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Petroleum Security Evaluation in China --Based on DHGF and Entropy Technology Model

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Abstract – *In order to protect the national petroleum security, combining with the actual situation in China, this paper establishes evaluation index system of petroleum security in China under the background of international oil price fluctuation, determines supply, consumption, trade, geopolitics and ecology 5 basic indexes and 15 specific indexes, and applies the DHGF (the combination of Delphi method, analytic hierarchy process, gray clustering analysis method and fuzzy evaluating method) and entropy technology model to evaluate China's petroleum security situation from 1995 to 2016. The result of evaluation shows that petroleum security was in a "relative dangerous" state from 2000 to 2013 and returned to "general" from 2014 to 2016. It is a new trial on evaluation method of petroleum security to evaluate China's petroleum security situation by using the DHGF and entropy technology model, which provides a new research idea and method for petroleum security evaluation.*

Keywords – China, DHGF and entropy technology model, petroleum security evaluation.

1. INTRODUCTION

Petroleum security is the core of national energy security strategy, which means that it can guarantee the continuous supply of oil to satisfy the national multiple demands (politics, economy, society, ecology, *etc*.), no matter how the international oil price changes. In recent years, international oil prices fluctuated sharply and remained at low levels, especially from the second half of 2014 its decline accelerated, which had a great influence on China's economy and petroleum safety and so on. As China's economic development entering a new normal and vigorously promoting alternative energy, oil demand growth slows down, but foreign-trade dependence of China's petroleum in 2016 still broke 60% and oil safety still faces many challenges. Firstly, domestic petroleum entered a new phase of low-grade resources exploration and exploitation and large increase in production is difficult. Secondly, crude oil imports mainly concentrate in the geopolitical unstable areas such as the Middle East, maritime transportation is too dependent on the Straits of Malacca, and risks such as onshore transnational pipeline emergencies still exist. Thirdly, the scale of oil reserves, the level of emergency response and the quality of international oil cooperation cannot fully adapt to the recent market pattern in which the fluctuation and frequency of international oil prices increased. Facing the profound adjustment of global energy pattern and the complex external environment of drastic fluctuations of international oil prices, this paper uses the DHGF (the combination of Delphi method, analytic hierarchy process, gray clustering analysis method and fuzzy evaluating method) and entropy technology model to evaluate the situation of China's petroleum security, which is of great significance to guarantee and enhance the level of petroleum security in China.

2. LITERATURE REVIEW

In recent years, scholars at home and abroad have made a great deal of research about petroleum security evaluation which can be divided into the following two main aspects:

The first one is the research of petroleum security evaluation index. Scholars constructed the petroleum security evaluation index system mainly from the factors of resource endowment, supply guarantee and demand consumption, *etc*. However, research has its own focus from the dominant factors affecting China's petroleum security. For example, Chang and Yao (2014) updated the China's energy safety evaluation index, mainly including resource availability, technological adaptability, social acceptability and resource endurance, which got rid of the past fixed evaluation framework. Aiming at the 9 ASEAN, Kanchana and Unesaki (2015) defined oil safety evaluation in terms of supply, society and environment, and selected 35 indexes to evaluate and analyze petroleum security situation. He Xianjie *et al.* (2006) quantitatively evaluated petroleum security from six aspects: domestic resource support capability, domestic production and supply capacity, international market supply capacity, national emergency control capability and international security control capability. Based on the perspective of non-traditional security, Liu Jian and Lu Po (2016) selected 21 indexes such as oil self-sufficiency rate and strategic reserve scale from the aspects of economic security, social security and environmental security to conduct an empirical analysis of China's petroleum security situation and compared with international level. Zhou Xinjun (2017) thought that with the continuous development of information technology and promotion of global energy ecological environment protection, the scale of energy security

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would continuously expand, which provided the basis for the current definition of petroleum safety.

The second one is the study of petroleum security evaluation method. There are many different types, for example, Eta-Macrom model, Wharton model, input-output model and so on. Li Guidong and Ma Guangxing (2011) used the entropy method to comprehensively evaluate China's petroleum security and utilized GM (1,1) model to forecast the oil safety level in the next five years. Guo Wei and Zhang Yu (2013) evaluated China's energy security by applying factor analysis and 3 Sigma rule. Fan Qiufang (2007, 2014) applied BP Neural Network, Analytic Hierarchy Process (AHP) method and Fuzzy Synthetic Evaluation Model to evaluate and pre-warn China's petroleum security (Ismail et al. 2017). Based on nested models of entropy method (EM), particle swarm optimization (PSO) and support vector machine (SVM), Lv Jun (2017) conducted the evaluation and scenario prediction to China's petroleum security.

