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Research on Comprehensive Evaluation of CCS Project Based on Integrated Cloud Model and Entropy Weight

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Abstract: To overcome the uncertainty of the weights and the assessment matrix, which are adopted by fuzzy comprehensive method, the entropy weight with objectivity is used to determine the weight in this paper. And the accurate assessment matrix are built using the fuzziness and randomness of comprehensive cloud model. Then the risk comprehensive assessment model of CCS project is established. So qualitative and quantitative assessment can be realized simultaneously combining with the characteristics of the project. To validate the risk degree of the project, an test example, which is composed of a group of index data provided by experts, is presented. The assessment results show that the risk level of investment project is higher and tends to the general level. And the results of comparative analysis show that the method is more accurate and close to the fact than the traditional fuzzy comprehensive method.

Keywords: CCS; Cloud model; Integrated Cloud; Entropy weight

1 Introduction

Fuzzy Comprehensive Evaluation is one of the most widely used method. Using the principle of maximum membership degree, the uncertainty is quantified by the mathematics formula and the reasonable comprehensive evaluation about the indexes can be obtained. In other words, Fuzzy Comprehensive Evaluation adopts accurate membership degree function to represent those fuzzy concepts. Based on the fact that the fuzzy nature of things will be eliminated by precise mathematics processing, the concept of cloud is presented [1]. Depending on the concept of cloud, the conversion between qualitative description and quantitative representation were realized and the correlation between the fuzziness and randomness was considered too. Now the cloud theory has been widely used in the evaluation and assessment system. Lv Hui-junet al firstly used the cloud theory in the assessment decision, which created a precedent for the application of cloud model[2].

The technology of CO_2 capture and storage (CCS) is one of the most effective way to implement the low-carbon economy and solve the greenhouse effect[3]. For the evaluation of CCS, Olafr Røsnes[4] et al. put forward the method of value chain. It provide the decision foundation for the decision maker to comprehensive analyses the project and the process of value creation. From the point of view of risk factors, including technology, society, policy, safety and economic, M.Gerstenberger[5]et al. put forward the logic tree risk assessment method to assign probabilities for each of the four main components of the CCS process (i.e., capture, transport, injection and storage) and carried out the assessment decision. Aiming at the problem of geological reservoir of CO_2, Debbie Polson et al. [6]describes a risk assessment method of geological reservoir assessment based on the Features, Events and Processes(FEPs) of a project-specific. Zhu lei et al. [7] established an investment assessment model of carbon capture and storage (CCS) based on real options theory. In this model, some uncertain factors, including the generating cost of thermal power, carbon price, the generating cost of thermal power with CCS, and the deployment investment in CCS technology, are considered. In general there are few scientific, objective and convenient risk assessment methods of project layer.

In this paper, we adopt the fuzzy comprehensive method to determine the risk assessment and Use the entropy weight to determine the index weight. By building the comprehensive cloud model to determine the evaluation matrix, the problem of the fuzziness and randomness of CCS project risk assessment is solved.

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2 Cloud Model

2.1 Cloud Theory

The concept of cloud model was put forward in the paper [1] .and the universality of the model was proved in the paper [8]. As the paper pointed out that the model has better applicability, and is the process of the conversion between qualitative description and quantitative representation become simpler.

Cloud model is defined as: Assuming that U is a quantitative universe described by accurate numerical value, C is the qualitative concept in the U domain, if $x \in U$ and x is a random implementation of C, $\mu(x) \in [0,1]$ is the certainty degree of x is a random number with stable tendency. If $\begin{array}{l}\mu : U- > [0,1] \\ x \in U, x- > \mu(x)\end{array}$, then the distribution of x in domain U is called cloud, and each x is called cloud droplet.

The expected value (*Ex*), entropy (*En*) and hyper entropy (*He*) are the numerical characteristics of cloud model ,they integrate the fuzziness and randomness and form the mapping between qualitative and quantitative. The *Ex* is the representative point of the qualitative concept. The E_n is the measure of the uncertainty of the qualitative concept, and is determined by randomness and fuzziness of the qualitative concept. The E_n is bigger, the range of cloud droplet is greater, and it means that the concept of qualitative become more fuzzy. The *He* is the measurement of uncertainty about entropy. It reflects the uncertainty cohesion of all points which are used to on behalf of the value of qualitative concept in the domain. Its value indirectly reflects the thickness of the cloud.

