

Optimization of Enhanced Geothermal System Power Generation Investment Scheme Based on Fuzzy VIKOR Model

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Abstract. In the future, Enhanced Geothermal System (EGS) power generation will be a hot spot for new energy investment development. How to optimize the EGS power generation investment program is an important issue to be solved by the government and enterprises. In order to improve the accuracy of the EGS investment project evaluation, this paper proposes a technical route to optimize the EGS power generation investment program. It comprehensively considers the ambiguity of the decision attributes and the conflict between the indicators. The index is calculated using the entropy method and the order relationship method. Comprehensive weights; using triangular fuzzy numbers instead of exact numbers to reduce the loss of decision information; using a multi-criteria compromised sorting method to obtain trade-off solutions to solve the problem that investment plans cannot be accepted by all decision makers when there are multiple conflicting indicators. Finally, taking an enterprise's EGS power generation project as an example, the effectiveness and rationality of the optimized technology route for the EGS power generation investment program are verified.

1 Introduction

EGS (Enhanced Geothermal System), including the initial concept of Hot Dry Rock (HDR), was originated at the Los Alamos National Laboratory (LANL) in the USA [1]. The patent on the concept, which dates from 1974, describes the formation of an entirely natural tank designed for obtaining geothermal energy. In more than 40 years of research and development of the EGS, the utilization technology has matured day by day. The development prospect is very promising because of its great value. The potential of EGS resources in China is huge and the prospect of development is wide, which is higher than that estimated by the US (57 trillion tons of standard coal). Preliminary estimates indicate that EGS resources in the 3-10km range are equivalent to 860 trillion tons of standard coal, of which 2 percent is equivalent to 4,040 times China's total energy consumption in 2010 [2-3]. In particular, at 3.5-7.5 km, the temperature of the EGS resources ranged from 150-250 °C, and the amount of resources was huge, equivalent to 215 trillion tons of standard coal. In recent years, China has raised its green development strategy to an unprecedented level. The exploitation and utilization of geothermal resources are faced with historic development opportunities and great potential. EGS, as the clean energy with the most application value and potential for use, will play a more important role in optimizing energy structure, preventing and controlling atmospheric pollution, improving people's lives, and

promoting the scientific and coordinated development of the economic and social ecological environment [4].

From the perspective of power construction costs, geothermal power generation is roughly 10,000 RMB installed 1KW, which is equivalent to the cost of wind power generation, but compared with solar photovoltaic power generation of about 100,000 RMB installed 1KW, the construction cost is much lower [5]. From the viewpoint of environmental protection value, the utilization ratio of EGS resources can reach 80%. Calculated according to the recoverable amount of 2% of China's EGS resources, it can replace the standard coal of 14.298 trillion tons, reducing CO₂ emissions by 0.2388 trillion RMB, reduce the emission of NO_x by 0.08579 trillion tons, reduce the emission of suspended dust by 0.1144 trillion tons, and reduce the coal ash residue by 1.4298 trillion tons [6]. From the perspective of natural conditions, the development and utilization of wind power, solar energy and tidal energy are all closely related to the climatic conditions, which often results in the instability and discontinuity of development and utilization. The development and utilization of geothermal energy do not have such problems.

For a long time in the future, as a significantly effective way of electricity generation, EGS will be a hot spot for new energy investment and development. In the face of a variety of EGS power generation investment plans, more comprehensive and reasonable decision-making system are needed. The optimization of EGS power generation investment plan is a multi-criteria decision-making problem. The decision-making process

needs to consider many factors such as resources, economy, environment and risk. The traditional multi-criteria decision-making problems mainly include analytic hierarchy process (AHP), analytic network process (ANP) and technique for order preference by similarity to ideal solution (TOPSIS). However, there are some problems in the application of existing multi-criteria decision-making methods to the selection of EGS power generation projects, which will reduce the accuracy of decision-making. On the one hand, due to the fact that the EGS power generation industry is still commercialized in China, there are few data available for reference in the investment decision-making process, and it is difficult to obtain the precise data needed for general methods. On the other hand, due to the complexity of decision-making issues and the conflict between the indicators of the EGS power generation project, the evaluation results may not be accepted by all policy makers. Based on the above problems, this paper proposes a preferred framework for the EGS power generation investment plan based on fuzzy set theory [7-8] and multi-criteria compromised sorting method [9-11]. The use of triangular fuzzy numbers to represent the decision values of each candidate item prevents the

loss of decision information. Through the multi-criteria compromised sorting method, ranking of a series of solutions with multiple conflicts or inconsistent indicators can be achieved, so as to better complete the optimization of the investment scheme of the EGS power generation.

