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Group Decision Making based on a New Evaluation Method and Hesitant Fuzzy Setting with an Application to an Energy Planning Problem

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ABSTRACT

In recent two decades, countries focused on extraction of the minimum amount of fossil fuels and utilization of the renewable energies based on their policies and environmental considerations. Thus, choosing the best renewable energy alternative plays a significant role on the investments. Among the classical decision approaches used in the literature, a hesitant fuzzy sets (HFSs) theory is an appropriate tool to deal with uncertain and imprecise conditions. The HFSs can help the decision makers or experts in an energy sector to consider some membership degrees for a renewable energy alternative regarding to the conflicted criteria under a set. The aim of this paper is to propose a hierarchical complex proportional assessment (COPRAS) method to consider subjective judgments and objective opinions based on the HFS theory for multi-criteria group decision making (MCGDM) problems. In addition, the hesitant fuzzy decision matrix and main criteria along with sub-criteria are defined based on linguistic variables and then are converted to hesitant fuzzy elements. In the proposed approach, weights of experts are different and computed by a proposed hesitant fuzzy entropy method. Also, the weights of main criteria are determined by a new relation in n levels of the hierarchy structure with experts' risk preferences. Finally, a real case study in Iran on the renewable energy selection in the hierarchy structure is presented and a hesitant fuzzy hierarchical complex proportional assessment (HF-HCOPRAS) method is applied in order to show the applicability of the proposed approach.

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1. INTRODUCTION

Since the beginning of civilization and natural resources have been significant for humans and countries, the renewable energies are recognized as one of important factors for social and economical development and for future life. These energies compared with fossil fuels are some main advantages such as reducing environmental pollutions (e.g., greenhouse gases and air pollutions), saving the nonrenewable energies and reducing production costs [1-4]. In this regard, choosing the most appropriate potential energy alternative among the criteria is very important for governments. To address the issues, multi-criteria decision making (MCDM) methods are utilized in many studies for dealing with this condition.

Akash et al. [5] utilized an analytical hierarchy process (AHP) method to compare and report the electricity power production objects in Jordan. Goletsis et al. [6] proposed an integrated methodology by combining the multi-criteria methods with group techniques to evaluate and rank the project proposals of energy in the USA. Also, they extended the multi-criteria ranking and hybrid PROMETHEE as well as ELECTRE-III methods. Polatidis and Haralambopoulos [7] presented the experience from a number of consultations with stakeholders involved in renewable energy projects, the difficulties that have risen, and they presented a methodological framework of multi-criteria decision making analysis and multi-participatory regarding to experience of some stakeholders with consultations that involved in renewable energy

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projects. Pohekar and Ramachandran [8] reviewed numerous published papers in energy planning decisions to analyze some decision-making methods based on priority setting, weighted averages, fuzzy principles, outranking and regarding to their combinations.

Ulutas [2] utilized the analytical network process (ANP) method to assess the energy policy problem and to determine the most suitable energy resources alternatives among the interactive attributes in Turkey. Loken [9] considered the multi-attributes decision making (MADM) methods to select the optimal solution for energy planning problems. Diakoulaki and Karangelis [10] assessed some varies scenarios based on cost-benefit analysis and MADM approaches for extending the power generation sector in Greece. Wang et al. [11] proposed a hierarchical decision making model to evaluate the nonrenewable and renewable energy resources for China. The results of their studies indicated that the renewable and coal energy could select as most energy alternatives. Banos et al. [12] expressed that the optimization methods could be applied in the sustainable energy. San Cristóbal [13] applied the MADM for selecting the best renewable energy plans regarding to renewable energy projects launched by the Spanish government. Erol and Kılkıs [14] utilized the AHP method for selecting the best energy source policy in Turkey. In their study, the energy policies were considered as sustainable, long-term and robust.

