang et al. [47]	Probabilistic uncertain linguistic term set	CRITIC, GRP	Site selection for hospital construction
Polcyn [48]	Spherical fuzzy set	TOPSIS-CRITIC	Determining value-added intellectual capital in farms
Haktanır et al. [49]	Picture fuzzy sets	CRITIC, REGIME	Wearable health technology application
Mishra et al. [50]	Fermatean Fuzzy Numbers	CRITIC, GLDS	Novel score function in MCDM
Yin et al. [51]		CRITIC-TOPSIS	Smart Community Governance
EBM method			
Pan et al. [52]	Interval-valued fuzzy sets	EBM	Bayesian network-based risk analysis
Zhu et al. [53]	Fuzzy preference relation	EBM	Decision fusion

(Continued)

Table 1 (continued)

Source	Type of fuzzy used	Methodology	Applications
Gao et al. [54]	Pythagorean fuzzy set	EBM	Negation of quantum mass function
Pang et al. [55]	Fuzzy fault tree	EBM	Fault analysis and diagnostic system in the electromagnet manufacturing process
Denoeux [56]	Epistemic random fuzzy sets	EBM	Quantification of uncertainty of scalar and vector quantities
CoCoSo method			
Wen et al. [57]	Probabilistic fuzzy linguistic term set	SWARA, CoCoSo	Clinical decision support systems–Selection of cold chain logistics management of medicine
Banihashemi et al. [58]	Triangular fuzzy numbers	CoCoSo	Investigating the environmental impacts of construction projects
Mishra et al. [59]	Hesitant fuzzy sets	CoCoSo	Ranking sustainable third-party reverse logistic providers
Qiyas et al. [60]	Logarithmic picture fuzzy set	CoCoSo	Drug selection for COVID-19
Tripathi et al. [61]	Intuitionistic fuzzy set	Generalized score functions, Parametric divergence measures, CoCoSo	Ranking and evaluating therapies for a medical decision-making problem
Ghoushchi et al. [62]	Spherical fuzzy set	SWARA, CoCoSo	Evaluation of wind turbine failure modes
Ghoushchi et al. [63]	Spherical fuzzy set	Best-worst method, CoCoSo	COVID-19 infodemic management strategies evaluation
Wang et al. [64]	T-spherical fuzzy sets	An extension of the CoCoSo method based on frank softmax aggregation operator	Multi-attribute group decision-making
Zhang et al. [65]	Spherical fuzzy sets	CoCoSo, D-CRITIC	Location selection of electric vehicle charging station

(Continued)

Table 1 (continued)

Source	Type of fuzzy used	Methodology	Applications
Su et al. [66]	Pythagorean fuzzy set	CoCoSo	Identifying technical challenges of blockchain technology for sustainable manufacturing paradigm

Note: CRITIC–Criteria importance through inter-criteria correlation; GRP–Grey Relational Projection; TOPSIS–Technique for order of preference by similarity to ideal solution; GLDS–Gained and lost dominance score MCDM–Multiple criteria decision making; EBM–Evidence based method; CoCoSo–Combined compromise solution; SWARA–Stepwise weight assessment ratio analysis; D-CRITIC–Distance correlation based CRITIC.

3 Methodology

The proposed integrated framework considers DHHFLTS as preference information used for modeling complex linguistic expressions to consider rating from experts in the natural language form flexibly. Experts provide her/his rating on HSMs based on the criteria. Also, experts rate the criteria used for determining the weights of criteria. Decision matrices from experts are used to calculate their relative importance by applying the procedure outlined in Section 3.2. This section also guides the formation of a criteria weight vector, which incorporates both the preference vector from experts on each criterion and the experts' weight vector. Finally, the decision matrices from experts, along with the criteria weight vector and experts' weight vector, are fed as input to Section 3.3 for determining the rank values of HSMs and ordering of HSMs.

CRITIC approach is extended to determine the weights of experts; a weighted evidence measure is put forward to determine the weights of criteria, and a CoCoSo-based ranking algorithm is developed for determining the rank ordering of HSMs. The stepwise procedure for these approaches is given below for clarity to readers.

3.1 Preliminaries

We provide some basics of linguistic sets for MCDM.

Definition 1 [67]: $FT = \{s_y | y = 0, 1, \ldots, g\}$ is an LTS with $g + 1$ as the cardinality and s_0 and s_g are the initial and final elements. Some postulates are,

- If $d > f$, then $s_d > s_f$
- Negation of $s_f = s_d$ if $d + f = g$.

Definition 2 [17]: FT is an LTS. Now, HFLTS is a continuous finite subset from FT that is given by,

$$TY = \{f, h(f) | f \in F\} \tag{1}$$

where $h(f)$ denotes continuous terms from FT, and $h(f) = \{s_y^v | v = 1, 2, \ldots, \#h(f), y = 0, 1, \ldots, g\}$ and $\#h(f)$ is the instance number.

Definition 3 [22]: FT is an LTS. $P = \{p_x^v | x = 0, 1, 2, \ldots, h\}$ is another LTS. Now DHHFLTS is given by,

$$DT = \left\{ s^v_{y<p^v_X>} | v = 1, 2, \ldots, \#dt, y = 0, 1, \ldots, g, x = 0, 1, 2, \ldots, h \right\} \tag{2}$$

where $\#dt$ is the instance number of double hierarchy element, y, and x are the primary and secondary hierarchy subscripts.

Note 1: A special case of DHHFLTS is called the double hierarchy linguistic term set, which has one instance or, in other words, $v = 1$.

Note 2: Let $dt_i = \left\{ s^v_{y<p^v_X>} | v = 1, 2, \ldots, \#dt, y = 0, 1, \ldots, g, x = 0, 1, 2, \ldots, h \right\}$ is called the double hierarchy hesitant fuzzy linguistic element (DHHFLE), and their collection forms the DHHFLTS. The two hierarchies are adapted from [68].

Definition 4 [22]: Two DHHFLEs are dt_1 and dt_2 as before. Some arithmetic operations are provided as,

$$dt_1 \bigotimes dt_2 = R^{-1} \left(\cup_{\gamma_1 \in R(dt_1), \gamma_2 \in R(dt_2)} (\gamma_1 \gamma_2) \right) \tag{3}$$

$$dt_1 \bigoplus dt_2 = R^{-1} \left(\cup_{\gamma_1 \in R(dt_1), \gamma_2 \in R(dt_2)} (\gamma_1 + \gamma_2 - \gamma_1 \gamma_2) \right) \tag{4}$$

$$\tau dt_1 = R^{-1} \left(\cup_{\gamma_1 \in R(dt_1)} 1 - (1 - \gamma_1)^\lambda \right) \lambda \geq 0 \tag{5}$$

$$dt_1^\tau = R^{-1} \left(\cup_{\gamma_1 \in R(dt_1)} (\gamma_1)^\lambda \right) \lambda \geq 0 \tag{6}$$

where R and R^{-1} are functions from [22].

Multiplication, addition, scalar multiplication, and power operation of DHHFLEs are shown in Eqs. (3)–(6).

Here, $R(z) = \dfrac{x + 2g}{4g}$ and $R^{-1}(z) = (2z - 1) . (2g)$ is used to perform arithmetic operations in Definition 4.

3.2 Weight Calculation

Determination of weights methodically is highly substantial for rational decision-making. In general, weight is an essential component in the decision process that influences MCDM owing to the diverse nature and trade-offs among entities. Experts and criteria pose a certain level of importance represented in the decision process through weights. Also, from MCDM, it is clear that experts and criteria are crucial components, and determining their weights is crucial. Works from Kao [69] and Koksalmis et al. [70] clarified the urge for methodical determination of weights, and they claim that direct assignment of weights causes inaccuracies and biases, which affect the decision process.