2 EGS power generation investment program evaluation index system

The construction of investment evaluation index system is the basic work for optimizing the investment project, and whether the index system is properly constructed will directly affect the accuracy of the project selection. EGS power generation project includes many aspects, especially when it is a government investment project, it needs to consider social and environmental factors. This paper will build 25 indicators through the five criteria of strengths, quality, economy, risk, and environment to evaluate a power generation project in EGS, as shown in Table 1.

Table 1. Evaluation index system of EGS power generation investment plan.

Guidelines	Primary indicators	Secondary indicators
(A) Advantage	(a) Resources	(a ₁) Exploitable resources
		(a ₂) EGS temperature
	(b) Location	(b ₁) Geological terrain conditions
		(b ₂) Mining depth
		(b ₃) Grid conditions
(B) Quality	(c) EGS system	(c ₁) Annual installed capacity
		(c ₂) Technical maturity
		(c ₃) Adaptability to local resources
		(c ₄) Resistance to geological disasters
	(d) Construction	(d ₁) Construction plan
		(d ₂) Construction management level
(C) Economic	(e) Investment	(e ₁) Fixed asset investment
		(e ₂) Liquidity investment
		(e ₃) Annual operating costs
	(f) Benefit	(f ₁) Internal Rate of Return(%)
		(f ₂) Payback period (a)
		(f ₃) Policy subsidies
(D) Risk	(g) Social risk	(g ₁) Policy change risk
		(g ₂) Project start-up operational risk
	(h) Technical risk	(h ₁) Construction technology risk
		(h ₂) Equipment installation technology risk
(E) Environment	(i) Positive effect	(i ₁) Pollutant emission reduction
		(i ₂) Energy saving effect
	(j) Negative effect	(j ₁) Sound pollution
		(j ₂) Air Pollution
		(j ₃) Water pollution

3 EGS power generation investment program optimization technical route

The technical route for the investment program optimization is based on the investment decision-making process of the EGS power generation project. The entire technical route is divided into three parts: The determination of alternatives for evaluation, the

establishment of indicator systems, the determination of weights, and the determination of optimal plans for investment plans. The specific technical route is shown in Fig. 1. Through the cooperation of these three parts, the scientific sequencing of alternatives can finally be achieved, assisting the investment decision of the hot rock power generation investment company.

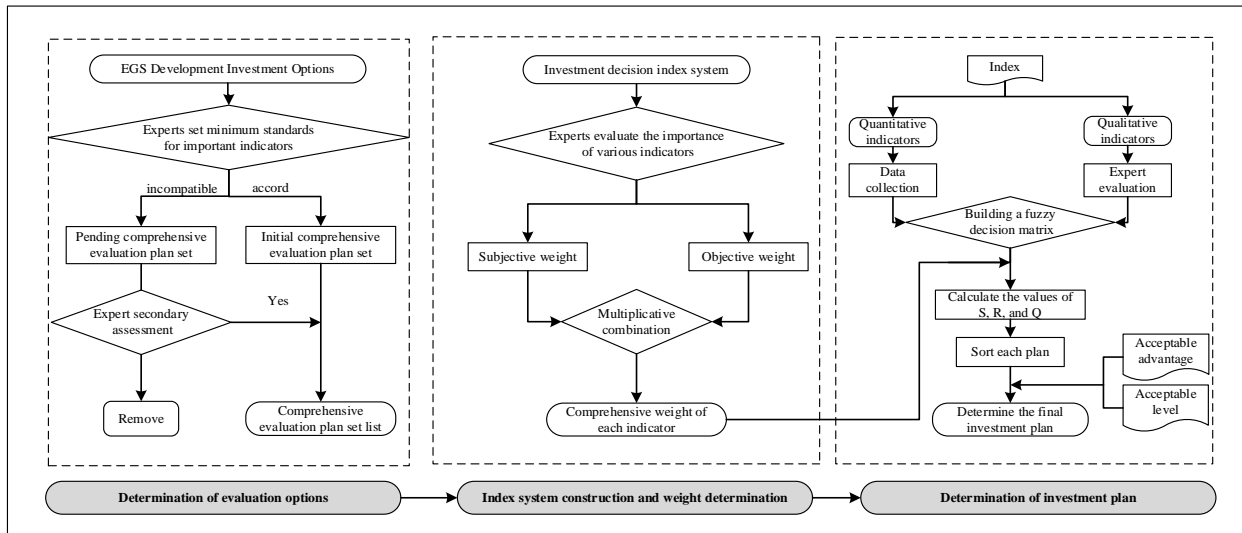


Fig. 1. EGS Power Generation Investment Optimization Technology Roadmap.

