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Study on Entropy Weighting Method of Quantitative Evaluation of Energy Security: The Case of Latin America

Lijuan Wu[1,*]

[1]*College of Science, Tianjin University of Commerce, Tianjin, China*
[*]*Corresponding author*

Abstract: *To further grasp the energy security situation in Latin America and explore the main influencing factors. Based on the data of 525 energy evaluation indicators in Latin America, the global time-series principal component analysis combined with the entropy weight method is used to analyze the energy security situation in the region. The results of the study show that the energy security scores obtained from the 525 samples range from -0.012 to 0.61, indicating that there are significant differences between countries in terms of energy security. Upper-middle-income countries have a more stable energy security situation relative to high-income countries, while lower-middle-income countries need to take measures to improve their energy security situation. Energy use, energy intensity levels, and renewable energy output are the main influencing factors of energy security in the region. The research methodology is able to objectively assess the energy security score and reflect the energy security situation in Latin America. Finally, conclusions are summarized and recommendations are made with a view to informing the opportunities and challenges facing energy security in Latin America, as well as providing lessons for maintaining and focusing on energy security in our country.*

Keywords: *Energy security, Quantitative evaluation, Global time-series principal component analysis, Entropy weight method, Latin America*

1. Introduction

Energy is the basis for the development of modern society, and energy security has a direct impact on geopolitical stability, sustainable development and the level of national economies[1]. Energy security has a direct impact on geopolitical stability, sustainable development and the level of national economies. Latin America is a concentration of developing countries, and as urbanization and industrialization continue to advance, energy consumption in Latin America is increasing, and problems such as frequent climate change, high fossil energy subsidies, and poor power system infrastructure are becoming more and more prominent. As the largest developing country, China's energy situation is a key area of national concern. From the perspective of energy utilization, China, as one of the world's largest energy consumers, has a high demand for energy supply and can benefit from the diversified resources in Latin America. From a geopolitical perspective, Latin America is an important node of China's "One Belt, One Road", and China's energy investment and cooperation can not only help to ensure the stability of energy supply, but also promote the stability and prosperity of the region and enhances China's political influence. China-Latin America energy cooperation can create a win-win situation. Therefore, a comprehensive assessment of energy security is not only of great significance for guaranteeing energy stability, promoting economic growth and realizing the goal of sustainable development in Latin America, but also of reference significance for promoting China-Latin American cooperation and safeguarding China's energy security.

Energy security evaluation aims at determining the security status of energy sources and fully exploiting the comprehensive situation of the research object through multi-dimensional analysis. The current methods of energy security evaluation can be broadly categorized into two types: First, quantitative evaluation based on the security of energy supply[2–4]. The second is the quantitative evaluation system of energy security focusing on the country or region[5–7]. For example, Meng Chao et al. used BP neural network to evaluate the security of coal in China, pointing out that the security of coal usage needs to be improved[8] . Based on five-year panel data, Su Jun et al. used factor analysis to classify the energy security of 124 countries in the world into five levels, and analyzed the reasons for the evolution of the global energy pattern and its characteristics[9].There are many evaluation methods for

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energy security, but there are two deficiencies: on the one hand, the research on energy security involves a wide range of fields, and the dimensions of evaluation indicators selected by some studies are too broad or single, which makes it difficult to accurately assess the energy security situation. On the other hand, there is less attention paid to the complexity of the evaluation method model, which is too high for experimental operation, and too low to affect the experimental accuracy[10–13]. On the other hand, less attention has been paid to the complexity of the evaluation model. In view of this, this paper starts from the three dimensions of economic level, energy supply and environmental sustainability, selects the main impact indicators of energy security in Latin America, constructs the global time-series principal component analysis-entropy weighting method of Latin America's energy security evaluation method, and quantitatively analyzes the trend of energy security in Latin America from 1990 to 2014. The main research methods are: using principal component analysis to extract principal components by conditionality reduction of energy security evaluation indexes, using entropy weight method to calculate the weights of each principal component and the energy security score of each sample, and based on this, the energy security situation and the main influencing factors of Latin American countries are analyzed.