In a word, there is a lot of related research about petroleum security evaluation (Jie and Xiaojun, 2017). As the change of China's economy, politic and ecological protection awareness as well as the adjustment of world energy structure, the definition and evaluation of China's petroleum security need to be further improved. This paper attempts to evaluate the situation of China's petroleum safety by using the DHGF and entropy technology model, which is a new trial on evaluation method of oil safety and provides a new research idea and method for petroleum security evaluation (Muhasin *et al.*, 2017).

3. BASIC PRINCIPLE OF THE DHGF AND ENTROPY TECHNOLOGY MODEL

The DHGF method is a from qualitative to quantitative mathematical method which applies Delphi method, Analytic Hierarchy Process (AHP), Gray Clustering Analysis method and Fuzzy Evaluating method, combining practical experience and scientific theory (Ramli *et al.*, 2017). The DHGF method can well solve the problems of unreasonable index system establishment, complex process and poor operation in the process of evaluation, but how to reduce the subjective factors of experts cannot be completely rational. Therefore, the entropy technology is introduced to correct it. Its basic steps are as follows.

3.1 Establish the Index System and Determine the Weights

After establishing the index system, one index weight is obtained by AHP and the other is obtained by entropy method. Then the final index weight is achieved by combination weighting method.

1. AHP

Judgment matrixes are obtained by experts conducting an evaluation of importance to the index system, containing one-dimensional index weights and two-dimensional index weights. a_{ij} is identified as the relative importance of the ith index to the jth one, so $\frac{1}{a_{ij}}$ is treated as the relative importance of the jth index to ith one. The value of a_{ij} is from 1 to 9. The larger the value, the more important i is than j. Then the consistency test is necessary after judgment matrixes are formed. On the ground of passing it, the index weights are calculated by the following formulas:

$$\overline{W}_i = \sum_{j=1}^{m} \frac{a_{ij}}{\sum_{k=1}^{m} a_{kj}} \qquad W_i = \frac{\overline{W}_i}{\sum_{j=1}^{m} \overline{W}_j}$$

in which a_{ij} indicates elements of judgment matrixes, $1 \le i, j \le m$. Finally the index weights can be expressed as follows:

$$W_{1i} = [W_1, W_2, W_3, \ldots, W_m]$$

in which $0 < W_i < 1$, and $\sum_{i=1}^{m} W_i = 1$.

2. Entropy method

Entropy method is an objective weighting method which determines the weight based on the original index data, and there is no subjective interference in the process of calculation.

Firstly, a 0 to 1 standardization is conducted to the index data matrix $X = (x_{ij})_{m\times n} (1 \le i \le m, 1 \le j \le n)$ through the formula:

$$x'_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \qquad (1 \le i \le m, 1 \le j \le n) \tag{1}$$

to get the standardized matrix. Then normalization is made whose result, that is the chance of each index, can be obtained by:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \qquad (1 \le i \le m, 1 \le j \le n) \tag{2}$$

According to the formula:

$$e_i = -\sum_{j=1}^{n} p_{ij} \text{ In } p_{ij} \qquad (1 \le i \le m) \tag{3}$$

The conditional entropy value of the ith evaluation index is calculated. When the values of are too concentrated, it is necessary to make a normalization to conditional entropy values. Then the entropy value of the ith index can be calculated on the basis of:

$$e_i = -\frac{1}{\ln n}\sum_{j=1}^{n} p_{ij} \ln p_{ij} \quad (1 \le i \le m) \tag{4}$$

and applying:

$$g_i = 1 - e_i \quad (1 \le i \le m) \tag{5}$$

calculates the coefficient of variation of the *i*th index, in which the coefficient of variation is inversely proportional to the entropy value. Finally, the index entropy method weights can be determined according to

$$W_{2i} = \frac{g_i}{\sum_{i=1}^{m} g_i} \tag{6}$$

3. Combination Weighting Method

Through obtaining the AHP weights and the entropy method weights, the final result of index weights can be calculated by using the following formula:

$$\overline{W_i} = \frac{W_{1i}W_{2i}}{\sum_{i=1}^{m} W_{1i}W_{2i}} \quad (i = 1, 2, 3, ..., m) \tag{7}$$