3.1 Determination of evaluation options

This article first screens the investment alternatives, and through the relevant screening process, removes some of the investment options from the investment alternatives that do not meet the requirements. The retained investment plans form an evaluation alternative set and enter the subsequent comprehensive evaluation link.

In the first step, the company invited experts from the EGS power generation field to form an expert committee to take charge of this assessment. In the second step, according to the opinions of the enterprise's decision makers and the project feasibility study report, the experts set the minimum standards for some important indicators (in the case of cost indicators, they are the maximum standards). If the value of the relevant indicator is higher than the minimum standard (the cost type indicator is below), the investment plan goes directly to the evaluation candidate set. The third step provides a second opportunity for investment plans that fail to enter the alternative set. Experts analyze the investment value of the project based on the feasibility study report and explore the investment potential of the project. If part of the investment indicators of the project are attractive, they are also allowed to enter the set of evaluation options after consensus of the experts. The fourth step, through these two rounds of assessment, forms a list of options for evaluation. Comprehensive

evaluation of the investment plan on the list, select the most appropriate investment plan.

3.2 Determination of index weights based on comprehensive integrated weighting method

Due to the large number of indicators and the weak correlation, this paper intends to adopt a comprehensive integrated weighting method that considers the objective conditions of each item's indicators and also includes the subjective opinions of experts on the importance of each index. The objective weights were determined by the method of entropy weight, and the subjective weights of each index were determined by using the group-based order relation method.

3.2.1 Objective weight calculation

The entropy weight method [12] is a method for determining the weight of an evaluation object based on the amount of information provided by the evaluation index observation value. In the comprehensive evaluation, this paper uses information entropy to obtain the degree of systematic information and evaluates the utility value of information.

According to the entropy method to determine the weight coefficient steps are as follows:

Step 1: Perform dimensionless operations on the attribute values of the j -th index of i -project

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}} \quad (1)$$

Step 2: Calculate the entropy of the j-th indicator

$$E(x_j) = -(lnn)^{-1} \sum_{i=1}^m P_{ij} \ln P_{ij} \quad (2)$$

Step 3: Calculate the objective weight of the j-th indicator

When $P_{ij} = 0$, then $E(x_j) = 0$, we can see $0 \leq E(x_j) \leq 1$, the degree of deviation of the j index attribute under each scheme $d_j = 1 - E(x_j)$, the objective weight of the j-th index

$$w_j^0 = \frac{d_j}{\sum_{j=1}^m d_j} \quad (j = 1, 2, \dots, m) \quad (3)$$

According to the entropy weight calculation formula above, the objective weights of the evaluation indexes of m EGS power generation investment plans are obtained.

3.2.2 Subjective weight calculation

Step 1: determine the order relationship

Each expert individually selects the most important index for the investment decision of EGS power generation projects from the index set $\{X_1, X_2, \dots, X_m\}$, marked as X_1^* , and then picks out the most important indicators from among the unselected indicators. Until all the indicators have been selected, this forms an index of importance: $X_1^* > X_2^* > \dots > X_m^*$.

Step 2: Determination of the ratio of the importance of each index

The ratio of the importance of the evaluation indicators X_{j-1} and X_j to the expert is denoted as r_k [13]. The table for the assignment of r_k is shown in Table 2:

$$\frac{w_{j-1}}{w_j} = r_j, \quad k = m, m-1, m-2, \dots, 3, 2 \quad (4)$$

Table 2. r_j assignment table.

r_j	Instructions
1.0	The evaluation index X_{k-1} has the same degree of importance as X_k
1.2	The evaluation index X_{k-1} is slightly more important than X_k
1.4	The evaluation index X_{k-1} is significantly more important than X_k
1.6	The evaluation index X_{k-1} is more important than X_k
1.8	Evaluation index X_{k-1} is more important than X_k