2. Overview Of The Study Area

Latin America is one of the least energy intensive regions in the world[14] , coal, oil and natural gas accounted for 74.4% of total primary energy demand in 2013. Hydroelectricity, bio fuels and waste, geothermal, wind and solar energy accounted for about 2.08 million tons of oil equivalent in 2013, which represents a decline of about 7% in the share of renewable energy in primary energy compared to the early 1970s. According to the data, Latin America uses a better share of renewable energy than the vast majority of the world's regions. However, excluding Brazil, the region's use of renewable energy has declined by about 14.2%, suggesting that there are large variations in energy use among the different countries in the region. Despite the resource endowment of the Latin American region, part of the demand for energy in this region is greater than its production. The deterioration of the Earth's climate environment, with temperatures rising year after year, the decline in the regulatory function of the Amazon rainforest, and the increase in extreme weather have made Latin America's power system a huge challenge[15] . In summary, energy security issues in Latin America are influenced by multiple factors, including energy supply, energy efficiency, and environmental sustainability. These factors are gradually becoming responsible for the stability of energy security in Latin America.

3. Data Sources And Research Methodology

3.1. Data Sources

The data used in this paper come from 1990 to 2014 and include 21 Latin American countries in the World Bank Development Indicators, as shown in Table 1.

Table 1: Income classification of Latin American countries.

high-income country	Upper middle-income countries	Lower middle-income countries
Chile, Panama, Uruguay, Trinidad and Tobago	Argentina, Brazil, Colombia, Costa Rica, Dominican Republic, Guatemala Jamaica, Mexico, Paraguay, Peru, Ecuador	Bolivia, Honduras, Haiti, Nicaragua, Suriname, El Salvador

3.2. Research Methodology

3.2.1. Selection of energy security indicators

In order to objectively and accurately evaluate the state of energy security in Latin America, this paper, based on data availability and data quality, refers to relevant literature[16–19] Thirteen indicators were selected as raw data for evaluating energy security, as shown in Table 2.

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Table 2: Description of Latin American indicators.

Variable	Indicator	unit
Emis1(x_1)	CO2 emissions (kg per 2010 US$ of GDP)	kg
Emis2(x_2)	CO2 emissions (metric tons per capita)	metric tons
Emis3(x_3)	CO2 emissions from electricity and heat production, total (% of total fuel combustion)	%
Emisi(x_4)	CO2 intensity (kg per kg of oil equivalent energy use)	kg
Electrate(x_5)	electrification rate	%
Eloss(x_6)	Electric power transmission and distribution losses (% of output)	%
Eimp(x_7)	Energy imports, net (% of energy use)	%
Enei(x_8)	Energy intensity level of primary energy	MJ/$2011 PPP GDP
Eneu1(x_9)	Energy use (kg of oil equivalent per capita)	kg of oil equivalent
Eneu2(x_{10})	Energy use (kg of oil equivalent) per $1000 GDP (constant 2011 PPP)	kg of oil equivalent
Foss(x_{11})	Fossil fuel energy consumption (% of total)	%
Rene1(x_{12})	Renewable electricity output (% of total electricity output)	%
Rene2(x_{13})	Renewable energy consumption (% of total final energy consumption)	%

3.2.2. Methods of analysis

Global time-series principal component analysis (GTPCA) arranges the cross-sectional data from traditional principal component analysis into a global time-series data table according to time, and then performs the dimensionality reduction analysis of energy security composite indexes. The Entropy weight method (EWM) can objectively assign principal component weights to avoid information overlapping[20]. GTPCA-EWM can simplify the evaluation index system and avoid the problem of cross-information caused by subjective weighting[21]. The main steps of the above method are. The main steps of the above method are: (1) KMO test and Bartlett's test of sphericity. (2) data standardization. (3) calculation of correlation coefficient matrix. (4) calculation of eigenvalues and eigenvectors of the correlation matrix. (5) selection of the first k principal components whose eigenvalue of the common factor is greater than 1 and whose cumulative variance contribution rate is greater than 85% and calculation of factor scores with the following equation for the factor scores:

$$F_k = \alpha_{k1}X_{k1} + \alpha_{k2}X_{k2} + \alpha_{k3}X_{k3} + \ldots \alpha_{kmxkm}(k = 1, 2, 3, \ldots, s) \tag{1}$$