In many hesitant situations and decision making problems, the experts or decision makers' (DMs) opinions are not expressed by crisp values, and it is difficult for them to determine exact values for the potential alternatives among the conflicted attributes or criteria. Thus, most of the assessment potential alternatives could be considered under uncertainty and expressed based on a fuzzy sets theory [e.g., 15, 16]. The fuzzy sets theory was first formalized and utilized by Zadeh [17] to cope with uncertain information based on membership values in interval [0, 1]. In last decade, the classical/modern fuzzy set theory and their extensions are very attractive and powerful tool for the authors to solve the decision making problems under uncertain conditions in energy fields. In this respect, Kahraman et al. [18] proposed the AHP and axiomatic design (AD) methods under the fuzzy environment to evaluate the renewable energy alternatives among the objective and subjective criteria. Kahraman and Kaya [19] proposed a MCDM methodology based on AHP method in fuzzy setting to choose the best policy among the energy policies alternatives. Kaya and Kahraman [20] presented an integrated VIKOR (vlsekriterijumska optimizacija i kompromisno resenje in the Serbian language)-AHP method based on the fuzzy sets theory to determine the most suitable renewable energy alternative in Istanbul. In addition, in their study, the best alternative among the energy production sites alternatives was determined by the same approach. Sadeghi et al. [21] focused on two decision making methods in a fuzzy environment to select the best renewable energy sources alternative among the criteria in Iran. In their study, the fuzzy AHP method was presented to specify the attributes' weights and then applied the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method to evaluate and rank the potential alternatives.

As represented in the literature review, the fuzzy sets theory could be successfully applied to deal with imprecise or hesitant situations. Hence, among the extensions of fuzzy sets, the hesitant fuzzy set (HFS) is suitable tool by considering some membership degrees for energy alternatives versus the attributes under a set. Thus, it is worthwhile for researchers to choose the HFS theory for solving the decision-making problems in an energy area. In this regard, Xu and Zhang [22] proposed an MADM approach based on a compromise ranking method in hesitant fuzzy setting to determine the most suitable energy policy alternative. In their study, a maximizing deviation method was presented to determine the optimal weight of attribute regarding to incomplete information. Zhang and Xu [23] presented an interval programming method based on linear programming technique for multi-dimensional analysis of preference to solve the MCGDM problems under hesitant fuzzy set environment. Then, they showed the applicability of the proposed method in energy project selection. Tavakkoli-Moghaddam et al. [24] proposed interval-valued hesitant fuzzy TOPSIS (IVHF-TOPSIS) method in order to compute the criteria weights. They considered a location problem to find the best site selection for a new factory with four DMs, three potential alternative and six criteria.

This paper proposes a hierarchical complex proportional assessment (COPRAS) method based on group decision analysis in hesitant fuzzy setting, namely HF-HCOPRAS to select the best energy alternative among the renewable energy alternatives versus the 15 subjective and objective main criteria. In sum, the main contributions of this study are expressed as follows:

- Proposing a complex proportional assessment method in a hierarchy structure based on HFSs theory;
- Establishing a group of experts to evaluate the renewable energy alternatives by linguistic variables that then converted to the hesitant fuzzy elements (HFEs);
- Determining the experts' weights based on the proposed hesitant fuzzy entropy method;
- Presenting the weights of main criteria or attributes based on a new index in *n* levels of a hierarchy structure; and

- Considering the subjective and objective attributes simultaneously with the experts' risk preferences.

This paper is arranged as follows. In Section 2, some basic mathematical preliminaries and concepts on the HFS are illustrated. In Sections 3 and 4, a case study about energy selection is presented and then the proposed HF-HCOPRAS method is applied to energy selection problem to indicate the feasibility of the proposed approach, respectively. In Section 5, some concluding remarks are represented.

2. PRELIMINARIES

Definition 1. Consider X as a reference set, then Xia and Xu [25] have indicated the HFS by function $h_E(\mathrm{x})$ that X returns to [0, 1].

$$E = \{< x, h_E(\mathrm{x}) >| \mathrm{x} \in \mathrm{X}\} \tag{1}$$

where $h_E(\mathrm{x})$ is denoted as set of membership degree for an object under [0,1], expressing the membership degree of object $x \in X$ to E.