Step 3: Calculation of Group Order Weights

If all experts form a consistent order relationship, the weight calculation formula is

$$\begin{cases} w_m^* = (1 + \sum_{k=2}^m \prod_{i=k}^m r_i^*)^{-1} \\ w_{j-1}^* = r_j^* w_j^*, \quad j = m, \dots, 2 \\ r_j^* = \frac{1}{L} \sum_{k=1}^L r_{kj}, \quad j = 2, \dots, m \end{cases} \quad (5)$$

Where: L represents the number of experts; r_{kj} represents the ratio of expert k to the importance of the indicator X_{j-1}^* and X_j^* ; w_j^* represents the weight of indicator j . If the ordering relationship formed by experts is inconsistent, assuming the h-order relationship is formed, the weight under each order relationship is calculated according to formula (5), and the final

comprehensive weight is obtained through the weighted average method.

$$w_j^1 = \sum_{s=1}^h k_s w_{js} \quad (6)$$

In the formula: w_{js} represents the weights under s sorting; k_s represents the number of experts forming the s -th sort.

3.2.3 Comprehensive weight calculation

The objective weights w_j^0 and subjective weights w_j^1 are combined by multiplication, and the adjusted comprehensive weights are as follows:

$$\tilde{w}_j = \frac{w_j^1 \times w_j^0}{\sum_{j=1}^m w_j^1 \times w_j^0} \quad (7)$$

3.3 Optimization based on fuzzy VIKOR investment plan

Suppose an EGS power generation project investment multi-criteria problem with K decision makers $L_k (k = 1, 2, \dots, K)$, n alternatives $P_i (i = 1, 2, \dots, n)$ and m decision indicators $C_j (j = 1, 2, \dots, m)$.

3.3.1 Initial fuzzy decision matrix

Let the initial fuzzy decision matrix be $X = (\tilde{X}_{ij})_{n \times m}$, which consists of two parts: the quantitative index decision value and the qualitative index decision value.

Table 3. Linguistic ratings and fuzzy numbers.

Linguistic Term (criteria)	Linguistic Term (alternative)	Fuzzy Triangular Number
Very Low	Very poor (VP)	(1, 1, 3)
Low	Poor (P)	(1, 3, 5)
Medium	Fair (F)	(3, 5, 7)
High	Good (G)	(5, 7, 9)
Very High	Very Good (VG)	(7, 9, 9)

Qualitative indicators are obtained through expert scoring. Experts use linguistic variables to score the qualitative indicators of alternatives. Then based on the relationship in Table 3, the scoring results will be converted into triangular fuzzy numbers. Suppose that the triangular fuzzy number $\tilde{X}_{ij}^k = (x_{ij1}^k, x_{ij2}^k, x_{ij3}^k)$ represents the decision value of the k th expert on the j th qualitative indicator of the i th equipment scheme, and λ_k represents the k -th expert decision weight $\tilde{X}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3})$ represents the index decision value of multiple experts.

$$\begin{cases} x_{ij1} = \sum_{k=1}^k \lambda_k x_{ij1}^k \\ x_{ij2} = \sum_{k=1}^k \lambda_k x_{ij2}^k \\ x_{ij3} = \sum_{k=1}^k \lambda_k x_{ij3}^k \end{cases} \quad (8)$$

For quantitative indicators, the real data is converted to triangular fuzzy numbers through fuzzification. Conversion method is

$$\begin{cases} x_{ij1} = d_{ij}(1 - \alpha_j) \\ x_{ij2} = d_{ij} \\ x_{ij3} = d_{ij}(1 + \beta_j) \end{cases} \quad (9)$$

In the formula: d_{ij} represents the real value of the j -th quantitative index of the i -th alternative; α and β represent the fluctuation coefficient of the data downwards and upwards in an uncertain environment, whose value is determined by the expert.