Commonly, researchers determine weights through partially known information or fully unknown information. In the former context, certain information about the weights of entities must be known apriori [71], which in practical cases poses an overhead. Latter context does not require such overhead, but weights are determined from the preference set. Popular approaches in the latter context are entropy measures [72], analytical hierarchy process [73], weighted ratio analysis [74], and alike.

Step 1: Prepare q decision matrices of $a \times b$ order with an HSM rated based on b criteria by q experts.

Step 2: Determine the score measure of DHHFLEs by applying Eq. (7). q matrices of $a \times b$ are formed.

$$A_{ij}^l = \sum_{v=1}^{\#dt} \left(y_{ij}^{v, \; xiv} \right) \tag{7}$$

where A_{ij}^l is the score value associated with HSM I based on criteria j for the data from expert l.

Step 3: Interrelationship among criteria are calculated by using Eq. (8), and intuitively, the hesitation of experts are captured.

$$\rho_{uv}^l = \frac{\sum_{j=1}^b \left(\left(A_{ij}^l - \overline{A_j^l} \right)_u \cdot \left(A_{ij}^l - \overline{A_j^l} \right)_v \right)}{\sqrt{\left(\sum_{j=1}^b \left(\left(A_{ij}^l - \overline{A_j^l} \right)_u \right)^2 \right), \left(\sum_{j=1}^b \left(\left(A_{ij}^l - \overline{A_j^l} \right)_v \right)^2 \right)}} \tag{8}$$

where $\overline{A_j^l}$ is the mean of accuracy value for expert l and $\overline{A_j^l}$ is the mean value of the score.

Step 4: The weights of experts are calculated by using Eq. (9), and it can be seen that these values are in the 0 to 1 range and sum to unity.

$$\eta_l = \frac{\sigma_l^2 \cdot \sum_v \rho_{uv}^l}{\sum_l \left(\sigma_l^2 \cdot \sum_v \rho_{uv}^l \right)} \tag{9}$$

where η_l is the weight of expert l.

The weight vector is obtained by applying Eq. (9). Based on the information value, it can be seen that the criterion with high information gains high importance. Besides the interrelationship factor among criteria, variability in the distribution concerning criteria is observed. Hence, the combined effect of interaction and variability plays a crucial role in determining criteria weights. From Eq. (9), the weights of experts are determined that of order $1 \times q$. Typically, any criterion with high interaction with other criteria and considerable variability in their distribution of choices gains high importance, which is mapped in the formulation presented above.

Step 5: Get opinion vectors from experts on each criterion. p vectors of $1 \times b$ are obtained. The score is determined by applying Eq. (7).

Step 6: Determine the weighted score by using Eq. (10), and a weighted score matrix of $p \times b$ is formed.

$$ws_{lj} = \eta_l . A_{lj} \tag{10}$$

where A_{lj} is the score determined via Eq. (7).

Step 7: Normalize the weighted score and determine the net evidence by using Eqs. (11) and (12).

$$ws_{lj}^* = \frac{ws_{lj}}{\sum_j ws_{lj}} \tag{11}$$

$$nws_j = p - \sum_{l=1}^p ws_{lj}^* \tag{12}$$

where ws_{lj}^* is the normalized weighted score, and nws_j is the net weighted score.

Step 8: Bayesian approximation is determined through Eq. (13) and a matrix of $p \times b$ order is obtained.

$$B_{lj} = \frac{\sum_{U \subseteq V} M(V)}{\sum_{Z \subseteq \Omega} M(Z) . |Z|} \tag{13}$$

where $|.|$ is the cardinality.

Consider n mutually exclusive assertions in the form $\Omega = (U_1, U_2, \ldots, U_n)$, and the basic probability assignment $M(.) : 2^\Omega \rightarrow [0, 1]$ is a mapping with an empty set equal to zero a full set equal to unity. Gupta et al. [75] claimed that the evidence measure needs complete solution space to determine the solution, and embedding Bayesian approximation to the measure reduces the search space to find the feasible solution, which inspired authors to present this formulation in the present section.

Step 9: Aggregate the approximation values from Step 8 by applying Eq. (14). A vector of $1 \times b$ is obtained, and further normalized to obtain the criteria weights.

$$w_j = \frac{\prod_{l=1}^{p} (B_{lj})^{\eta_l}}{\sum_j \prod_{l=1}^{p} (B_{lj})^{\eta_l}} \tag{14}$$

3.3 Ranking Algorithm with CoCoSo

This section presents a novel ranking algorithm for determining a suitable HSM from a set of HSMs. In general, ranking is a crucial phase of MCDM that supports selecting a suitable HSM and ordering HSMs. A combined compromise solution (CoCoSo) is an attractive ranking approach that performs ranking from multiple stages by determining rank values via different compromise solutions, which are combined to obtain a cumulative ranking of HSMs that supports the rational selection of a suitable HSM. Besides, the CoCoSo approach is simple and elegant with three operations, namely sum, minimum, and maximum, to determine the compromise solutions.

Driven by the features, a ranking algorithm is put forward with the CoCoSo formulation in this section. The steps for calculation are given below:

Step 1: Consider p decision matrices of $a \times b$ order from the previous section for determining rank values of HSMs. Weight vectors of criteria and experts are also considered from the previous section.

Step 2: Apply Eq. (15) to aggregate data from Step 1. p matrices of $a \times b$ are aggregated to form a single matrix of $a \times b$.

$$ADT_{ij} = \left\{ \prod_{l=1}^{p} y_{ij}^{\eta_l}, \prod_{l=1}^{p} x_{ij}^{\eta_l} \right\} \tag{15}$$

where y and x are the subscripts of primary and secondary hierarchies.

Step 3: Determine the score values by applying Eqs. (7) and (10) is applied to determine the weighted score values. A matrix of $a \times b$ order is obtained.

Step 4: Determine three-stage compromise solutions for the HSMs using Eqs. (16)–(18). Each equation yields a vector of $1 \times a$ order.

$$X_i = \sum_{j=1}^{b} \left(\frac{ws_{ij}}{\sum_i ws_{ij}} \right) \tag{16}$$

$$X_2 = \sum_{j=1}^{b} \left(\frac{ws_{ij}}{min_i (ws_{ij})} \right) \tag{17}$$

$$X_3 = \sum_{j=1}^{b} \left(\frac{ws_{ij}}{max_i (ws_{ij})} \right) \tag{18}$$

where ws_{ij} is the weighted score value, min(.) and max(.) are the minimum and maximum operators.

Step 5: Combine the compromise solutions from Step 4 to obtain a net ranking vector of $1 \times a$. Eq. (19) is applied to obtain the rank values.

$$NX_i = \sqrt[3]{X_1.X_2.X_3} + \left(\frac{X_1 + X_2 + X_3}{3} \right) \tag{19}$$

where NX_i is the net rank value of HSM i.

The HSMs are ordered based on the NX_i values, and the HSM is a high value preferred, and so on. Hence, the HSMs are arranged in descending order.

