Advances in Computer, Signals and Systems (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2022.060108
ISSN 2371-8838 Vol. 6 Num. 1

Selection of Wind Turbines with Multi-Criteria Group Decision Making Approach in Linguistic Q-Rung Orthopair Fuzzy Environment

Siyang Zhao*

College of Economic and Management, North China Electric Power University, Beinong Street, Beijing, China
**corresponding author*

Keywords: Linguistic q-rung orthopair fuzzy set, Wind turbine, Hamacher operator.

Abstract: Recently, wind power technology has been extensively applied in the world. Wind turbine is the fundamental equipment of the entire power generation system, and its selection involves many factors, such as technology, economy, environment and suppliers. The correlation of evaluation indexes and the uncertainty of decision-making environment further increases the complexity of selection. Based on it, this paper proposes a new multi-criteria group decision making (MCGDM) method based on weighted Lq-ROF Hamacher average (WLq-ROFHA) operator. Due to the flexibility and universality of linguistic q-rung orthopair fuzzy (Lq-ROF) set in expressing linguistic fuzzy information, Lq-ROF is chosen to express evaluation information. Firstly, the qualitative criterion from multiple angles is selected to build the wind turbine evaluation criteria system; secondly, considering the conflict and correlation between the criteria, we propose the Lq-ROF Hamacher average (Lq-ROFHA) operator and WLq-ROFHA operator, and study several properties of the proposed operators. The statistical variance (SV) method is used to determine the attribute weight to consider the hesitation degree of decision-makers' preference.

1. Introduction

With the rapid development of urbanization, people's demand for energy is constantly increasing. The use of oil, coal and other fuels has caused great environmental pollution problems, and the amount of fuel reserves is decreasing day by day, so the traditional fossil fuels have been unable to meet the needs of social development. The global energy landscape is changing and entering a diversified era dominated by clean energy. The utilization of clean, efficient and green renewable energy such as wind energy, tidal energy, solar energy, biomass energy and geothermal energy is increasing, and the development of renewable energy is the main way to solve the energy crisis. Compared with other renewable energy, wind energy has become the focus of energy reform in various countries due to its advantages of relatively mature technology, abundant resources and flexibility in utilization [1]. Recently, wind power has become the fastest-growing form of energy use in the world, and its proportion in the global power structure is gradually increasing [2]. Based on the latest data from the Global Wind Energy Council [3], by the end of 2019, the global cumulative installed wind power capacity reached 651.1GW, an increase of 10% compared to 2018. The new installed capacity in 2019 is 60.4GW, making it the second year of increase after 63.6GW in 2015.

The working principle of wind turbines is that the wind drives the rotation of the fan blades, which transfer mechanical energy through the spindle gearbox to the generator, which converts mechanical energy into electrical energy within the range of speed. The efficiency and development prospects of wind farms depend on the location of wind farms, the layout of the site and the selection of efficient wind turbines [4]. Wind Turbines is the key equipment in the entire power generation system [5]. Taking a 5MW onshore wind power generation project as an example, the cost of wind turbines accounts for 64% of the total investment [6]. With the development of fan manufacturing enterprises in the world, different types of fans with different technical routes and performance parameters emerge one after another. The choice of wind turbine is related to the annual power generation and overall efficiency of wind power plant, and its selection design needs to combine its own characteristics, plant terrain features [7], economic benefits, environmental impact and other factors, which increases the complexity of the selection problem. In practical selection decision, some factors come into conflict with each other, such as hub height and energy output efficiency, rotor diameter and rated wind speed. The optimization of one factor will have a negative impact on other factors, so the conflict and contradiction of criteria should be fully considered [8]. Based on the problem of wind turbine selection, a new MCGDM model is constructed in this paper, which provides a scientific and reliable decision basis for decision makers (DMs).

2. Literature Review

2.1. Wind Turbine Selection

Wind turbine selection involves technology, economy, environment and customer satisfaction. At present, scholars have applied a variety of decision models to the selection of wind turbines. In this paper, the latest research literature in this field has been sorted out, as shown in Table 1.

Although a large number of scholars have used modelling to explore this problem, the defects of the existing research are as follows:

The decision-making model can't consider the complexity of the conflicts among the indicators; The evaluation angle is single. There are many researches on the selection of technical level, but the selection of indicators is too specialized. In the actual decision-making, it is difficult to obtain accurate technical values; Decision-making methods are complex and outdated, such as particle swarm optimization algorithm and genetic algorithm, which increase the complexity of decision calculation; The expression of the evaluation information and the degree of hesitation were not considered, and most of the methods adopt quantitative evaluation. Some decisions involve only one expert, making the decision matrix limited. Based on the existing research, this paper proposed a new MCGDM method based on WLq-ROFHA operator.

Table 1: Method of wind turbine selection problem.

Methods	Literature
AHP	[9]
AHP	[10]
The Unified And-Or Operator	[11]
The Unified And-Or Operator	[12]
Fuzzy Airthmetic Mean Operator	[8]

ISM , FANP	[13]
TOPSIS , EDAS ,Borda	[14]
MOEAs	[15]
Weighted Sum Approach	[16]
PSO , DE , GA	[17]
AHP	[18]
PSO	[19]
BOCR , AHP	[13]
VIKOR , AHP	[20]
IFN , Fuzzy Measure	[21]

2.2. Research Situation of Our Method

2.2.1. Lq-ROFS

How to express and characterize uncertain information is a key research content in fuzzy MCDM problem. Liu et al. [22] proposed the concept of Lq-ROFS which satisfy the condition, where is the membership degree (MD) and is the non-membership degree (NMD). Compared with linguistic intuitionistic fuzzy set (LIFS) and linguistic Pythagorean fuzzy set (LPFS), Lq-ROFS can broaden the range of evaluation information by changing the value of parameter q [23]. With the wide application of Lq-ROFSs, scholars combine them with information aggregation operators to carry out a series of researches. Liu et al. [24]presented the Lq-ROF weighted averaging operator and Lq-ROF weighted geometric operator; Liu et al. [25] defined the entropy measure of the Lq-ROFS and applied the power average operator and the Muirhead mean operator to the Lq-ROFS, and combined with the concrete example to calculate; Li et al.[26] extended the Heronian mean operator and similar operators to the Lq-ROFS, and applied this method to the MCDM problem; Rong et al. [27]proposed complex Lq-ROFS and a series of operational laws, and adopted Maclaurin symmetric mean operator to integrate the evaluation results; Liu et al.[28]defined the comparison method of probabilistic linguistic q-rung orthopair fuzzy number(Lq-ROFN), and used weighted averaging operator to evaluate values; Liu et al.[29] presented the concept of uncertain Lq-ROFS, and extended the aggregation operators such as weighted average operator, ordered weighted average operator and hybrid weighted average operator to the environment of the fuzzy set.