Where x is the standardized original index data, α is the factor coefficients of each component. (6) Min-Max standardization of each principal component. (7) calculation of the information entropy of each principal component. (8) information utility value according to the information entropy. (9) determination of the weights of each principal component w_k In order to better characterize the energy security situation and quantitatively evaluate the composite scores, the scores of each principal component are first multiplied by the weights of the previous k principal components and then accumulated to obtain the energy security composite score, which is calculated as the formula for the energy security composite scores. In order to better characterize the energy security situation and quantitatively evaluate the comprehensive score, each principal component score and the first k principal component weights are multiplied and then added up to obtain the comprehensive energy security score, whose formula is

$$F = \sum_{K=1}^{S} w_K \times F_K \tag{2}$$

4. Energy security assessment in Latin America

4.1. Regional energy security profiles

Descriptive statistical analysis of the time-series data table shows that the average value of net energy imports (Eimp) is-3.588, a negative value that indicates that all 21 Latin American countries were net exporters of energy between 1990 and 2014. The average value of energy consumption from fossil fuels (Foss) is 64.953 and the value of renewable energy consumption (Rene2) is 35.335, with the former being

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almost twice as high as the latter. The percentage of renewable energy generation (Rene1) is 54.583%, which indicates that renewable energy accounts for 1/2 of the total electricity generation in Latin America (Table 3). Therefore, we can interpret this as the presence of several net exporters of energy in the LAC region during the period, with more dependence on fossil fuels than on renewable energy sources.

Table 3: Descriptive statistics of raw data.

Variable	Obs	Mean	Std. Dev.	Min	Max
Emis1	525	0.381	0.215	0.021	1.727
Emis2	525	2.291	2.398	0.025	15.676
Emis3	525	28.957	15.031	0.000	71.399
Emisi	525	1.905	0.617	0.132	3.825
Electrate	525	1406.148	1097.005	18.969	6661.101
Eloss	525	16.090	9.970	0.000	66.490
Eimp	525	-3.588	79.271	-294.762	90.327
Enei	525	5.106	3.326	2.273	21.148
Eneu1	525	1282.055	2002.822	191.883	14228.582
Eneu2	525	10.075	3.334	2.069	18.727
Foss	525	64.953	21.779	4.393	99.930
Rene1	525	54.583	29.518	0.000	100.000
Rene2	525	35.335	21.800	0.350	95.040

4.2. Determination of the principal components of the evaluation

Principal component analysis was applied to downscale the 13 main energy indicators, including Emis1, Emis2, and Emis3. The specific evaluation process is as follows:

4.2.1. Data standardization

The original data were standardized for polar deviation and the correlation coefficient matrix was plotted, and as can be seen in Figure 1, the absolute value of the correlation coefficient between most of the variables is greater than 0.5, and the variable correlation between Foss and Rene2 is the highest of 0.96, which indicates that the variable correlation between the indicators is stronger, and there is a certain amount of information overlap, which makes it suitable for dimensionality reduction by applying GTPCA.