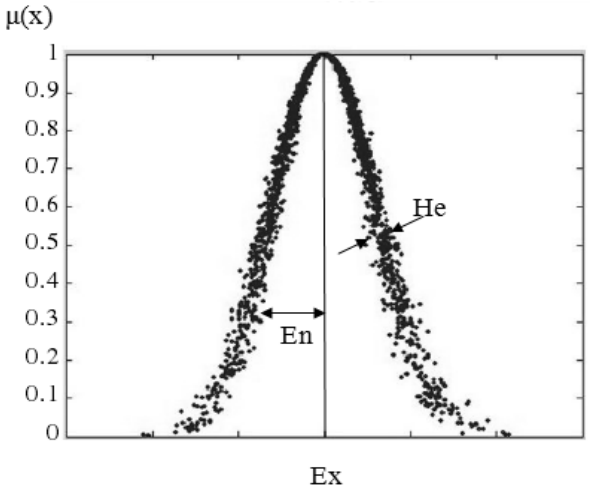

Figure 1: Cloud and its numerical characteristics.

2.2 Integrated cloud

Under the same domain, there may be two or more same type cloud. They are gathered and the floating clouds are generated. Its essence is that the multiple qualitative concepts are combined as a more general concept[9]. In paper [10], various comprehensive characteristics and digital features of Integrated Cloud are presented. It means that several qualitative variables can be expressed in a comprehensive cloud

In order to describe the assessment matrix by using digital features of Integrated Cloud, we need to use a cloud, denoted asE_x,E_n,H_e, to describe the relationships between all the scores of each index value and the comment level in the comment set. All clouds are conceptually "Both A and B", combining these clouds to generate the Integrated Cloud. In view of this feature, the following formula shows the digital characteristics of the Integrated Cloud:

$$\left\{\begin{array}{l} \mathrm{E}_x = (E_{x1} \times E_{n1} + E_{x2} \times E_{n2} + ... + E_{xn} \times E_{nn})/(E_{n1} + E_{n2} + ... + E_{nn}) \\ E_n = E_{n1} + E_{n2} + ... + E_{nn})/n \\ H_e = (H_{e1} \times E_{n1} + H_{e2} \times E_{n2} + ... + H_{en} \times E_{nn})/(E_{n1} + E_{n2} + ... + E_{nn}) \end{array}\right. \quad (1)$$

3 Entropy weight method

For an assessment system, weight is the key factors to affect the assessment results. Its accuracy will directly affect the final evaluation conclusions. Entropy weight method is a way to quantify and aggregate the information of each index which will be evaluated. In this paper, we use the entropy weight method to determine the weights. Then the value of the index weight can be more objectively reflected. According to the difference degree of evaluation value of each index, we can calculate the weights of each index by using the information entropy. The following is the calculation steps:

(1)Establish the index assessment matrix and normalize the matrix by the principle of the bigger the optimal type, then following matrix can be obtained$X = \begin{bmatrix} X_{11}, X_{12}, ..., X_{1n} \\ X_{21}, X_{22}, ..., X_{2n} \\ ... \\ X_{m1}, X_{m2}, ..., X_{mn} \end{bmatrix}$

(2)Calculate the proportion $P_{ij}$of the *jth* evaluation value of the *i th* factor according to$P_{ij} = \frac{x_{ij}}{\sum\limits_{j=1}^{m} x_{ij}}$;

(3)Calculate the entropy value e_i of the *i th* factor according to $e_i = -\frac{1}{\ln m} \sum\limits_{j=1}^{m} P_{ij} \ln P_{ij}$where $0 \leq e_i \leq 1$;

(4)Calculate difference coefficient f_i of the *i th* factor *where* $f_i = 1 - e_i$ and the value determines the importance of the factor f_i.

(5)Define the weight ω_{ij} according to $\omega_{ij} = \frac{f_i}{\sum\limits_{j=1}^{m} f_i}$, where ω_i is the weight by using entropy weight method.

4 The fuzzy comprehensive assessment model based on cloud model

For the evaluation system, the weight is the key factors to affect the assessment results, its accuracy will directly affect the final assessment conclusion. Weight has fuzziness and randomness, we adopt cloud model to describe the weight, the parameters *Ex* and *He* can well describe the fuzziness and randomness in mathematical sense, so the cloud is fit for describing the weight.

The steps of model establishment are as follows:

(1)Establish the factor set U and comment set V for assessment.

(2)Calculate the weight $W = [W_1, W_2, ..., W_m]$ using entropy method

(3)Establish a comprehensive evaluation matrix R based on cloud model, where$R = \begin{bmatrix} r_{11}, r_{12}, ..., r_{1n} \\ r_{21}, r_{22}, ..., r_{2n} \\ ... \\ r_{m1}, r_{m2}, ..., r_{mn} \end{bmatrix}$, r_{ij} is the degree of membership , the subscript i denotes the *i th* factor and j denotes the corresponding the *j th* comment. In this paper, we use the Trapezium-Cloud model to estimate its value of the degree of membership.