2.2.2. Hamacher Operator

Hamacher operators are widely used in MCDM problems because they can accurately deal with fuzzy information and the correlation between criteria. Chen et al.[30]combined the Hamacher weighted average opeartor and the Hamacher weighted geometric operator with proportional interval T2 hesitant fuzzy set, and proposed the Ham-PIT2HPWA operator and the Ham-PIT2HPWG operator; Wu et al. [31] proposed some Hamacher aggregation operators in the single-valued neutrosophic 2-tuple linguistic environment, and analyzed their sensitivity to prove their feasibility; Tan et al. [32]presented a family of hesitant fuzzy Hamacher operators, which are used to aggregate hesitant fuzzy information; In the study of the selection of financial technologies, Mao et al.[33]used probabilistic linguistic term set to represent the evaluation information of DMs, and Hamacher operators were applied to aggregate the evaluation information; Liu et al.[34] combined the Hamacher aggregation operator with neutrosophic set, and proposed a series of generalized aggregation operators. Some scholars have applied the Hamacher operational laws to the q-ROFS environment and proposed q-ROF Hamacher Average Operator and the weighted q-ROF Hamacher Average Operator [35], the dual hesitant q-ROF Hamacher hybrid average operator, the dual hesitant q-ROF Hamacher hybrid geometric operator etc [36]. Based on previous studies, this paper expands the deformation of traditional Hamacher Operators and applies them to Lq-ROFS problem.

3. Wind Turbine Evaluation Criteria System

3.1. Technical Characteristics

- Rotor diameter: refers to the length of the rotor blades. The rotor blades are used to capture the wind and transfer it to the axis of the rotor. A larger rotor diameter means a wider scanning area and more wind energy can be obtained.
- Hub height: refers to the height from the ground to the sweep surface of the wind wheel. Wind speed depends on the height and location of the site, and the higher the hub height means the more wind power the turbine receives.
- Capacity factor: refers to the ratio between the actual capacity of a generating system and its rated capacity, it's a unitless ratio factor. The larger the capacity factor is, the better the generation effect of the generation system is.
- Operational convenience: turbine structure and design affect the actual operation of the operation and convenience.
- Availability: refers to the normal operation of the generator set after deducting the failure of the generation system and the failure of the turbine equipment, and is an important index to evaluate the operation condition of the wind turbine.
- Rated wind speed: refers to the specified wind speed output when the wind turbine reaches the rated power, also known as the design wind speed.
- Cut-in wind speed: refers to the minimum wind speed at which a wind turbine is operating. It’s a negative criterion. A smaller cut wind speed allows the turbine to operate at low wind speed.
- Field compliance: the selection of turbines should be adapted to the actual layout of the wind farm. The field compliance is the criterion to measure the match of turbines and power plants in a specific region.
- Technical reliability: higher reliability means easier replacement of parts, lower failure rates, more timely maintenance, etc., resulting in longer equipment life cycle, lower maintenance costs and better economic benefits.

3.2. Economic Benefit

- Capital cost: refers to the initial cost of building a turbine, including turbine equipment, transportation and system installation. It’s a negative criterion.
- Operation and maintenance cost: wind turbine daily operation and maintenance costs, including regular maintenance, parts replacement, equipment maintenance and other parts. It’s a negative criterion.
- Net present value: refers to the difference between the sum of discounted cash flows at each stage of the life cycle of a wind power project and the initial investment. The criterion is related to the life of wind power unit, power unit price and other factors, and is an index to evaluate the net income of wind power system.

3.3. Environmental Issues

- Land use: refers to the area of land needed to build a wind power system. It can be measured by the number of units of land that can be built on. It’s a negative criterion.
- Noise emission: refers to the wind turbine operation process is affected by the airflow and its own components rotation, blades and unit components emit large noise. It’s a negative criterion.
- Visual impact: the design and layout of wind farms should fully consider the conformance with the surrounding environment and reduce the visual nuisance to observers. It’s a negative criterion.
- Impact on eco-systems: the construction of wind power system will cause great damage to soil and vegetation, and the noise, electromagnetic effect and so on will pose great threat to the local ecological environment and wildlife habitat environment. It’s a negative criterion.

3.4. Supplier Performance

- Satisfaction level of supplier: this is an important indicator to evaluate the performance of suppliers, which is related to equipment reliability, timely maintenance service, technical support for replacement of parts and other factors provided by suppliers.
- R&D capability of supplier: refers to the supplier's ability to update technology and develop new technology. It determines the level of subsequent application and improvement of turbine equipment.
- Delivery: refers to the time it takes for the buyer to receive the equipment after the turbine order is placed. It’s a negative criterion.
- Integration capability of system: refers to the ability of equipment, components, operators, communications technology, and other discrete parts of a power generation system to be integrated into a whole.

4. Preliminaries

4.1. Lq-ROFS

Definition1: [37]Let $S=\{s_i \mid i=0,1,\cdots,t\}$ be a linguistic term set, $\forall s_i \in S$,then S can be depicted as:

$$S=\left\{\begin{matrix} s_0=extremely\ poor, s_1=very\ poor, s_3=medium, \\ s_4=good, s_5=very\ good, s_6=extremely\ good. \end{matrix}\right\} \tag{1}$$

Definition2: [38] Let $X=\{x_1,x_2,\cdots,x_n\}$ be a fixed set, the q-ROFS A on X is defined as:

$$A=\left\{\left\langle x_j, u_A\left(x_j\right), v_A\left(x_j\right)\right\rangle \mid x_j \in X\right\} \tag{2}$$

Where $u_A\left(x_j\right)$ and $v_A\left(x_j\right)$ signify the MD and NMD of x_j in A ,with $u_A\left(x_j\right) \in [0,1]$, $v_A\left(x_j\right) \in [0,1]$ and $0 \le u_A\left(x_j\right)^q + v_A\left(x_j\right)^q \le 1, (q \ge 1)$. $\pi_A\left(x_j\right) = \sqrt[q]{\left(1-u_A\left(x_j\right)^q - v_A\left(x_j\right)^q\right)}$ is the indeterminacy degree (IND). In addition, we call $\left(u_A(x), v_A(x)\right)$ as a q-rung orthopair fuzzy number (q-ROFN), which can be written as $A=\left(u_A, v_A\right)$.