From Fig. 1, it is clear that an integrated approach for HSM selection is put forward. Preferences in natural language are modeled as DHHFLTS, allowing experts to express their opinions flexibly. Further, experts' weights are determined via the CRITIC method, which is used along with the opinion vector from experts on criteria to determine the weights of criteria. Evidence measure is put forward for determining weights of criteria. Besides, a ranking algorithm is proposed for determining the ordering of HSMs based on the data from experts and weight vectors of experts and criteria. The model shows that three-stage rank vectors are determined, which are further combined to form the final rank ordering, which is typically a compromise solution for each HSM.
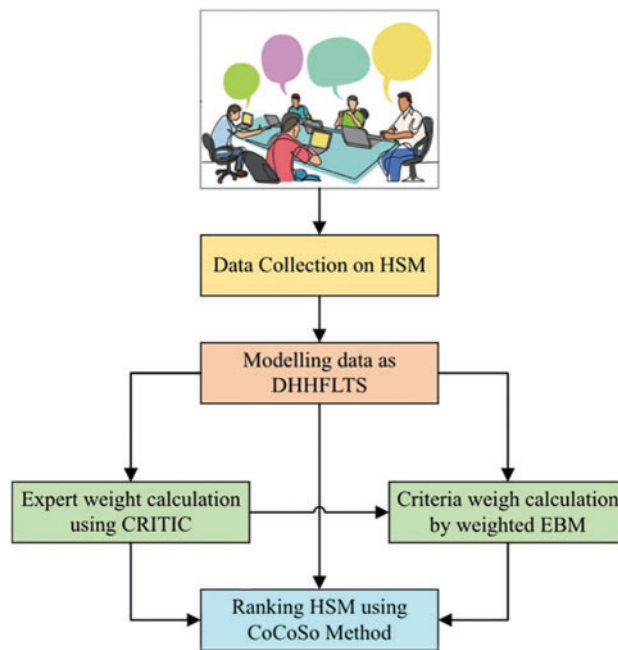

Figure 1: HSM selection model with DHHFLTS preference information

4 Case Study

This section presents an example of HSM selection to exemplify the usefulness of the proposed model. Typically, there is a high energy demand in India, and the nation needs to balance both demand and the ecosystem. For such reasons, countries globally started focusing on sustainable or renewable energy forms that emit less or zero carbon and prevent the planet from climate change and global warming [76]. Energy from hydrogen is a clean form of energy, and India has always shown keen interest in hydrogen energy adoption. As per the recent report from economictimes.indiatimes.com,

India has a demand of about 9 million tonnes in 2020, which will increase to about 11 million tonnes by 2030.

Further, a report from S&P Global shows that about 26 projects in India primarily focus on meeting the energy demand and considerably reducing emissions of greenhouse gases to provide a sustainable and green ecosystem. These projects allowed India to generate close to 2,550,000 tonnes every year, so the demand and eco-friendliness aspects can be satisfied. Based on these discussions, it is clear that hydrogen as a kind of clean energy is attractive, and its use can reduce carbon trace and the ill effects of climate change [12].

Interestingly, storing hydrogen energy is crucial, and it accounts maximum for the success of hydrogen-based clean energy utilization. As a result, researchers have actively worked on mechanisms for hydrogen storage [77]. Owing to diverse methods for hydrogen storage and multiple criteria that influence the selection of a viable storage method, the problem is seen as an MCDM problem. In the present study, a panel of four experts has seven to eight years of experience in energy storage and distribution. These experts include a senior professor from the sustainable energy division, technical personnel from the energy sector, finance and audit personnel, and an industry professional from the hydrogen energy-driven sector. These experts are invited via emails and phone calls to participate in the decision process. Based on their approval, we circulated a questionnaire to these experts for data collection concerning criteria and alternatives. These experts surf the web sources for multiple storage options, and based on their expertise and voting, five HSMs are shortlisted. These candidates are rated based on 12 criteria that are from technical, socio-economic, and environmental categories. Criteria considered for rating these HSMs are storage capacity, need for R&D, geo-diversity, technical support, demographic growth, job creation, security aspect, public safety, government support, monitoring and maintenance risk, total cost, and pollution. Five alternative storage methods are salt caverns, cryogenic tanks, storage on host metals, pressure cylinders, and chemical bond-based storage:

- Salt cavern storage is a method of storing various substances, such as natural gas, petroleum, and chemicals, in large underground caverns created in salt deposits. These caverns are created by injecting water into the salt deposit, which dissolves the salt and creates a void space. Once the cavern is formed, it can be used to store a variety of materials.

- Cryogenic tanks are specialized containers designed to store materials at extremely low temperatures. They are used to store and transport liquefied gases such as nitrogen, oxygen, argon, and helium, as well as liquefied natural gas (LNG). Cryogenic tanks are typically made of high-strength materials such as stainless steel or aluminum and are insulated to minimize heat transfer and maintain the extremely low temperatures required for the stored materials.

- Storage on host metals refers to a process in which hydrogen or other gases are stored on the surface of a host metal, such as palladium, titanium, or zirconium. The process involves adsorption, in which gas molecules adhere to the surface of the metal, creating a stable and reversible storage system.

- Pressure cylinders are containers that are designed to store gases under high pressure. They are commonly used for the storage and transport of compressed gases, such as oxygen, nitrogen, argon, and carbon dioxide. Pressure cylinders are made of high-strength materials such as aluminum or steel and are designed to withstand the high pressures that are generated by the stored gases.

- Chemical bond-based storage refers to the storage of energy using chemical bonds in molecules or compounds. This type of storage is often used for energy sources such as batteries and fuel

cells. The energy is stored in the chemical bonds of the molecules, which can be released through chemical reactions when the energy is needed.

It must be noted that data is collected from experts by circulating questionnaires, and the sample questionnaire is provided in Table A1 of the Appendix section. Experts give her/his rating in the natural language form that is then modeled as DHHFLTS. Data is collected from experts on HSMs rated over criteria and on each criterion. For ease of representation, let us denote experts as EX_1, EX_2, EX_4, and EX_3. HSMs are denoted as D_1, D_2, ..., D_5 and criteria are denoted by RB_1, RB_2, ..., RB_{12}. The steps for ranking HSMs are given below:

Step 1: Construct three matrices of 5×12 order by considering five HSM-rated over 12 criteria by using Likert scales to form complex expressions in the natural language form. Four experts provide her/his rating information in the natural form that is modeled to DHHFLTS (refer to Table 2).

Table 2: Preference matrices from experts

RB	D_1	D_2	D_3	D_4	D_5
			EX_1		
RB_1	$\begin{Bmatrix} s_{7<p_7>} \\ s_{2<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_8>} \\ s_{9<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{2<p_6>} \\ s_{3<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_5>} \\ s_{7<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_8>} \\ s_{7<p_8>} \end{Bmatrix}$
RB_2	$\begin{Bmatrix} s_{5<p_2>} \\ s_{3<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{2<p_4>} \\ s_{6<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_7>} \\ s_{6<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_9>} \\ s_{4<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_5>} \\ s_{4<p_5>} \end{Bmatrix}$
RB_3	$\begin{Bmatrix} s_{5<p_4>} \\ s_{4<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_9>} \\ s_{4<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_7>} \\ s_{4<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{9<p_7>} \\ s_{5<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_9>} \\ s_{5<p_9>} \end{Bmatrix}$
RB_4	$\begin{Bmatrix} s_{3<p_4>} \\ s_{6<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_8>} \\ s_{7<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_3>} \\ s_{7<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_6>} \\ s_{4<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_5>} \\ s_{6<p_5>} \end{Bmatrix}$
RB_5	$\begin{Bmatrix} s_{7<p_8>} \\ s_{2<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_2>} \\ s_{3<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_5>} \\ s_{7<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_6>} \\ s_{7<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{3<p_7>} \end{Bmatrix}$
RB_6	$\begin{Bmatrix} s_{6<p_4>} \\ s_{4<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_5>} \\ s_{8<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_8>} \\ s_{3<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_2>} \\ s_{6<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_3>} \\ s_{3<p_3>} \end{Bmatrix}$
RB_7	$\begin{Bmatrix} s_{7<p_6>} \\ s_{7<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_5>} \\ s_{4<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_6>} \\ s_{4<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_6>} \\ s_{6<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_7>} \\ s_{4<p_7>} \end{Bmatrix}$
RB_8	$\begin{Bmatrix} s_{7<p_7>} \\ s_{5<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_5>} \\ s_{4<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_7>} \\ s_{7<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_5>} \\ s_{8<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_3>} \\ s_{7<p_3>} \end{Bmatrix}$
RB_9	$\begin{Bmatrix} s_{6<p_6>} \\ s_{4<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_3>} \\ s_{9<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_3>} \\ s_{4<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_8>} \\ s_{7<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_6>} \\ s_{8<p_6>} \end{Bmatrix}$
RB_{10}	$\begin{Bmatrix} s_{3<p_8>} \\ s_{6<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_2>} \\ s_{3<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_8>} \\ s_{8<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_4>} \\ s_{8<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_7>} \\ s_{7<p_7>} \end{Bmatrix}$