3.3.2 Initial fuzzy matrix standardization

Since the original quantitative index values have different dimensions, they cannot be directly compared and standardization is required before evaluation. After the normalized matrix is $A = (\tilde{A}_{ij})_{n \times m}$, the standardized method is

$$\tilde{A}_{ij} = \begin{cases} \left(\frac{x_{ij1}}{x_{j3}^+}, \frac{x_{ij2}}{x_{j3}^+}, \frac{x_{ij3}}{x_{j3}^+} \right), & c_i \in \Omega_b \\ \left(\frac{x_{j1}^-}{x_{ij3}}, \frac{x_{j1}^-}{x_{ij2}}, \frac{x_{j1}^-}{x_{ij1}} \right), & c_i \in \Omega_c, x_{j1}^- \neq 0 \\ \left(1 - \frac{x_{ij3}}{x_{j3}^+}, 1 - \frac{x_{ij2}}{x_{j3}^+}, 1 - \frac{x_{ij1}}{x_{j3}^+} \right), & c_i \in \Omega_c, x_{j1}^- = 0 \end{cases} \quad (10)$$

Where: $x_{j3}^+ = \max_i\{x_{ij3}\}$; $x_{j1}^- = \min_i\{x_{ij1}\}$; Ω_b represents a profitable index; Ω_c represents a cost index.

3.3.3 Ordering and optimization of investment programs

The purpose of this section is to sort the alternatives by a fuzzy multi-criteria compromise solution ranking method and make decisions according to the corresponding regulations.

Step 1: determine the positive and negative fuzzy ideal solution of each index

Positive fuzzy ideal solution

$$\tilde{F}_j^+ = (a_{j1}^+, a_{j2}^+, a_{j3}^+) \quad (11)$$

In the formula: $a_{j1}^+ = \max_i\{a_{ij1}\}$; $a_{j2}^+ = \max_i\{a_{ij2}\}$; $a_{j3}^+ = \max_i\{a_{ij3}\}$.

Negative fuzzy ideal solution

$$\tilde{F}_j^- = (a_{j1}^-, a_{j2}^-, a_{j3}^-) \quad (12)$$

In the formula: $a_{j1}^- = \min_i\{a_{ij1}\}$; $a_{j2}^- = \min_i\{a_{ij2}\}$; $a_{j3}^- = \min_i\{a_{ij3}\}$.

Step 2: Calculate the fuzzy distance

The vertex method is used to determine the distance between two triangular fuzzy numbers.

$$D(\tilde{F}_j^+, \tilde{U}_{ij}) = \sqrt{\frac{1}{3}[(a_{j1}^+ - a_{ij1})^2 + (a_{j2}^+ - a_{ij2})^2 + (a_{j3}^+ - a_{ij3})^2]} \quad (13)$$

$$D(\tilde{F}_j^+, \tilde{F}_j^-) = \sqrt{\frac{1}{3}[(a_{j1}^+ - a_{j1}^-)^2 + (a_{j2}^+ - a_{j2}^-)^2 + (a_{j3}^+ - a_{j3}^-)^2]} \quad (14)$$

Step 3: Calculate group effect value S_i and individual regret value R_i

$$S_i = \sum_{j=1}^m w_j D(\tilde{F}_j^+, \tilde{U}_{ij}) / D(\tilde{F}_j^+, \tilde{F}_j^-) \quad (15)$$

$$R_i = \max_i [D(\tilde{F}_j^+, \tilde{U}_{ij}) / D(\tilde{F}_j^+, \tilde{F}_j^-)] \quad (16)$$

Step 4: Calculate the comprehensive index value of multiple criteria and multiple compromises

$$S^+ = \min_i\{S_i\} \quad S^- = \max_i\{S_i\} \quad (17)$$

$$R^+ = \min_i\{R_i\}, \quad R^- = \max_i\{R_i\} \quad (18)$$

$$Q_i = v \frac{S_i - S^+}{S^- - S^+} + (1 - v) \frac{R_i - R^+}{R^- - R^+} \quad (19)$$

Where v denotes the coefficient of the decision mechanism, $v > 0.5$ denotes the decision based on the group effect, $v > 0.5$ denotes the decision based on the individual regret criterion, $v = 0.5$ denotes that the group effect and individual regrets are taken into account simultaneously to make the decision [9-11].

Step 5: Determine the compromise

According to the ascending ordering of S_i , R_i , and Q_i values for each device scheme, let B^1 and B^2 be the top 2 rankings after sorting by Q_i values. If B^1 satisfies the following two conditions, it is a trade-off solution.

Condition 1: Acceptable advantages

$$Q(B^2) - Q(B^1) \geq 1/(n - 1) \quad (20)$$

Where n is the number of evaluation alternatives.