Definition 2. Some basic relations are introduced by Xia and Xu [25] as follows:

$$h_1 \oplus h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \{\gamma_1 + \gamma_2 - \gamma_1 . \gamma_2\} \tag{2}$$

$$h_1 \otimes h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \{\gamma_1 . \gamma_2\} \tag{3}$$

$$h^{\lambda} = \cup_{\gamma \in h} \{\gamma^{\lambda}\} \tag{4}$$

$$\lambda h = \cup_{\gamma \in h} \{1 - (1 - \gamma)^{\lambda}\} \tag{5}$$

Definition 3. Consider some HFEs, and then the summation and subtraction relations are represented as follows:

$$\overset{n}{\underset{i=1}{\oplus}} h_i = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \ldots, \gamma_n \in h_n} \left\{1 - \prod_{i=1}^{n} (1 - \gamma_i)\right\} \tag{6}$$

$$h_1 \otimes h_2 \otimes \ldots \otimes h_n = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \ldots, \gamma_n \in h_n} \left\{\prod_{i=1}^{n} \gamma_i\right\} \tag{7}$$

Definition 4. The subtraction and division operations for HFEs introduced by Liao and Xu [26] as follows:

$$h_1 - h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \begin{Bmatrix} \dfrac{\gamma_1 - \gamma_2}{1 - \gamma_2} & if\ \gamma_1 \geq \gamma_2\ and\ \gamma_2 \neq 1; \\ 0 & otherwise \end{Bmatrix} \tag{8}$$

$$\frac{h_1}{h_2} = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \begin{Bmatrix} \dfrac{\gamma_1}{\gamma_2} & if\ \gamma_1 \leq \gamma_2\ and\ \gamma_2 \neq 0; \\ 1 & otherwise \end{Bmatrix} \tag{9}$$

Definition 5. Xia and Xu [25] defined some hesitant fuzzy aggregation relations. In this regard, the hesitant fuzzy averaging (HFA) and the hesitant fuzzy weighted averaging (HFWA) relations are represented respectively as follows:

$$HFA(h_1, h_2, \ldots, h_n) = \overset{n}{\underset{j=1}{\oplus}} \left(\frac{1}{n} h_j\right) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \ldots, \gamma_n \in h_n} \left\{1 - \prod_{j=1}^{n} \left(1 - \gamma_j^{\lambda}\right)^{\frac{1}{n}}\right\} \tag{10}$$

$$HFWA(h_1, h_2, \ldots, h_n) = \overset{n}{\underset{j=1}{\oplus}} \left(w_j h_j\right) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \ldots, \gamma_n \in h_n} \left\{1 - \prod_{j=1}^{n} \left(1 - \gamma_j^{\lambda}\right)^{w_j}\right\} \tag{11}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ are the weight vector of $h_j\ (j = 1, 2, \ldots, n)$.

Definition 6. Zhu et al. [27] state that the normalized hesitant fuzzy decision matrix $\left(B = (b_{ij})_{m \times n}\right)$ can be obtained by the following relation. In this regard, let $H = (h_{ij})_{m \times n}$ be a hesitant fuzzy decision matrix, then we have:

$$b_{ij} = \cup_{t_{ij} \in b_{ij}} = \begin{cases} \{\gamma_{ij}\} & \text{for possitive criteria} \\ \{1 - \gamma_{ij}\} & \text{for negative criteria} \end{cases} \quad \forall i = 1, \ldots, m;\ j = 1, \ldots, n \tag{12}$$

3. PROPOSED HF-HCOPRAS METHOD

The following steps are given to present the proposed method.

Step 1. Establish the hesitant fuzzy decision matrix according to a group of experts (k=1, 2, …, K).

Step 2. Compute the importance of the experts proposed the hesitant fuzzy entropy method.