Definition3: [22] Let $X=\{x_1,x_2,\cdots,x_n\}$ be a fixed set, $S=\{s_1,s_2,\cdots,s_t\}$ be a linguistic term set. An Lq-ROFS defined in X is represented by:

$$A=\left\{\left\langle x, s_u(x), s_v(x)\right\rangle | x\in X\right\} \tag{3}$$

where $s_u(x), s_v(x)\in S_{[0,t]}$,and $s_u(x)$ represents the linguistic membership degree, $s_v(x)$ represents the linguistic non-membership degree. $\forall x\in X$, the condition $u^q+v^q\le t^q\ (q\ge 1)$ is satisfied, then we call $A=(s_u, s_v)$ as an Lq-ROFN, and we regard $\chi_{[0,\ t]}$ as the set of Lq-ROFNs on the basis of $S_{[0,\ t]}$. $\pi_A(x)=s_{\sqrt[q]{\left(t^q-u^q-v^q\right)}}$ is the IND.

Definition4:[22]Let $a_1=(s_{u1}, s_{v1})$ and $a_2=(s_{u2}, s_{v2})\in\chi_{[0,\ t]}$ be two Lq-ROFNs, $\lambda>0$,the operational rules can be depicted as:

$$a_1\oplus a_2=\left(s_{\left(u_1^q+u_2^q-\frac{u_1^q u_2^q}{t^q}\right)^{\frac{1}{q}}}, s_{\frac{v_1 v_2}{t}}\right) \tag{4}$$

$$a_1\otimes a_2=\left(s_{\frac{u_1 u_2}{t}}, s_{\left(v_1^q+v_2^q-\frac{v_1^q v_2^q}{t^q}\right)^{\frac{1}{q}}}\right) \tag{5}$$

$$\lambda a_1=\left(s_{\left(t^q-t^q\left(1-\frac{u_1^q}{t^q}\right)^{\lambda}\right)^{\frac{1}{q}}}, s_{t\left(\frac{v_1}{t}\right)^{\lambda}}\right) \tag{6}$$

$$a_1^{\lambda}=\left(s_{t\left(\frac{u_1}{t}\right)^{\lambda}}, s_{\left(t^q-t^q\left(1-\frac{v_1^q}{t^q}\right)^{\lambda}\right)^{\frac{1}{q}}}\right) \tag{7}$$

Definition5: [22] Let $a_1=(s_{u1}, s_{v1})$ and $a_2=(s_{u2}, s_{v2})\in\chi_{[0,\ t]}$ be two Lq-ROFNs, where $q\ge 1$, then the Hamming distance is defined by:

$$d_H(a_1, a_2)=\frac{\left|u_1^q-u_2^q\right|+\left|v_1^q-v_2^q\right|+\left|\pi_1^q-\pi_2^q\right|}{2t^q} \tag{8}$$

where $\pi_j=\sqrt[q]{(2t)^q-u_j^q-v_j^q}\ (j=1,2), q\ge 1$.

Definition6: [22] Let $a=(s_u, s_v)\in\chi_{[0,\ t]}$ be an Lq-ROFN, its score function and the accurate function can be defined as:

$$S(a)=\sqrt[q]{\frac{t^q+u^q-v^q}{2}} \tag{9}$$

$$H(a)=\sqrt[q]{u^q+v^q} \tag{10}$$

Definition7: [22] Let $a_1 = \left(s_{u1}, s_{v1}\right)$ and $a_2 = \left(s_{u2}, s_{v2}\right) \in \chi_{[0,\ t]}$ be two Lq-ROFNs, based on Definition6, then if $S\left(a_1\right) \succ S\left(a_2\right)$, then $a_1 \succ a_2$; if $S\left(a_1\right) = S\left(a_2\right)$,then, if $H\left(a_1\right) \succ H\left(a_2\right)$,then $a_1 \succ a_2$;if $H\left(a_1\right) = H\left(a_2\right)$,then $a_1 = a_2$.

4.2. Hamacher Operations of Lq-ROFS

Hamacher[39]proposed Hamacher t-norm and t-conorm for constructing aggregation operators in 1978. The flexibility of information processing is increased because of the parameter change involved in its operation. The Hamacher t-norm and t-conorm are defined as follows:

$$T\left(a,b\right) = a \otimes b = \frac{ab}{\gamma + \left(1-\gamma\right)\left(a+b-ab\right)}, \gamma > 0 \tag{11}$$

$$T*\left(a,b\right) = a \oplus b = \frac{a+b-ab-\left(1-\gamma\right)ab}{1-\left(1-\gamma\right)\left(ab\right)}, \gamma > 0 \tag{12}$$

Definition8: Let $a = \left(s_u, s_v\right)$, $a_1 = \left(s_{u1}, s_{v1}\right)$ and $a_2 = \left(s_{u2}, s_{v2}\right) \in \chi_{[0,\ t]}$ be three Lq-ROFNs, then their Hamacher operations are depicted as $\left(\lambda, \gamma > 0\right)$:

$$a_1 \oplus a_2 = \left(s_{T_{u1}}, s_{T_{v1}}\right) \qquad T_{u1} = t\sqrt[q]{\frac{t^q\left(\left(u_1\right)^q + \left(u_2\right)^q\right) - \left(2-\gamma\right)\left(u_1\right)^q\left(u_2\right)^q}{t^{2q} - \left(1-\gamma\right)\left(u_1\right)^q\left(u_2\right)^q}}$$

$$T_{v1} = \frac{tv_1v_2}{\sqrt[q]{t^{2q}\gamma + \left(1-\gamma\right)\left(\left(v_1\right)^q t^q + \left(v_2\right)^q t^q - \left(v_1\right)^q\left(v_2\right)^q\right)}} \tag{13}$$

