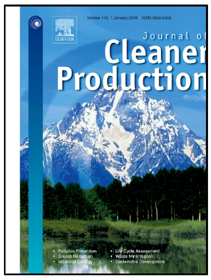
Accepted Manuscript



Linguistic hesitant fuzzy multi-criterion decision-making for renewable energy: A case study in Jilin

Jiahang Yuan, Cunbin Li, Wenle Li, Ding Liu, Xiaopeng Li

PII:	S0959-6526(17)32689-6
DOI:	10.1016/j.jclepro.2017.11.038
Reference:	JCLP 11177
To appear in:	*Journal of Cleaner Production*
Received Date:	30 April 2017
Revised Date:	12 October 2017
Accepted Date:	06 November 2017

Please cite this article as: Jiahang Yuan, Cunbin Li, Wenle Li, Ding Liu, Xiaopeng Li, Linguistic hesitant fuzzy multi-criterion decision-making for renewable energy: A case study in Jilin, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.11.038

Linguistic hesitant fuzzy multi-criterion decision-making for renewable energy: A case study in Jilin

Jiahang Yuan*, Cunbin Li, Wenle Li, Ding Liu, Xiaopeng Li
(School of Economics and Management, North China Electric Power University, Beijing, P.R. China)

Abstract: Renewable energy is the inevitable choice for the sustainable development of society and economy. How to select the most appropriate renewable energy for a region is a complex multi-criterion decision making (MCDM) problem. Taking Jilin Province as an example, this paper proposes a new MCDM method. In order to better express the hesitancy, inconsistency and uncertainty of decision makers' preferences, linguistic hesitant fuzzy set (LHFS) is proposed. On the basis of cloud model, the rule of transforming LHFS to quantitative values is defined. Subsequently, the distance measure and support measure are established. In consideration of the interdependency of criteria, an LHFS aggregation operator based on improved Choquet integral is proposed. Finally, the ranking result of the aggregated LHFS corresponding to each renewable energy alternative is obtained according to the expectation values. The result shows that the preferred renewable energy for Jilin is biomass energy, followed by wind energy, hydro energy and solar energy. The validation analysis and comparison analysis are given to demonstrate the effectiveness of the proposed method.

Key words: Renewable energy; linguistic hesitant fuzzy set; cloud model; Choquet integral

1 Introduction

Energy has played an important role in the social and economic development of the world. So far, fossil fuels have occupied the vast majority of energy consumption. Nearly 81% of the world's energies are provided by fossil fuels. It is predicted that the world's average growth rate of energy consumption is 1.8% per year until 2030[1]. With the growing demand of energy, conventional energy, especially for fossil fuels, raised fears of carbon emission, environment pollution and the depletion of fossil fuels. Such concerns drove many countries to develop and utilize renewable energy.

Renewable energy is sustainable and environmentally friendly, for its energy is provided by naturally replenished outflow of energy without consuming natural resources. Thus, renewable energy has been paid more attention over the world in recent years. Various policies and investments were implemented to promote the utilization and development of renewable energy in different countries. In 2013, more than 144 countries made different renewable energy targets and policies to support renewable energy development. By 2013, renewable energy had supplied approximately 19% of the world's final energy consumption. In 2015, renewable energy contributed 23% to electricity generation, which is estimated to reach 45% in 2040. In the future, renewable energy will gradually substitute for conventional energy and eventually dominate energy industry.

Solar energy, wind energy, hydro energy, geothermal and biomass energy are different forms of renewable energy. The selection of an appropriate renewable energy for a given jurisdiction is important, as the sensible energy planning will develop new economic markets and create employment opportunities[2]. More importantly, the right energy selection will improve the structure of energy utilization. However, the selection process is a complex decision-making which involves comprehensive trade-offs[2], for each energy alternative has its own advantages and disadvantages from different perspectives. For example, wind energy is free of contamination, but has poor stability. In addition, decision-makers may have different opinions due to different experience and specialty.

Determining the preferred renewable energy can be classified as a multi-criterion decision-making (MCDM) problem. MCDM methods are very suitable for its solution, for MCDM methods enable the clear recognition of the influences of subjective issues on the final ranking of alternatives[3] and solve complex issues with poor data systems[4]. In the previous studies, some MCDM methods such as AHP (Analytic Hierarchy Process)[5], PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations)[6], ELECTRE (ELimination Et Choix Traduisant la REalité)[7], and multi-participatory framework[8] were applied on energy selection. In recent years, the above models combined with fuzzy theory were extensively used in energy planning, which has got a series of achievements. Suganthi et al. (2015) made a review on the application of fuzzy logic in renewable energy. Soft computing techniques such as fuzzy logic, neural network and genetic algorithm were adopted in energy modeling to precisely map the energy systems[9]. Kahraman et al. (2009) combined axiomatic design with AHP to make renewable energy decision by the evaluation scores that are expressed as linguistic terms or fuzzy numbers[10]. Cavallaro (2013) illustrated the economic advantages of nuclear energy compared to traditional energy alternatives by decision-making methods based on fuzzy functions and fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution)[11]. Erol and Kilkis (2012) developed an MCDM method based on AHP to facilitate energy planning activities in Aydin, Turkey. The results showed solar energy investments had the highest priority[12]. Yazdni-Chamzini et al. (2012) proposed an integrated COPRAS-AHP (COmplex PRoportional ASsessment Analytic Hierarchy Process) to select the best alternative of renewable energy[13].

Due to the vagueness and the limitation of human feelings, it is hard for decision makers to use crisp values to express their assessments. Linguistic terms, such as “extremely high”, “high” and “low”, are usually used to describe the vagueness of subjective cognition[14]. With fuzzy set, linguistic terms are easier to realize the transition from subjective, incomplete and vague information to quantification[15]. Hence, fuzzy linguistic descriptors which involve ambiguity and uncertainty acquired from the preferences are suitable for dealing with evaluation information.

Kaya and Kahraman (2010) deemed that it was easy for an energy planning expert to make evaluation by using linguistic terms, and proposed a modified fuzzy TOPSIS methodology under linguistic terms to make decision in energy planning[16]. Sengui et al. (2015) analyzed MCDM methods and then proposed a decision-making method based on fuzzy TOPSIS and interval entropy for Turkey’s energy supply systems. Weights were calculated by the entropy methodology and the ranking result was obtained by three α-cutting levels. They found that hydropower was the most appropriate alternative for Turkey[17]. Erdogan and Kaya (2015) put forward type-2 fuzzy sets to express experts’ evaluation values on energy alternatives with respect to multi criteria in order to overcome uncertainties in the decision making process. Fuzzy AHP and TOPSIS were combined to deal with the MCDM problem based on interval type-2 fuzzy set. At last, the proposed method obtained a road map of energy policy for Turkey[18]. Egilmez et al. (2015) proposed a four-stage evaluation method based on intuitionistic fuzzy set for the environmental sustainability performance of 27 U.S. and Canada metropoles. Their conclusion showed that CO_2 emissions and public transport had the greatest influence on the sustainability scores[19]. Doukas et al. (2013) used linguistic variables for evaluating the energy and environmental corporate policies of small medium enterprises and proposed a multi-criterion decision-making framework based on 2-tuple TOPSIS method[20]. Mousavi and Moghaddam (2015) put forward a hierarchical complex proportional assessment method using hesitant fuzzy set (HFS), which considers subjective and objective information for renewable energy MCDM problem. They also discussed the HFS's ability in dealing with uncertain and imprecise conditions[21]. In this regard, Xu and Zhang (2013) proposed an MCDM method based on maximizing deviation and TOPSIS, in which the evaluation values are hesitant fuzzy sets. Then they applied their method to an energy policy selection problem[22]. Onar et al. (2015) considered the vagueness, ambiguity and subjectivity in the evaluation processes, and proposed an interval-valued intuitionistic fuzzy (IVIF) pairwise comparison based evaluation using a new linguistic scale for wind energy technology selection. Their approach realized the overall performance measurement of wind energy technology alternatives through the aggregation of IVIF pairwise comparison matrices and the calculation of score judgment and possibility degree matrices[23]. Yao and Li (2014) proposed a new score function using hesitant fuzzy information, which measures the deviation of hesitant fuzzy elements. By the basic operator, the assessment model was applied in the new energy planning for sustainable development[24].

From the history research, we can find that the crisp or conventional approaches tend to be less effective in dealing with the vagueness or imprecision in energy evaluation. Although there are many achievements in fuzzy MCDM, there still exist some drawbacks. (1) The vagueness sources from human evaluation contain unquantifiable information, uncertain information and hesitant information. The fuzzy tools in history research usually ignore hesitant information. (2) Most transformation methods fail to generate the fuzziness and randomness of linguistic terms when transforming qualitative concepts to quantitative values. (3) History research usually assumes that the criteria are independent of each other in MCDM problems, which is almost nonexistent in reality. To solve the hesitant problem, this paper extends HFSs to linguistic term sets and presents the concept of linguistic hesitant fuzzy set (LHFS) [25] to describe the evaluation information in renewable energy selection. LHFS allows several possible linguistic values to represent the membership degree of an element to a set, which is a powerful tool to express uncertain information. For the problem of transformation, there are three main transformation methods by computing with words: linguistic computational model based on membership functions, 2-tuple linguistic model and linguistic symbolic model based on ordinal scales. The three methods all fail to generate an expression with both fuzziness and randomness. The cloud model introduced by Dr. Li is an uncertainty transformation model between qualitative concepts and quantitative description. For qualitative concepts, the cloud model utilizes normal membership function and normal distribution to detail its fuzziness and randomness. Simultaneously, the cloud model has three numerical characteristics, which represent the mathematical properties of linguistic values. In summary, the cloud model can not only express the fuzziness and randomness of linguistic terms but also render the transformation between quantitative values and qualitative concepts more objective and interchangeable[26]. Thus, the cloud model would make great contributions to renewable energy MCDM.

The interdependency of criteria remains a strong barrier for MCDM methods to surmount. For MCDM problems with relevant criteria, fuzzy measures have been used as an effective tool to determine the weights, followed by the use of fuzzy integral which is a nonlinear aggregation operator aggregating partial evaluations based on fuzzy measures[27]. Fuzzy measures have non-additive character compared to classical measures. Sugeno proposed λ fuzzy measure that the fuzzy measure of a set of criteria can be calculated as long as the fuzzy measures of its subsets are known. At present, there are two main methods to determine λ: subjective grade and objective calculation. Both methods have obvious drawbacks that human factors have great influences on subjective grade methods and objective calculation methods. In this case, this paper utilizes the Sigmoid function to determine λ fuzzy measure, which considers the objective information in decision-making and the preference of decision makers. Subsequently, an LHFS aggregation operator based on improved fuzzy integral is proposed.

This paper aims to select renewable energy for Jilin Province of China. An MCDM model based on cloud model and improved fuzzy integral for LHFS is proposed. The main contributions can be classified in three ways. Firstly, although linguistic fuzzy theory has been already applied in the research, linguistic hesitant fuzzy set is used in the energy selection problem for the first time. Secondly, we introduce the cloud model to accomplish the transformation from LHFS to quantitative values, which is a contribution to fuzzy decision-making. Thirdly, we propose a new aggregation operator based on improved fuzzy integral to build a comprehensive set of independent criteria for renewable energy evaluation systems. The remainder of this paper unfolds as follows: Section 2 introduces the background information of renewable energy development in Jilin. Linguistic hesitant fuzzy sets, cloud model, Choquet integral and some related rules are given in Section 3. Section 4 shows the decision making method. In Section 5, multiple criteria for renewable energy evaluation, an example, discussion, managerial implications, method validation, comparison and sensitivity analysis are given. Section 6 ends the paper with some concluding remarks.