Condition 2: Acceptable stability in the decision-making process

B^1 must also be ranked first in the order of S_i , R_i . If there is a condition that cannot be satisfied, a series of tradeoffs will be generated, including the following two conditions:

Case 1: If only condition 2 cannot be met, B^1 and B^2 are tradeoff solutions;

Case 2: If the condition is not satisfied, B^1 , B^2 , ..., B^N are all trade-off solutions, and B^N is satisfied by the relation $Q(B^N) - Q(B^1) < 1/(n - 1)$. The maximum N value is determined.

4 Example analysis

A new energy investment company plans to invest in the EGS power station project in northwestern China. Through the previous research, a number of potential investment plans have been formed. The following multi-criteria decision-making is used to select the EGS power generation investment with high value.

4.1 Determination of evaluation options

According to the company's strategy and regional hot rock development and utilization policy, the company has identified five potential investment plans, labeled T_1 , T_2 , T_3 , T_4 and T_5 . The company invited five experts in the field of investment in the hot rock power generation project to optimize this plan. After the minimum standards and expert second evaluation, the final investment plans T_1 , T_3 and T_4 carry out the subsequent comprehensive evaluation, renumbered as D_1 , D_2 and D_3 , respectively.

4.2 Calculation of indicator weights

After the assessment of the options was finalized, the Committee of Experts began to calculate the index weights. First, the expert committee evaluates each of the three alternatives based on the project feasibility report,

and calculates the objective weights based on the entropy method. Secondly, five experts ranked the importance of each index in the indicator system, forming a total of 1 order relations, 2 order relations 2, and 2 order relations 3, and calculated subjective weights based on the order relation method. Finally, the subjective weights and objective weights are calculated by the formula of the multiplicative combination and the comprehensive weights are calculated. The specific weights are shown in Table 4.

4.3 Optimization of investment program

4.3.1 Obtaining and standardizing fuzzy decision data

First, each secondary index is classified by nature and type. Indicators $a_1, a_2, b_1, c_1, e_1-e_3$, and f_1-f_3 are quantitative indicators, and others are qualitative indicators. In the same way, indicators $e_1-e_3, f_1, f_2, g_1, g_2, h_1, h_2, j_1-j_3$ are cost indicators, and others are profit-oriented indicators.

Second, due to the different nature of the secondary indicators, different methods are needed to obtain their

fuzzy decision values. Experts (S_1, S_2, S_3, S_4, S_5) use linguistic variables to score the qualitative indicators of each investment plan. Then the expert scoring results are converted into triangular fuzzy numbers according to Table 3, and the fuzzy decision value of each expert's qualitative indicator is obtained, as shown in Table 5. According to formula (8), each expert's decision value is summarized and the comprehensive decision value of the qualitative indicator is obtained.

After the determination of the qualitative indicator decision value is completed, the expert committee needs to negotiate the fluctuation coefficient of each quantitative indicator. The upward volatility coefficient indicates the magnitude of the growth of the decision value under uncertainty, and the downward fluctuation coefficient indicates the magnitude of the decline of the decision value. Obtain specific quantitative decision-making values from the project feasibility study report, and then convert the real data into triangular fuzzy numbers according to formula (9) to obtain quantitative fuzzy decision values. Finally, according to formula (10), the fuzzy decision data is standardized so that the decision values of each index are comparable. The standardized data is shown in Table 6.

Table 4. Determination of subjective and objective weights.

Guidelines	First-level indicators	Secondary indicators	w_j^0	w_j^1	\bar{w}_j
Advantage (0.3212)	Resources (0.2312)	a_1	0.0802	0.0921	0.1443
		a_2	0.0625	0.0712	0.0869
	Location (0.0900)	b_1	0.0186	0.0164	0.0060
		b_2	0.0132	0.0104	0.0027
		b_3	0.0681	0.0612	0.0814
Quality (0.2898)	EGS system (0.2716)	c_1	0.0754	0.0715	0.1053
		c_2	0.0528	0.0422	0.0435
		c_3	0.0423	0.0315	0.0260
		c_4	0.0603	0.0822	0.0968
	Construction (0.0182)	d_1	0.0022	0.0087	0.0004
		d_2	0.0286	0.0319	0.0178
Economic (0.2301)	Investment (0.1111)	e_1	0.0674	0.0717	0.0944
		e_2	0.0321	0.0218	0.0137
		e_3	0.0137	0.0115	0.0031
	Benefit (0.1189)	f_1	0.0627	0.0705	0.0863
		f_2	0.0372	0.0381	0.0277
		f_3	0.0188	0.0134	0.0049
Risk (0.0649)	Social risk (0.0487)	g_1	0.0501	0.0429	0.0420
		g_2	0.0211	0.0163	0.0067
	Technical risk (0.0162)	h_1	0.0259	0.0118	0.0060
		h_2	0.0177	0.0295	0.0102
Environment (0.0940)	Positive effect (0.0298)	i_1	0.0301	0.0289	0.0170
		i_2	0.0225	0.0292	0.0128
	Negative effect	j_1	0.0288	0.0231	0.0130