$$a_1 \otimes a_2 = \left(s_{T_{u2}}, s_{T_{v2}}\right) \qquad T_{u2} = \frac{tu_1u_2}{\sqrt[q]{t^{2q}\gamma + \left(1-\gamma\right)\left(\left(u_1\right)^q t^q + \left(u_2\right)^q t^q - \left(u_1\right)^q\left(u_2\right)^q\right)}}$$

$$T_{v2} = t\sqrt[q]{\frac{t^q\left(\left(v_1\right)^q + \left(v_2\right)^q\right) - \left(2-\gamma\right)\left(v_1\right)^q\left(v_2\right)^q}{t^{2q} - \left(1-\gamma\right)\left(v_1\right)^q\left(v_2\right)^q}} \tag{14}$$

$$\lambda a_1 = \left(s_{T_{u3}}, s_{T_{v3}}\right) \qquad T_{u3} = t\sqrt[q]{\frac{\left(t^q + \left(\gamma-1\right)\left(u_1\right)^q\right)^\lambda - \left(t^q - \left(u_1\right)^q\right)^\lambda}{\left(t^q + \left(\gamma-1\right)\left(u_1\right)^q\right)^\lambda + \left(\gamma-1\right)\left(t^q - \left(u_1\right)^q\right)^\lambda}}$$

$$T_{v3} = \frac{t\left(v_1\right)^\lambda \sqrt[q]{\gamma}}{\sqrt[q]{\left(t^q\gamma + \left(1-\gamma\right)\left(v_1\right)^q\right)^\lambda + \left(\gamma-1\right)\left(v_1\right)^{q\lambda}}} \tag{15}$$

$$a_1^\lambda = \left(s_{T_{u4}}, s_{T_{v4}}\right) \qquad T_{u4} = \frac{t\left(u_1\right)^\lambda \sqrt[q]{\gamma}}{\sqrt[q]{\left(t^q\gamma + \left(1-\gamma\right)\left(u_1\right)^q\right)^\lambda + \left(\gamma-1\right)\left(u_1\right)^{q\lambda}}}$$

$$T_{v4} = t\sqrt[q]{\frac{\left(t^q + \left(\gamma-1\right)\left(v_1\right)^q\right)^\lambda - \left(t^q - \left(v_1\right)^q\right)^\lambda}{\left(t^q + \left(\gamma-1\right)\left(v_1\right)^q\right)^\lambda + \left(\gamma-1\right)\left(t^q - \left(v_1\right)^q\right)^\lambda}} \tag{16}$$

5. The Lq-ROFHA and WLq-ROFHA Operator

Based on the theoretical basis proposed in section4, this section combines the Hamacher average operator and weighted Hamacher average operator with Lq-ROFS to construct Lq-ROFHA operator and WLq-ROFHA operator.ot should be included after the section title number.

5.1. Lq-ROFHA Operator

Definition9. Let $a_i=\left(s_{ui},s_{vi}\right)\in\chi_{[0,\ t]}\left(i=1,2,\cdots,n\right)$ be a collection of Lq-ROFNs, then the Lq-ROFHA operator is defined as follows:

$$Lq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=\overset{n}{\underset{i=1}{\oplus}}\left(\frac{1}{n}\left(a_i\right)\right) \tag{17}$$

According to Lq-ROF Hamacher operations, the following theorem from Definition9 can be obtained.

Theorem1 Let $a_i=\left(s_{ui},s_{vi}\right)\in\chi_{[0,\ t]}\left(i=1,2,\cdots,n\right)$ be a collection of Lq-ROFNs, where $\gamma>0$, then for any $q>0$, the aggregated value by using the Lq-ROFHA operator is still a Lq-ROFN, and:

$$Lq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=\left(s_{H_{ui}},s_{H_{vi}}\right) \tag{18}$$

$$H_{ui}=\sqrt[q]{\frac{t^q\prod_{i=1}^{n}\left(t^q+(\gamma-1)\left(u_i\right)^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{n}\left(t^q+(\gamma-1)\left(u_i\right)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}}$$

$$H_{vi}=\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{n}\left(v_i\right)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{n}\left(t^q\gamma+(1-\gamma)\left(v_i\right)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{n}\left(v_i\right)^{q\frac{1}{n}}}}$$

Proof1 (1) According to Equation (3) of Definition8, we can get the result:

$$\frac{1}{n}\left(a_i\right)=\left(s_{\sqrt[q]{\frac{t^q\left(t^q+(\gamma-1)\left(u_i\right)^q\right)^{\frac{1}{n}}-t^q\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}{\left(t^q+(\gamma-1)\left(u_i\right)^q\right)^{\frac{1}{n}}+(\gamma-1)\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}}},s_{\frac{t\left(v_i\right)^{\frac{1}{n}}\sqrt[q]{\gamma}}{\sqrt[q]{\left(t^q\gamma+(1-\gamma)\left(v_i\right)^q\right)^{\frac{1}{n}}+(\gamma-1)\left(v_i\right)^{q\frac{1}{n}}}}}\right) \tag{19}$$

(2) Then, for the results $\overset{n}{\underset{i=1}{\oplus}}\left(\frac{1}{n}\left(a_i\right)\right)$,let $n=2$,according to Equation (1) of Definition8, we obtain the following result:

$$\left(\frac{1}{n}(a_1)\oplus\frac{1}{n}(a_2)\right)$$

$$=\left(s_{\sqrt[q]{\frac{t^q\left(t^q+(\gamma-1)(u_1)^q\right)^{\frac{1}{n}}-t^q\left(t^q-(u_1)^q\right)^{\frac{1}{n}}}{\left(t^q+(\gamma-1)(u_1)^q\right)^{\frac{1}{n}}+(\gamma-1)\left(t^q-(u_1)^q\right)^{\frac{1}{n}}}}},s_{\frac{t(v_1)^{\frac{1}{n}}\sqrt[q]{\gamma}}{\sqrt[q]{\left(t^q\gamma+(1-\gamma)(v_1)^q\right)^{\frac{1}{n}}+(\gamma-1)(v_1)^{q\frac{1}{n}}}}}\right)\oplus\left(s_{\sqrt[q]{\frac{t^q\left(t^q+(\gamma-1)(u_2)^q\right)^{\frac{1}{n}}-t^q\left(t^q-(u_2)^q\right)^{\frac{1}{n}}}{\left(t^q+(\gamma-1)(u_2)^q\right)^{\frac{1}{n}}+(\gamma-1)\left(t^q-(u_2)^q\right)^{\frac{1}{n}}}}},s_{\frac{t(v_2)^{\frac{1}{n}}\sqrt[q]{\gamma}}{\sqrt[q]{\left(t^q\gamma+(1-\gamma)(v_2)^q\right)^{\frac{1}{n}}+(\gamma-1)(v_2)^{q\frac{1}{n}}}}}\right)$$