(Continued)

Table 2 (continued)

RB	D_1	D_2	D_3	D_4	D_5
RB_{11}	$\begin{Bmatrix} s_{6<p_3>} \\ s_{3<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_3>} \\ s_{9<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_7>} \\ s_{6<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_8>} \\ s_{2<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_4>} \\ s_{3<p_4>} \end{Bmatrix}$
RB_{12}	$\begin{Bmatrix} s_{5<p_7>} \\ s_{5<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_8>} \\ s_{5<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{6<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_7>} \\ s_{6<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_2>} \\ s_{4<p_2>} \end{Bmatrix}$
			EX_2		
RB_1	$\begin{Bmatrix} s_{4<p_6>} \\ s_{9<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_3>} \\ s_{9<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_3>} \\ s_{6<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_9>} \\ s_{6<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{9<p_2>} \\ s_{9<p_2>} \end{Bmatrix}$
RB_2	$\begin{Bmatrix} s_{9<p_9>} \\ s_{9<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_8>} \\ s_{4<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_9>} \\ s_{4<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_7>} \\ s_{7<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_6>} \\ s_{4<p_6>} \end{Bmatrix}$
RB_3	$\begin{Bmatrix} s_{5<p_7>} \\ s_{6<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{2<p_5>} \\ s_{7<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{2<p_5>} \\ s_{2<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_5>} \\ s_{7<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{3<p_7>} \end{Bmatrix}$
RB_4	$\begin{Bmatrix} s_{7<p_7>} \\ s_{6<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_9>} \\ s_{5<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_6>} \\ s_{8<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_5>} \\ s_{9<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_2>} \\ s_{6<p_2>} \end{Bmatrix}$
RB_5	$\begin{Bmatrix} s_{2<p_8>} \\ s_{9<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{9<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{7<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_2>} \\ s_{8<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_4>} \\ s_{7<p_4>} \end{Bmatrix}$
RB_6	$\begin{Bmatrix} s_{2<p_7>} \\ s_{8<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{2<p_4>} \\ s_{3<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_6>} \\ s_{5<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{9<p_6>} \\ s_{8<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_3>} \\ s_{7<p_3>} \end{Bmatrix}$
RB_7	$\begin{Bmatrix} s_{7<p_5>} \\ s_{4<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{9<p_2>} \\ s_{4<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_9>} \\ s_{4<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{9<p_3>} \\ s_{4<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_6>} \\ s_{8<p_6>} \end{Bmatrix}$
RB_8	$\begin{Bmatrix} s_{4<p_7>} \\ s_{7<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_4>} \\ s_{5<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_5>} \\ s_{5<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_2>} \\ s_{8<p_4>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_3>} \\ s_{5<p_3>} \end{Bmatrix}$
RB_9	$\begin{Bmatrix} s_{9<p_3>} \\ s_{4<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_6>} \\ s_{8<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_9>} \\ s_{6<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_6>} \\ s_{5<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_2>} \\ s_{8<p_2>} \end{Bmatrix}$
RB_{10}	$\begin{Bmatrix} s_{3<p_4>} \\ s_{4<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_6>} \\ s_{4<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_5>} \\ s_{7<p_3>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_6>} \\ s_{6<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_2>} \\ s_{4<p_2>} \end{Bmatrix}$
RB_{11}	$\begin{Bmatrix} s_{4<p_6>} \\ s_{5<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_8>} \\ s_{8<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_4>} \\ s_{5<p_5>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_5>} \\ s_{8<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_7>} \\ s_{4<p_7>} \end{Bmatrix}$
RB_{12}	$\begin{Bmatrix} s_{7<p_4>} \\ s_{7<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_5>} \\ s_{3<p_7>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_9>} \\ s_{7<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_9>} \\ s_{6<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{5<p_4>} \\ s_{5<p_4>} \end{Bmatrix}$
			EX_3		
RB_1	$\begin{Bmatrix} s_{8<p_2>} \\ s_{8<p_6>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_3>} \\ s_{3<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_6>} \\ s_{7<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{6<p_7>} \\ s_{2<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_6>} \\ s_{4<p_6>} \end{Bmatrix}$
RB_2	$\begin{Bmatrix} s_{4<p_6>} \\ s_{2<p_8>} \end{Bmatrix}$	$\begin{Bmatrix} s_{4<p_7>} \\ s_{6<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{8<p_8>} \\ s_{7<p_2>} \end{Bmatrix}$	$\begin{Bmatrix} s_{3<p_7>} \\ s_{6<p_9>} \end{Bmatrix}$	$\begin{Bmatrix} s_{7<p_9>} \\ s_{7<p_9>} \end{Bmatrix}$

(Continued)

Table 2 (continued)