3.2 Calculate the Evaluation Weight Matrix by Grey Clustering Analysis

3.2.1. Determine the Index Data Matrix

According to the established index system, index data is calculated and sorted out as the sample of index data by collecting the original index data. The index data matrix is expressed as:

$$X = (x_{ij})_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1 \le i \le m \ \ 1 \le j \le n)$$

3.2.2 Confirm the Evaluation Grade

The determination of evaluation grade is based on the evaluation object. $V = [V_1, V_2, ..., V_s]$ (*s* indicates the number of grade) means the size of safety degree.

3.2.3. Determine the Grey Classifications of Evaluation

Based on the evaluation grade, grey classifications are confirmed by using definite weighted functions. k subclass definite weight function of index x_i is $f_i^k(\bullet)$ and $x_i^k(1), x_i^k(2), x_i^k(3), x_i^k(4)$ are turning points of different grade of index data. Therefore typical definite weighted functions can be expressed as $f_i^k = [x_i^k(1), x_i^k(2), x_i^k(3), x_i^k(4)]$, which usually have three expressions:

a. Upper limit measure: $x_i^k(3), x_i^k(4)$ do not exist, so $f_i^k(\bullet)$ is denoted as $f_i^k = [x_i^k(1), x_i^k(2), -, -]$ and expressed to be

$$f_i^k(x_{ij}) = \begin{cases} 0 & x_{ij} \in (-\infty, x_i^k(1)) \\ \dfrac{x_{ij} - x_i^k(1)}{x_i^k(2) - x_i^k(1)} & x_{ij} \in [x_i^k(1), x_i^k(2)] \\ 1 & x_{ij} \in (x_i^k(2), \infty) \end{cases}$$

b. Intermediate measure: $x_i^k(2)$ coincides with $x_i^k(3)$, so $f_i^k(\bullet)$ is denoted as $f_i^k = [x_i^k(1), x_i^k(2), -, x_i^k(4)]$ and expressed to be

$$f_i^k(x_{ij}) = \begin{cases} 0 & x_{ij} \notin (x_i^k(1), x_i^k(4)) \\ \dfrac{x_{ij} - x_i^k(1)}{x_i^k(2) - x_i^k(1)} & x_{ij} \in [x_i^k(1), x_i^k(2)] \\ \dfrac{x_i^k(4) - x_{ij}}{x_i^k(4) - x_i^k(2)} & x_{ij} \in (x_i^k(2), x_i^k(4)] \end{cases}$$

c. Lower limit measure: $x_i^k(1), x_i^k(2)$ do not exist, so $f_i^k(\bullet)$ is denoted as $f_i^k = [-, -, x_i^k(3), x_i^k(4)]$ and expressed to be

$$f_i^k(x_{ij}) = \begin{cases} 1 & x_{ij} \in [0, x_i^k(3)) \\ \dfrac{x_i^k(4) - x_{ij}}{x_i^k(4) - x_i^k(3)} & x_{ij} \in [x_i^k(3), x_i^k(4)] \\ 0 & x_{ij} \notin (0, x_i^k(4)) \end{cases}$$

3.2.4 Calculate the Grey Statistic Numbers

Putting index data into the above definite weighted functions, the weight $f_i^k(x_{ij})\ (1 \le k \le s)$ of x_{ij} in the *k*th evaluation grade is obtained. Then grey statistic number n_{ik} of index data matrix and total grey statistic number n_i are calculated according to the following formulas:

$$n_{ik} = \sum_{j=1}^{n} f_i^k(x_{ij}) \qquad\qquad n_i = \sum_{k=1}^{s} n_{ik}$$

3.2.5. Calculate the Fuzzy Evaluation Weight Matrix

According to the formula $r_{ik} = \dfrac{n_{ik}}{n_i}$, grey weight of the ith index in the kth evaluation grade is calculated, and then the fuzzy evaluation weight matrix R is obtained:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1s} \\ r_{21} & r_{22} & \cdots & r_{2s} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{ms} \end{bmatrix}$$

