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Evaluation of green and efficient development of shale gas resources in China

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ABSTRACT

Green and efficient development is an inevitable requirement for sustainable development of shale gas industry in China. This paper selects 24 indicators from five dimensions of resource endowment, economy, technology, environment and policy to construct the evaluation indicator system of green and efficient development of shale gas resources in China, and applies the fuzzy-AHP method to comprehensively evaluate the green and efficient development of shale gas resources in China. The results show that the influencing extent on shale gas green and efficient development is resource endowment, technology, policy, economy and environment in turn, and resource endowment and development technology are the key to green and efficient development of shale gas in China. However, to realize the green and efficient development of China's shale gas, the coordinated development of all aspects is necessary. Therefore, some suggestions are put forward based on the development status of China's shale gas industry.

Keywords: shale gas, green and efficient development, fuzzy-AHP method, fuzzy comprehensive evaluation

1. INTRODUCTION

As an unconventional gas, shale gas is a clean and efficient emerging energy source, which has attracted increasing attention worldwide in recent years[1-6]. According to the statistical results of EIA, the technically recoverable reserves of shale gas resources in China are 31.6 trillion cubic meters, which ranks China as first in the world. And China has realized the commercial development of shale gas in 2016, following the United States and Canada. Therefore, shale gas has broad development prospects and great potential value, and will become an important strategic replacement of conventional oil and gas resources in the future[7]. Shale Gas Development Plan (2016-2020) issued by National Energy Administration proposed that the production of shale gas should be greatly increased to make it an important part of China's natural gas supply. However, there are huge problems in the development of China's shale gas resources. First, the conditions of China's shale gas accumulation are complex, and the key technology of shale gas exploitation cannot make a breakthrough. Second, the development of shale gas causes an adverse influence on the environment, such as water consumption, water pollution, carbon emission and so on[8]. These problems lead to the high development cost and serious environmental damage of shale gas resources in China, which is not conductive to the green and efficient development and utilization of China's shale gas. Therefore, it is urgent to scientifically evaluate the situation of green and efficient development of shale gas resources for promoting the coordinated development of economic, social and environmental benefits of shale gas resources.

According to the existing research on the development and utilization of shale gas resources, it is found that the key words involve economic benefit[9, 10], water resource problems[8, 11, 12], risks and obstacles[13, 14], sustainable development of the industry[15, 16], etc. However, these studies make qualitative and quantitative research only from three or four aspects of resource, environment, market, society and development and utilization[7, 14-16]. The aspects involved are not comprehensive enough and the indicators involved are relatively few. Therefore, this paper takes 24 indicators from five dimensions of resource endowment, economy, technology, environment and policy to construct the evaluation indicator system of green and efficient development of shale gas resources in China, and uses the fuzzy-AHP method to make a comprehensive evaluation.

2. METHOD

2.1 Establishment of evaluation indicator system

The green and efficient development of shale gas resources refers to the maximized efficient exploitation and utilization of shale gas by advanced technology and modern management under the support of government policies with the principle of not damaging or reducing the damage to the environment. Considering the objective demand of green development in the new era and drawing lessons from the relevant research on the development and utilization of shale gas resources, 24 indicators are chosen from five dimensions of resource endowment, economy, technology, environment and policy to establish the evaluation indicator system of shale gas green and efficient development, as shown in Table 1.

Table 1 Evaluation indicator system of shale gas green and efficient development

Target layer	Criterion layer	Indicator layer
The comprehensive evaluation of shale gas green and efficient development(A)	Resource endowment(B1)	Volume of production(C11)
		Proved reserves(C12)
		Effective thickness(C13)
		Utilization ratio of gas resource(C14)
	Economic aspects(B2)	Development cost of single well(C21)
		Shale gas price(C22)
		Payback period(C23)
		Economic returns(C24)
		Return on assets of enterprise(C25)
	Technological aspects(B3)	Exploration technology(C31)
		Development technology(C32)
		Resource evaluation technology(C33)
		Integration technology of geology and engineering(C34)
		Gas extraction technology(C35)
		Production equipment level(C36)
	Environmental aspects(B4)	Water pollution(C41)
		Air pollution(C42)
		Noise pollution(C43)
		Land pollution(C44)
	Policy aspects(B5)	Finance and taxation policy(C51)
		Industrial technology policy(C52)
		Land policy(C53)
		Environment policy(C54)
		Laws and regulations(C55)