To Trapezium-Cloud Model, there are multi-values belonging to the concept. In general, the model can be represented by the values of four characteristics, namely A(E_{x1},E_{x2},E_n,H_e), where $E_{x1} \leq E_{x2}$[11]. If $E_{x1} = E_{x2}$, then A is the Normal Cloud, otherwise A is the Trapezium-Cloud[7]. Trapezium-Cloud Model can well represent a range of values of certain conceptsso the Trapezium-Cloud model is adopted as comments model.

The comments range is 1 to 10, if V is in the range, then its degree of membership is 1. If V is outside the range, then its degree of membership is as follows:

$$\begin{cases} E_x = (V_{\min} - V)/10 \\ E_n = (V_{\min} - E_x)/3 \quad , V < V_{\min} \\ H_e = k_1 \\ E_x = (V - V_{\max})/10 \\ E_n = (V_{\max} - E_x)/3 \quad , V > V_{\max} \\ H_e = k_2 \end{cases} \tag{2}$$

where, k_1 and k_2 are constants. Their values can be artificially adjusted according to the fuzzy threshold. So we use the simulation experiments to adjust their values.

According to the formula (1), all the clouds of each index are processed depending on the Integrated Cloud model . Then the standard Integrated Cloud models of each index can be obtained. According to the parameter *Ex* of Trapezium-

Cloud, the assessment matrix R can be established, where, $R = \begin{bmatrix} E_{x11}, E_{x13}, ..., E_{x1n} \\ E_{x21}, E_{x23}, ..., E_{x2n} \\ ... \\ E_{xm1}, E_{xm3}, ..., E_{xmn} \end{bmatrix}$.

(4) Calculate the comprehensive assessment results $A = W \circ R$, using the fuzzy synthesis operator W.

$$A = W \circ R$$

5 CCS projects comprehensive assessment index system

5.1 The index system

After analyzing the national and international research achievements, the comprehensive risk evaluation index system of CCS project is established in this paper. To establish the system, some principles including science, systematicness and certainty of evaluation index are adopted. Figure 2 demonstrates the basic architecture of the system. It is obvious that these index factors are fuzzy and random, and the cloud model is appropriate to describe these factors,

In general, the risk assessment level of CCS project can be set five levels, namely V={Highest , Higher , General , Lower , Lowest}. To quantify the subjective evaluation, the corresponding five levels based on semantics scale are defined, then the quantitative standards of risk assessment level are obtained, where table 1 shows the quantitative standards of risk evaluation.

Table 1: Quantitative standard of risk evaluation

Value Range	Grade
$[9-10]$	Highest
$[7-9)$	Higher
$[5-7)$	General
$[3-5)$	Lower
$[0-3)$	Lowest

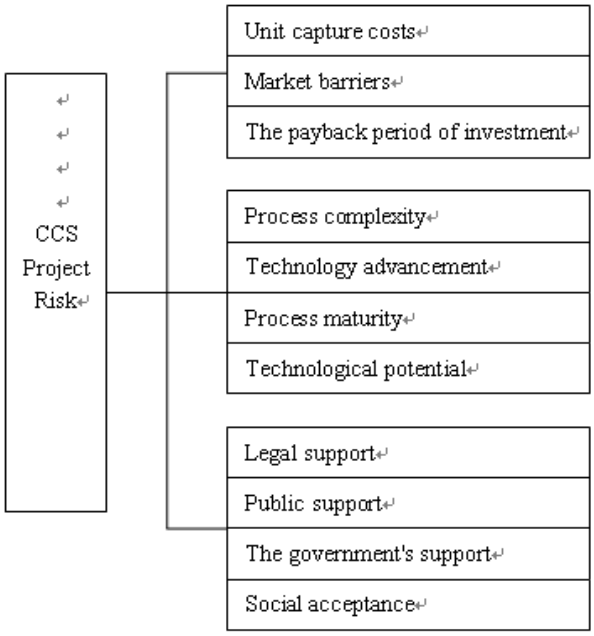

Figure 2: The comprehensive evaluation index system of risk

5.2 CCS project risk evaluation calculation

According to the established index system and evaluation standard, we chooses a special CCS project as the evaluation object. On the basis of a large number of relevant empirical research, the evaluation index value(10 points) is confirmed after consulting the views of the 10 experts. Table 2 shows the expert score about the various indexes.