3.3 Achieve the Evaluation Result by Fuzzy Comprehensive Evaluation

3.3.1 Calculate the Fuzzy Comprehensive Evaluation Matrix

Based on multiplying the above index weight $\overline{W_i}$ by the index fuzzy evaluation weight matrix *R*, the fuzzy comprehensive evaluation matrix *C* is obtained:

$$C=[C_1,C_2,...,C_s]=\overline{W_i}\cdot R=[\overline{W_1},\overline{W_2},...,\overline{W_m}]\cdot\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1s} \\ r_{21} & r_{22} & \cdots & r_{2s} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{ms} \end{bmatrix}$$

in which normalizing *C* satisfies $\sum_{k=1}^{s} C_k = 1$.

3.3.2 Obtain the Final Evaluation Result

Evaluation grade matrix Z of each year is calculated, that is $Z=[z_1,z_2,...,z_s]$. Then the final evaluation result can be obtained according to the maximum membership principle.

4. EMPIRICAL ANALYSIS

4.1 Establishment of petroleum security evaluation index system and classification of petroleum security grade

4.1.1 Establishment of Petroleum Security Evaluation Index System

According to the previous research, combined with the current international and domestic actual situation, 15 indexes are established based on the scientific, systematic, representative and operative principles from the perspective of supply, consumption, trade, geopolitics and ecology, containing 12 quantitative indexes and 3 qualitative ones (Khan *et al.*, 2017; Shoaib *et al.*, 2017). Quantitative indexes mainly come from BP world energy statistics, IEA energy statistical reports and China Statistical Yearbook. Qualitative indexes adopt experts grading method who are mainly scholars in relative research of petroleum security and industry personnel working in the petroleum industry (shown in Table 1).

Table 1. Petroleum security evaluation indexes.

Basic indexes	Specific indexes	Formulas
Supply security	Petroleum reserve production ratio	Remaining recoverable petroleum reserves/petroleum production
	Petroleum production	Petroleum production
	The level of proved petroleum reserves	Proved petroleum reserves
Consumption security	Growth rate of petroleum consumption	Petroleum consumption growth/petroleum consumption of last year
	Growth elasticity of petroleum consumption	Growth rate of petroleum consumption /growth rate of GDP
	Rate of petroleum to primary energy consumption	Petroleum consumption /primary energy consumption
Trade security	Oil price	Oil price
	Volatility of oil price	(the highest price-the lowest price）/average price of petroleum
	Foreign-trade dependence	Net annual import volume of petroleum/national annual consumption
	Import concentration	The sum of petroleum net import volume of the top 3 or top 5 countries with its largest import petroleum/total volume of its net import petroleum
Geopolitics security	Geopolitical pattern	Stabilization of geopolitical pattern
	Transportation channel safety	Stabilization and diversification of transportation channel
Ecology security	Carbon emission intensity of petroleum consumption	The influence degree of petroleum consumption on China's carbon emission
	Rate of renewable energy to energy consumption	Renewable energy consumption/total energy consumption
	Energy conversion rate	Energy conversion rate

4.1.2 *Classification of Petroleum Security Grades*

According to the 1 to 9 scaling method from T.L. Saaty, an American operational research expert, petroleum security evaluation indexes are classified into five grades: A, B, C, D and E, respectively representing safe, relative safe, general, relative dangerous and dangerous. The value represents the reduction of security level from 9 to 1. And security grade of each single evaluation index is determined mainly on the basis of general international standards, domestic and foreign economy, current situation of petroleum economic development and experts' advisement, specifically shown in Table 2.

Table 2. Petroleum security evaluation index grades and scores.