Step 2.1. Normalize the hesitant fuzzy decision matrix for each expert based on definition 6.

$$P_k = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} & \begin{pmatrix} \mu_{11}^k & \mu_{12}^k & \cdots & \mu_{1n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{m1}^k & \mu_{m2}^k & \cdots & \mu_{mn}^k \end{pmatrix}_{m \times n} \end{matrix} \tag{13}$$

Step 2.2. Construct the ξ_{ij}^k matrix for each expert as follows:

$$\xi_{ij}^k = \begin{cases} \dfrac{\mu_{ij}^k}{1 - \prod_{i=1}^{m} (1 - \mu_{ij}^k)} & \text{if } \mu_{ij}^k \leq 1 - \prod_{i=1}^{m} (1 - \mu_{ij}^k) \text{ and } 1 - \prod_{i=1}^{m} (1 - \mu_{ij}^k) \neq 0 \\ 1 & \text{Otherwise} \end{cases} \tag{14}$$

Step 2.3. Determine the hesitant fuzzy entropy $\left(\varsigma_k\right)$ for the experts by the following relation.

$$\varsigma_k = \left[\prod_{i=1}^{m}\left(\prod_{j=1}^{n}\left(1-\xi_{ij}^{k}\right)^{Ln\left(\xi_{ij}^{k}\right)}\right)\right]^{-\frac{1}{Ln(m)}} \quad (15)$$

Step 2.4. Compute the weight of each expert $\left(\lambda_k\right)$ according to a degree of deviation for each expert.

$$\lambda_k = \frac{1-\varsigma_k}{\sum_{k=1}^{K}\left(1-\varsigma_k\right)} \quad (16)$$

Step 3. Determine the normalized significance of each main criterion $\left(\omega_j^*\right)$ by the following relation in n levels of a hierarchy structure.

$$\omega_j^* = \frac{\prod_{J}\left(1-\prod_{k=1}^{K}\left(1-\varpi_J^k\right)^{\lambda_k}\right)}{\sum_{j}\left[\prod_{J}\left(1-\prod_{k=1}^{K}\left(1-\varpi_J^k\right)^{\lambda_k}\right)\right]} \quad \forall J \approx j, j', \ldots, j^n \quad (17)$$

Step 4. Normalize the hesitant fuzzy decision matrix based on definition 6 and then construct the weighted normalized hesitant fuzzy decision matrix.

$$\zeta_k = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \left[\begin{array}{cccc} \omega_1^*\left\{\mu_{11}^1,\mu_{11}^2,\ldots,\mu_{11}^k\right\} & \omega_2^*\left\{\mu_{12}^1,\mu_{12}^2,\ldots,\mu_{12}^k\right\} & \cdots & \omega_n^*\left\{\mu_{1n}^1,\mu_{1n}^2,\ldots,\mu_{1n}^k\right\} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_1^*\left\{\mu_{m1}^1,\mu_{m1}^2,\ldots,\mu_{m1}^k\right\} & \omega_2^*\left\{\mu_{m2}^1,\mu_{m2}^2,\ldots,\mu_{m2}^k\right\} & \cdots & \omega_n^*\left\{\mu_{mn}^1,\mu_{mn}^2,\ldots,\mu_{mn}^k\right\} \end{array}\right]_{m\times n} \end{array} \quad (18)$$

Step 5. Calculate the sums ι_i of criteria values regarding to positive criteria for each candidate alternative.

$$\iota_i = 1-\prod_{k=1}^{K}\left(\prod_{j=1}^{r}\left(1-\mu_{ij}^k\right)\right)^{\frac{1}{K}} \quad \forall i = 1,2,\ldots,m \quad (19)$$

where the number of positive criteria is denoted by r.

Step 6. Compute the sums τ_i of criteria values according to negative criteria for each candidate alternatives.

$$\tau_i = 1-\prod_{k=1}^{K}\left(\prod_{j=r+1}^{n}\left(1-\mu_{ij}^k\right)\right)^{\frac{1}{K}} \quad \forall i = 1,2,\ldots,m \quad (20)$$

Step 7. Determine the smaller value of τ_i as below:

$$\tau_{\min} = \min_i\left(\tau_i\right) \quad \forall i = 1,2,\ldots,m \quad (21)$$

Step 8. Calculate the relative importance of each candidate alternatives (ϑ_i).