$$=\left(s_{\sqrt[q]{\frac{t^q\prod_{i=1}^{2}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{2}}-t^q\prod_{i=1}^{2}\left(t^q-(u_i)^q\right)^{\frac{1}{2}}}{\prod_{i=1}^{2}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{2}}+(\gamma-1)\prod_{i=1}^{2}\left(t^q-(u_i)^q\right)^{\frac{1}{2}}}}},s_{\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{2}(v_i)^{\frac{1}{2}}}{\sqrt[q]{\prod_{i=1}^{2}\left(t^q\gamma+(1-\gamma)(v_i)^q\right)^{\frac{1}{2}}+(\gamma-1)\prod_{i=1}^{2}(v_i)^{q\frac{1}{2}}}}}\right)\tag{20}$$

(3) For the results $\bigoplus_{i=1}^{n}\left(\frac{1}{n}(a_i)\right)$,let $n=k$,then we can obtain the result:

$$\bigoplus_{i=1}^{k}\left(\frac{1}{n}(a_i)\right)=\left(s_{\sqrt[q]{\frac{t^q\prod_{i=1}^{k}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{k}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{k}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}}},s_{\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{k}(v_i)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{k}\left(t^q\gamma+(1-\gamma)(v_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k}(v_i)^{q\frac{1}{n}}}}}\right)\tag{21}$$

When $n=k+1$, then we can get:

$$\overset{k+1}{\underset{i=1}{\oplus}}\left(\frac{1}{n}(a_i)\right)=\left(\overset{k}{\underset{i=1}{\oplus}}\left(\frac{1}{n}(a_i)\right)\right)\oplus\left(\frac{1}{n}(a_{k+1})\right)$$

$$=\left(s\sqrt[q]{\frac{t^q\prod_{i=1}^{k}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{k}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{k}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}},\, s\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{k}(v_i)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{k}\left(t^q\gamma+(1-\gamma)(v_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k}(v_i)^{q\frac{1}{n}}}}\right)\oplus$$

$$\left(s\sqrt[q]{\frac{t^q\left(t^q+(\gamma-1)(u_{k+1})^q\right)^{\frac{1}{n}}-t^q\left(t^q-(u_{k+1})^q\right)^{\frac{1}{n}}}{\left(t^q+(\gamma-1)(u_{k+1})^q\right)^{\frac{1}{n}}+(\gamma-1)\left(t^q-(u_{k+1})^q\right)^{\frac{1}{n}}}},\, s\frac{t\sqrt[q]{\gamma}(v_{k+1})^{\frac{1}{n}}}{\sqrt[q]{\left(t^q\gamma+(1-\gamma)(v_{k+1})^q\right)^{\frac{1}{n}}+(\gamma-1)(v_{k+1})^{q\frac{1}{n}}}}\right)$$

$$=\left(s\sqrt[q]{\frac{t^q\prod_{i=1}^{k+1}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{k+1}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{k+1}\left(t^q+(\gamma-1)(u_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k+1}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}},\, s\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{k+1}(v_i)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{k+1}\left(t^q\gamma+(1-\gamma)(v_i)^q\right)^{\frac{1}{n}}+(\gamma-1)\prod_{i=1}^{k+1}(v_i)^{q\frac{1}{n}}}}\right) \tag{22}$$

The results show that the Theorem1is valid when $n=k+1$, so it is valid for any n.

By adjusting the value of γ, Theorem1 leads to the following special cases:

Remark1 When $\gamma=1$, the Lq-ROFHA operator reduces to the Lq-ROF average (Lq-ROFA) operator.

$$Lq-ROFA(a_1,a_2,\cdots,a_n)=\left(s\sqrt[q]{\frac{t^q\prod_{i=1}^{n}\left(t^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{n}\left(t^q-(u_i)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{n}\left(t^q\right)^{\frac{1}{n}}}},\, s\frac{t\prod_{i=1}^{n}(v_i)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{n}\left(t^q\right)^{\frac{1}{n}}}}\right) \tag{23}$$

Remark2 When $\gamma=2$, the Lq-ROFHA operator transforms into the Lq-ROF Einstein average (Lq-ROFEA) operator.

$$Lq-ROFEA\left(a_1,a_2,\cdots,a_n\right)=\left(s_{\sqrt[q]{\frac{t^q\prod_{i=1}^{n}\left(t^q+\left(u_i\right)^q\right)^{\frac{1}{n}}-t^q\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}{\prod_{i=1}^{n}\left(t^q+\left(u_i\right)^q\right)^{\frac{1}{n}}+\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\frac{1}{n}}}}},s_{\frac{\sqrt[q]{2}t\prod_{i=1}^{n}\left(v_i\right)^{\frac{1}{n}}}{\sqrt[q]{\prod_{i=1}^{n}\left(2t^q-\left(v_i\right)^q\right)^{\frac{1}{n}}+\prod_{i=1}^{n}\left(v_i\right)^{q\frac{1}{n}}}}}\right) \tag{24}$$

We can also conclude that the Lq-ROFHA operator has the following properties

Property1(Idempotency) Let $a_i=\left(s_{ui},s_{vi}\right)\in\chi_{[0,\ t]}\left(i=1,2,\cdots,n\right)$ be a collection of Lq-ROFNs, any Lq-ROFNs are equal, if $a_i=a=\left(s_u,s_v\right)$ then

$$Lq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=a \tag{25}$$

Property2(Commutativity) If $a_i^{'}$ is any permutation of $a_i\left(i=1,2,\cdots,n\right)$,the following relation can be obtained:

$$Lq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=Lq-ROFHA\left(a_1^{'},a_2^{'},\cdots,a_n^{'}\right) \tag{26}$$

Proof Let $a_i^{'}\left(i=1,2,\cdots,n\right)$ is any permutation of $a_i\left(i=1,2,\cdots,n\right)$, according to Definition7, it can be obtained:

$$Lq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=\overset{n}{\underset{i=1}{\oplus}}\left(\frac{1}{n}\left(a_i\right)\right)=\overset{n}{\underset{i=1}{\oplus}}\left(\frac{1}{n}\left(a_i^{'}\right)\right)=Lq-ROFHA\left(a_1^{'},a_2^{'},\cdots,a_n^{'}\right) \tag{27}$$