	(0.0642)	j_2	0.0259	0.0243	0.0123
		j_3	0.0418	0.0477	0.0389

Table 5. Fuzzy decision values of qualitative indicators.

Index	D_1					D_2					D_3				
	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
b_1	M	M	H	M	H	M	L	M	H	M	H	L	H	M	M
b_3	L	M	M	M	H	H	M	M	M	M	M	M	L	M	H
c_2	H	M	L	M	L	L	H	L	L	M	L	M	L	M	L
c_3	L	VL	VL	L	M	L	L	M	M	L	M	L	M	L	L
c_4	H	VH	H	VH	M	H	M	H	VH	H	H	M	H	H	VH
d_1	VH	M	H	H	VH	M	H	VH	H	M	VH	H	H	H	M
d_2	H	L	H	M	H	H	H	M	H	H	H	H	M	M	H
g_1	H	H	M	H	L	L	H	H	H	M	H	H	L	H	VH
g_2	H	M	L	H	M	H	H	L	M	VH	VH	L	M	H	H
h_1	M	M	H	M	H	M	H	M	H	L	H	H	M	M	M
h_2	VH	VH	H	VH	M	VH	VH	H	H	H	M	M	H	H	VH
i_1	H	M	L	H	M	H	H	H	M	L	H	M	VH	L	M
i_2	VH	VH	H	M	H	H	M	VH	H	H	VH	H	L	H	H
j_1	H	M	H	H	VH	VH	H	H	H	M	H	VH	H	VH	H
j_2	H	H	M	VH	H	H	VH	M	H	H	H	H	M	H	H
j_3	M	L	M	VL	VL	L	M	VL	VL	M	M	L	L	VL	L

Table 6. Decision values after standardization for each scenario and Fuzzy distance calculation table.

Index	D_1	D_2	D_3	$D(\bar{F}_j^+, \bar{A}_{1j})$	$D(\bar{F}_j^+, \bar{A}_{2j})$	$D(\bar{F}_j^+, \bar{A}_{3j})$	$D(\bar{F}_j^+, \bar{F}_j^-)$
a_1	(0.62,0.78,0.83)	(0.81,0.94,1.00)	(0.72,0.86,0.91)	0.17	0.00	0.09	0.17
a_2	(0.85,0.94,1.00)	(0.71,0.85,0.92)	(0.79,0.88,0.95)	0.00	0.11	0.06	0.11
b_1	(0.75,0.80,0.86)	(0.82,0.88,0.95)	(0.87,0.92,1.00)	0.13	0.05	0.00	0.13
b_2	(0.83,0.91,1.00)	(0.65,0.79,0.91)	(0.70,0.86,0.94)	0.00	0.14	0.09	0.14
b_3	(0.68,0.82,0.92)	(0.72,0.89,1.00)	(0.68,0.82,0.93)	0.07	0.00	0.06	0.07
c_1	(0.45,0.66,0.83)	(0.56,0.78,0.94)	(0.62,0.83,1.00)	0.17	0.06	0.00	0.17
c_2	(0.81,0.90,1.00)	(0.62,0.75,0.86)	(0.68,0.82,0.89)	0.00	0.16	0.11	0.16
c_3	(0.55,0.67,0.83)	(0.68,0.75,0.87)	(0.79,0.86,1.00)	0.20	0.12	0.00	0.20
c_4	(0.72,0.85,0.95)	(0.66,0.79,0.91)	(0.81,0.89,1.00)	0.06	0.12	0.00	0.12
d_1	(0.78,0.87,0.96)	(0.81,0.90,1.00)	(0.72,0.82,0.93)	0.03	0.00	0.08	0.08
d_2	(0.39,0.49,0.72)	(0.51,0.60,0.78)	(0.59,0.71,1.00)	0.24	0.15	0.00	0.24
e_1	(0.23,0.41,1.00)	(0.15,0.31,0.55)	(0.21,0.35,0.68)	0.00	0.27	0.19	0.27
e_2	(0.81,0.86,0.91)	(0.83,0.92,1.00)	(0.80,0.82,0.90)	0.15	0.00	0.08	0.15
e_3	(0.77,0.83,0.96)	(0.81,0.88,1.00)	(0.74,0.81,0.89)	0.04	0.00	0.09	0.09
f_1	(0.71,0.83,0.93)	(0.84,0.95,1.00)	(0.81,0.89,0.96)	0.11	0.00	0.05	0.11
f_2	(0.76,0.85,0.97)	(0.74,0.82,0.91)	(0.83,0.91,1.00)	0.06	0.09	0.00	0.09
f_3	(0.63,0.81,1.00)	(0.56,0.79,0.91)	(0.55,0.78,0.83)	0.00	0.07	0.11	0.11
g_1	(0.66,0.81,1.00)	(0.61,0.73,0.90)	(0.65,0.78,0.94)	0.00	0.08	0.04	0.08