$$\vartheta_i = \iota_i + \left(1-\iota_i\right)\left(\frac{1-\left(\prod_{i}^{m}\left(1-\tau_i\right)\right)^{\tau_{\min}}}{1-\left(\prod_{i}^{m}\left(1-\frac{\tau_{\min}}{\tau_i}\right)\right)^{\tau_i}}\right) \quad \forall i = 1,2,\ldots,m \quad (22)$$

Step 9. Compute the utility degree (θ_i) in what following for each alternative.

$$\theta_i = \frac{\vartheta_i}{\max_i\left(\vartheta_i\right)} \times 100 \quad (23)$$

Step 10. Select the best alternative based on maximum value of utility degrees values and rank them by mentioned procedure.

4. CASE STUDY FOR THE ENERGY PLANNING PROBLEM

In this section, a real case study for renewable energy selection is considered to indicate the feasibility of the proposed HF-HCOPRAS method. Data are obtained by the SUNA Organization' experts in Iran. To cope the issue, 15 alternatives ($A_i, i = 1,2,\ldots,m$), four main criteria ($C_{j'}, j' = 1,2,\ldots,n'$) and 15 criteria ($C_j, j = 1,2,\ldots,n$) are considered for evaluating the renewable energy selection problem. The mentioned alternatives and criteria are defined below, and also the criteria are represented in Table 1. In addition, the hierarchical structure of the case study is depicted in Figure 1.

A_1: Biomass energy;
A_2: Geothermal energy;
A_3: Hydropower;
A_4: Solar energy;
A_5: Wind energy,
and,
C_1: Technology;
C_2: Environmental;
C_3: Social;
C_4: Economical.

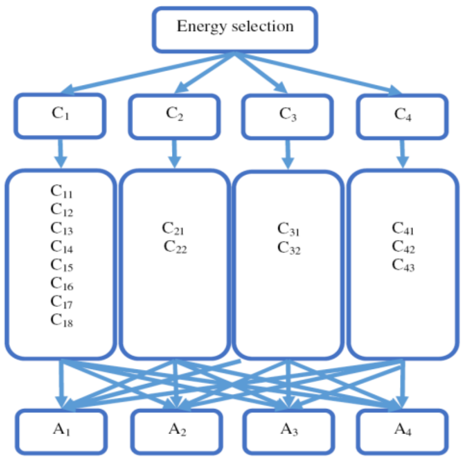

Figure 1. Hierarchical structure of the decision energy problem

TABLE 1. Energy selection criteria

Subjective criteria	Objective criteria
C_{11}: Feasibility	C_{16}: Maintenance and repair
C_{12}: Confidence level	C_{17}: Longevity
C_{13}: Reliability	C_{18}: Efficiency
C_{14}: Duration of the implementation	C_{41}: Implementation cost
C_{15}: Continuity and predictability of performance	
C_{21}: Pollution emission	
C_{22}: Land degradation	
C_{31}: Social acceptance	
C_{32}: Employment level	
C_{42}: Available budget	
C_{43}: Economic factors	

TABLE 2. Linguistic terms for rating the significant criteria

		DM's risk preferences		
Hesitant linguistic variables	**Hesitant interval-valued fuzzy elements**	**Pessimist**	**Moderate**	**Optimist**
Very high (VH)	[0.90, 0.90]	0.90	0.90	0.90
High (H)	[0.75, 0.80]	0.75	0.775	0.80
Medium (M)	[0.50, 0.55]	0.50	0.525	0.55
Low (L)	[0.35, 0.40]	0.35	0.375	0.40
Very low (VL)	[0.10, 0.10]	0.10	0.10	0.10