2 Background

As an old industrial base in the northeast of China, Jilin consumed a large amount of energy every year. The proven energy reserves of Jilin are 14.56×10^8 tons of standard coal equivalent calculated in terms of equal value, which account for 0.23% of China's energy reserves. There is a huge gap between the energy reserves of Jilin and its development demand, so import becomes the main channel to narrow the gap. At present, 50% of energy in Jilin depends on import. The lack of energy self-sufficiency ability and the high proportion of low-grade energy consumption are two development bottlenecks in Jilin. In addition, traditional energy places a huge burden on the environment. Selecting an appropriate renewable energy plan will not only promote economy development, but also reform the structure of energy in Jilin. The main promising renewable energy that can be utilized in Jilin includes: biomass energy, wind energy, hydro energy and solar energy. Currently, Jilin faces an urgent problem: how to determine the priority of these renewable energy alternatives so that the government can make some related policies to promote renewable energy development.

2.1 Biomass energy

The biomass energy in Jilin mainly comes from straw, livestock excrement and forestry waste, among which power generation mainly uses straw. With the advanced agriculture, there are a large number of crop stalks. The straw resources available for power generation in Jilin are about 31.33 million tons, which are 15.56 million tons of standard coal equivalent calculated in terms of equal value. As shown in Fig. 1, straw resources are mainly distributed in the central region, whose straw resources exceed half of those in the province, accounting for 63.47%; the western region is less than the former, accounting for 26.57%; the eastern region is the minimum, accounting for 9.96%. In 2013, the development and utilization of biomass energy made initial progress that seven biomass power plants have been built with total installed capacity of more than 160 MW. In 2014, biomass power plants provided 1.005 billion KWh of electricity for the users in Jilin, which saves 787,500 tons of standard coal equivalent calculated in terms of equal value, not only reducing carbon emission and waste pollution but also promoting the employment of farmers. In 2015, the government attached great importance to the comprehensive utilization and industrialization of straw by introducing policies to support relevant enterprises.

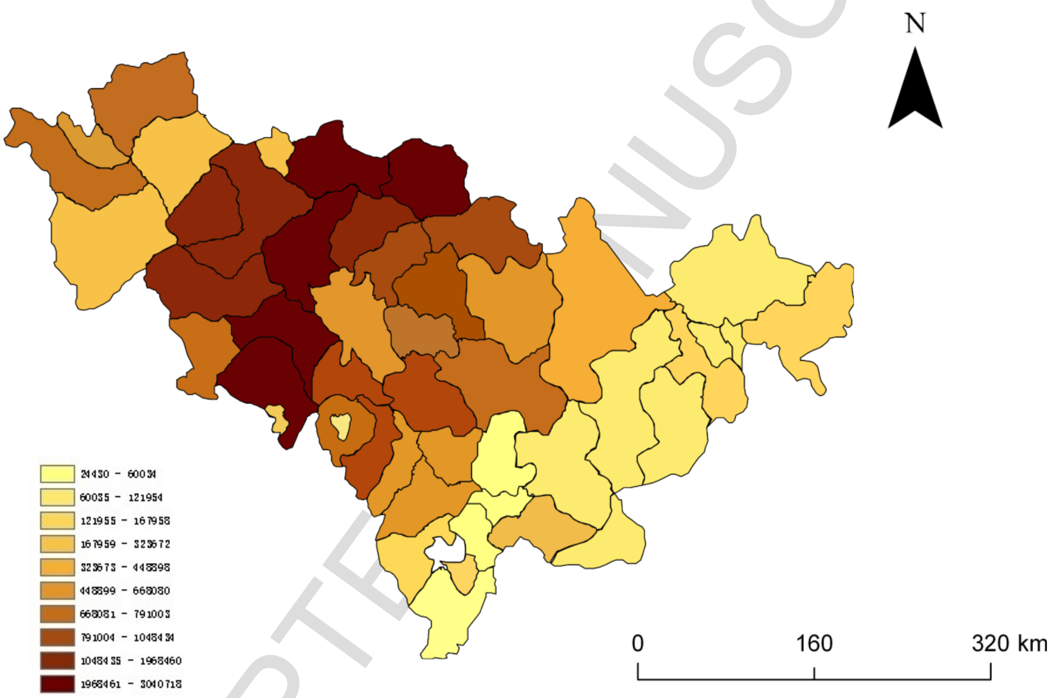


Fig. 1. The distribution of straw resources in Jilin

2.2 Wind energy

Jilin is in the high latitude area, so its wind energy reserves are relatively abundant. Nationwide, the total amount of wind energy resources in Jilin ranks fifth in the country. According to the reserves and availability of wind energy, Jilin can be divided into two areas, namely, abundant area and available area. Abundant areas are mainly in a few areas, such as Wangqing and Hunchun in the east, Tongyu and Gan'an in the west. Apart from these areas, other areas within Jilin are available areas. As shown in Fig. 2, some regions have flat terrain and vast area with a level of wind power density over 4. So these regions are very conducive to develop wind energy resources and become key areas using wind energy in Jilin, such as Baicheng, Songyuan and Siping.

In recent years, with the rapid development of wind power industry, the wind power installed capacity in Jilin has grown fast from 79 MW in the beginning to current 6.93 GW, which indicates wind power has become the second largest direct scheduling power supply in Jilin. From 2009 to 2013, the construction of wind power in Jilin has advanced rapidly: the proportion of wind power installed capacity in the direct scheduling installed capacity increased from 11.74% to 19.4%; the percentage of wind power installed capacity in the province's installed capacity rose from 7.87% to 20.49%. In 2013, the cumulative wind power installed capacity ran up to 4.3799 GW including new wind power installed capacity of 382.5 MW. In 2014, Jilin approved a total capacity of 6.68 GW with under construction capacity of about 2.61 GW. Till 2015, the cumulative approved capacity reached 6.93 GW with under construction capacity of 2.49 GW and generating capacity of 6 billion KWh.

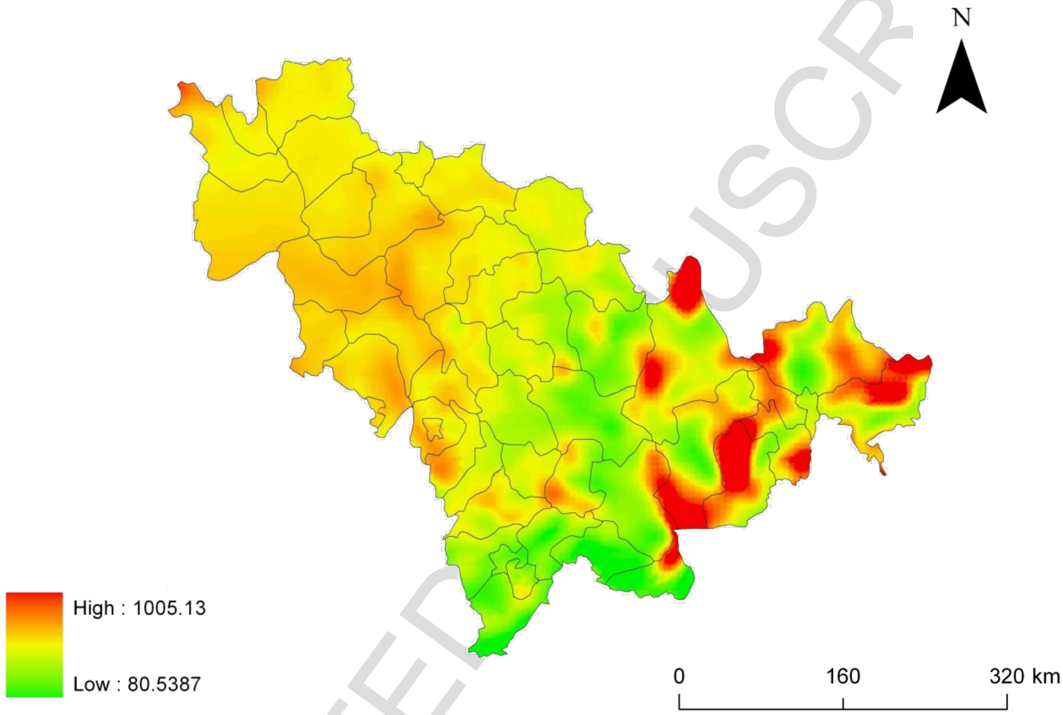


Fig. 2. The distribution of wind power density in Jilin at the height of 70 meters

2.3 Hydro energy

The hydro energy in Jilin is mainly distributed over Songhua river, Yalu river and Tumen river. The technical exploitation amount is 5.1155 GW, in which 3.89 GW have been developed. In 2016, there are 262 hydropower stations in Jilin. The installed capacity is 585 MW and the generating capacity is 913.95 GWh. So far, the cascade development of hydro energy in Songhua River has been basically completed. Apart from some hydropower stations with expansion capacity, no big hydropower stations can be built. Although there are some potential for the development and utilization of hydro energy resources, it is difficult to develop them. Furthermore, hydropower is affected by rainfall and dry season, which cannot supply power steadily. So the main task of hydropower station is peak regulation.

2.4 Solar energy

As shown in Fig. 3, the solar energy resources are not ample enough in Jilin. Therefore, the development of photovoltaic power generation in Jilin is slow without the cost advantage of large-scale development. In 2013, the cumulative grid-connected capacity of photovoltaic power generation in Jilin reached 10 MW. In 2014, the cumulative installed capacity of photovoltaic power generation in Jilin achieved 60 MW. In 2015, the cumulative installed capacity of photovoltaic power generation in Jilin ran up to 70 MW, in which 60 MW are from photovoltaic plants and 10 MW are from distributed photovoltaic systems.