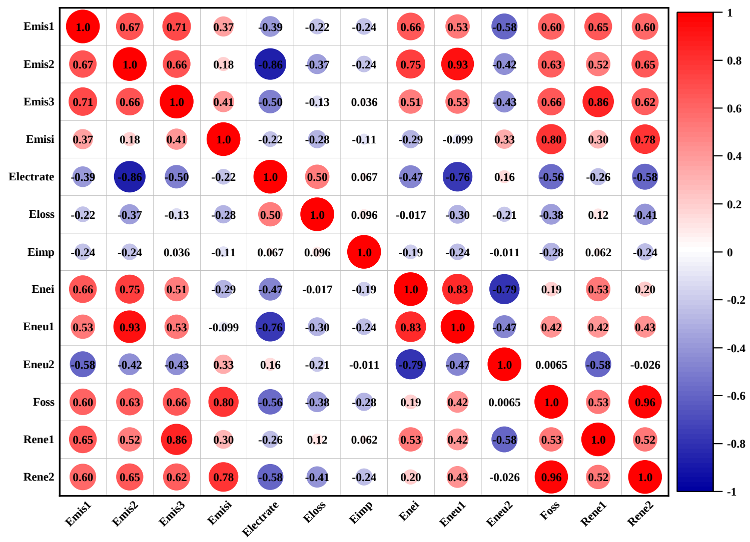

Figure 1: Correlation coefficient matrix.

4.2.2. Calculation of eigenvalues and cumulative variance contribution

From Figure 2, we can see that the eigenvalues of the first four principal components are 6.271, 2.647, 1.633, and 1.060, with a cumulative contribution rate of 89.3%, which indicates that the first four principal components basically include the information of the 13 energy indicators. Therefore, the first four principal components were selected as the public factors for evaluating energy security in Latin America.

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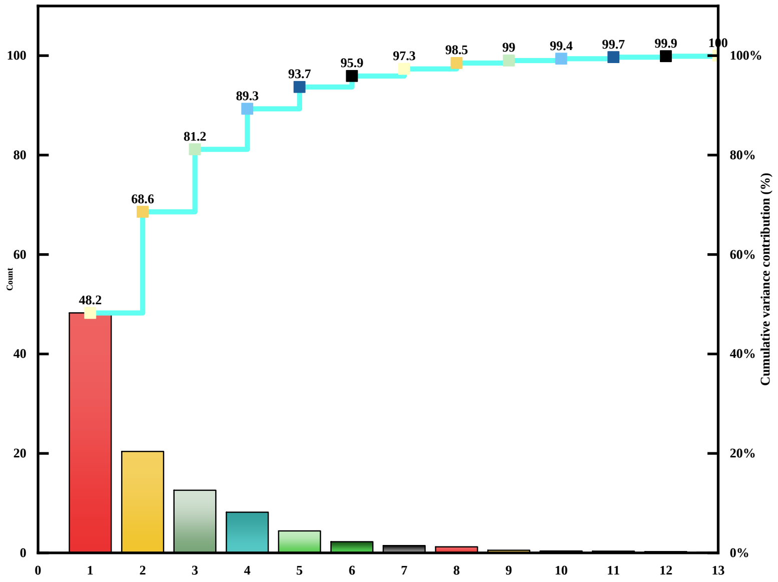

Figure 2: Plot of eigenvalues, principal component contributions and cumulative contributions.

4.2.3. Calculation of rotating factor loadings and determination of evaluation indicators

Observing the interrelationships of the variables within the composite index (see Table 4), the absolute values of the factor loadings of Enei, Rene1, Emis1, Emis3, Eneu1, Eneu2 in the first principal component are all higher than 0.6, and these indexes can be considered to be a composite measure of the level of the energy economy. The factor loadings of Emisi, Foss, and Rene2 in the second principal component are all higher than 0.8. The second principal component of Emisi, Foss and Rene2 factor loadings are all higher than 0.8, of which Emisi and Foss loadings reach 0.946 and 0.881, these indicators mainly point to a comprehensive measure of carbon emissions, per capita fossil energy consumption and renewable energy consumption factors. The third principal component of Emis2, Eneu1, Electrate, Eloss loadings of these indicators can be regarded as a comprehensive measure of the energy supply. The fourth principal component of Eimp loadings of up to 0.6. Eimp in the fourth principal component has a high loading value of 0.971, this indicator can be measured by net energy imports. It can be seen that the environment, energy supply and energy economy are important factors affecting energy security in Latin America.