TABLE 3. Linguistic terms for rating the candidate alternatives

		DM's risk preferences		
Hesitant linguistic variables	**Hesitant interval-valued fuzzy elements**	**Pessimist**	**Moderate**	**Optimist**
Extremely high (EH)	[1.00, 1.00]	1	1	1
Very very high (VVH)	[0.90, 0.90]	0.90	0.90	0.90
Very high (VH)	[0.80, 0.90]	0.80	0.85	0.90
High (H)	[0.70, 0.80]	0.70	0.75	0.80
Moderately high (MH)	[0.60, 0.70]	0.60	0.65	0.70
Medium (M)	[0.50, 0.60]	0.50	0.55	0.60
Moderately low (ML)	[0.40, 0.50]	0.40	0.45	0.50
low (L)	[0.25, 0.40]	0.25	0.325	0.40
Very low (VL)	[0.10, 0.25]	0.10	0.175	0.25
Very very low (VVL)	[0.10, 0.10]	0.10	0.10	0.10

TABLE 4. Rating the energies under subjective main criteria by linguistic variables

Main criteria	Alternatives	DM_1	DM_2	DM_3
C_{11}	A_1	MH	H	M
	A_2	H	H	MH
	A_3	M	M	H
	A_4	VH	VH	VH
	A_5	H	M	VH
C_{12}	A_1	ML	H	ML
	A_2	M	M	MH
	A_3	L	M	L
	A_4	VH	H	H
	A_5	M	M	H
C_{13}	A_1	M	H	M
	A_2	MH	H	MH
	A_3	ML	H	M
	A_4	VVH	VH	VH
	A_5	H	VH	MH
C_{14}	A_1	MH	L	H
	A_2	ML	M	M
	A_3	MH	H	H
	A_4	VVL	L	VL
	A_5	L	M	ML
C_{15}	A_1	ML	M	M
	A_2	M	M	MH
	A_3	L	M	ML
	A_4	VH	H	H
	A_5	MH	H	MH
C_{21}	A_1	ML	L	ML
	A_2	VL	L	ML
	A_3	M	ML	M
	A_4	VVL	VL	VVL
	A_5	VVL	VL	VVL
C_{22}	A_1	MH	M	M
	A_2	ML	M	L
	A_3	MH	H	VH
	A_4	VL	L	VVL
	A_5	ML	L	VL
C_{31}	A_1	MH	M	MH
	A_2	H	M	H
	A_3	ML	H	M
	A_4	H	H	VVH
	A_5	VH	H	H
C_{32}	A_1	H	M	MH
	A_2	H	M	H
	A_3	ML	H	L
	A_4	VVH	H	VVH
	A_5	H	H	VH
C_{42}	A_1	M	M	M
	A_2	MH	M	MH
	A_3	L	M	VL
	A_4	VH	H	VVH
	A_5	VH	H	VH
C_{43}	A_1	MH	M	M
	A_2	MH	M	H
	A_3	ML	H	ML
	A_4	VH	H	VVH
	A_5	H	H	MH

TABLE 5. Rating renewable energies under objective criteria

	Maintenance and repair	Longevity	Efficiency	Implementation cost
A_1	35	30	38	1500
A_2	30	30	85	1750
A_3	120	30	75	2000
A_4	15	30	33	2250
A_5	40	20	35	1000

TABLE 6. Values under objective criteria

	Maintenance and repair	Longevity	Efficiency	Implementation cost
A_1	0.15	0.21	0.14	0.18
A_2	0.13	0.21	0.32	0.21
A_3	0.50	0.21	0.28	0.24
A_4	0.06	0.21	0.12	0.26
A_5	0.17	0.14	0.13	0.12

TABLE 7. Rating of the criteria weights by the linguistic variables

	DM_1	DM_2	DM_3
C_1	H	VH	H
C_{11}	VH	H	H
C_{12}	H	H	VH
C_{13}	VH	H	VH
C_{14}	H	VH	H
C_{15}	H	H	H
C_{16}	VH	H	H
C_{17}	H	H	H
C_{18}	VH	H	H
C_2	M	H	L
C_{21}	L	H	M
C_{22}	L	H	M
C_3	H	M	M
C_{31}	H	M	L
C_{31}	M	H	H
C_4	VH	H	VH
C_{41}	H	VH	H
C_{42}	H	VH	VH
C_{43}	H	H	VH

The linguistic terms and their hesitant fuzzy values for evaluating the significance of criteria and possible alternatives versus the criteria according to experts' risk preferences are represented in Tables 2 and 3, respectively. In the energy selection problem, three DMs are considered, in which the first DM is pessimistic, the second DM is moderate and other is optimistic.