g_2	(0.28,0.53,1.00)	(0.17,0.44,0.63)	(0.22,0.48,0.71)	0.00	0.23	0.17	0.23
h_1	(0.43,0.62,0.85)	(0.50,0.69,0.87)	(0.56,0.77,1.00)	0.14	0.09	0.00	0.14
h_2	(0.05,0.10,0.38)	(0.08,0.21,1.00)	(0.06,0.16,0.59)	0.36	0.00	0.24	0.36
i_1	(0.54,0.72,0.83)	(0.62,0.77,1.00)	(0.49,0.69,0.81)	0.11	0.00	0.14	0.14
i_2	(0.60,0.82,0.97)	(0.48,0.69,0.89)	(0.60,0.82,1.00)	0.02	0.12	0.00	0.12
j_1	(0.12,0.23,1.00)	(0.09,0.13,0.29)	(0.10,0.18,0.63)	0.00	0.41	0.22	0.41
j_2	(0.15,0.28,0.45)	(0.31,0.43,1.00)	(0.26,0.39,0.63)	0.34	0.00	0.22	0.34
j_3	(0.53,0.67,1.00)	(0.41,0.49,0.61)	(0.50,0.62,0.78)	0.00	0.26	0.13	0.26

4.3.2 Optimization and ranking of investment programs

According to equations (11) and (12), the fuzzy positive ideal solution \tilde{F}_j^+ and the fuzzy negative ideal solution \tilde{F}_j^- for each index are determined. Then calculate the fuzzy distance according to equations (13) and (14). The calculation results are shown in Table 6.

According to equations (10), (11) and (14), calculate the maximum group effect S_i , the minimum regret value R_i , and the multi-criteria compromise solution ranking method synthesis index value Q_i (where ν takes 0.5). The calculation results are shown in Table 7.

Table 7. Table of S_i , R_i and Q_i values.

Index	D_1	D_2	D_3
S_i	0.60	0.54	0.43
R_i	0.14	0.10	0.08
Q_i	0	0.53	1

Roots S_i , R_i , and Q_i sort the alternatives in ascending order, and select the plan according to the decision criteria. D_1 is the scheme ranked first in the ascending order of Q_i value, satisfying $Q(D_1) - Q(D_2) > 0.5$, but does not satisfy condition 2, so D_1 and D_2 are trade-off solutions. Therefore, D_1 and D_2 are the final solutions determined according to the fuzzy multi-criteria compromise solution sorting method. New energy companies can invest in these two options.

5 Conclusion

EGS will be the key clean energy for development and utilization worldwide in the future. This paper constructs an evaluation index system for the EGS power generation investment scheme, which uses the entropy weight method and the order relationship analysis method based on group relations to calculate the comprehensive weight of the index as well. Combining the fuzzy set theory with the multi-criteria compromised sorting method, the optimal technical route for the EGS power generation investment scheme was proposed. Through this technical route, an optimal solution that takes into account the largest group effect and the smallest individual regret can be obtained, and the conflict between the ambiguity of the decision attribute and the index is properly solved.

Using this technical route, the case analysis of an EGS power plant project of a company was conducted. The results of the decision show good accuracy, which proves the validity and practicability of the framework.

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