W={0.0325,0.0436,0.0358,0.0314,0.0311,0.0436,0.1025,0.2014,0.1062,0.2706,0.1013}

Calculate the weight of each index according to the entropy weight method, then the following weights can be obtained:W={0.0325,0.0436,0.0358,0.0314,0.0311,0.0436,0.1025,0.2014,0.1062,0.2706,0.1013}

Calculate the digital featuresE_x,E_n,$H_e$according to comprehensive cloud model, where each *Ex* is the element of the evaluation matrix R, then the following evaluation matrix can be acquired:

Table 2: The expert score

Index			The	value	of	expert	score			
Unit capture costs	8	6	8	7	6	8	7	6	8	6
Market barriers	6	8	7	6	9	7	8	7	8	6
The payback period of investment	7	8	8	6	6	8	7	6	8	7
Process complexity	7	6	7	6	9	8	6	9	8	6
Technology advanced	9	7	8	9	6	5	8	6	6	6
Process maturity	7	8	8	7	7	9	6	7	6	6
Technological potential	8	7	8	6	8	7	6	7	8	9
Legal support	7	9	7	8	7	8	7	9	8	8
Public support	8	8	7	7	6	8	7	8	8	8
The government's support	8	8	8	9	8	8	8	8	9	7
Social acceptance	6	9	8	8	6	9	7	6	7	9

Depending on the fuzzy synthesis operator, we can calculate the comprehensive evaluation results:A={ 0.29,0.65,0.32, 0.23,0.19}. As can be seen, the result of "Higher" risk comment is 0.65, the result of "General" risk comment is 0.32. According to the evaluation results, there is a greater risk to the implement the project, but using the conclusion, namely "Higher but in the direction of General", to describe its risk is more appropriate.

Table 3: Assessment matrix

Highest	Higher	General	Lower	Lowest
1.99	6.71	6.09	1.98	1.99
2.73	6.44	3.22	2.18	2.21
1.89	7.57	3.12	2.09	2.13
3.68	4.48	4.30	2.17	2.26
3.89	3.68	5.30	1.96	2.23
2.83	6.44	3.11	2.08	2.16
2.52	7.28	2.39	2.37	1.90
3.06	7.80	0.79	2.79	2.16
1.49	9.92	1.48	2.49	2.30
2.75	7.80	1.09	3.09	1.84
4.34	4.27	3.54	2.47	2.11

The fuzzy comprehensive analysis method is based on the experts opinions to obtain weight set. According to the corresponding relationship between index set and evaluation set, the membership function and the assessment matrix can be built. Then the comprehensive assessment results of comments set can be calculated by means of synthesis operator. In addition, the determination of the membership degree of each criterion and weight often need consider the expert advice. According to the calculation method of synthesis operator described in formula (3), the results are {0.167,0.272,0.268,0.176,0.118}. It is clear that the maximum value of the results is 0.272, and the assessment result can be denoted as "Higher". But it is so closely to 0.268 that is the numerical value of grade "General". In addition, Weights and assessment matrix directly dependent on the numerical value from experts. This lead to the whole process and the results of the evaluation become fuzzy and random. Table 4 is the weight and assessment matrix.

Compared with the traditional fuzzy comprehensive analysis method, the evaluation value of the Integrated Cloud model is "Higher", and the value of former model is "General". So the cloud model can better integrate the correlation

Table 4: Weight and Assessment matrix

Weight	Highest	Higher	General	Lower	Lowest
0.056	0.20	0.32	0.29	0.11	0.09
0.076	0.19	0.30	0.32	0.18	0.01
0.108	0.15	0.34	0.29	0.12	0.10
0.135	0.27	0.25	0.23	0.13	0.13
0.083	0.19	0.19	0.30	0.20	0.12
0.054	0.15	0.34	0.31	0.11	0.09
0.086	0.15	0.32	0.24	0.16	0.13
0.107	0.14	0.28	0.26	0.22	0.11
0.093	0.15	0.19	0.15	0.28	0.23
0.1	0.11	0.29	0.34	0.16	0.11
0.102	0.13	0.23	0.25	0.25	0.14
Result	0.167	0.272	0.268	0.176	0.118

between fuzziness and randomness, and it has higher accuracy than the former. Obviously, the result obtained by the method has higher precision, and is more close to the actual. At the same time, this method not only considers errors, but also has a better effect on dealing with the random problem.

6 Conclusion

Cloud model can realize the interconversion between qualitative and quantitative. Through the traditional fuzzy analysis method, we can obtain the weights and evaluation matrix, but they are both fuzzy and random. By combining the Integrated Cloud model and entropy weight method, we present a novel method to realize the risk assessment of CCS project. By a specific example, the validity and feasibility of the method were proved. Compared with evaluation results of traditional fuzzy method, the higher accuracy and precision can be guaranteed by harmonizing the fuzziness and randomness. It will be used to offer scientific decision-making basis for CCS projects investment assessment.

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