Evaluation category	Evaluation indexes	Index grades and scores				
		A (9 score)	B (7 score)	C (5 score)	D (3 score)	E (1 score)
Supply security	Petroleum reserve production ratio R_{11}	>40	25~40	12~25	5~12	0~5
	Petroleum production R_{12}	>400	300~400	200~300	100~200	0~100
	The level of proved petroleum reserves R_{13}	<30	30~45	45~55	55~75	>75
Consumption security	Growth rate of petroleum consumption R_{21}	<0	0~5	5~7	7~16	>16
	Growth elasticity of petroleum consumption R_{22}	<0.4	0.4~0.6	0.6~0.8	0.8~1.0	>1.0
	Rate of petroleum to primary energy consumption R_{23}	0~10	10~24	24~26	26~50	50~100
Trade security	Oil price R_{31}	<20	20~33	33~37	37~80	>80
	Volatility of oil price R_{32}	-20~10	10~30	30~40	40~80	>80
	Foreign-trade dependence R_{33}	0~10	10~29	29~31	31~60	>60
	Import concentration R_{34}	0~20	20~48	48~52	52~80	80~100
Geopolitics security	Geopolitical pattern R_{41}	Very stable	stable	Relative stable	dangerous	Very dangerous
	Transportation channel safety R_{42}	Very safe	safe	Relative safe	dangerous	Very dangerous
Ecology security	Carbon emission intensity of petroleum consumption R_{51}	Very low	low	general	high	Very high
	Rate of renewable energy to energy consumption R_{52}	>25	25~15	15~10	5~10	0~5
	Energy conversion rate R_{53}	>90	75~90	60~75	40~60	0~40

4.2 Determine Petroleum Security Evaluation Index Weight

4.2.1 *Determine Petroleum Security Evaluation Index Weight by AHP*

Established petroleum security evaluation index system contains 5 one-dimensional evaluation indexes and 15 two-dimensional ones. Degree of petroleum security is set as target layer A. 5 one-dimensional indexes (petroleum supply, consumption, trade, geopolitics and ecology security) are set as rule layer R, and 15 two-dimensional indexes directly influencing one-dimensional ones are set as index layer X.

Based on the assessment of petroleum security evaluation index system importance, R layer and X layer judgment matrixes of evaluation index are obtained. Then using the AHP software, R layer basic index weights and X layer specific index weights are achieved, seen in Table 3.

4.2.2 *Determine Petroleum Security Evaluation Index Weight by Entropy Method*

a. Standardizing data

Each sorted-out index data of 1995, 2000, 2005 and 2010 to 2016 (decision matrix $X=(x_{ij})_{m\times n}$)is shown in Table 4, which is conducted a standardization by the formula(1) to get the standardized matrix, seen in Table 5.

b. Calculating entropy method weights

According to the above formulas (2) ~ (6), the entropy method weights of evaluation indexes are calculated by using matlab software, shown in Table 6.

4.2.3 *Calculating Combination Weights*

On the basis of specific index weights by AHP in Table 3 and by entropy method in Table 6, combination evaluation index weights is obtained according to the formula (7), shown in Table 6.

Table 3. Index weights by AHP.

Basic indexes	Basic index weights	Specific indexes	Specific index weights W_{1i}
Supply security	0.2893	Petroleum reserve production ratio	0.1561
		Petroleum production	0.0473
		The level of proved petroleum reserves	0.0859
Consumption security	0.0483	Growth rate of petroleum consumption	0.0276
		Growth elasticity of petroleum consumption	0.0138
		Rate of petroleum to primary energy consumption	0.0069
Trade security	0.1365	Oil price	0.0190
		Volatility of oil price	0.0393
		Foreign-trade dependence	0.0678
		Import concentration	0.0104
Geopolitics security	0.4526	Geopolitical pattern	0.1509
		Transportation channel safety	0.3017
Ecology security	0.0733	Carbon emission intensity of petroleum consumption	0.0458
		Rate of renewable energy to energy consumption	0.0100
		Energy conversion rate	0.0175

Table 4. Petroleum security evaluation index data from 1995 to 2016.