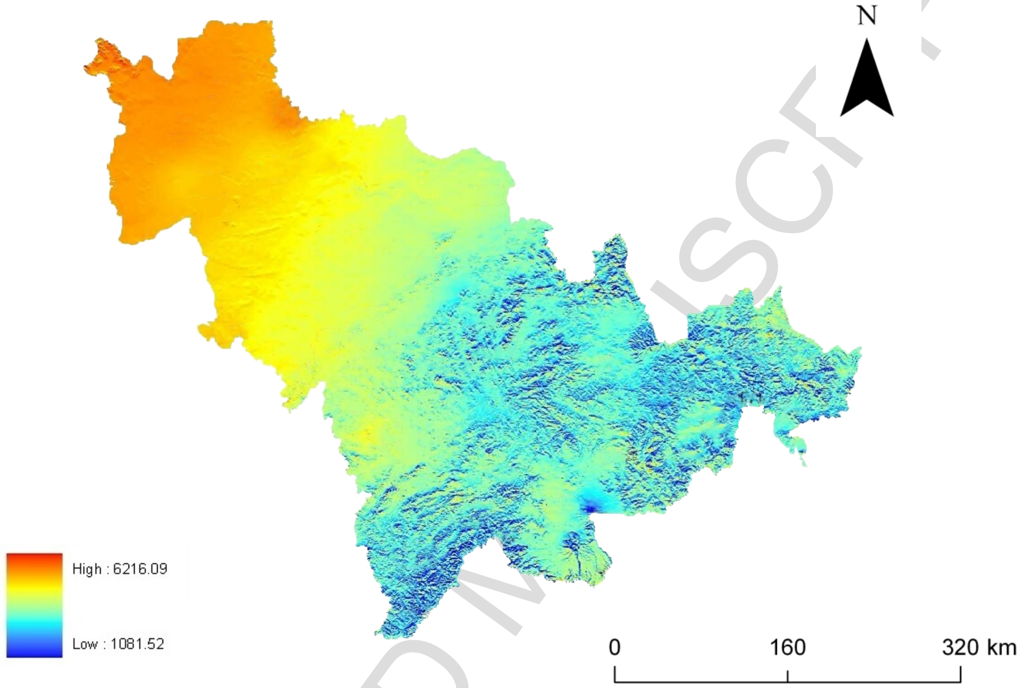


Fig. 3. The distribution of solar energy in Jilin

3 Preliminaries

3.1 Linguistic hesitant fuzzy set (LHFS)

Definition 1[25]. Suppose that there is a linguistic term set $S=\{s_0,s_1,...,s_{t-1}\}$, linguistic hesitant fuzzy set (LHFS) LH on S is a set whose element is a combination of $s_{\theta(i)}$ and $lh(s_{\theta(i)})$, denoted by $LH=\left\{\left(s_{\theta(i)},lh(s_{\theta(i)})\right)\middle|s_{\theta(i)}\in S\right\}$, where $lh(s_{\theta(i)})=\left\{r_1,r_2,...,r_{m_i}\right\}$ is a set with m_i values in [0,1] denoting the possible membership degrees of the linguistic term $s_{\theta(i)}\in S$.

Definition 2. Suppose that LH_1 and LH_2 are two LHFSs. The operation rules are shown as follows:

(1) $LH_1\oplus LH_2=\bigcup_{\left(s_{\theta(i)},lh(s_{\theta(i)})\right)\in LH_1,\left(s_{\theta(j)},lh(s_{\theta(j)})\right)\in LH_2}\left\{\left(s_{\theta(i)+\theta(j)},\bigcup_{r_i\in lh(s_{\theta(i)}),r_j\in lh(s_{\theta(j)})}1-(1-r_i)(1-r_j)\right)\right\}$

(2) $LH_1\otimes LH_2=\bigcup_{\left(s_{\theta(i)},lh(s_{\theta(i)})\right)\in LH_1,\left(s_{\theta(j)},lh(s_{\theta(j)})\right)\in LH_2}\left\{\left(s_{\theta(i)\theta(j)},\bigcup_{r_i\in lh(s_{\theta(i)}),r_j\in lh(s_{\theta(j)})}r_ir_j\right)\right\}$

(3) $\lambda LH_1=\bigcup_{\left(s_{\theta(i)},lh(s_{\theta(i)})\right)\in LH_1}\left\{\left(s_{\lambda\theta(i)},\bigcup_{r_i\in lh(s_{\theta(i)})}1-(1-r_i)^{\lambda}\right)\right\},\lambda\in[0,1]$

(4) $LH_1^\lambda = \bigcup_{(s_{\theta(i)}, lh(s_{\theta(i)})) \in LH_1} \left\{ \left(s_{\theta(i)^\lambda}, \bigcup_{r_i \in lh(s_{\theta(i)})} r_i^\lambda \right) \right\}, \lambda \in [0,1]$

Proposition 1. Let LH_1 and LH_2 be two LHFSs, and we have:

(1) $LH_1 \oplus LH_2 = LH_2 \oplus LH_1$

(2) $LH_1 \otimes LH_2 = LH_2 \otimes LH_1$

(3) $\lambda(LH_1 \oplus LH_2) = \lambda LH_1 \oplus \lambda LH_2$, $\lambda \in [0,1]$

(4) $(LH_1 \otimes LH_2)^\lambda = LH_1^\lambda \otimes LH_2^\lambda$, $\lambda \in [0,1]$

(5) $(\lambda_1 + \lambda_2)LH_1 = \lambda_1 LH_1 \oplus \lambda_2 LH_1, \lambda_1, \lambda_2 \in [0,1]$

(6) $LH_1^{\lambda_1+\lambda_2} = LH_1^{\lambda_1} \otimes LH_1^{\lambda_2}, \lambda_1, \lambda_2 \in [0,1]$

Definition 3. Let LH be an LHFS. We define $E(LH) = s_{e(LH)}$ as the expectation function and $D(LH) = s_{\nu(LH)}$ as the variance function, where $e(LH) = \frac{1}{|index(LH)|}\left(\sum_{\theta(i) \in index(LH)} \frac{\theta(i)}{|lh(s_{\theta(i)})|} \sum_{r \in lh(s_{\theta(i)})} r \right)$,

$\nu(LH) = \frac{1}{|index(LH)|}\left(\sum_{\theta(i) \in index(LH)} \left(\frac{\theta(i)}{|lh(s_{\theta(i)})|} \sum_{r \in lh(s_{\theta(i)})} r - e(LH) \right)^2 \right)$, $|lh(s_{\theta(i)})|$ is the count of real numbers in $lh(s_{\theta(i)})$, and $|index(LH)|$ is the cardinality of $index(LH)$; $index(LH) = \left\{ \theta(i) \middle| (s_{\theta(i)}, lh(s_{\theta(i)})) \in LH, s_{\theta(i)} \in S, lh(s_{\theta(i)}) \neq \{0\} \right\}$.

For two LHFSs LH_1 and LH_2, if $E(LH_1) < E(LH_2)$, then $LH_1 < LH_2$; if $E(LH_1) > E(LH_2)$, then $LH_1 > LH_2$; if $E(LH_1) = E(LH_2)$, then $\begin{cases} LH_1 < LH_2, \text{ if } D(LH_1) > D(LH_2) \\ LH_1 = LH_2, \text{ if } D(LH_1) = D(LH_2) \\ LH_1 > LH_2, \text{ if } D(LH_1) < D(LH_2) \end{cases}$.

3.2 Cloud model

Definition 4[28]. Suppose U is a quantitative domain described by accurate values, T is a qualitative concept on U, $x (x \in U)$ is a random instantiation of concept T that satisfies $x \sim N(Ex, En'^2)$ and $En' \sim N(En, He^2)$, $y = e^{-\frac{(x-Ex)^2}{2(En')^2}}$ $(y \in [0,1])$ is the certainty degree of x belonging to T, then we define the distribution of x in the domain U as normal cloud and use (x, y) to represent the cloud drop.

In a cloud, there are three numerical characteristics: expectation Ex, entropy En and hyper entropy He, which describe the fuzziness and randomness[29]. Then, a qualitative concept can be expressed by cloud (Ex, En, He).

Definition 5[30]. Let $A(Ex_1, En_1, He_1)$ and $B(Ex_2, En_2, He_2)$ be two clouds in the domain. Some operation rules are:

(1) $A + B = \left(Ex_1 + Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2} \right)$

(2) $A - B = \left(Ex_1 - Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2} \right)$

(3) $A \times B = \left(Ex_1 Ex_2, \sqrt{(En_1 Ex_2)^2 + (En_2 Ex_1)^2}, \sqrt{(He_1 Ex_2)^2 + (He_2 Ex_1)^2} \right)$

(4) $\lambda A = (\lambda Ex_1, \sqrt{\lambda} En_1, \sqrt{\lambda} He_1)$

(5) $A^\lambda = (Ex_1^\lambda, \sqrt{\lambda} Ex_1^{\lambda-1} En_1, \sqrt{\lambda} Ex_1^{\lambda-1} He_1)$

Definition 6[31]. Let $A(Ex_1, En_1, He_1)$ and $B(Ex_2, En_2, He_2)$ be two clouds in the domain, the Hamming distance between A and B is:

$$d(A,B)=\left|\left(1-\frac{(En_1)^2+(He_1)^2}{(En_1)^2+(He_1)^2+(En_2)^2+(He_2)^2}\right)Ex_1-\left(1-\frac{(En_2)^2+(He_2)^2}{(En_1)^2+(He_1)^2+(En_2)^2+(He_2)^2}\right)Ex_2\right| \quad (1)$$

Definition 7[32]. Let $CD = xy$ be the score function of a cloud drop (x, y) contributing to the concept T. For cloud A composed of cloud drops, the expected value $\overline{CD}$ is defined as the overall score of A belonging to the concept T.

According to the above definition, we can compare clouds. But in reality, we are unaware of the distribution of CD, and it is too rigid to acquire $\overline{CD}$. We can only use enough cloud drops as samples to estimate $\overline{CD}$ [30]. Given the numerical characteristics and applied forward normal cloud generator[28], n cloud drops $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ can be produced. Then $\overline{CD}$ can be estimated as follows:

$$\overline{CD} = \frac{1}{n}\sum_{i=1}^{n} x_i y_i \quad (2)$$

Suppose that there are two clouds A and B, if $\overline{CD}(A) > \overline{CD}(B)$, then $A > B$; if $\overline{CD}(A) < \overline{CD}(B)$, then $A < B$; if $\overline{CD}(A) = \overline{CD}(B)$, then $A = B$.

Definition 8[33]. Let $S = \{s_0, s_1, ..., s_{t-1}\}$ be the linguistic term set, where t is an odd number. Interval $[X_{\min}, X_{\max}]$ is a valid domain. We use cloud model $C_i(Ex_i, En_i, He_i)$ to represent linguistic value s_i, $i = 0,1,...,t-1$. For example, $S = \{s_0, s_1, ..., s_6\}$, s_0=very poor, s_1=poor, s_2=slightly poor, s_3 =normal, s_4=slightly good, s_5=good, s_6=very good. we generate seven clouds based on 3σ principle and the idea of golden section. According to 3σ principle, the closer to the center of the domain, the smaller the entropy and hyper entropy of the cloud. Experts just need to give He_3, and then seven clouds can be calculated using golden section method, as shown in Table 1.