In this respect, the hesitant fuzzy decision matrix for the subjective criteria regarding to DMs' risk preferences is represented in Table 4 by the linguistic variables. In addition, the evaluation of possible alternatives under the objective attributes or criteria is expressed by crisp values that transformed to hesitant fuzzy values and then the final hesitant fuzzy decision matrix for the subjective and objective criteria. The mentioned results are shown in Tables 5-9.

TABLE 8. Criteria weights by the HFEs, final DMs and criteria weights

	DM_1	DM_2	DM_3	ω_j^*
λ_k	0.3333	0.3333	0.3333	
C_1	0.75	0.90	0.80	
C_{11}	0.90	0.775	0.80	0.07558
C_{12}	0.75	0.775	0.90	0.07443
C_{13}	0.90	0.775	0.90	0.07867
C_{14}	0.75	0.90	0.80	0.07505
C_{15}	0.75	0.775	0.80	0.07025
C_{16}	0.90	0.775	0.80	0.07558
C_{17}	0.75	0.775	0.80	0.07025
C_{18}	0.90	0.775	0.80	0.07558
C_2	0.50	0.775	0.40	
C_{21}	0.35	0.775	0.55	0.03860
C_{22}	0.35	0.775	0.55	0.03860
C_3	0.75	0.525	0.55	
C_{31}	0.75	0.525	0.40	0.03985
C_{31}	0.50	0.775	0.80	0.04885
C_4	0.90	0.775	0.90	
C_{41}	0.75	0.90	0.80	0.07867
C_{42}	0.75	0.90	0.90	0.08202
C_{43}	0.75	0.775	0.90	0.07802

As represented in Table 10, the possible alternatives are ranked based on their utility degrees. In this respect, A_4 is selected as most appropriate energy regarding to conflicted criteria. Ranking the alternatives is compared by the method that is based on the possible alternatives ranked by the TOPSIS method. The same results of ranking show that the proposed HF-HCOPRAS method is feasible. In addition, the proposed approaches have some properties caused to be powerful.

TABLE 9. Computational results of the proposed ranking method

	ι_i	τ_i	ϑ_i	θ_i (%)
A_1	0.30399	0.12937	0.35789	82.52
A_2	0.33503	0.13902	0.38653	89.12
A_3	0.29502	0.10570	0.34962	80.61
A_4	0.38619	0.17028	0.43373	100
A_5	0.35803	0.16140	0.40775	94.01
$\tau_{\min}$		0.10570		

TABLE 10. Ranking of the potential alternatives and comparison analysis

	Utility degree (%)	Ranked by proposed HF-HCOPRAS method	Ranked by TOPSIS-based method
A_1	82.52	4	4
A_2	89.12	3	3
A_3	80.61	5	5
A_4	100	1	1
A_5	94.01	2	2

In this regard, the complex proportional assessment method is extended in the hierarchy structure with experts' risk preferences to consider *n* levels of the criteria under the hesitant fuzzy conditions. Also, the HF-HCOPRAS assist the experts to decrease the errors by assigning some membership degrees under a set for an object according to adopt the HFS theory. Hence, evaluations of the possible alternatives among the subjective criteria and the criteria/main criteria weight are considered by linguistic variables because of difficulty of judgments in [0, 1]. In addition, the relative significance of criteria and main criteria are calculated by new operations. Also, the experts' weights are determined by new operations based on the proposed entropy method that is applied in the procedure of the proposed HF-HCOPRAS approach.