Indexes	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Petroleum reserve production ratio	14.48	15.07	13	11.7	12	12.2	12.2	11.9	11.9	12
Petroleum production	149	162.6	181.4	203.0	202.9	207.5	210.0	211.4	212.6	210.5
The level of proved petroleum reserves	23.2	28.5	32.03	34.6	32.7	29.8	26.5	23.1	24.5	25.7
Growth rate of petroleum consumption	12.77	6.48	6.6	10.4	4.93	5.01	4.64	3.89	4.4	5
Growth elasticity of petroleum consumption	1.45	0.8	0.67	1	0.54	0.56	0.6	0.53	0.64	0.75
Rate of petroleum to primary energy consumption	20.4	24.6	20.9	17.6	17.7	17.7	17.8	17.5	18.6	18.8
Oil price	17.02	28.5	54.52	79.5	111.26	111.67	108.66	98.95	52.39	42.25
Volatility of oil price	7.6	58.6	42.5	28.5	39.9	0.37	2.7	8.93	47.05	19.35
Foreign-trade dependence	18.33	31.13	42.9	54.8	55.2	56.4	58.4	59.5	60.6	61.2
Import concentration	74.05	59.21	61.01	61.06	57.74	59	58.5	58.6	58.39	59.2
Geopolitical pattern	4	3	3	3	3	3	4	4	5	5
Transportation channel safety	1	3	3	3	3	3	4	4	4	4
Carbon emission intensity of petroleum consumption	1	1	3	3	3	3	3	5	5	5
Rate of renewable energy to energy consumption	6.1	6.7	7.1	9	9.1	9.4	9.7	10.3	10.4	10.6
Energy conversion rate	65.5	69.4	71.1	72.5	72.2	72.7	73	73.5	74.3	75.1

Data sources: BP Statistical Yearbook of 2016; IEA; China Statistical Yearbook.

Table 5. Standardization of oil security evaluation index data from 1995 to 2016.

Indexes	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Petroleum reserve production ratio	0.824	1.000	0.385	0.000	0.089	0.148	0.148	0.059	0.059	0.089
Petroleum production	0.000	0.213	0.509	0.849	0.848	0.919	0.959	0.981	1.000	0.967
The level of proved petroleum reserves	0.008	0.469	0.776	1.000	0.834	0.582	0.295	0.000	0.121	0.226
Growth rate of petroleum consumption	1.000	0.291	0.305	0.733	0.117	0.126	0.084	0.0000	0.057	0.125
Growth elasticity of petroleum consumption	1.000	0.293	0.152	0.510	0.010	0.032	0.076	0.000	0.1196	0.239
Rate of petroleum to primary energy consumption	0.408	1.000	0.478	0.014	0.028	0.028	0.042	0.000	0.154	0.181
Oil price	0.000	0.121	0.396	0.660	0.995	1.000	0.968	0.865	0.373	0.266
Volatility of oil price	0.373	1.000	0.847	0.715	0.823	0.448	0.419	0.360	0.000	0.262
Foreign-trade dependence	0.000	0.298	0.573	0.850	0.860	0.888	0.934	0.960	0.986	1.000
Import concentration	1.000	0.090	0.200	0.203	0.000	0.077	0.046	0.0527	0.0399	0.089
Geopolitical pattern	0.500	0.000	0.000	0.000	0.000	0.000	0.500	0.500	1.000	1.000
Transportation channel safety	0.000	0.667	0.667	0.667	0.667	0.667	1.000	1.000	1.000	1.000
Carbon emission intensity of petroleum consumption	0.000	0.000	0.500	0.500	0.500	0.500	0.500	1.000	1.000	1.000
Rate of renewable energy to energy consumption	0.000	0.133	0.222	0.644	0.666	0.733	0.800	0.933	0.955	1.000
Energy conversion rate	0.000	0.406	0.583	0.729	0.697	0.750	0.781	0.833	0.916	1.000

Data sources: calculate according to the data in Table 4.

Table 6. Index weights by entropy and combination weight method.

Indexes	Entropy method weights W_{2i}	Combination weights $\overline{W_i}$
Petroleum reserve production ratio	0.1058	0.2952
Petroleum production	0.0165	0.0140
The level of proved petroleum reserves	0.0732	0.1124
Growth rate of petroleum consumption	0.1041	0.0514
Growth elasticity of petroleum consumption	0.1165	0.0287
Rate of petroleum to primary energy consumption	0.1199	0.0148
Oil price	0.0464	0.0158
Volatility of oil price	0.0433	0.0304
Foreign-trade dependence	0.0131	0.0159
Import concentration	0.1343	0.0250
Geopolitical pattern	0.1051	0.2833
Transportation channel safety	0.0106	0.0572
Carbon emission intensity of petroleum consumption	0.0521	0.0427
Rate of renewable energy to energy consumption	0.0382	0.0068
Energy conversion rate	0.0208	0.0065

4.3 Confirm Petroleum Security Fuzzy Evaluation Weight Matrix by Grey Clustering Analysis

4.3.1 Establishment of Petroleum Security Evaluation Index Data Matrix

Original index data of petroleum security in the Table 4 is set as index data matrix

$$X = (x_{ij})_{m \times n} \ (1 \le i \le m, 1 \le j \le n, m = 1, 2...15, n = 1, 2, ...10)$$

4.3.2 Determination of Petroleum Security Evaluation Grades

China's petroleum security grades are divided into five ones: A, B, C, D and E, respectively representing safe, relative safe, general, relative dangerous and dangerous. Each index classification can be seen in the Table 2.