5.2. WLq-ROFHA Operator

Definition10 Let $a_i=\left(s_{ui},s_{vi}\right)\in\chi_{[0,\ t]}\left(i=1,2,\cdots,n\right)$ be a collection of Lq-ROFNs, the weight vector is $\omega=\left[\omega_1,\omega_2,\cdots,\omega_n\right]^T$, where ω_i shows the importance of a_i ,satisfying $\omega_i\in\left[0,1\right]$ and $\sum_{i=1}^{n}\omega_i=1$,then the WLq-ROFHA operator is defined as follows:

$$WLq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=\omega_1a_1\oplus\omega_2a_2\oplus\cdots\oplus\omega_na_n=\overset{n}{\underset{i=1}{\oplus}}\omega_ia_i \tag{28}$$

According to Definition8, the following theorem can be obtained:

Theorem2 Let $a_i=\left(s_{ui},s_{vi}\right)\in\chi_{[0,\ t]}\left(i=1,2,\cdots,n\right)$ be a collection of Lq-ROFNs, where $\gamma>0$,then for any $q>0$, the aggregated value by using the WLq-ROFHA operator is still a WLq-ROFN, and:

$$WLq-ROFHA\left(a_1,a_2,\cdots,a_n\right)=\left(s_{W_{ui}},s_{W_{vi}}\right) \tag{29}$$

$$W_{ui}=\sqrt[q]{\frac{t^q\prod_{i=1}^{n}\left(t^q+\left(\gamma-1\right)\left(u_i\right)^q\right)^{\omega_i}-t^q\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\omega_i}}{\prod_{i=1}^{n}\left(t^q+\left(\gamma-1\right)\left(u_i\right)^q\right)^{\omega_i}+\left(\gamma-1\right)\prod_{i=1}^{n}\left(t^q-\left(u_i\right)^q\right)^{\omega_i}}}$$

$$W_{vi}=\frac{t\sqrt[q]{\gamma}\prod_{i=1}^{n}(v_i)^{\omega_i}}{\sqrt[q]{\prod_{i=1}^{n}\left(t^q\gamma+(1-\gamma)(v_i)^q\right)^{\omega_i}+(\gamma-1)\prod_{i=1}^{n}(v_i)^{q\omega_i}}}$$

6. An MCGDM Algorithm Using the WLq-ROFHA Operator

6.1. The Description of the MCGDM Problem

For a MCGDM problem, let $X=\{x_1,x_2,\cdots,x_m\}$ be a set of m alternatives, let $C=\{c_1,c_2,\cdots,c_n\}$ be a set of n criteria, let $E=\{e_1,e_2,\cdots,e_l\}$ be a set of l DMs. $\omega=[\omega_1,\omega_2,\cdots,\omega_n]$ is the weight vector of the criterion E_j, with $\omega_j\ge 0$ and $\sum_{j=1}^{n}\omega_j=1\left(j=1,2,\cdots,n\right)$. $\mu=[\mu_1,\mu_2,\cdots,\mu_l]$ is the weight vector of expert e_k, with $\mu_k\ge 0$ and $\sum_{k=1}^{l}\mu_k=1\left(k=1,2,\cdots,l\right)$. The evaluation value of the alternative x_i under the criterion c_j given by the DM e_k is expressed by the Lq-ROFNs $r_{ij}^k=\left(s_{uij}^k,s_{vij}^k\right)\left(i=1,2,\cdots,m;\ j=1,2,\cdots,n;k=1,2,\cdots,l\right)$,then the Lq-ROFS decision matrix $R^k=\left[r_{ij}^k\right]_{m\times n}=\left[\left(s_{uij}^k,s_{vij}^k\right)\right]_{m\times n}$ can be expressed as:

$$R^k=\left(r_{ij}^k\right)_{m\times n}=\begin{array}{c|cccc|} & E_1 & E_2 & \cdots & E_n \\ X_1 & r_{11}^k & r_{12}^k & \cdots & r_{1n}^k \\ X_2 & r_{21}^k & r_{22}^k & \cdots & r_{2n}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_m & r_{m1}^k & r_{m2}^k & \cdots & r_{mn}^k \end{array} \tag{30}$$

6.2. The Descision Steps of Proposed Approach

This paper uses WLQ-ROFHA operator to solve MCGDM problem. The steps of the WLq-ROFHA operator are as follows:

Step1: Normalize the group decision matrix.

According to the criterion type, the initial decision matrix R^k is standardized to obtain the standardized decision matrix $R^{k'}=\left[r_{ij}^{k'}\right]_{m\times n}=\left[\left(s_{uij}^{k'},s_{vij}^{k'}\right)\right]_{m\times n}$.

$$r_{ij}^{k'}=\begin{cases}\left(s_{uij}^k,s_{vij}^k\right) & if\ j\in N_b \\ \left(s_{vij}^k,s_{uij}^k\right) & if\ j\in N_c\end{cases}\quad\left(i=1,2,\cdots,m;\ j=1,2,\cdots,n;k=1,2,\cdots,l\right) \tag{31}$$

Where N_b represents the set of benefit criteria, and N_c represents the set of cost criteria.

Step2: Compute the criteria weights.

In this paper, SV method is used to determine criteria weights. SV was first proposed by Liu et al. [40], which was used to solve the decision problem of completely unknown attribute weight. Its advantage is that it can fully consider the fuzzy hesitation degree of DMs in evaluating each attribute.

DMs have a higher preference degree and hesitation degree for a certain attribute, which means that the attribute has a higher weight. By capturing as much uncertain information as possible to make relatively accurate decisions.

(1) Construct the attribute preference information evaluation matrix $M=\left[b_{kj}\right]_{l\times n}$, where l is the DMs set, n is the attribute set, and b_{kj} is the preference information of DM k on attribute j.

(2) Calculate the accuracy function $H\left(b_{kj}\right)$ according to Definition6, and substitute it into the following formula:

$$\sigma_j^2=\frac{\sum_{k=1}^{l}\left(H\left(b_{kj}\right)-\overline{H\left(b_{kj}\right)}\right)^2}{l-1}\left(k=1,2,\cdots,l;j=1,2,\cdots,n\right) \tag{32}$$

Where $\overline{H\left(b_{kj}\right)}$ represents the mean value of the accuracy function of b_{kj}.