Table 1. Seven clouds generated by golden section method

Cloud	Ex	En	He
$C_0(Ex_0, En_0, He_0)$	$X_{\min}$	$\frac{En_5}{0.618}$	$\frac{He_5}{0.618}$
$C_1(Ex_1, En_1, He_1)$	$Ex_3 - \frac{(X_{\max} - X_{\min})}{4}$	$\frac{En_4}{0.618}$	$\frac{He_4}{0.618}$
$C_2(Ex_2, En_2, He_2)$	$Ex_3 - 0.382 \times \frac{(X_{\max} - X_{\min})}{4}$	$0.382 \times \frac{(X_{\max} - X_{\min})}{12}$	$\frac{He_3}{0.618}$
$C_3(Ex_3, En_3, He_3)$	$\frac{(X_{\min} + X_{\max})}{2}$	$0.618 \times En_4$	Given He_3
$C_4(Ex_4, En_4, He_4)$	$Ex_3 + 0.382 \times \frac{(X_{\max} - X_{\min})}{4}$	$0.382 \times \frac{(X_{\max} - X_{\min})}{12}$	$\frac{He_3}{0.618}$
$C_5(Ex_5, En_5, He_5)$	$Ex_3 + \frac{(X_{\max} - X_{\min})}{4}$	$\frac{En_4}{0.618}$	$\frac{He_4}{0.618}$
$C_6(Ex_6, En_6, He_6)$	$X_{\max}$	$\frac{En_5}{0.618}$	$\frac{He_5}{0.618}$

Definition 9[34]. Suppose $S = \{s_0, s_1, ..., s_{t-1}\}$ is a linguistic term set and s_i is represented by cloud

$C_i(Ex_i, En_i, He_i)$. The valid domain is $[X_{\min}, X_{\max}]$. $LH = \left\{ \left(s_{\theta(i)}, lh(s_{\theta(i)}) \right) \middle| s_{\theta(i)} \in S, lh(s_{\theta(i)}) = \left\{ r_1, r_2, ..., r_{m_i} \right\} \right\}$ is an LHFS. We define the comprehensive cloud of LH as $C^*_{LH}(Ex^*_{LH}, En^*_{LH}, He^*_{LH})$.

$$Ex^*_{LH} = \frac{1}{|index(LH)|} \left(\sum_{\theta(i) \in index(LH)} \frac{Ex_{\theta(i)}}{|lh(s_{\theta(i)})|} \left(\sum_{r \in lh(s_{\theta(i)})} r \right) \right) \quad (3)$$

$$En^*_{LH} = \sqrt{\frac{1}{|index(LH)|} \sum_{\theta(i) \in index(LH)} \left(En_{\theta(i)} \right)^2} \quad (4)$$

$$He^*_{LH} = \sqrt{\frac{1}{|index(LH)|} \sum_{\theta(i) \in index(LH)} \left(He_{\theta(i)} \right)^2} \quad (5)$$

Definition 10. Suppose $S = \{s_0, s_1, ..., s_{t-1}\}$ is a linguistic term set and s_i is represented by cloud $C_i(Ex_i, En_i, He_i)$. LH_1 and LH_2 are two LHFSs. The valid domain is $[X_{\min}, X_{\max}]$. The distance between LH_1 and LH_2 is defined as follows:

$$d(LH_1, LH_2) = \frac{1}{X_{\max} - X_{\min}} \left| \left(1 - \frac{(En^*_{LH_1})^2 + (He^*_{LH_1})^2}{(En^*_{LH_1})^2 + (He^*_{LH_1})^2 + (En^*_{LH_2})^2 + (He^*_{LH_2})^2} \right) Ex^*_{LH_1} - \left(1 - \frac{(En^*_{LH_2})^2 + (He^*_{LH_2})^2}{(En^*_{LH_1})^2 + (He^*_{LH_1})^2 + (En^*_{LH_2})^2 + (He^*_{LH_2})^2} \right) Ex^*_{LH_2} \right| \quad (6)$$

3.3 Fuzzy measure

Definition 11. Let $X = \{x_1, x_2, ..., x_n\}$ be a finite set and $P(X)$ be the power set of X. $g: P(X) \to [0,1]$ is a set of functions. If $g: P(X) \to [0,1]$ satisfies the conditions:

(1) $g(\varnothing) = 0, g(X) = 1$

(2) $\forall A, B \in P(X)$, if $A \subseteq B$, then $g(A) \le g(B)$

Then g is called fuzzy measure. If $g: P(X) \to [0,1]$ satisfies the condition when $\forall A, B \in P(X)$, $A \cap B = \varnothing$, and $\lambda > -1$, then:

$$g(A \cup B) = g(A) + g(B) + \lambda g(A) g(B) \quad (7)$$

We define g as the fuzzy measure function of λ.

Theorem 1. Let $X = \{x_1, x_2, ..., x_n\}$ be a finite set and $g_i = g(\{x_i\})$ be the measure density of x_i. For any set $A \subseteq X$, the λ fuzzy measure of A is:

$$g(A) = \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} g_{i_2} + ... + \lambda^{n-1} g_1 g_2 ... g_n = \frac{1}{\lambda} \left[\prod_{i \in A} (1 + \lambda g_i) - 1 \right] \quad (8)$$

Proof.

When $A = \{x_1\}$, $\frac{1}{\lambda} \left[\prod_{i=1}^{1} (1 + \lambda g_i) - 1 \right] = \frac{1}{\lambda} \left[(1 + \lambda g_1) - 1 \right] = g_1 = g(\{x_1\})$.

Suppose when $A = \{x_1, x_2, ..., x_n\}$, $g(\{x_1, x_2, ..., x_n\}) = \frac{1}{\lambda} \left[\prod_{i=1}^{n} (1 + \lambda g_i) - 1 \right]$ is true.

Based on (7),

$$g\left(\{x_1,x_2,...,x_n,x_{n+1}\}\right)=g\left(\{x_1,x_2,...,x_n\}\right)+g\left(\{x_{n+1}\}\right)+\lambda g\left(\{x_1,x_2,...,x_n\}\right)g\left(\{x_{n+1}\}\right)$$
$$=\frac{1}{\lambda}\left[(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)-1\right]+g_{n+1}+\left[(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)-1\right]g_{n+1}$$
$$=\frac{1}{\lambda}\left\{(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)-1+\lambda g_{n+1}+\lambda g_{n+1}\left[(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)-1\right]\right\}$$
$$=\frac{1}{\lambda}\left\{(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)+\lambda g_{n+1}(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)-1\right\}$$
$$=\frac{1}{\lambda}\left[(1+\lambda g_1)(1+\lambda g_2)...(1+\lambda g_n)(1+\lambda g_{n+1})-1\right]$$
$$=\frac{1}{\lambda}\left[\prod_{i=1}^{n+1}(1+\lambda g_i)-1\right]$$

According to the mathematical induction, the theorem is true.
According to Equation (8) and the boundedness of fuzzy measure $g(X)=1$, we get the value of λ from:

$$\prod_{i=1}^{n}(1+\lambda g_i)=\lambda+1 \quad (9)$$

3.4 Choquet integral

Definition 12. Let g be a fuzzy measure on $(X,P(X))$ and f be a measurable crisp value function. Choquet integral of f with respect to g is:

$$\int f\,dg=\int_{-\infty}^{0}\left[g(A_\alpha)-g_X\right]d_\alpha+\int_{0}^{\infty}g(A_\alpha)d_\alpha \quad (10)$$

where $A_\alpha=\left\{x\middle|f(x)\geq\alpha\right\},\alpha\in(-\infty,+\infty)$.
For a finite discrete set $X=\{x_1,x_2,...,x_n\}$, the Choquet integral is:

$$\int f\,dg=\sum_{i=1}^{n}\left[g(A_{(i)})-g(A_{(i+1)})\right]f(x_{(i)}) \quad (11)$$

where (i) is the subscript of $x_{(i)}$ which satisfies $f(x_{(1)})\leq f(x_{(2)})\leq\ldots\leq f(x_{(n)})$, $A_{(i)}=\left\{x_{(i)},x_{(i+1)},\ldots,x_{(n)}\right\}$, $A_{(n+1)}=\varnothing$.
Definition 13[35]. Let $X=\{x_1,x_2,...,x_n\}$ be the criteria in decision-making and $\Delta d=(\Delta d_1,\Delta d_2,...,\Delta d_n)$ be the information gain set. We define the mapping $\Delta d\rightarrow g$ as the measure density transformation function of criterion x_j, as shown in Equation (12).

$$g_j=\frac{1}{1+e^{-\delta\Delta d_j}} \quad (12)$$

where $\delta\in(0,+\infty)$ is the adjustment coefficient of the measure density transformation function. The measure density transformation function figure is shown in Fig. 4.

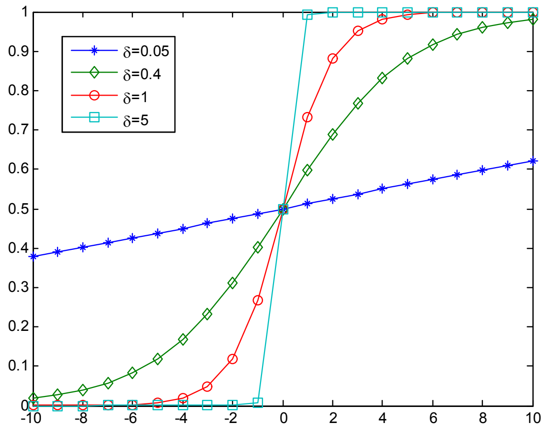


Fig. 4. The measure density transformation function figure

3.5 Linguistic hesitant fuzzy Choquet integral operator

Definition 14. Let g be a fuzzy measure on $X=\{x_1,x_2,...,x_n\}$. $LH_{ij}=\left\{\left(s_{\theta(ij)},lh(s_{\theta(ij)})\right)\middle|s_{\theta(ij)}\in S\right\}$ $(j=1,...,n)$ are LHFSs on X. The linguistic hesitant fuzzy Choquet integral (LHFCI) operator is:

$$LHFCI\left(LH_{i1},LH_{i2},...,LH_{in}\right)=$$

$$\bigcup_{\left(s_{\theta(i1)},lh(s_{\theta(i1)})\right)\in \mathrm{LH}_{i1},...,\left(s_{\theta(in)},lh(s_{\theta(in)})\right)\in \mathrm{LH}_{in}}\left\{\left(s_{\prod_{j=1}^{n}\theta(ij)^{\omega_{ij}}},\bigcup_{r_{i1}\in lh(s_{\theta(i1)}),...,r_{in}\in lh(s_{\theta(in)})}\prod_{j=1}^{n}(r_{i\sigma(j)})^{g(A_{\sigma(j)})-g(A_{\sigma(j-1)})}\right)\right\} \quad (13)$$

where ω_{ij} is the weight associated with LH_{ij}. $\sigma(1),\sigma(2),...,\sigma(n)$ are a permutation of $1,2,...,n$ and satisfy $C^*_{LH_{i\sigma(1)}}\geq C^*_{LH_{i\sigma(2)}}\geq...\geq C^*_{LH_{i\sigma(n)}}$. $A_{\sigma(j)}=\left\{x_{\sigma(1)},x_{\sigma(2)},...,x_{\sigma(j)}\right\}$ and $A_{\sigma(0)}=\varnothing$.

4 Decision-making steps

Suppose the decision-making problem for renewable energy planning is composed of m alternatives and n criteria denoted as $A=\{A_1,A_2,...,A_m\}$ and $X=\{x_1,x_2,...,x_n\}$ respectively. $\omega=(\omega_1,\omega_2,...,\omega_n)$ is the criterion weight vector. The evaluation value of alternative A_i with respect to criterion x_j is represented as LHFS $LH_{ij}=\left\{\left(s_{\theta(ij)},lh(s_{\theta(ij)})\right)\middle|s_{\theta(ij)}\in S\right\}$, where $S=\{s_0,s_1,...,s_{t-1}\}$ is a linguistic term set and $lh(s_{\theta(ij)})$ is the membership degree. Thus, the initial decision matrix $LH=(LH_{ij})_{m\times n}$ is obtained.