4.3.3. Determination of Petroleum Security Evaluation Grey Classifications

Petroleum security evaluation grey classifications are confirmed on the basis of petroleum security evaluation grade by using definite weight functions. According to the definition, the specific forms of *k* subclass definite weight functions of index x_i to $f_i^k(\bullet)\ (i=1,2,3,...,15;k=1,2,3,4,5)$ are as below.

Taking the petroleum reserve production ratio evaluation index as an example, specific expressions of established definite weight functions are also shown below.

Other indexes' definite weight functions can be achieved in the same way.

4.3.4. Confirmation of Grey Statistic Numbers and Fuzzy Evaluation Weight Matrix

Each data in petroleum security evaluation index data matrix $X=(x_{ij})_{m\times n}$ is put into corresponding definite weight functions, and then grey statistical number of each index can be calculated using the formula(8)(seen in Table 7). According to the grey statistical numbers in Table 7 and the formula (9), petroleum security fuzzy evaluation weight matrix *R* is calculated.

$$f_1^1=[-,-,0,5]\quad f_1^2=[0,5,-,12]\quad f_1^3=[5,12,-,25]\quad f_1^4=[12,25,-,40]\quad f_1^5=[25,40,-,-]$$

$$f_2^1=[-,-,0,100]\quad f_2^2=[0,100,-,200]\quad f_2^3=[100,200,-,300]\quad f_2^4=[200,300,-,400]\quad f_2^5=[300,400,-,-]$$

$$f_{14}^1=[-,-,0,5]\quad f_{14}^2=[0,5,-,10]\quad f_{14}^3=[5,10,-,15]\quad f_{14}^4=[10,15,-,25]\quad f_{14}^5=[15,25,-,-]$$

$$f_1^1(x)=\begin{cases}0 & x>5\\ \frac{5-x}{5} & 0<x<5\\ 1 & x<0\end{cases}\qquad f_1^2(x)=\begin{cases}0 & x<0,x>12\\ \frac{x}{5} & 0<x\le 5\\ \frac{12-x}{7} & 5<x\le 12\end{cases}\qquad f_1^3(x)=\begin{cases}0 & x<5,x>25\\ \frac{x-5}{7} & 5<x\le 12\\ \frac{25-x}{13} & 12<x\le 25\end{cases}$$

$$f_1^4(x)=\begin{cases}0 & x<12,x>40\\ \frac{x-12}{13} & 12<x\le 25\\ \frac{40-x}{15} & 25<x\le 40\end{cases}\qquad f_1^5(x)=\begin{cases}0 & x<25\\ \frac{x-25}{15} & 25<x\le 40\\ 1 & x>40\end{cases}$$

Table 7. Petroleum security evaluation index grey statistics.

Indexes	n_{i1}	n_{i2}	n_{i3}	n_{i4}	n_{i5}
Petroleum reserve production ratio	0.000	0.072	9.483	0.534	0.000
Petroleum production	0.000	1.074	8.347	0.579	0.000
The level of proved petroleum reserves	0.000	0.000	0.622	8.421	0.956
Growth rate of petroleum consumption	10.000	0.981	2.466	1.973	6.572
Growth elasticity of petroleum consumption	8.000	6.550	3.150	3.150	10.000
Rate of petroleum to primary energy consumption	10.000	0.000	6.050	3.798	6.500
Oil price	0.149	1.197	0.654	9.124	5.876
Volatility of oil price	9.473	2.463	0.435	2.133	6.058
Foreign-trade dependence	3.217	5.308	0.828	4.438	10.000
Import concentration	6.901	3.099	0.000	0.000	10.000
Geopolitical pattern	0.000	2.500	6.500	1.000	0.000
Transportation channel safety	0.500	3.000	6.500	0.000	0.000
Carbon emission intensity of petroleum consumption	1.000	3.500	4.000	1.500	0.000
Rate of renewable energy to energy consumption	0.000	2.580	7.160	0.260	0.000
Energy conversion rate	0.000	0.000	2.053	7.940	0.007