RB	D_1	D_2	D_3	D_4	D_5
RB_3	$\left\{\begin{array}{c} s_{3<p_7>} \\ s_{6<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_8>} \\ s_{5<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_4>} \\ s_{3<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_3>} \\ s_{6<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_8>} \\ s_{6<p_8>} \end{array}\right\}$
RB_4	$\left\{\begin{array}{c} s_{4<p_5>} \\ s_{7<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_4>} \\ s_{8<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_5>} \\ s_{3<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_4>} \\ s_{8<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_9>} \\ s_{4<p_9>} \end{array}\right\}$
RB_5	$\left\{\begin{array}{c} s_{4<p_3>} \\ s_{5<p_6>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_8>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_4>} \\ s_{6<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_8>} \\ s_{8<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_6>} \\ s_{6<p_6>} \end{array}\right\}$
RB_6	$\left\{\begin{array}{c} s_{6<p_6>} \\ s_{6<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_6>} \\ s_{6<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_7>} \\ s_{5<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_4>} \\ s_{3<p_2>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_6>} \\ s_{6<p_6>} \end{array}\right\}$
RB_7	$\left\{\begin{array}{c} s_{3<p_5>} \\ s_{8<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_9>} \\ s_{5<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_6>} \\ s_{4<p_2>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_3>} \\ s_{3<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_5>} \\ s_{8<p_5>} \end{array}\right\}$
RB_8	$\left\{\begin{array}{c} s_{9<p_3>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_4>} \\ s_{2<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_3>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_8>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_6>} \\ s_{5<p_6>} \end{array}\right\}$
RB_9	$\left\{\begin{array}{c} s_{8<p_4>} \\ s_{6<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_6>} \\ s_{9<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_3>} \\ s_{3<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_7>} \\ s_{4<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_4>} \\ s_{2<p_4>} \end{array}\right\}$
RB_{10}	$\left\{\begin{array}{c} s_{8<p_6>} \\ s_{3<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_9>} \\ s_{8<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_7>} \\ s_{9<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_4>} \\ s_{7<p_2>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_8>} \\ s_{7<p_8>} \end{array}\right\}$
RB_{11}	$\left\{\begin{array}{c} s_{6<p_9>} \\ s_{6<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_6>} \\ s_{6<p_6>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_2>} \\ s_{4<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_8>} \\ s_{6<p_2>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_4>} \\ s_{6<p_4>} \end{array}\right\}$
RB_{12}	$\left\{\begin{array}{c} s_{5<p_2>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_8>} \\ s_{5<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_3>} \\ s_{7<p_6>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_4>} \\ s_{7<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_5>} \\ s_{4<p_5>} \end{array}\right\}$
			EX_4		
RB_1	$\left\{\begin{array}{c} s_{9<p_5>} \\ s_{3<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_5>} \\ s_{6<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_2>} \\ s_{2<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_3>} \\ s_{5<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_4>} \\ s_{8<p_4>} \end{array}\right\}$
RB_2	$\left\{\begin{array}{c} s_{3<p_4>} \\ s_{8<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_7>} \\ s_{7<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_9>} \\ s_{4<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_3>} \\ s_{4<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_4>} \\ s_{4<p_4>} \end{array}\right\}$
RB_3	$\left\{\begin{array}{c} s_{6<p_7>} \\ s_{5<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_8>} \\ s_{4<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{8<p_4>} \\ s_{4<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_6>} \\ s_{6<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_2>} \\ s_{4<p_2>} \end{array}\right\}$
RB_4	$\left\{\begin{array}{c} s_{7<p_6>} \\ s_{8<p_7>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_8>} \\ s_{9<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_5>} \\ s_{6<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_9>} \\ s_{5<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_4>} \\ s_{3<p_4>} \end{array}\right\}$
RB_5	$\left\{\begin{array}{c} s_{4<p_7>} \\ s_{4<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_6>} \\ s_{9<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_6>} \\ s_{8<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_4>} \\ s_{6<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{7<p_4>} \\ s_{7<p_4>} \end{array}\right\}$
RB_6	$\left\{\begin{array}{c} s_{8<p_8>} \\ s_{3<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_7>} \\ s_{4<p_2>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_4>} \\ s_{7<p_3>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{2<p_6>} \\ s_{5<p_5>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_7>} \\ s_{4<p_7>} \end{array}\right\}$
RB_7	$\left\{\begin{array}{c} s_{6<p_4>} \\ s_{7<p_9>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{6<p_7>} \\ s_{9<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{4<p_7>} \\ s_{8<p_4>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{3<p_3>} \\ s_{4<p_8>} \end{array}\right\}$	$\left\{\begin{array}{c} s_{5<p_7>} \\ s_{5<p_7>} \end{array}\right\}$

(Continued)

Table 2 (continued)

RB	D_1	D_2	D_3	D_4	D_5
RB_8	$\left\{\begin{array}{c}s_{6<p_5>}\\s_{8<p_9>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_7>}\\s_{8<p_4>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{3<p_8>}\\s_{7<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{8<p_4>}\\s_{2<p_7>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{7<p_5>}\\s_{7<p_5>}\end{array}\right\}$
RB_9	$\left\{\begin{array}{c}s_{4<p_5>}\\s_{5<p_4>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{6<p_6>}\\s_{5<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_7>}\\s_{6<p_6>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_4>}\\s_{5<p_4>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_3>}\\s_{4<p_3>}\end{array}\right\}$
RB_{10}	$\left\{\begin{array}{c}s_{8<p_6>}\\s_{7<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{5<p_9>}\\s_{5<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{7<p_9>}\\s_{7<p_6>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{8<p_8>}\\s_{6<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{3<p_8>}\\s_{3<p_8>}\end{array}\right\}$
RB_{11}	$\left\{\begin{array}{c}s_{3<p_9>}\\s_{6<p_6>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{5<p_3>}\\s_{2<p_6>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{7<p_6>}\\s_{3<p_5>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_5>}\\s_{5<p_3>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{2<p_5>}\\s_{2<p_5>}\end{array}\right\}$
RB_{12}	$\left\{\begin{array}{c}s_{7<p_5>}\\s_{5<p_4>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{3<p_7>}\\s_{9<p_4>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_4>}\\s_{7<p_3>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{8<p_8>}\\s_{3<p_8>}\end{array}\right\}$	$\left\{\begin{array}{c}s_{4<p_6>}\\s_{4<p_6>}\end{array}\right\}$

$FT = \{s_y | when\ y = 1 - disastrous, y = 2 - worse, y = 3 - bad, y = 4 - dissatisfactory, y = 5\ is\ normal, y = 6\ is\ satisfactory\ and\ y = 7 - good, y = 8 - better, y = 9 - perfect\}$ and $P = \{p_x | when\ x = 1 - critically, x = 2 - nothighly, x = 3 - notso, x = 4 - somewhat, x = 5 - simply, x = 6 - just, x = 7 - so, x = 8 - highly, x = 9 - considerably\}$ are the linguistic terms for two hierarchies considered in this study. Table 2 describes the rating information from experts on HSMs based on diverse criteria. DHHFLTS is utilized for this purpose. Four experts give their rating on five HSMs based on 12 criteria.

Step 2: Determine the weights of experts by considering data from Step 1 and the procedure in Section 3.2.

Interrelationship values among criteria are calculated by using Eq. (8), and the heatmaps associated with the interactions of criteria for each expert's preference are determined. Later, Eq. (9) is applied to determine the information vector and, finally, the weights of experts. From Eq. (8), it can be seen that four 12×12 interaction matrices are obtained that are represented as heatmaps in Figs. 2–5 for experts EX_1, EX_2, EX_3, and EX_4, respectively. The colors in each square denote the heat range, and the bar to the right denotes the correlation value among criteria. The lighter the color of the square, the higher the correlation value. Pearson correlation measure is applied to calculate the interaction among criteria. The variation vector is calculated with order 1×4, and from Eq. (9), the weights are calculated as 0.14, 0.40, 0.13, and 0.33, respectively.