2.2 Fuzzy-AHP model

In the 1970s, Saaty put forward the Analytic Hierarchy Process (AHP) for the first time, of which the core idea is to stratify the complex problem, determine the hierarchical level according to the dominant subordinate relationship and the relative importance in the same level by calculation and comparison, and finally obtain the weight value of each indicator. The fuzzy set theory was proposed by Zadeh in 1965, which is usually used to address the problem when the data is inaccurate and unreliable. Therefore, combing fuzzy set theory and Analytic Hierarchy Process (AHP), this paper establishes a fuzzy-AHP comprehensive evaluation model to study the green and efficient development of shale gas resources in China. The specific steps are as follows.

(1) Establishment of judgment matrix

Based on establishing the indicator system and determining the subordination relationship of each indicator, the inter-comparisons of relative importance of evaluation indicators, i.e. the weights, are conducted quantitatively in the multiple layers of the hierarchy. 1-9 scale method can be used in the quantitative standard and judgment scale of indicator weights. The numbers of 1, 3, 5, 7 and 9 denote equal importance, weak importance, demonstrated importance, strong importance and extreme importance, respectively; whereas 2, 4, 6 and 8 are the scale values corresponding to the intermediate state between the above judgments. The judgment matrix obtained can be expressed as:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} \\ a_{21} & a_{22} & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix}$$

in which, a_{ij} represents the relative importance of indicator *i* to indicator *j*.

(2) Calculation of weight value

Determining the weight of each indicator in the criterion layer and indicator layer by the geometric average approximation method:

$$\overline{w}_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \quad (i = 1, 2, 3, \cdots\cdots, m)$$

And then normalizing them:

$$w_i = \frac{\overline{w}_i}{\sum_{i=1}^{n} \overline{w}_i} \quad (i = 1, 2, 3, \cdots\cdots, n)$$

(3) Consistency test

Calculating the consistency indicator of judgment matrix:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

in which, $\lambda_{\max}$ is the maximum eigenvalue of judgment matrix; *n* is the order of judgment matrix, *n*>1.

Establishing the discriminant of consistency test, which is expressed by the consistency ratio *CR*:

$$CR = \frac{CI}{RI}$$

in which, *RI* is the average random consistency index, specifically shown in Table 2. When *CR*<0.1, the consistency is considered acceptable; otherwise, the judgment matrix needs to be adjusted and modified until the consistency test is passed.

Table 2 The value of average random consistency index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46

(4) Establishment of comment set

In this paper, the comment set $V = \{v_1, v_2, v_3, v_4, v_5\}$ ={low, relative low, middle, relative high, high} is set, as shown in Table 3.

Table 3 Comment grade table

Comment grade	Low	Relative low	Middle	Relative high	High
Grade score	10	30	50	70	90

(5) Establishment of evaluation matrix

The evaluation matrix *R* is expressed as

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

in which, R_i is the evaluation vector of the *i*th factor, r_{ij} is the contribution degree, i.e. the frequency distribution of the *i*th(1⩽*i*⩽*m*) factor on the *j*th(1⩽*j*⩽*n*) comment. The normalized matrix satisfied $\sum_{j=1}^{n} r_{ij} = 1$.

(6) Calculation of fuzzy comprehensive evaluation vector and evaluation score

The weighted average method $M(\bullet, \oplus)$ is used to synthesis the weights of indicators and evaluation matrixes for obtaining the fuzzy comprehensive evaluation vectors and then calculate the fuzzy comprehensive evaluation score through the comment set. Specifically, the fuzzy comprehensive evaluation results of criterion layer and target layer can be obtained by the following formulas:

$$B = W \bullet R = (w_1, w_2, \cdots, \ w_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

$$\eta = B \bullet V^T$$

in which, B is fuzzy comprehensive evaluation vector; η is fuzzy comprehensive evaluation score.

3. RESULTS ANALYSIS AND DISCUSSION

3.1 Results

The weight of each indicator calculated according to AHP method is based on the relative importance of indicators given by 15 authoritative experts within China's energy, environment and policy related fields, and the calculations all pass the consistency test. The results of indicator weight are listed in Table 4.