(3) Standardize the variance σ_j^2.

$$\omega_j=\frac{\sigma_j^2}{\sum_{j=1}^{n}\sigma_j^2} \tag{33}$$

Where, ω_j represents the weight of the j criterion, satisfying $\omega_j\in\left[0,1\right]$ and $\sum_{j=1}^{n}\omega_j=1$.

Step3: Aggregate of all DMs information.

The standardized decision matrices $R^{k'}$ are aggregated by using the WLq-ROFHA operator to obtain their respective aggregation matrices $R^{k''}=\left[r_{ij}^{k''}\right]_{m\times 1}$.

$$r_{ij}^{k''}=WLq-ROFHA\left(r_{i1}^{k'},r_{i2}^{k'},\cdots,r_{in}^{k'}\right)=\left(s_{uij}^{''},s_{vij}^{''}\right)=\left(s_{W_{uij}},s_{W_{vij}}\right) \tag{34}$$

$$W_{uij}=\sqrt[q]{\frac{t^q\prod_{j=1}^{n}\left(t^q+(\gamma-1)\left(u_{ij}\right)^q\right)^{\omega_j}-t^q\prod_{j=1}^{n}\left(t^q-\left(u_{ij}\right)^q\right)^{\omega_j}}{\prod_{j=1}^{n}\left(t^q+(\gamma-1)\left(u_{ij}\right)^q\right)^{\omega_j}+(\gamma-1)\prod_{j=1}^{n}\left(t^q-\left(u_{ij}\right)^q\right)^{\omega_j}}}$$

$$W_{vij}=\frac{t\sqrt[q]{\gamma}\prod_{j=1}^{n}\left(v_{ij}\right)^{\omega_j}}{\sqrt[q]{\prod_{j=1}^{n}\left(t^q\gamma+(1-\gamma)\left(v_{ij}\right)^q\right)^{\omega_j}+(\gamma-1)\prod_{j=1}^{n}\left(v_{ij}\right)^{q\omega_j}}}$$

Step4: Calculate the collective overall values.

WLq-ROFHA operator is used to aggregate $R^{k''}$ to obtain comprehensive evaluation matrix $R^{''}=\left[r_i^{''}\right]_{m\times 1}$.

$$r_i^{''}=WLq-ROFHA\left(r_i^{1''},r_i^{2''},\cdots,r_i^{l''}\right)=\left(s_{ui},s_{vi}\right) \tag{35}$$

Step5: Calculate the score function and accuracy function.

The score function $S\left(r_i^{''}\right)$ and the accuracy function $H\left(r_i^{''}\right)$ are calculated according to Definition6.

Step6: Rank.

Rank $S\left(r_i^{''}\right)$ and $H\left(r_i^{''}\right)$ according to Definition7 to get the best alternative.

7. Conclusion

The purpose of this study is to establish a new method for wind turbine selection. Firstly, the evaluation criteria system of wind turbine is constructed by comprehensively considering various indexes, and each sub-criterion is described in detail, so as to provide a reasonable and effective tool for DMs. In order to solve the complexity of decision environment and the correlation among criteria, this paper proposes a decision framework based on WLq-ROFHA operator. Specifically, this paper uses Lq-ROFS to express the evaluation information of experts, which is more in line with the language habits of experts and fully expresses the fuzziness of information. Two classes of Hamacher Operators are introduced for information aggregation. SV method was used to identify the attribute weight to consider the preference of DMs for each criterion. The method in this paper also shows some limitations, such as expert judgment has a great influence on the overall scheme, fuzzy numbers and linguistic variables should be used to evaluate the information to increase the accuracy of decision making, the evaluation criteria system is not complete. The author will further improve the proposed method in the future research, and implement the method to a variety of decision-making problems.

References

[1] Aghbashlo, M., Tabatabaei, M., Hosseini, S.S., Dashti, B. and Mojarab Soufiyan, M. (2018) Performance assessment of a wind power plant using standard exergy and extended exergy accounting (EEA) approaches. Journal of Cleaner Production,171,127–136.

[2] Shoaib, M., Siddiqui, I., Rehman, S., Khan, S. and Alhems, L.M. (2019) Assessment of wind energy potential using wind energy conversion system. Journal of Cleaner Production, 216,346–360.

[3] GWEC. Global wind energy outlook 2010. Global Wind Energy Council, Brussels, Belgium 2011.

[4] Mittal, P. and Mitra, K. (2018) Determining layout of a wind farm with optimal number of turbines: A decomposition-based approach. Journal of Cleaner Production, 202, 342–359.

[5] Kouloumpis, V., Sobolewski, R.A. and Yan, X. (2020) Performance and life cycle assessment of a small-scale vertical axis wind turbine. Journal of Cleaner Production, 2020,247.

[6] Renewable, U.K. (2011) The economics of wind energy. Renewable UK 2011. http:// www.bwea.com/ (accessed March 3, 2021).

[7] Ramadan, H.S. (2017) Wind energy farm sizing and resource assessment for optimal energy yield in Sinai Peninsula, Egypt. Journal of Cleaner Production,161,1283–1293.

[8] Rehman, S. and Khan, S.A. (2016) Fuzzy logic based multi-criteria wind turbine selection strategy - A case study of Qassim, Saudi Arabia. Energies (Basel),9.

[9] Sağlam, Ü. (2018) A two-stage performance assessment of utility-scale wind farms in Texas using data envelopment analysis and Tobit models. Journal of Cleaner Production,201,580–598.

[10] Bagočius, V., Zavadskas, E.K. and Turskis, Z. (2014) Multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function. Journal of Civil Engineering and Management,20,590–599.

[11] Khan, S.A. and Rehman, S. (2012) On the use of Unified And-Or fuzzy aggregation operator for multi-criteria decision making in wind farm design process using wind turbines in 500 kW - 750 kW range. IEEE International Conference on Fuzzy Systems.

[12] Rehman, S., Khan, S.A. and Alhems, L.M. (2020) A rule-based fuzzy logic methodology for multi-criteria selection of wind turbines. Sustainability (Switzerland), 12, 1–21.