Step 3: Form three opinion vectors of 1×12 to determine the weights of the criteria. DHFLEs are used for rating, and the procedure in Section 3.2 is applied for weight calculation.
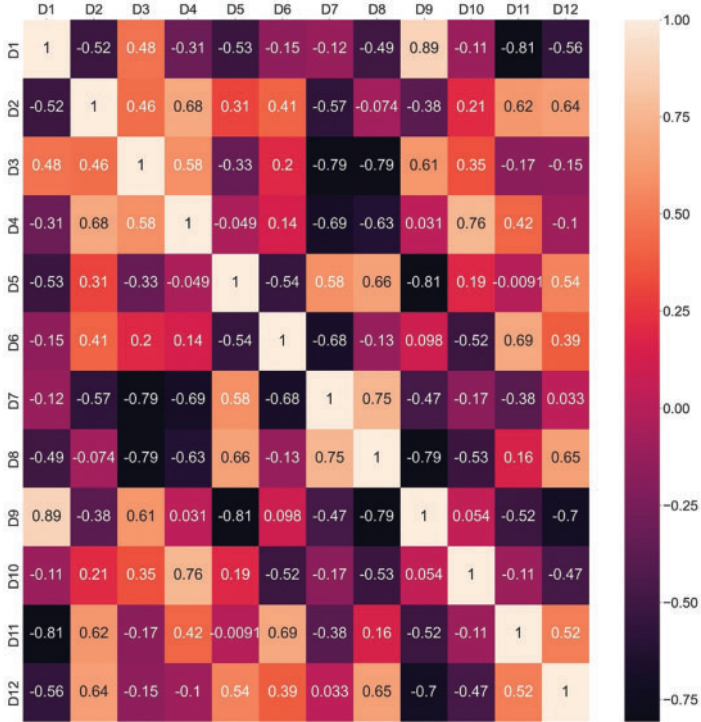
Figure 2: Interrelationship among criteria based on Pearson correlation for EX_1
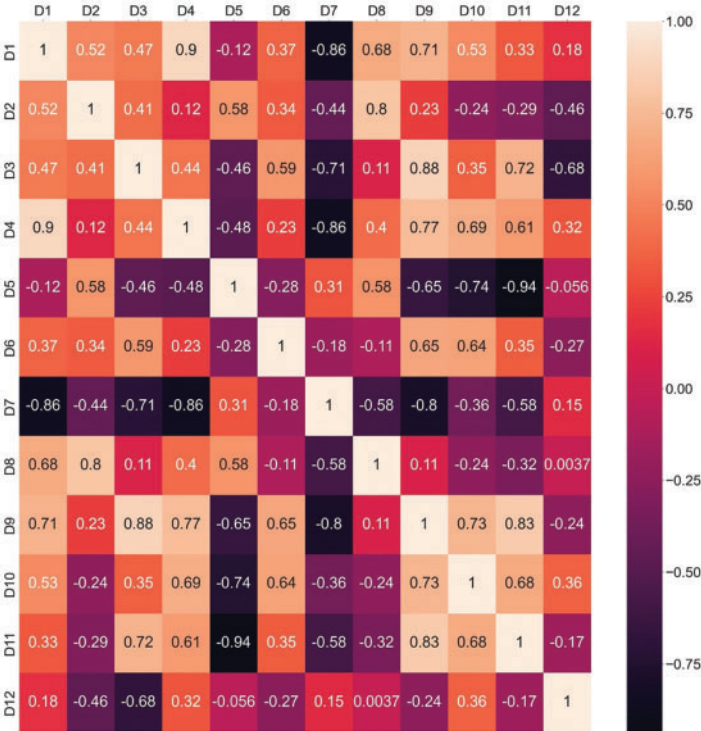

Figure 3: Interrelationship among criteria based on Pearson correlation for EX_2
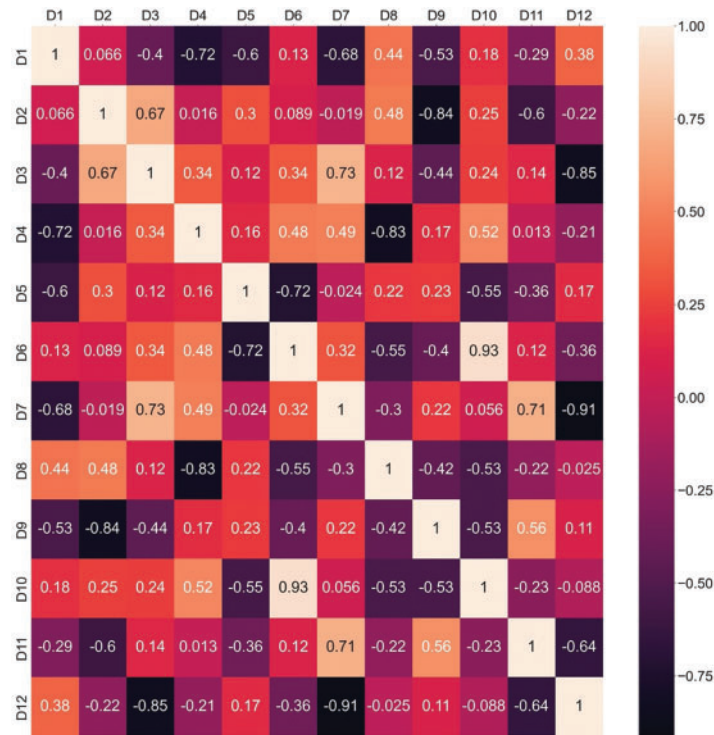
Figure 4: Interrelationship among criteria based on Pearson correlation for EX_3
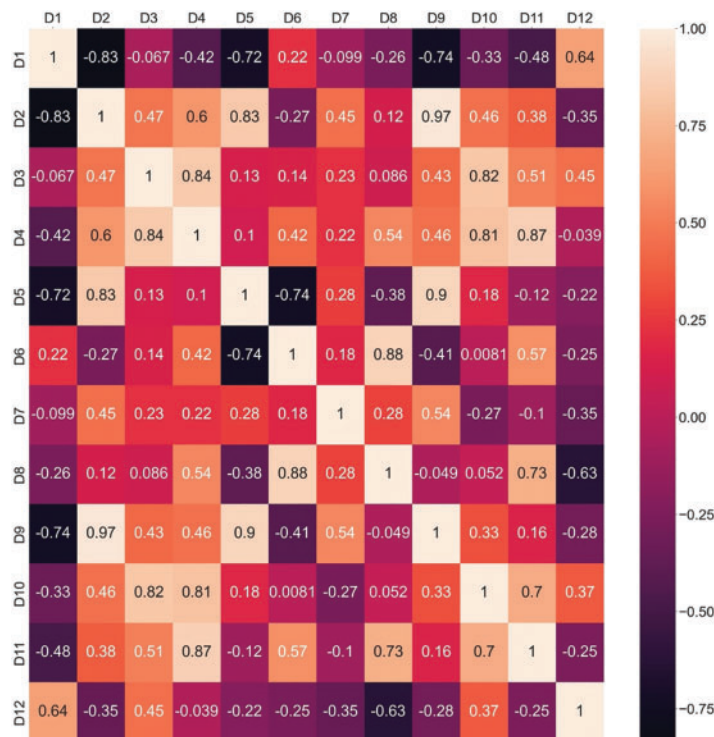

Figure 5: Interrelationship based on Pearson correlation for EX_4

Table 3 provides the opinion vectors from experts on criteria, which are in the DHHFLTS form. Four experts give their rating on 12 criteria that are considered as input, along with experts' weights from Step 2. By applying Eqs. (13) and (14), the weights of criteria are calculated as 0.15, 0.05, 0.15, 0.14, 0.17, 0.02, 0.07, 0.04, 0.08, 0.01, 0.11, and 0.01, respectively.

Table 3: Experts' rating of criteria for weight calculation

EX	RB_1	RB_2	RB_3	RB_4	RB_5	RB_6	RB_7	RB_8	RB_9	RB_{10}	RB_{11}	RB_{12}
EX_1	$\{s_{6<p_7>}\}$	$\{s_{4<p_4>}\}$	$\{s_{3<p_7>}\}$	$\{s_{5<p_7>}\}$	$\{s_{9<p_6>}\}$	$\{s_{4<p_2>}\}$	$\{s_{3<p_7>}\}$	$\{s_{4<p_5>}\}$	$\{s_{3<p_8>}\}$	$\{s_{3<p_3>}\}$	$\{s_{8<p_7>}\}$	$\{s_{8<p_6>}\}$
EX_2	$\{s_{6<p_5>}\}$	$\{s_{8<p_9>}\}$	$\{s_{7<p_4>}\}$	$\{s_{5<p_6>}\}$	$\{s_{9<p_4>}\}$	$\{s_{7<p_9>}\}$	$\{s_{2<p_9>}\}$	$\{s_{4<p_3>}\}$	$\{s_{5<p_7>}\}$	$\{s_{2<p_4>}\}$	$\{s_{2<p_8>}\}$	$\{s_{2<p_4>}\}$
EX_3	$\{s_{8<p_8>}\}$	$\{s_{3<p_6>}\}$	$\{s_{7<p_8>}\}$	$\{s_{6<p_6>}\}$	$\{s_{7<p_7>}\}$	$\{s_{6<p_2>}\}$	$\{s_{7<p_7>}\}$	$\{s_{9<p_7>}\}$	$\{s_{6<p_9>}\}$	$\{s_{4<p_7>}\}$	$\{s_{5<p_5>}\}$	$\{s_{8<p_2>}\}$
EX_4	$\{s_{5<p_3>}\}$	$\{s_{5<p_4>}\}$	$\{s_{8<p_5>}\}$	$\{s_{4<p_8>}\}$	$\{s_{7<p_2>}\}$	$\{s_{6<p_4>}\}$	$\{s_{5<p_7>}\}$	$\{s_{3<p_8>}\}$	$\{s_{5<p_3>}\}$	$\{s_{7<p_8>}\}$	$\{s_{5<p_8>}\}$	$\{s_{4<p_3>}\}$

Step 4: Rank the HSMs based on the data from Step 1, weight vectors from Step 2 and Step 3, and the algorithm proposed in Section 3.3.