Table 4 Weight of evaluation indicators

Criterion layer	Weight	Indicator layer	Single-sort weight	Comprehensive weight
B1	0.3229	C11	0.4393	0.1418
		C12	0.1036	0.0334
		C13	0.1464	0.0473
		C14	0.3107	0.1003
B2	0.1405	C21	0.3785	0.0532
		C22	0.2645	0.0372
		C23	0.1098	0.0154
		C24	0.1704	0.0240
		C25	0.0768	0.0108
B3	0.2447	C31	0.2388	0.0584
		C32	0.3008	0.0736
		C33	0.0911	0.0223
		C34	0.0723	0.0177
		C35	0.1656	0.0405
		C36	0.1314	0.0322
B4	0.1065	C41	0.3905	0.0416
		C42	0.2761	0.0294
		C43	0.1381	0.0147

		C44	0.1953	0.0208
		C51	0.3681	0.0683
		C52	0.2372	0.044
B5	0.1854	C53	0.1033	0.0191
		C54	0.1256	0.0233
		C55	0.1658	0.0307

Then, the fuzzy membership of each indicator in the evaluation system relative to the comment grade in the comment set is scored through questionnaire survey to obtain the fuzzy evaluation matrix of green and efficient development of shale gas resources in China. Finally, the fuzzy comprehensive evaluation results of criterion layer and target layer are achieved by synthetizing the weights of indicators and evaluation matrixes, as shown in Table 5 and Table 6.

Table 5 Fuzzy evaluation results of criterion layer

Matrix	Fuzzy synthesis	Indicator	Low	Relative low	Middle	Relative high	High	Evaluation score
	W1 · R1	B1	0.0366	0.3386	0.1646	0.1650	0.2952	56.87
	W2 · R2	B2	0.2583	0.3127	0.2905	0.1142	0.0242	36.66
R	W3 · R3	B3	0.0750	0.2489	0.3228	0.2558	0.0974	51.04
	W4 · R4	B4	0.3480	0.3711	0.2367	0.0331	0.0110	29.76
	W5 · R5	B5	0.1975	0.1168	0.2565	0.3559	0.0733	49.81

Table 6 Fuzzy evaluation results of target layer

Indicator	Fuzzy synthesis	Low	Relative low	Middle	Relative high	High	Evaluation score
B	W · R	0.1401	0.2754	0.2457	0.2014	0.1373	48.41

3.2 Discussion

It can be seen from Table 5 and Table 6 that the fuzzy comprehensive evaluation score of green and efficient development of shale gas resources in China is 48.41. According to the score grade in Table 3, it belongs to low to middle grade, and indicates that the green and efficient development of China's shale gas is still in the initial stage of exploration. From the view of five dimensions, the influencing extent on shale gas green and efficient development is resource endowment, technology, policy, economy and environment in turn, and the corresponding evaluation score is 56.87, 51.04, 49.81, 36.66 and 29.76 respectively, which demonstrates that resource endowment and development technology are the key to green and efficient development of shale gas in China. However, to realize the green and efficient development of China's shale gas, the coordinated development of resource endowment, technology, policy, economy and environment five aspects is necessary. The specific situations of these five aspects are analyzed and discussed according to Table 4.

3.2.1 Resource endowment

In terms of resource endowment, the weight of volume of production and utilization ratio of gas resource is 43.9% and 31% respectively, accounting for a large proportion of resource endowment. It is indicated that production and utilization ratio of resource seriously restrict the green and efficient development of shale gas in China. China has 36 trillion cubic meters of technical recoverable reserves, ranking first in the world, while the United States has 24 trillion cubic meters. In 2019, the production of shale gas in the United States is 632.1 billion cubic meters, while that of China is only 15 billion cubic meters. Although China is rich in shale gas resources, its resource endowment conditions are relatively poor. Compared with the United States, shale gas distribution areas in China have complex geological structure, poor surface conditions, deep burial depth, discontinuous reservoirs, low gas content. These cause that the production of single well does not meet the target, and the utilization rate of resources is very low.