$$R = \begin{bmatrix} 0 & 0.0071 & 0.9399 & 0.0529 & 0 \\ 0 & 0.1074 & 0.8347 & 0.0579 & 0 \\ 0 & 0 & 0.0622 & 0.8422 & 0.0952 \\ 0.4547 & 0.0446 & 0.1121 & 0.0897 & 0.2988 \\ 0.2593 & 0.2123 & 0.1021 & 0.1021 & 0.3241 \\ 0.3795 & 0 & 0.2296 & 0.1441 & 0.2467 \\ 0.0088 & 0.0704 & 0.0385 & 0.5367 & 0.4458 \\ 0.4607 & 0.1198 & 0.0212 & 0.1037 & 0.3456 \\ 0.1352 & 0.2231 & 0.0348 & 0.1865 & 0.4203 \\ 0.3451 & 0.1550 & 0 & 0 & 0.5000 \\ 0 & 0.2500 & 0.6500 & 0.1000 & 0 \\ 0.0500 & 0.3000 & 0.6500 & 0 & 0 \\ 0.1000 & 0.3500 & 0.4000 & 0.1500 & 0 \\ 0 & 0.2580 & 0.7160 & 0.0260 & 0 \\ 0 & 0 & 0.2053 & 0.7940 & 0.0007 \end{bmatrix}$$

Table 8. China's petroleum security grade from 1995 to 2016.

Time	A	B	C	D	E	Security degree
1995	0.3107	0.1229	0.1846	0.0810	0.3009	Safe
2000	0.2607	0.0911	0.2555	0.1733	0.2195	Safe
2005	0.2072	0.1214	0.2223	0.2282	0.2207	Relative dangerous
2010	0.1852	0.1431	0.1987	0.2378	0.2352	Relative dangerous
2011	0.1295	0.1422	0.2297	0.2877	0.2109	Relative dangerous
2012	0.1080	0.1476	0.2565	0.2789	0.2089	Relative dangerous
2013	0.0997	0.1642	0.2996	0.2439	0.1925	General
2014	0.0857	0.1857	0.3272	0.2259	0.1756	General
2015	0.0805	0.1916	0.3718	0.2049	0.1512	General
2016	0.1133	0.1843	0.3405	0.1972	0.1648	General

4.4 Calculate the Final Evaluation Result by Fuzzy Evaluating

Based on $C = [C_1, C_2, C_3, C_4, C_5] = \overline{W_i} \cdot R$, fuzzy evaluation matrix of petroleum security $C = [0.0685 \quad 0.1288 \quad 0.5546 \quad 0.1754 \quad 0.0727]$ can be obtained by calculating and normalizing. Multiplying the standardized data of petroleum security evaluation index from 1995 to 2016 with petroleum security evaluation index grey statistics and making a normalization, the situation of China's petroleum security is shown in Table 8 according to the maximum membership principle.

As shown in Table 8, petroleum security degree in China fluctuated from 1995 to 2016. In 1995-2012 petroleum security state decreased gradually. During this period, with the rapid development of China's economy, growth rate of oil demand speeded up, gap between oil supply and demand expanded gradually, foreign-trade dependence increased year after year, oil price rose, geopolitical risk deteriorated and ecological environment didn't get improved very well. After 2013, international oil prices continued to fall, until now still being at low prices, which has a great influence on upstream industry of petroleum, but import costs declined relatively and China's economic development stepped into new normal, oil consumption growth slowing down, more attention to energy structure adjustment and promoting the development of green energy and low carbon. Therefore, from 2013 to 2016 petroleum security state appeared “general”.

5. CONCLUSIONS

This paper applies the DHGF and entropy technology model to China's petroleum security evaluation, which is only a brave attempt and provides a new research idea and method for petroleum security evaluation in China. Its method system still needs to be further improved and developed. Hoping that the ideas and related research in this paper can provide some reference for further studies in this field.

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