[13] Lee, A.H.I., Chen, H.H. and Kang, H.Y. (2009) Multi-criteria decision making on strategic selection of wind farms. Renewable Energy, 34, 120–126.

[14] Supciller, A.A. and Toprak, F. (2020) Selection of wind turbines with multi-criteria decision-making techniques involving neutrosophic numbers: A case from Turkey. Energy, 207.

[15] Montoya, F.G., Manzano-Agugliaro, F., López-Márquez, S., Hernández-Escobedo, Q. and Gil. C. (2014) Wind turbine selection for wind farm layout using multi-objective evolutionary algorithms. Expert Systems with Applications, 41, 6585–6595.

[16] Rehman, S. and Khan, S.A. (2017) Multi-Criteria Wind Turbine Selection using Weighted Sum Approach. vol. 8.

[17] Dong, Y., Wang, J., Jiang, H. and Shi, X. (2013) Intelligent optimized wind resource assessment and wind turbines selection in Huitengxile of Inner Mongolia, China. Applied Energy, 109, 239–253.

[18] Shirgholami, Z., Namdar Zangeneh, S. and Bortolini, M. (2016) Decision system to support the practitioners in the wind farm design: A case study for Iran mainland. Sustainable Energy Technologies and Assessments, 16, 1–10.

[19] Chowdhury, S., Mehmani, A., Zhang, J. and Messac, A. (2016) Market suitability and performance tradeoffs offered by commercialwind turbines across differingwind regimes. Energies (Basel), 9.

[20] Kaya, T. and Kahraman, C. (2010) Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. Energy, 35, 2517–2527.

[21] Wu, Y., Chen, K., Zeng, B., Yang, M., Li, L. and Zhang, H. (2017) A cloud decision framework in pure 2-tuple linguistic setting and its application for low-speed wind farm site selection. Journal of Cleaner Production, 142, 2154–2165.

[22] Liu, P. and Liu, W. (2019) Multiple-attribute group decision-making based on power Bonferroni operators of linguistic q-rung orthopair fuzzy numbers. International Journal of Intelligent Systems, 34, 652–689.

[23] Liu, Z., Li, L. and Li, J. (2019) q-Rung orthopair uncertain linguistic partitioned Bonferroni mean operators and its application to multiple attribute decision-making method. International Journal of Intelligent Systems, 34, 2490–2520.

[24] Liu, D., Liu, Y. and Wang, L. (2020) The reference ideal TOPSIS method for linguistic q-rung orthopair fuzzy decision making based on linguistic scale function. Journal of Intelligent and Fuzzy Systems, 39, 4111–4131.

[25] Liu, P. and Liu, W. (2019) Multiple-attribute group decision-making method of linguistic q-rung orthopair fuzzy power Muirhead mean operators based on entropy weight. International Journal of Intelligent Systems, 34, 1755–1794.

[26] Li, L., Zhang, R., Wang, J. and Shang, X. (2018) Some q-rung orthopair linguistic Heronian mean operators with their application to multi-attribute group decision making. Archives of Control Sciences, 28, 551–583.

[27] Rong, Y., Liu, Y. and Pei, Z. (2020) Complex q-rung orthopair fuzzy 2-tuple linguistic Maclaurin symmetric mean operators and its application to emergency program selection. International Journal of Intelligent Systems,35,1749–1790.

[28] Liu, D. and Huang, A. (2020) Consensus reaching process for fuzzy behavioral TOPSIS method with probabilistic linguistic q-rung orthopair fuzzy set based on correlation measure. International Journal of Intelligent Systems, 35, 494–528.

[29] Liu, Z., Xu, H., Yu, Y. and Li, J. (2019) Some q-rung orthopair uncertain linguistic aggregation operators and their application to multiple attribute group decision making. International Journal of Intelligent Systems, 34, 2521–2555.

[30] Chen, Z.S., Yang, Y., Wang, X.J., Chin, K.S. and Tsui, K.L. (2019) Fostering linguistic decision-making under uncertainty: A proportional interval type-2 hesitant fuzzy TOPSIS approach based on Hamacher aggregation operators and andness optimization models. Information Sciences, 500, 229–258.

[31] Wu, Q., Wu, P., Zhou, L., Chen, H. and Guan, X. (2018) Some new Hamacher aggregation operators under single-valued neutrosophic 2-tuple linguistic environment and their applications to multi-attribute group decision making. Computers and Industrial Engineering, 116, 144–162.

[32] Tan, C., Yi, W. and Chen, X. (2015) Hesitant fuzzy Hamacher aggregation operators for multicriteria decision making. Applied Soft Computing Journal, 26, 325–349.

[33] Mao, X.B., Wu, M., Dong, J.Y., Wan, S.P. and Jin, Z. (2019) A new method for probabilistic linguistic multi-attribute group decision making: Application to the selection of financial technologies. Applied Soft Computing Journal, 77, 155–175.

[34] Liu, P., Chu, Y., Li, Y. and Chen, Y. (2014) Some Generalized Neutrosophic Number Hamacher Aggregation Operators and Their Application to Group Decision Making, vol. 16.

[35] Darko, A.P. and Liang, D. (2020) Some q-rung orthopair fuzzy Hamacher aggregation operators and their application to multiple attribute group decision making with modified EDAS method. Engineering Applications of Artificial Intelligence, 87.

[36] Wang, P., Wei, G., Wang, J., Lin, R. and Wei, Y. (2019) Dual hesitant q-rung orthopair fuzzy Hamacher aggregation operators and their applications in scheme selection of construction project. Symmetry (Basel), 11.

[37] Wu, Q., Wu, P., Zhou, L., Chen, H. and Guan, X. (2018) Some new Hamacher aggregation operators under single-valued neutrosophic 2-tuple linguistic environment and their applications to multi-attribute group decision making. Computers and Industrial Engineering, 116, 144–162.

[38] Yager, R.R. (2017) Generalized Orthopair Fuzzy Sets. IEEE Transactions on Fuzzy Systems, 25.

[39] Hamacher, H. (1978) Uber logische verknunpfungenn unssharfer aussagen undderen zugenhorige bewertungsfunktione. Prog Cybern Syst Res, 3, 276–288.

[40] Liu, S., Chan, F.T.S. and Ran, W. (2016) Decision making for the selection of cloud vendor: An improved approach under group decision-making with integrated weights and objective/subjective attributes. Expert Systems with Applications, 55, 37–47.