In Table 4, the rank values of five HSMs are presented in the last column, which can be determined based on the three-stage of compromise ranking values viz., sum, minimum, and maximum depicted as X_1, X_2, and X_3, respectively (calculated using Eqs. (16)–(18)). Based on Table 4, it can be seen that the ordering of HSM is determined as $D_1 \succ D_4 \succ D_2 \succ D_3 \succ D_5$, with *the D_1* method being the highly preferred HSM. D_4 is also closely preferred for hydrogen storage.

Table 4: CoCoSo ranking parameters

RB	X_1	X_2	X_3	NX_i
D_1	2.61	19.52	10.28	18.86
D_2	2.48	18.81	9.87	18.11
D_3	2.42	18.12	9.61	17.55
D_4	2.59	19.40	10.33	18.81
D_5	2.89	13.76	7.58	13.57

5 Sensitivity and Comparative Investigation

This section reveals the effect of criteria weights on ranking order, and a two-way comparison with extant models is performed by considering studies from the application and methodical perspectives. Since there are 12 criteria, a 1×12 weight vector is obtained. Based on the rotation of weights, 12 sets of weight vectors are obtained that are used along with the preference data for rank estimation. Each weight set will yield a rank vector of 1×5 order, and as a result, 12 such vectors are determined. It must be noted that single-bit left rotation is applied to the weight vector of 1×12, and hence, 12 new sets of 1×12 are obtained. When these sets are applied to the ranking algorithm along with the preference data, compromise rank values for each HSM are determined.

In Fig. 6, we consider 12 new weight vectors of order 1×12 order, which are obtained by rotating the weights. Rotation here refers to assigning the weight of criterion 12 to criterion 1, criterion 1 to criterion 2, criterion 2 to criterion 3, and so on. Likewise, we get 12 sets of weight vectors, which are

fed as input to the ranking algorithm for determining the ordering of HSMs. In general, if there are n criteria, n sets of criteria weights can be obtained by rotation each of order $1 \times n$. From Fig. 6, it can be inferred that the framework proposed is robust even after criteria weights are adequately altered to form new sets. Intuitively, it can be seen that though there is a change in rank values, the rank orders do not change, indicating that the framework is robust and weight alterations do not majorly affect the decision process.
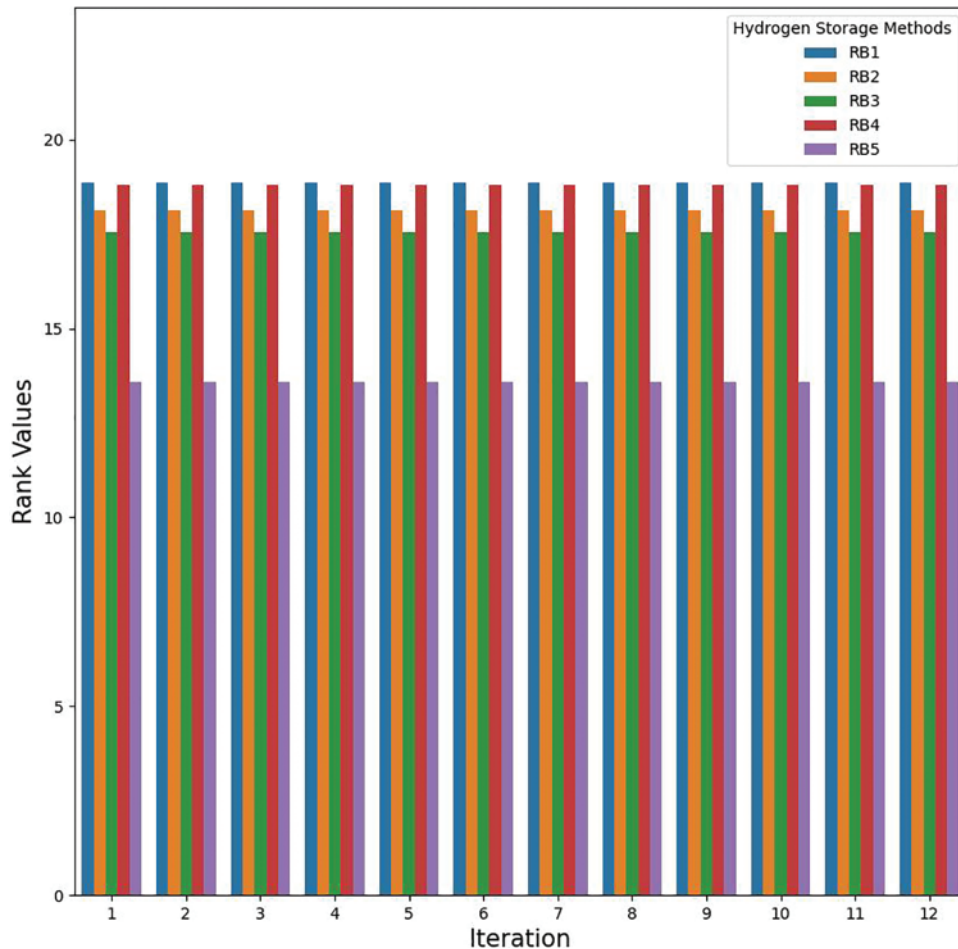
Figure 6: Criteria-based sensitivity analysis

From the application point of view, extant HSM models are considered such as Wu et al. [9], Çolak et al. [12], Guo et al. [15], and Dhumraz et al. [16] for comparison with the proposed framework which is summarized in Table 5.

Table 5 provides a summarized view of the novelties. These novelties are explained as follows:

- DHHLFTS is utilized for modeling uncertainty effectively by considering preferences in the natural language form and presenting complex expressions with two hierarchies where the secondary hierarchy is the concrete supplement of the primary hierarchy.
- The weights of both experts and criteria are methodically determined with a focus on capturing the variability in the distribution of opinions and hesitation of experts.

- Further, the interrelationship among experts is also captured during the importance assessment of experts, which needs to be improved in the extant models.
- Additionally, unlike extant models, the importance of experts is embedded in the formulation of criteria weight assessment, which offers an intuitive advantage of the inclusion of potential information in the weight calculation.
- Unlike some extant models, the proposed framework does not involve pairwise comparison, which reduces computational overhead and mitigates the management of consistency issues.
- Also, unlike extant models, the proposed model allows the inclusion of experts' weights in both ranking and criteria weight estimation, which provides a sense of rational determination of rank values as experts play a crucial role in MCDM by offering their choices on both alternatives (HSMs) and criteria.
- Ranking of HSM is possible from three dimensions, such as the sum, minimum, and maximum operations, which yield a compromise vector of HSM that is cumulatively combined to obtain the final ordering of HSM.