Step 1. Compute the comprehensive cloud. Distinguish cost criteria and benefit criteria. Transform cost criterion $LH_{ij}=\left\{\left(s_q,lh(s_{\theta(ij)})\right)\middle|s_{\theta(ij)}\in S\right\}$ to benefit criterion $LH'_{ij}=\left\{\left(s_{(t-1)-q},lh(s_{\theta(ij)})\right)\middle|s_{\theta(ij)}\in S\right\}$, and then we get the normalized decision matrix $LH'=(LH'_{ij})_{m\times n}$. Set the valid domain $[X_{\min},X_{\max}]$ and He_3, and then use cloud $C_q(Ex_q,En_q,He_q)$ to represent linguistic term s_q, $s_q\in S$. Based on Definition 9, the comprehensive clouds $C^*_{LH_{ij}}(Ex^*_{LH_{ij}},En^*_{LH_{ij}},He^*_{LH_{ij}})$ are obtained.

Step 2. Compute the distance by (14).

$$d(LH_{ij},LH_{ik})=\frac{1}{X_{\max}-X_{\min}}\left|\left(1-\frac{(En^*_{LH_{ij}})^2+(He^*_{LH_{ij}})^2}{(En^*_{LH_{ij}})^2+(He^*_{LH_{ij}})^2+(En^*_{LH_{ik}})^2+(He^*_{LH_{ik}})^2}\right)Ex^*_{LH_{ij}}-\right.$$
$$\left.\left(1-\frac{(En^*_{LH_{ik}})^2+(He^*_{LH_{ik}})^2}{(En^*_{LH_{ij}})^2+(He^*_{LH_{ij}})^2+(En^*_{LH_{ik}})^2+(He^*_{LH_{ik}})^2}\right)Ex^*_{LH_{ik}}\right| \quad (14)$$

Step 3. Compute the support by (15).

$$Sup(LH_{ij},LH_{ik})=1-d(LH_{ij},LH_{ik}),j,k=1,2,...,n,j\neq k \quad (15)$$

Step 4. Compute the weight ω_{ij} associated with LH_{ij}. Experts give the weight ω_j of criterion x_j. Subsequently, ω_{ij} can be calculated by (16).

$$\omega_{ij}=\frac{\omega_j\left(1+\sum_{k=1,k\neq j}^{n}Sup(LH_{ij},LH_{ik})\right)}{\sum_{j=1}^{n}\omega_j\left(1+\sum_{k=1,k\neq j}^{n}Sup(LH_{ij},LH_{ik})\right)} \quad (16)$$

Step 5. Compute the fuzzy measures of criteria. The information gain set $\Delta d=(\Delta d_1,\Delta d_2,...,\Delta d_n)$ is calculated by (17).

$$\Delta d_j=\left(X_{\max}-X_{\min}\right)\times\left\{\sum_{i=1}^{m}d(C^*_{LH_{ij}}(Ex^*_{LH_{ij}},En^*_{LH_{ij}},He^*_{LH_{ij}}),C_0(Ex_0,En_0,He_0))-\right.$$
$$\left.\sum_{i=1}^{m}d(C^*_{LH_{ij}}(Ex^*_{LH_{ij}},En^*_{LH_{ij}},He^*_{LH_{ij}}),C_{t-1}(Ex_{t-1},En_{t-1},He_{t-1}))\right\} \quad (17)$$

Set the value of δ, and then calculate λ by Equation (12) and Equation (9). Subsequently, the fuzzy measures of criteria can be acquired by (8).

Step 6. Aggregate the LHFSs. Determine the sequence of the comprehensive clouds by the cloud model comparison rules in Definition 7. Subsequently, aggregate the normalized decision matrix by the LHFCI operator.

Step 7. Rank LH_i according to the expectation value, $i=1,2,...,m$.

The schematic diagram of the proposed method is shown in the appendix.

5 A case study for Jilin

5.1 Selection of criteria

The most common criteria for renewable energy evaluation involve technical, environmental, social and economic aspects. Considering the facts of renewable energy development in Jilin and some previous studies, this paper selects four primary criteria and ten secondary criteria as evaluation criteria.

Technical criterion. This criterion contains four parts: (1) Efficiency. Efficiency indicates the ratio of produced power to the input energy. (2) Availability. Availability is the ratio of power generation hours in a year to the total hours of a year. (3) Capacity. Capacity represents the ratio of generated power in a period of time to the power produced by power plant operating at full capacity during the same time. (4) Resource density. The criterion covers the ownership of resources in unit area.

Environmental criterion. With the environment problem growing in intensity, environmental awareness has enjoyed popular support nowadays. Environmental criterion considers two parts: (1) Noise pollution. (2) Air pollution.

Social criterion. Social criterion can be expressed into two aspects: (1) Social acceptance. Social acceptance reflects the agreement among social institutions. (2) Job creation. This criterion embodies direct or indirect employment and deployment services.

Economical criterion. Costs are usually the first thing that decision makers consider in power plant construction. There are two criteria in economical criterion. (1) Capital cost. Capital cost is the total expenses needed to bring a power plant to a commercially operable status. (2) Operating and maintenance cost. This criterion involves the outlays on operation and maintenance of a power plant.

5.2 Case study

According to the 13th five-year plan of renewable energy development in Jilin Province, the government needs to determine the priority of the development of renewable energy in Jilin. There are four alternatives: solar energy A_1, wind energy A_2, biomass energy A_3 and hydro energy A_4. Three experts from Economy and Technology Research Institute, State Grid and Magisterial Energy Navigator form a decision-maker group. Experts give their evaluation information by LHFSs shown in Table 2. The linguistic term set is $S = \{s_0, s_1, ..., s_6\}$, where s_6=extremely good or extremely high, s_5=very good or very high, s_4=good or high, s_3=fair or medium, s_2=bad or low, s_1=very bad or very low, s_0=extremely bad or extremely low.

Table 2. Linguistic assessment of the renewable energy alternatives based on LHFSs

Primary criteria	Secondary criteria	alternatives	Evaluation values
Technical criterion	Efficiency x_1	A_1	$\{(s_3, 0.5, 0.6), (s_4, 0.5)\}$
		A_2	$\{(s_1, 0.7), (s_2, 0.4)\}$
		A_3	$\{(s_5, 0.6, 0.7)\}$
		A_4	$\{(s_5, 0.3, 0.5, 0.6)\}$
	Availability x_2	A_1	$\{(s_3, 0.7), (s_1, 0.5)\}$
		A_2	$\{(s_2, 0.4), (s_1, 0.7)\}$
		A_3	$\{(s_4, 0.6), (s_5, 0.7)\}$
		A_4	$\{(s_4, 0.5, 0.7)\}$
	Capacity x_3	A_1	$\{(s_3, 0.6, 0.8)\}$
		A_2	$\{(s_2, 0.5, 0.7, 0.8)\}$
		A_3	$\{(s_5, 0.6), (s_6, 0.4)\}$
		A_4	$\{(s_6, 0.5), (s_5, 0.6, 0.7)\}$
	Resource density x_4	A_1	$\{(s_3, 0.7), (s_2, 0.5)\}$
		A_2	$\{(s_4, 0.7, 0.8)\}$
		A_3	$\{(s_1, 0.6), (s_2, 0.5)\}$
		A_4	$\{(s_2, 0.5, 0.8)\}$
Environmental criterion	Noise pollution x_5	A_1	$\{(s_3, 0.5), (s_4, 0.8, 0.9)\}$
		A_2	$\{(s_5, 0.6, 0.7)\}$
		A_3	$\{(s_3, 0.5, 0.6)\}$
		A_4	$\{(s_2, 0.5), (s_1, 0.6)\}$
	Air pollution x_6	A_1	$\{(s_5, 0.5, 0.7)\}$
		A_2	$\{(s_5, 0.6), (s_4, 0.5)\}$
		A_3	$\{(s_2, 0.4, 0.6, 0.7)\}$
		A_4	$\{(s_3, 0.5), (s_4, 0.7)\}$
Social criterion	Social acceptance x_7	A_1	$\{(s_3, 0.6, 0.8), (s_4, 0.6)\}$
		A_2	$\{(s_5, 0.6), (s_6, 0.5)\}$
		A_3	$\{(s_3, 0.5, 0.6)\}$

		A_4	$\{(s_3, 0.4, 0.6, 0.7)\}$
	Job creation x_8	A_1	$\{(s_4, 0.5), (s_5, 0.6)\}$
		A_2	$\{(s_4, 0.7), (s_5, 0.6), (s_6, 0.4)\}$
		A_3	$\{(s_2, 0.5, 0.6)\}$
		A_4	$\{(s_3, 0.7), (s_2, 0.5)\}$
Economical criterion	Capital cost x_9	A_1	$\{(s_3, 0.5), (s_4, 0.7)\}$
		A_2	$\{(s_4, 0.3, 0.4, 0.5, 0.6)\}$
		A_3	$\{(s_2, 0.4, 0.6)\}$
		A_4	$\{(s_2, 0.6), (s_1, 0.5)\}$
	Operating and maintenance cost x_{10}	A_1	$\{(s_5, 0.5), (s_4, 0.5, 0.7)\}$
		A_2	$\{(s_5, 0.8), (s_6, 0.5)\}$
		A_3	$\{(s_1, 0.5, 0.7)\}$
		A_4	$\{(s_2, 0.6, 0.8)\}$

Step 1. x_5, x_6, x_9 and x_{10} are cost criteria, so we transform the LHFSs of x_5, x_6, x_9 and x_{10} in Table 2, as shown in Table 3. Let the domain be [0,10] and $He_3 = 0.1$. According to Definition 8, seven clouds are calculated to represent $S = \{s_0, s_1, ..., s_6\}$. Seven clouds are: $C_0(0, 0.833, 0.424)$, $C_1(2.5, 0.515, 0.262)$, $C_2(4.045, 0.318, 0.162)$, $C_3(5, 0.197, 0.1)$, $C_4(5.955, 0.318, 0.162)$, $C_5(7.5, 0.515, 0.262)$, $C_6(10, 0.833, 0.424)$. Based on Definition 9, the comprehensive clouds $C^*_{LH_{ij}}(Ex^*_{LH_{ij}}, En^*_{LH_{ij}}, He^*_{LH_{ij}})$ are obtained, as shown in Table 4.