3.2.2 Economic aspect

In the economic aspect, the weight of development cost of single well and shale gas price is 37.85% and 26.45% respectively, which manifests that development cost and price are the main economic factors affecting shale gas resources development in China. The economic viability of a shale gas project mainly depends on investment cost and revenue, in which the investment cost primarily includes exploration cost, drilling engineering cost, fracturing engineering cost and surface engineering cost while the revenue mainly hinge on the production and price of shale gas. The cost of shale gas development in the United States has already reached the standard of commercial development, while China is still in the stage of exploration and the cost is 2-3 times that of the United States. Recently affected by the downturn of international oil price, the possibility of shale gas price rising is very small. So exorbitant investment cost seriously affects the efficient development of China's shale gas.

3.2.3 Technological aspect

The weight of development technology and exploration technology in the aspect of technology accounts for a large proportion, 30.08% and 23.88% respectively. due to the particularity of shale gas reservoir, which requires the technology quite high, some special drilling technology and stimulation measures are necessary. The key core technologies in the shale gas development are horizontal well drilling technology and hydraulic fracturing technology. At present, through introduction, absorption and reinnovation, China has basically mastered the exploration and development technology of shallow shale gas below 3500 meters, and formed relative mature matching technology for exploration and development. However, some key engineering technologies and equipment still lack. For example, the special bits for ultra-long horizontal drilling and the rotary steering tools mainly rely on foreign companies. In addition, the technology and equipment of more than 3500 meters deep strata need to be broken through. These technologies seriously restrict the green and efficient development of shale gas resources in China.

3.2.4 Environmental aspect

Hydraulic fracturing is the main technology of shale gas exploitation at present, which leads to the consumption of a large amount of water resources and water environmental pollution. This is just reflected in our results that the weight of water pollution accounts for the largest proportion, up to 39.05%. The mainly pollutants involved are drilling fluid, fracturing fluid, production wastewater, etc. Due to the limitation of current technology, most water resources cannot be recycled, causing different degrees of pollution to the surface water and groundwater around the block. While the second in weight in the environmental aspect is air pollution with the value of 27.61%, which primarily contains construction dust, exhaust gas from construction machinery, methane leakage during the process of exploitation and so on. Although China attaches great importance to the ecological environment of shale gas and has accumulated some practical experience, there are still a series of problems affecting the green development of shale gas, such as imperfect environmental standards, environmental unfriendly use of chemical agents, etc.

3.2.5 Policy aspect

In the aspect of policy, the weight of finance and taxation policy and industrial technology policy accounts for a large proportion, 36.81% and 23.72% respectively, which indicates that these two policies are the main policy factors influencing the green and efficient development of shale gas in China. For the United States, shale oil and gas started with the support of government fiscal policies, and then obtained achievement through technological progress. While China's shale gas is in the stage of exploration at present, and the government has issued some finance and taxation policies to encourage shale gas enterprises to actively invest and develop. For instance, since 2019 the exploitation and utilization of unconventional natural gas are subsidized according to the principle of "more production more subsidies" instead of the quota standard, and from April 1, 2018 to March 31, 2021 the resource tax of shale gas is reduced by 30% at the prescribed rate of 6%. As for industrial technology policy, the state has not issued special scientific research support for the development of shale gas industrialization. The coverage of special policies is not enough and the scattered policies are difficult to form the policy joint force, which constrain the green and efficient development of shale gas industry.

4. CONCLUSIONS AND SUGGESTIONS

This paper selects 24 indicators from five dimensions of resource endowment, economy, technology, environment and policy to construct the evaluation indicator system of green and efficient development of shale gas resources in China, and applies the fuzzy-AHP method to comprehensively evaluate the green and efficient development of shale gas resources in China. The results show that the influencing extent on shale gas green and efficient development is resource endowment, technology, policy, economy and environment in turn, and resource endowment and development technology are the key to green and efficient development of shale gas in China. However, to realize the green and efficient development of China's shale gas, the coordinated development of various aspects is necessary. Therefore, some suggestions are put forward based on the development status of China's shale gas industry：

(1) strengthening scientific and technological research to realize the autonomous production of key technologies and equipment;

(2) enhancing the innovation of development mechanism and digital intelligent management to increase the scale development of shale gas;
(3) reinforcing the special policy support of shale gas and perfect the relevant laws and regulations, such as special technical funds, low-cost special credit and mining right regulation, etc;
(4) improving the environmental protection standard, the environmental supervision of whole process and the disclosure of environmental information to strengthen the green development of shale gas.

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