Table 5: Characteristics summarization–HSM selection models proposed *vs.* others

Context	Proposed	Wu et al. [9]	Çolak et al. [12]	Guo et al. [15]	Dhumraz et al. [16]
Input	DHHFLTS	IT2FS	HFS	PLTS	BPFS
Complex expression	Modeled effectively	Not modeled	Not modeled	Moderately modeled	Not modeled
Natural language form	Considered	Not considered	Not considered	Moderately Considered	Not considered
Experts' weights	Yes	No	No	Yes	No
Hesitation of experts	Considered	Not considered	Not considered	Considered	Not considered
Distribution variability	Considered	Not considered	Not considered	Considered	Not considered
Experts' interrelationship	Captured	Not captured	Not captured	Not captured	Not captured
Role of experts' weights	Both in criteria weight and ranking	Not considered	Not considered	Only in ranking	Not considered
Three-stage ranking	Possible	Not possible	Not possible	Not possible	Possible
Pairwise comparison overhead	Not present	Present	Not present	Present	Not present
Consistency issue	Not present	Present	Not present	Present	Not present

Extant DHHFLTS-based models such as Teng et al. [25], Krishankumar et al. [26], Liu et al. [33], and Gou et al. [21] are compared with the proposed integrated model to understand the efficacy from the methodical perspective. Consistency measure is testified by providing the data to all these models and obtaining rank values, which are further given to Spearman correlation for determining the coefficient values. Proposed *vs.* other models yield values as 1.0, 0.60, 1.0, 0.50, and 0.60, respectively, and the values are depicted in Fig. 7. The decision matrices presented in Table 2 of Section 4 are

considered by these models as the source of data and the criteria weights are determined from Section 4. These data are fed as input to all the models (both proposed and extant) to determine rank values, which are then given as input to Spearman correlation for determining the consistency coefficient (refer to Fig. 7).
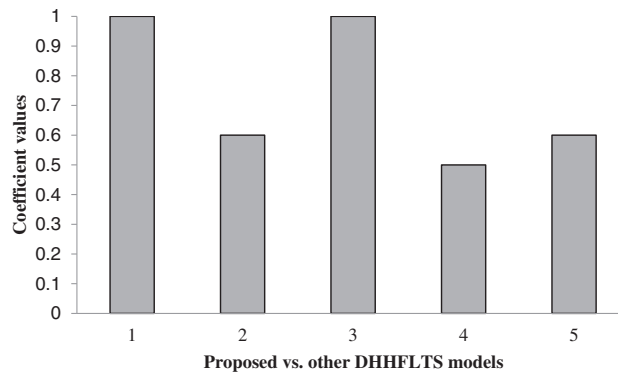

Figure 7: Proposed *vs.* other methods–Consistency test (in X axis 1 is Proposed *vs.* Proposed; 2 is Proposed *vs.* [24]; 3 is Proposed *vs.* [25]; 4 is Proposed *vs.* [35]; and 5 is Proposed *vs.* [22]) (1, 0.6, 1, 0.5, 0.6)

Data from Step 4 is fed as input to different models and the rank values are determined as $D_1 \succ D_4 \succ D_2 \succ D_3 \succ D_5$ by applying the proposed model, $D_1 \succ D_4 \succ D_2 \succ D_5 \succ D_3$ by applying the model in [24], $D_1 \succ D_4 \succ D_2 \succ D_3 \succ D_5$ by applying the model in [25], $D_1 \succ D_2 \succ D_3 \succ D_5 \succ D_4$ by applying the model in [35], and $D_1 \succ D_4 \succ D_2 \succ D_5 \succ D_3$ by applying the model in [22].

6 Conclusion

This paper presents a new integrated model with DHHFLTS as preference information and adds value to the hydrogen storage domain. The proposed model is utilized for the rational selection of storage methods for hydrogen by presenting integrated methods with reduced human intervention. The weights of experts and criteria are determined methodically with appropriate capturing of hesitation and interrelationship among entities. Besides, the variability in the distribution of preferences by experts is also captured during the decision process.

A three-stage ranking with a compromise solution strategy is put forward that determines final ordering based on sum, minimum, and maximum utility operations. Also, unlike other models for HSM selection, the developed model can effectively consider rating in the natural language form that is modeled as complex linguistic expressions. From the theoretical sense, the model is novel and focuses on the methodical calculation of decision parameters that eventually reduces human intervention.

Apart from the theoretical strength, it can be seen that the developed model is consistent with the extant models and has a robust nature to the alteration of criteria weights. From the comprehensive sensitivity analysis of weights and Spearman correlation, the inference can be made. Some implications of the study are: (i) the developed model is a ready-to-use tool that can effectively provide decisions with mathematical support to stakeholders; (ii) the framework can consider natural language preferences and model them as DHHFLTS; (iii) the model can be used effectively, provided that experts gain some training with the framework and the DHHFLTS structure to arrive at meaningful inference; (iv) the tool can be used in a bi-directional way by both scientists who develop HSM and

organization/stakeholders that plan on adopting a certain method for hydrogen storage; and (v) finally, features such as hesitation, interrelationship, and uncertainty are handled effectively by the framework.

Besides these superiorities, some limitations are: (i) unavailability of values cannot be handled by the present model, and (ii) partial information on weights cannot be modeled by the current model. As for future scope, plans are made to tackle the limitations of the present model. Also, new methods are planned with DHHFLTS for addressing HSM selection. Also, new applications in the business, sustainability, environment, and economy can experiment with the proposed model. Also, a new structure with probability variants can be experimented with, and the inclusion of recommendation and machine learning concepts is also considered.

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Availability of Data and Materials: The data and materials are provided in the manuscript itself.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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Appendix

A sample questionarre is provided in Table A1 for clarity to readers on how data is collected.

Table A1: Sample questionnaire from an expert–HSM rated over criteria

Question(s)	Rating

EX_1 rating D_1 with respect to 12 criteira									
Give your opinion on the storage capacity	11	12	13	14	15	16	17	18	19
	21	22	23	24	25	26	27	28	29
	31	32	33	34	35	36	37	38	39
	41	42	43	44	45	46	47	48	49
	51	52	53	54	55	56	57	58	59
	61	62	63	64	65	66	67	68	69
	71	72	73	74	75	76	77	78	79
	81	82	83	84	85	86	87	88	89
	91	92	93	94	95	96	97	98	99

Give your opinion on the need for R&D
Give your opinion on the geo-diversity
Give your opinion on the technical support
Give your opinion on the demographic growth
Give your opinion on the job creation
Give your opinion on the security aspect
Give your opinion on the public safety
Give your opinion on the government's support
Give your opinion on the risk aspect
Give your opinion on the cost aspect
Give your opinion on the pollution

It must be noted that such a 9×9 matrix is considered for each question, and experts shade the position that reflects the double hierarchy information that she/he chooses for a particular HSM rated based on a specific criterion. $FT = \{s_y | when\ y = 1 - disastrous, y = 2 - worse, y = 3 - bad, y = 4 - dissatisfactory, y = 5\ is\ normal, y = 6\ is\ satisfactory\ and\ y = 7 - good, y = 8 - better, y = 9 - perfect\}$ and $P = \{p_x | when\ x = 1 - critically, x = 2 - nothighly, x = 3 - notso, x = 4 - somewhat, x = 5 - simply, x = 6 - just, x = 7 - so, x = 8 - highly, x = 9 - considerably\}$ are the linguistic terms for two hierarchies considered in this study.

So 11 is called 'critically disastrous,' likewise 42 is called 'not highly dissatisfactory,' 35 is called 'simply bad,' and so on.