Table 3. The transformation of the LHFSs

Primary criteria	Secondary criteria	alternatives	Evaluation values
Environmental criterion	Noise pollution x_5	A_1	$\{(s_3, 0.5), (s_2, 0.8, 0.9)\}$
		A_2	$\{(s_1, 0.6, 0.7)\}$
		A_3	$\{(s_3, 0.5, 0.6)\}$
		A_4	$\{(s_4, 0.5), (s_5, 0.6)\}$
	Air pollution x_6	A_1	$\{(s_1, 0.5, 0.7)\}$
		A_2	$\{(s_1, 0.6), (s_2, 0.5)\}$
		A_3	$\{(s_4, 0.4, 0.6, 0.7)\}$
		A_4	$\{(s_3, 0.5), (s_2, 0.7)\}$
Economical criterion	Capital cost x_9	A_1	$\{(s_3, 0.5), (s_2, 0.7)\}$
		A_2	$\{(s_2, 0.3, 0.4, 0.5, 0.6)\}$
		A_3	$\{(s_4, 0.4, 0.6)\}$
		A_4	$\{(s_4, 0.6), (s_5, 0.5)\}$
	Operating and maintenance cost x_{10}	A_1	$\{(s_1, 0.5), (s_2, 0.5, 0.7)\}$
		A_2	$\{(s_1, 0.8), (s_0, 0.5)\}$
		A_3	$\{(s_5, 0.5, 0.7)\}$
		A_4	$\{(s_4, 0.6, 0.8)\}$

Table 4. The comprehensive cloud matrix

	A_1	A_2	A_3	A_4
x_1	(2.864,0.265,0.135)	(1.684,0.428,0.218)	(4.875,0.515,0.262)	(3.500,0.515,0.262)
x_2	(2.375,0.551,0.280)	(1.684,0.605,0.308)	(4.412,0.605,0.308)	(3.573,0.318,0.162)
x_3	(3.500,0.197,0.100)	(2.697,0.318,0.162)	(4.250,0.979,0.498)	(4.938,0.979,0.498)
x_4	(2.761,0.374,0.190)	(4.466,0.318,0.162)	(1.761,0.605,0.308)	(2.629,0.318,0.162)

x_5	(3.781,0.374,0.190)	(4.875,0.515,0.262)	(2.750,0.197,0.100)	(1.761,0.605,0.308)
x_6	(4.500,0.515.0.262)	(3.739,0.605,0.308)	(2.292,0.318,0.162)	(3.334,0.374,0.190)
x_7	(3.537,0.265,0.135)	(4.750,0.693,0.352)	(2.750,0.197,0.100)	(2.833,0.197,0.100)
x_8	(3.739,0.428,0.218)	(4.223,0.594,0.303)	(2.225,0.318,0.162)	(2.761,0.265,0.135)
x_9	(3.334,0.374,0.190)	(2.680,0.318,0.162)	(2.023,0.318,0.162)	(1.839,0.605,0.308)
x_{10}	(3.662,0.605,0.308)	(5.500,0.979,0.498)	(1.500,0.515,0.262)	(2.832,0.318,0.162)

Step 2. Calculate the distance by (14).

Step 3. Calculate the support by (15).

Step 4. Experts give the weight vector of criteria ω=(0.05627, 0.0602, 0.0711, 0.0363, 0.1237, 0.09318, 0.07624, 0.11488, 0.18175, 0.1862). Based on (16), we get $(\omega_{ij})_{4\times10}$ associated with $(LH_{ij})_{4\times10}$.

$$\omega_{ij}=\begin{pmatrix} 0.057 & 0.058 & 0.066 & 0.038 & 0.125 & 0.095 & 0.075 & 0.117 & 0.189 & 0.182 \\ 0.059 & 0.059 & 0.072 & 0.033 & 0.122 & 0.096 & 0.078 & 0.117 & 0.185 & 0.179 \\ 0.056 & 0.060 & 0.068 & 0.036 & 0.118 & 0.096 & 0.073 & 0.119 & 0.189 & 0.186 \\ 0.056 & 0.060 & 0.068 & 0.038 & 0.121 & 0.095 & 0.073 & 0.117 & 0.179 & 0.192 \end{pmatrix}$$

Step 5. Drawing the experience from [35], set $\delta=0.5$. Then, we obtain the measure densities by (12): $g_1=0.50042$, $g_2=0.50027$, $g_3=0.50084$, $g_4=0.50067$, $g_5=0.5008$, $g_6=0.50014$, $g_7=0.50058$, $g_8=0.50026$, $g_9=0.50126$, $g_{10}=0.50161$. Parameter $\lambda=-1$ is calculated by (9). Subsequently, we obtain the fuzzy measures by (8): $g\left(\{x_1,x_2\}\right)=0.75034$, $g\left(\{x_1,x_3\}\right)=0.75063$,…, $g\left(\{x_1,x_2,x_3\}\right)=0.87538$,…, $g\left(\{x_1,x_2,x_3,x_4\}\right)=0.93777$,…, $g\left(\{x_1,x_2,...,x_{10}\}\right)=1$.

Step 6. By Definition 7, we calculate $\overline{CD}\left(C^*_{LH_{1j}}\right)$ and then rank them. The ranking result is $\overline{CD}\left(C^*_{LH_{16}}\right)>\overline{CD}\left(C^*_{LH_{15}}\right)>\overline{CD}\left(C^*_{LH_{18}}\right)>\overline{CD}\left(C^*_{LH_{110}}\right)>\overline{CD}\left(C^*_{LH_{17}}\right)>\overline{CD}\left(C^*_{LH_{13}}\right)>\overline{CD}\left(C^*_{LH_{19}}\right)>$ $\overline{CD}\left(C^*_{LH_{11}}\right)>\overline{CD}\left(C^*_{LH_{14}}\right)>\overline{CD}\left(C^*_{LH_{12}}\right)$, so we get $\sigma(1)=6$, $\sigma(2)=5$, $\sigma(3)=8$, $\sigma(4)=10$, $\sigma(5)=7$, $\sigma(6)=3$, $\sigma(7)=9$, $\sigma(8)=1$, $\sigma(9)=4$, $\sigma(10)=2$,

$g\left(A_{\sigma(1)}\right)-g\left(A_{\sigma(0)}\right)=g\left(\{x_6\}\right)-g(\varnothing)=0.50014$, $g\left(A_{\sigma(2)}\right)-g\left(A_{\sigma(1)}\right)=g\left(\{x_6,x_5\}\right)-g\left(\{x_6\}\right)=0.25033$,

$g\left(A_{\sigma(3)}\right)-g\left(A_{\sigma(2)}\right)=g\left(\{x_6,x_5,x_8\}\right)-g\left(\{x_6,x_5\}\right)=0.12483$,

$g\left(A_{\sigma(4)}\right)-g\left(A_{\sigma(3)}\right)=g\left(\{x_6,x_5,x_8,x_{10}\}\right)-g\left(\{x_6,x_5,x_8\}\right)=0.06255$,

$g\left(A_{\sigma(5)}\right)-g\left(A_{\sigma(4)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7\}\right)-g\left(\{x_6,x_5,x_8,x_{10}\}\right)=0.03111$,

$g\left(A_{\sigma(6)}\right)-g\left(A_{\sigma(5)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3\}\right)-g\left(\{x_6,x_5,x_8,x_{10},x_7\}\right)=0.01555$,

$g\left(A_{\sigma(7)}\right)-g\left(A_{\sigma(6)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9\}\right)-g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3\}\right)=0.00777$,

$g\left(A_{\sigma(8)}\right)-g\left(A_{\sigma(7)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9,x_1\}\right)-g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9\}\right)=0.00387$,

$g\left(A_{\sigma(9)}\right)-g\left(A_{\sigma(8)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9,x_1,x_4\}\right)-g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9,x_1\}\right)=0.00193$,

$g\left(A_{\sigma(10)}\right)-g\left(A_{\sigma(9)}\right)=g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9,x_1,x_4,x_2\}\right)-g\left(\{x_6,x_5,x_8,x_{10},x_7,x_3,x_9,x_1,x_4\}\right)=0.00096.$

Then, we obtain LH_1, LH_2, LH_3 and LH_4 by the LHFCI operator.

Step 7. Calculate the expectation value of LH_i according to Definition 3. $E(LH_1)=s_{1.6245}$, $E(LH_2)=s_{1.8245}$, $E(LH_3)=s_{2.1638}$, $E(LH_4)=s_{1.7623}$. Thus, $A_3\succ A_2\succ A_4\succ A_1$. The best energy alternative for Jilin is biomass energy, followed by wind energy, hydro energy, and solar energy.

5.3 Discussion

The result shows that biomass energy is the most appropriate renewable energy. But now in Jilin, wind energy is still the main resource of power generation. From 2006, the wind power installed capacity has increased by 26 times, while the load has increased by only 1.5 times. The proportion of wind power in direct scheduling installed capacity rose from 2.7% to current 23.25%. The discrepancy between the growth of wind power supply and the growth of load put pressure on wind power consumption. The wind curtailment problem of wind power industry in Jilin Province was serious, ranked fourth in the country. The amount of abandoned wind power per month achieved 2.7 billion KWh; the wind curtailment rate ran up to 32%; the annual average utilization hours of wind turbine were only 1610 hours, the fewest in the country. The main reason for this phenomenon is the slow development of industrial economy in Jilin Province, whose power demand cannot keep pace with power supply so that oversupply occurred. So in the future energy planning, wind energy cannot maintain vigorous development.

Although hydro energy developed well in some regions of China, there are some limitations in Jilin. During the 11th five-year plan and the 12th five-year plan, a number of small hydroelectric projects have completed. However, there exist two problems in the development of small hydropower stations. One is low electricity price. Some small hydropower stations operate with the 0.28 yuan/kwh standard, which cannot ensure benefits and normal operation. The other are limitations on connecting to grid, operation and management. The connection formalities are difficult to go through. Because of the limitation on power generation in the wet season, the small hydropower units have few utilization hours and cannot fully create investment benefits.

As for solar energy, although the price of polycrystalline silicon materials has fallen significantly, its costs are still much higher than those of conventional energy so that it is difficult to expand the scale of development and compete with conventional energy in the short term. Therefore, photovoltaic power generation is still in its infancy. At this stage, the state gives priority to develop areas with abundant solar energy resources. The solar energy resources are not ample enough in Jilin so that the development of photovoltaic power generation in Jilin is slow without the cost advantage of large-scale development. Simultaneously, Jilin has not yet formulated policies on land or electricity price subsidies to encourage photovoltaic power generation, which limits the market demand and extensive application of photovoltaic power generation.

5.4 Managerial implications

To develop renewable energy in Jilin, we give the following managerial implications[36]:

(1) Jilin should develop energy management system and operation mechanism that are adequate for renewable energy development. It is important to keep energy market open and competitive, which is helpful to accelerate the reform of electricity market. Jilin has large amounts of wind energy surplus, so it is necessary to strengthen the management of electricity demand and build a new management style to deal with the dynamic and adjustable electricity load associated with stochastic power.

(2) Jilin should plan a long term energy price and tax policy. Renewable energy wants to stay competitive in the market, the encouraging pricing and taxation mechanism needs to be improved. To develop renewable energy on a large scale, a long term supporting system for pricing mechanism which considers environment cost should be established.

(3) Jilin must improve the technical innovation for renewable energy, including the development of low-speed turbine (4.5–5.5 m/s), energy storage technology, wind-solar hybrid power supply system, intelligent electric grid, the improvement of PV efficiency and the evaluation of wind resources at different scales[36].

(4) Jilin should expand the funding sources and enhance the efficiency of fund management for renewable energy. The government of Jilin needs to invest for renewable energy research institute and infrastructure in the short run. In the medium term, the electricity price of renewable energy should be regulated and controlled by government in order to encourage the utilization of renewable energy. In the long term, the government can broaden funding sources to ensure sufficient funds for renewable energy development by using a proportion of environmental and carbon taxes[36].

In addition, renewable energy administration is governed by many executive departments in China. Lack of communication, low efficiency and conflicts of interests among some governmental departments are unavoidable. For these problems, the local government can integrate administrative power and coordinate these departments to promote the development of renewable energy.

5.5 Validation of the proposed model

There are three criteria to verify the validity of decision-making methods[37].

Criterion 1. When a non-optimal alternative is displaced by another worse alternative under the premise of not changing the relative importance of each decision criterion, the best alternative remains unchanged.

Criterion 2. Let A , B and C be three alternatives. If $A \succ B$ and $B \succ C$, then $A \succ B \succ C$. Namely, the sequence of the alternatives is transitive.