5. CONCLUSIONS

The renewable energy selection is an important issue for making the decision in planning. Countries have focused on this issue for social and economical development regarding to decrease the environmental pollutions. Hence, selecting the most appropriate candidate renewable energy alternative is very important, in which the group decision analysis under extension of the fuzzy sets theory could deal with these complex situations. The goal of this study is to propose a complex proportional assessment method in the hierarchy structure under a hesitant fuzzy environment. In addition, an entropy method in the hesitant fuzzy setting condition is proposed to compute weights of experts. Also, the optimal weights of main criteria are determined based on a new relation for *n* levels of the hierarchy structure. Then, these weights are applied in a procedure of the proposed HF-HCOPRAS method with experts' risk preferences. Finally, the proposed approach is considered to solve the renewable energy selection problem under four criteria and 15 main criteria. The same ranking results of the proposed method and the conventional TOPSIS method show the suitability of the proposed HF-HCOPRAS approach. However, this proposed approach is preferable to the classical methods or fuzzy decision making methods. In the proposed approach, a group of experts is established to assign their preferences opinions by some membership degrees for a renewable energy alternative among the 15 main criteria under a set to margin of errors. Also, the hierarchy structure of the proposed HF-HCOPRAS assists to solve the problems by *n* levels of the hierarchy structure. Therefore, based on this study, the solar energy is an appropriate alternative for the studied region. It is obvious that ranking of the energy resources does not mean that we eliminate the energy resources with lower scores in the planning; however, it shows the relative importance of each energy resource versus others and more attention to these energy resources for making the decision in the energy area. In addition, the spatial and temporal factors (e.g., seasons, duration of day and geographic regions) should be more attention for an appropriate investment on energy resources. About the solar energy as the first rank can be denoted that affordable acquisition and exploitation from the solar energy requires the information gathering on the basis of radiation levels in each region. This goal is reached from the country by considering some factors such as average daily air temperature, relative humidity, sunny hours, evaporation, wind speed and soil temperature. Moreover, about the wind energy as the second rank can be explained, in which the maximum power density of the wind energy has been observed on average in warm seasons (i.e., spring and summer), and the minimum power density of the wind energy has been provided in autumn. However, the wing speed and its continuous throughout the year are appropriate in some regions of the country for constructing wind turbines due to their geographical conditions (e.g., valleys, strait and peaks). For future research, other MCGDM methods (e.g., VIKOR and PSI) can be utilized and their ranking results can be compared with the proposed approach.

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Group Decision Making based on a New Evaluation Method and Hesitant Fuzzy Setting with an Application to an Energy Planning Problem

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چکیده

در دو دهه اخیر، کشورها متمرکز بر حداقل استخراج منابع فسیلی شده اند و از انرژی های تجدیدپذیر بر مبنای سیاستهای کشورها و ملاحظات محیطی استفاده کرده اند. بنابراین انتخاب بهترین گزینه انرژی نقش بسزایی در این خصوص خواهد داشت. از میان رویکردهای تصمیم گیری سنتی موجود در ادبیات موضوع، تئوری مجموعه های فازی تردیدی یک ابزار مناسب برای برخورد با عدم قطعیتهاست. این ابزار می تواند به خبرگان و تصمیم گیران در بخش انرژی با درنظر گرفتن چندین تابع عضویت برای یک گزینه انرژی در مقابل با یک معیار کمک نماید. هدف این مقاله ارائه یک مدل ارزیابی سلسله مراتبی گروهی با در نظر گرفتن معیارهای کمی و کیفی بر مبنای تئوری مجموعه های فازی تردیدی برای مسائل تصمیم گیری گروهی چند معیاره می باشد. ماتریس تصمیم گروهی فازی تردیدی و زیرمعیارها و معیارها بر اساس متغیرهای زبانی تعریف شده و به عناصر فازی تردیدی تبدیل می شوند. در این رویکرد وزن خبرگان متفاوت بوده و براساس یک روش فازی تردیدی پیشنهادی انتروپی محاسبه می شوند. هم چنین وزن معیارها با استفاده از یک رابطه جدید در چند سطح سلسله مراتبی با اولویتهای ریسک خبرگان تعیین می شود. سرانجام یک مطالعه موردی در ایران در خصوص انتخاب انرژی تجدید پذیر با ساختار سلسله مراتبی ارائه می شود و مدل ارزیابی فازی تردیدی سلسله مراتبی گروهی به کارگرفته می شود تا کاربردپذیری این رویکرد نمایش داده شود.

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