Criterion 3. When the original MCDM problem is split into several sub-problems, the combined result of sub-problems is identical to the result of the original MCDM problem.

To test Criterion 1, we modify $LH_{ij} = \left\{ \left(s_{\theta(ij)}, lh(s_{\theta(ij)}) \right) \middle| s_{\theta(ij)} \in S \right\}$ of A_1 (non-optimal alternative) in Table 1 to $LH_{ij} = \left\{ \left(s_{\theta(ij)}, lh(s_{\theta(ij)}) - 0.3 \right) \middle| s_{\theta(ij)} \in S \right\}$. Following the steps in the paper, we obtain the ranking result $A_3 \succ A_2 \succ A_4 \succ A_1$. The best alternative is still A_3, which confirms the proposed method is valid under Criterion 1.

To test Criterion 2 and Criterion 3, we decompose the initial alternative set into two smaller sets $\{A_1, A_2, A_3\}$ and $\{A_1, A_2, A_4\}$. Following the steps in the paper, we obtain the ranking results $A_3 \succ A_2 \succ A_1$ and $A_2 \succ A_4 \succ A_1$. After combining of the two ranking results, we get the final ranking $A_3 \succ A_2 \succ A_4 \succ A_1$ which is the same as the original result. Hence the proposed method is valid under Criterion 2 and Criterion 3.

5.6 Comparison with other methods

In order to show the differences between LHFCI operator and others, we use other operators to repeat the case study. The results are shown in Table 5. When we use fuzzy power weighted average (FPWA) operator or fuzzy power weighted geometric (FPWG) operator, the best alternative is identical to LHFCI operator, which reflects the validity of LHFCI operator. FPWA operator and FPWG operator aggregate criteria based on weights, which repeatedly consider the overlapping information among criteria. For example, social criterion has a strong correlation relationship with environmental criterion. Social acceptance will be high if a renewable energy alternative causes less pollution. However, LHFCI operator can eliminate the interdependency among criteria during the aggregation. Thus, LHFCI operator in this paper is a better choice for renewable energy evaluation. Some authors put forward the conversion of linguistic terms into trapezoidal fuzzy numbers.

Fan and Liu gave the corresponding function of linguistic terms and trapezoidal fuzzy numbers. The result calculated by Fan and Liu's method differs from that of this paper. The reason is that cloud model and trapezoidal fuzzy numbers reflect different things. Trapezoidal fuzzy numbers focus on the average in criteria, while cloud model has three parameters which represent the average, the fuzziness and the randomness. Therefore, linguistic terms can be more clearly delineated by cloud model than by trapezoidal fuzzy numbers.

Gitinavard proposed a compromise ranking MCDM method with interval-valued hesitant fuzzy sets. When using Gitinavard's model in this paper, we have to change our evaluation. Firstly, three decision makers must give three groups of evaluation information. So we extend the shorter information in Table 2. Secondly, we delete the membership degrees of all linguistic terms. For example, the first row should be "$\{(s_3),(s_4),(s_3)\}$" instead of "$\{(s_3,0.5,0.6),(s_4,0.5)\}$". After the modification, we obtain $A_4 \succ A_3 \succ A_2 \succ A_1$. The difference is mainly because of the modification of the initial data. Extending the shorter data is a common method when dealing with the hesitant information, but it has effects on the results which is the main disadvantage of ordinary MCDM methods.

In summary, LHFCI operator and cloud model are more suitable for renewable energy evaluation. So the method based on LHFCI operator and cloud model is an improvement for the former MCDM methods.

Table 5. The comparison results

method	Ranking result
This paper	$A_3 \succ A_2 \succ A_4 \succ A_1$
FPWA operator[38]	$A_3 \succ A_2 \succ A_1 \succ A_4$
FPWG operator[39]	$A_3 \succ A_2 \succ A_1 \succ A_4$
Fan and Liu's method[40]	$A_2 \succ A_3 \succ A_4 \succ A_1$
Gitinavard's method[41]	$A_4 \succ A_3 \succ A_2 \succ A_1$

5.7 Sensitivity analysis

The weights of criteria in this paper are given by experts. So we make a sensitivity analysis by varying the weights and observe the ranking result. We set six cases to change the weights. Case 1 is the weights in this paper. We find that the largest weight is x_{10}, and then we change weight of x_{10} from 0.1862 to 0 in Case 2. Other weights are changed proportionally. For example, weight of x_1 is computed as $0.0563+\frac{0.0563}{1\text{-}0.1862}\times(0.1862\text{-}0 \ =0.0691$. The other weights are computed in the same way in Table 6. The sensitivity ranking result is shown in Fig. 5. We observe that the ranking results are changed with different weights, which indicates that the proposed method is sensitive to the variation of weights. In Case 2, wind energy is the most appropriate alternative. In Case 6, hydro energy instead of solar energy becomes the last choice. In addition, wind energy and biomass energy are the most appropriate alternative among different cases.

Table 6. Weights of criteria

case	1	2	3	4	5	6
x_1	0.0563	0.0691	0.0519	0.0346	0.0173	0
x_2	0.0602	0.0740	0.0555	0.0370	0.0185	0
x_3	0.0711	0.0874	0.0655	0.0437	0.0218	0
x_4	0.0363	0.0446	0.0335	0.0223	0.0112	0
x_5	0.1237	0.1520	0.1140	0.0760	0.0380	0
x_6	0.0932	0.1145	0.0859	0.0572	0.0286	0
x_7	0.0762	0.0937	0.0703	0.0468	0.0234	0
x_8	0.1149	0.1412	0.1059	0.0706	0.0353	0
x_9	0.1818	0.2233	0.1675	0.1117	0.0558	0

x_{10}	0.1862	0.0000	0.2500	0.5000	0.7500	1

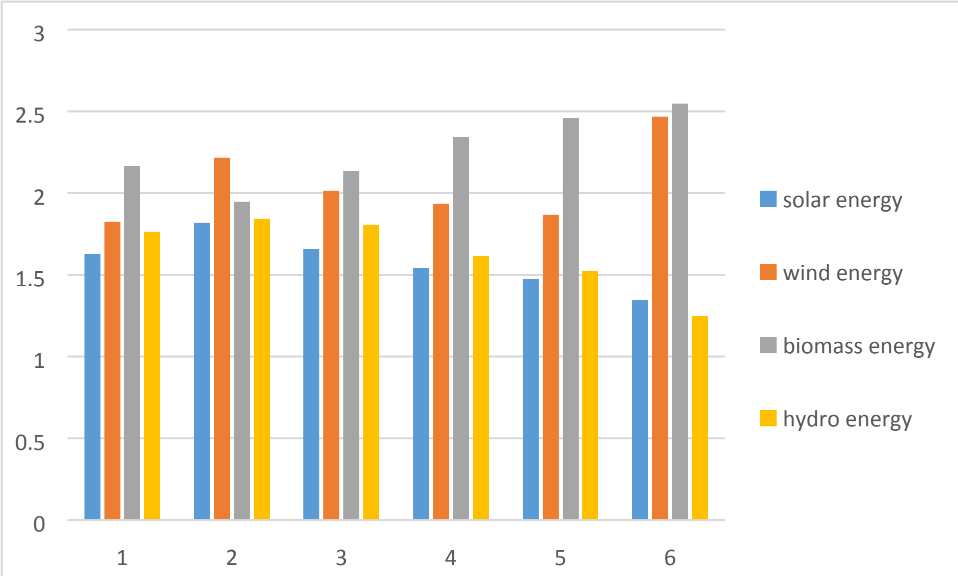


Fig. 5. Ranking of renewable energy when weights are changed

6 Conclusion

According to Jilin's five-year plan, renewable energy development is an important issue for government. The selection of renewable energy can be regarded as an MCDM problem. This paper presents an MCDM method with linguistic hesitant fuzzy sets, which combines hesitant fuzzy sets with linguistic fuzzy sets to express the complexity of uncertain environment and the vagueness of human cognition. The proposed approach uses cloud model to handle the randomness and fuzziness from the subjective judgments of experts and defines an improved Choquet integral operator to aggregate LHFSs in consideration of the interdependency of criteria.

In terms of Jilin, the most suitable renewable energy is biomass energy, followed by wind energy, hydro energy and solar energy. Subsequently, we adopt three criteria to test the method and compare the method with other methods, verifying the validity and superiority of the proposed method.

The main contributions of this paper are:

(1) It introduces LHFS to express the evaluation information of renewable energy MCDM problem, which is the first application of LHFS in renewable energy selection.

(2) It defines an improved Choquet integral operator to aggregate LHFSs. Based on the defined operator and cloud model, a new MCDM method with universality is proposed, which can be applied to not only renewable energy selection problem but also other MCDM problems.

(3) It uses the concept of comprehensive cloud instead of the deviation of decision results by extending the shorter LHFS.

(4) It adopts the proposed approach to deal with real problem and finds the best renewable energy alternative for Jilin, linking up theory with practice.

Please note that the ranking result does not mean that decision makers can omit the renewable energy with low-ranking, especially in long term energy planning. The ranking result just demonstrates the relative significance of each energy versus other energy options and more regard for the front energies when the energy department making short term energy planning. In future research, we will consider more criteria during the decision-making process, including season, duration of day and geographic region. In addition, we can obtain results according to different scenarios.

Acknowledgement The authors would like to acknowledge the supports from National Natural Science Foundation of China (No. 71271084, No. 71671065), the Fundamental Research Funds for Central Universities (2016XS74) and the technology project of State Grid (5204BB1600CN).
Declaration The authors declare that there is no conflict of interests regarding the publication of this manuscript.

Reference

[1] Y. Celikbilek and F. Tuysuz, "An integrated grey based multi-criteria decision making approach for the evaluation of renewable energy sources," *Energy*, vol. 115, pp. 1246–1258, 2016.

[2] L. Zhang, P. Zhou, S. Newton, J. Fang, D. Zhou, and L. Zhang, "Evaluating clean energy alternatives for Jiangsu, China: An improved multi-criteria decision making method," *Energy*, vol. 90, no. 1, pp. 953–964, 2015.

[3] E. Georgopoulou , D. Lalas, L. Papagiannakis."A multicriteria decision aid approach for energy planning problems: The case of renewable energy option". European Journal of Operational Research. vol. 103, no. 1, pp. 38-54, 1997.

[4] M.E. Arce, Á. Saavedra, J. L. Míguez, E. Granada. "The use of grey-based methods in multi-criteria decision analysis for the evaluation of sustainable energy systems: A review". *Renewable and Sustainable Energy Reviews*. vol. 47, pp. 924-932, 2015.

[5] R.P. Hamalainen and R. Karjalainen."Decision support for risk analysis in energy policy". *European Journal of Operational Research*, vol.56, no.2, pp.172-183, 1992.

[6] M. Goumas and V. Lygerou. "An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects" *European Journal of Operational Research*, vol. 123, no.3, pp. 606-613. 2000.

[7] M.Beccali, M.Cellura and M.Mistretta. "Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology", *Renewable Energy*, vol. 28, no. 13, pp.2063-2087. 2003.

[8] H. Polatidis and D. Haralambopoulos. "Local Renewable Energy Planning: A Participatory Multi-Criteria Approach", *Energy Sources*, vol. 26, no.13, pp.1253-1264. 2004.

[9] L. Suganthi, S. Iniyan, and A. Samuel, "Applications of fuzzy logic in renewable energy systems – A review," *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 585–607, 2015.

[10] C. Kahraman, İ. Kaya, and S. Cebi, "A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process," *Energy*, vol. 34, no. 10, pp. 1603–1616, 2009.

[11] F. Cavallaro, "Assessment of Nuclear Energy Competiveness Using a Multi-Criteria Fuzzy Approach," *International Journal of Energy Optimization and Engineering*, vol. 2, no. 1, pp. 21–36, 2013.

[12] Oz. Erol and B. Kikis, "An energy source policy assessment using analytical hierarchy process," *Energy Conversion and Management*, vol. 63, pp. 245–252, 2012.

[13] A. Yazdni-Chamzini, M. Fouladgar, E. Zavadskas, and S. Moini, "Selecting the optimal renewable energy using multi criteria decision making," *Journal of Business Economics and Management*, vol. 14, no. 5, pp. 957–978, 2013.

[14] J.H. Yuan, C.B. Li, F.Q. Xu, B.J. Sun and W.L. Li. "A group decision making approach in interval-valued

intuitionistic hesitant fuzzy environment with confidence levels". *Journal of Intelligent and Fuzzy Systems*. vol. 31, no.3, pp. 1909-1919. 2016.

[15] C.B. Li, J.H Yuan. "A new multi-attribute decision-making method with three-parameter interval grey linguistic variable". *International Journal of Fuzzy Systems*. vol.19, no.2, pp.292-300, 2017.

[16] T. Kaya and C. Kahraman, "Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology," *Expert Systems with Applications*, vol. 38, no. 6, pp. 6577–6585, 2011.

[17] U. Sengui, M. Eren, S. Shiraz, V. Gezder, and A. Sengul, "Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey," *Renewable Energy*, vol. 75, pp. 617–625, 2015.

[18] M. Erdogan and I. Kaya, "An integrated multi-criteria decision-making methodology based on type-2 fuzzy sets for selection among energy alternatives in Turkey," *Iranian Journal of Fuzzy Systems*, vol. 12, no. 1, pp. 1–25, 2015.

[19] G. Egilmez, S. Gumus, and M. Kucukvar, "Environmental sustainability benchmarking of the U.S. and Canada metropoles: An expert judgment-based multi-criteria decision making approach," *Cities*, vol. 42, pp. 31–41, 2015.

[20] H. Doukas, A. Tsiousi, V. Marinakis, and J. Psarras, "Linguistic multi-criteria decision making for energy and environmental corporate policy," *Information Sciences*, vol. 258, no. 10, pp. 328–338, 2014.

[21] M. Mousavi and R. Tavakkoli-Moghaddam, "Group Decision Making based on a New Evaluation Method and Hesitant Fuzzy Setting with an Application to an Energy Planning Problem," *International Journal of Engineering*, vol. 28, no. 9, pp. 1303–1311, 2015.

[22] Z. Xu and X. Zhang, "Hesitant fuzzy multi-attribute decision making based on TOPSIS with incomplete weight information," *Knowledge-Based Systems*, vol. 52, pp. 53–64, 2013.

[23] S. Onar, B. Oztaysi, irem Otay, and C. Kahraman, "Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets," *Energy*, vol. 90, no. 1, pp. 274–285, 2015.

[24] H. Yao and W. Li, "A new assessment method of new energy in regional sustainable development based on hesitant fuzzy information," *Journal of Industrial Engineering and Management*, vol. 7, no. 5, pp. 1334–1346, 2014.

[25] F. Meng, X. Chen, and Q. Zhang, "Multi-attribute decision analysis under a linguistic hesitant fuzzy environment," *Information Sciences*, vol. 267, pp. 287–305, 2014.

[26] J. Wang, P. Lu, H. Zhang, and X. Chen, "Method of multi-criteria group decision-making based on cloud aggregation operators with linguistic information," *Information Sciences*, vol. 274, pp. 177–191, 2014.

[27] M. Grabisch and C. Labreuche, "A decade of application of the Choquet and Sugeno integrals in multi-criteria decision aid," *A Quarterly Journal of Operations Research*, vol. 6, no. 1, pp. 1–44, 2008.

[28] D. Li, C. Liu, and W. Gan, "A new cognitive model: Cloud model," *International Journal of Intelligent Systems*, vol. 24, pp. 357–375, 2009.

[29] D. Li, H. Meng, and X. Shi, "Membership cloud and membership cloud generators," *Journal of Computer Research & Development*, vol. 32, no. 6, pp. 16–21, 1995.

[30] J. Wang, L. Peng, H. Zhang, and X. Chen, "Method of multi-criteria group decision-making based on cloud aggregation operators with linguistic information," *Information Sciences*, vol. 274, pp. 177–191, 2014.

[31] J. Wang and T. Liu, "Uncertain linguistic multi-criteria group decision-making approach based on integrated cloud," *Control and Decision*, vol. 27, no. 8, pp. 1185–1190, 2012.

[32] J. Wang and W. Yang, "Multiple criteria group decision making method based on intuitionistic normal cloud by Monte Carlo simulation," *System Engineering Theory and Practice*, vol. 33, no. 11, pp. 2859–2865, 2013.

[33] H. L. Wang and Y. Q. Feng, "On multiple attribute group decision making with linguistic assessment information based on cloud model," *Control and Decision*, vol. 20, no. 6, p. 679–681+685, 2009.

[34] C. Zhu, L. Zhu, and X. Zhang, "Linguistic hesitant fuzzy power aggregation operators and their applications in multiple attribute decision-making," *Information Sciences*, vol. 367–368, pp. 809–826, 2016.

[35] Z. Chang and L. Cheng, "Multi-Attribute Decision Making Method based on Mahalanobis-Taguchi System and fuzzy integral," *Journal of Industrial Engineering/Engineering Management*, vol. 29, no. 3, pp. 107–115, 2015.

[36] X.J. Yang, H.J. Hu, T.W. Tan and J.Y. Li. "China's renewable energy goals by 2050". *Environmental Development*. Vol. 20, p.83-90. 2016

[37] J. Yuan and C. Li, "A New Method for Multi-Attribute Decision Making with Intuitionistic Trapezoidal Fuzzy Random Variable," *International journal of fuzzy systems*, vol. 19, no. 1, pp. 15–26. 2017.

[38] R. R. Yager, "The power average operator," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 31, pp. 724–731, 2001.

[39] Z. Xu and R. R. Yager, "Power-geometric operators and their use in group decision making," *IEEE Transactions on Fuzzy Systems*, vol. 18, no. 1, pp. 94–105, 2010.

[40] Z. Fan and Y. Liu, "A method for group decision-making based on multi-granularity uncertain linguistic information," *Expert Systems with Applications*, vol. 37, no. 5, pp. 4000–4008, 2010.

[41] H. Gitinavard, S.M. Mousavi and B. Vahdani. "Soft computing based on hierarchical evaluation approach and criteria interdependencies for energy decision-making problems: A case study," *Energy*, vol.118, no. 1, pp. 556-577. 2017.

Appendix

Nomenclature

Linguistic hesitant fuzzy set (LHFS)

linguistic term set $S=\{s_0,s_1,...,s_{t-1}\}$

Linguistic hesitant fuzzy set $LH=\left\{\left(s_{\theta(i)},lh(s_{\theta(i)})\right)\middle|s_{\theta(i)}\in S\right\}$

the expectation function of LHFS $E(LH)=s_{e(LH)}$

the variance function of LHFS $D(LH)=s_{v(LH)}$

Cloud model

U a quantitative domain
T a qualitative concept on U
$x(x\in U)$ a random instantiation
expectation Ex, entropy En and hyper entropy He
(x,y) the cloud drop

$CD=xy$ the score function of a cloud drop (x,y)

$\overline{CD}$ expected value
$C^*_{LH}(Ex^*_{LH},En^*_{LH},He^*_{LH})$ the comprehensive cloud of LH
$d(LH_1,LH_2)$ the distance between LH_1 and LH_2

Fuzzy measure

$X=\{x_1,x_2,...,x_n\}$ a finite set

g the fuzzy measure

Choquet integral

f Choquet integral
$g_j=\dfrac{1}{1+e^{-\delta\Delta d_j}}$ the measure density transformation function
$\delta\in(0,+\infty)$ the adjustment coefficient of the measure density transformation function
$LHFCI(LH_{i1},LH_{i2},...,LH_{in})$ linguistic hesitant fuzzy Choquet integral (LHFCI) operator

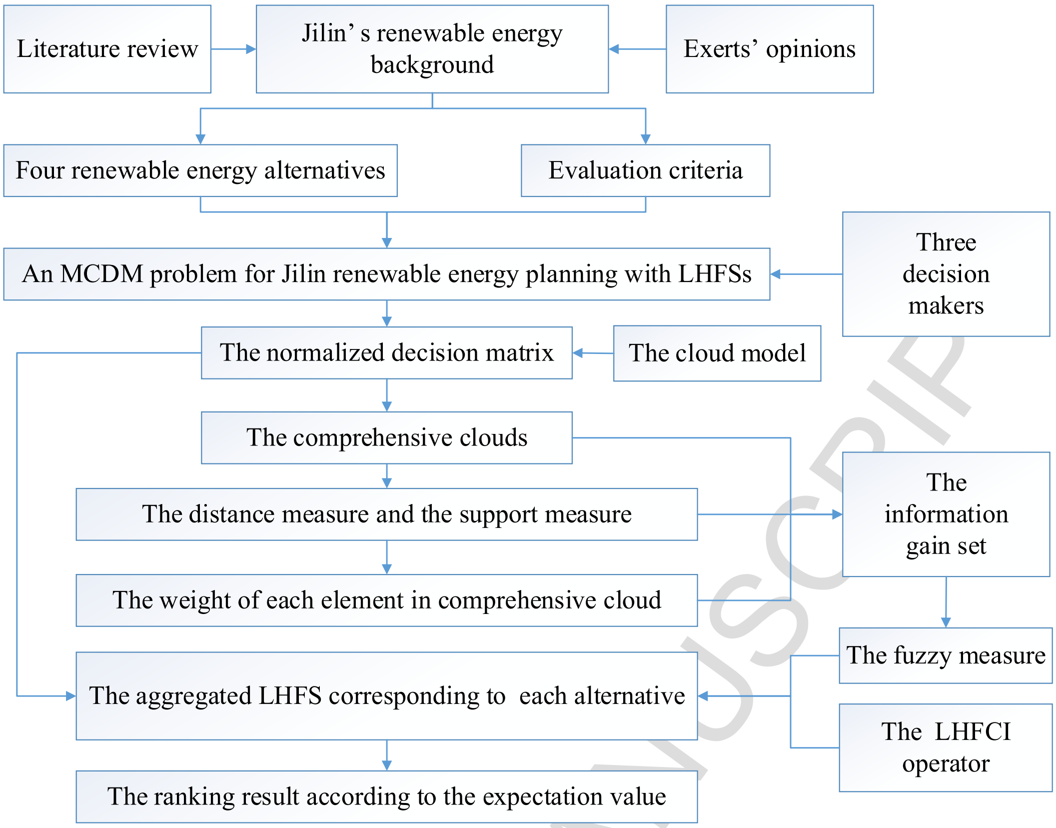


Fig. 6. The schematic diagram of the proposed method