Table 4: Factor loadings analysis table.

Variable	Component 1	Component 2	Component 3	Component 4
Emis1	**0.675**	0.51	0.179	-0.187
Emis2	0.586	0.298	**0.713**	-0.14
Emis3	**0.635**	**0.617**	0.2	0.209
Emisi	-0.233	**0.946**	0.038	-0.017
Electrate	-0.257	-0.246	**-0.866**	-0.047
Eloss	0.264	-0.224	**-0.749**	0.034
Eimp	-0.045	-0.121	-0.058	**0.971**
Enei	**0.886**	-0.115	0.352	-0.17
Eneu1	0.628	0.027	**0.710**	-0.173
Eneu2	**-0.913**	0.141	0.049	-0.017
Foss	0.155	**0.881**	0.354	-0.165
Rene1	**0.751**	0.541	-0.077	0.201
Rene2	0.155	**0.859**	0.388	-0.134

4.3. GTPCA-EWM Composite Score and Evaluation

Based on the time-series principal component analysis method to determine the four main indicator factors for energy security evaluation, the entropy weight method is used to calculate the weight of each evaluation indicator. The weights of this indicator system under the three assignment methods are listed (see Table 5). It is found through calculation that GTPCA uses the cumulative variance contribution rate to assign weights, and the weight sum is 89.3%, which is not normalized. As can be seen from Figure. 1,

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there is correlation between the indicators of the principal components, and there is the problem of overlapping of information resulting in the duplication of the invalid information to be assigned; and GTPCA-EWM, the weight of F_1 is enhanced by 26.4% compared with EWM, F_2 decreases by 9.9%, F_3 decreases by 8.4%, and F_4 decreased by 8%. This suggests that the increase in the composite measure of energy economy level comes from the redistribution of overlapping information on F_2 , F_3 and F_4 .

Table 5: Comparison of the weights of the three methods.

ingredient / methodologies	F_1	F_2	F_3	F_4
GTPCA	0.482	0.204	0.126	0.0815
EWM	0.247	0.304	0.230	0.218
GTPCA-EWM	0.511	0.205	0.146	0.138

This leads to the GTPCA-EWM composite score calculation formula:

$$F = 0.07X_1 + 0.06X_2 + 0.13X_3 - 0.01X_4 - 0.04X_5 + 0.04X_6 + 0.13X_7 + 0.08X_8 + 0.05X_9 - 0.12X_{10} + 0.02X_{11} + 0.14 X_{12} + 0.02X_{13} \quad (3)$$

Equation (c) is a model for the comprehensive evaluation of energy security in Latin America, which is substituted into the indicator data to obtain a comprehensive energy security score for the 21 countries.

4.3.1. Trends in energy evolution based on time series

The trend in the energy security scores of the countries is shown in Figure 3. The results show that the energy security scores of Chile, Panama, Uruguay, and Trinidad and Tobago have generally shown a downward evolution from 1990 to 2014, but have improved, with the decline in the composite scores of each country remaining within 0.06 in 2014, which suggests that the issue of energy security is not only related to the level of the economy, but is also influenced by factors such as the environment, energy supply and energy efficiency. The energy security scores of Latin American countries at the upper-middle-income level have followed an almost uniform evolution, with Colombia, the Dominican Republic, Jamaica and Paraguay experiencing increases in their energy security scores. Guatemala's energy security score declined by about 9 percent around 2000 compared to 1990, making it one of the most energy-insecure upper-middle-income Latin American countries. Jamaica maintains the lowest energy security score among upper-middle-income countries. Energy security is more stable in upper-middle-income countries relative to high-income countries. The energy security scores of Latin American countries at the lower and middle income levels have continued to decline. Of these, Haiti, Honduras and El Salvador saw their composite scores drop by about 20 per cent, 19 per cent and 10 per cent, respectively. The energy economies of countries at the lower and middle income levels are more susceptible to disruptions in the volatile international market, and reducing dependence on imported energy sources is a top priority in addressing the energy security of this group of countries.

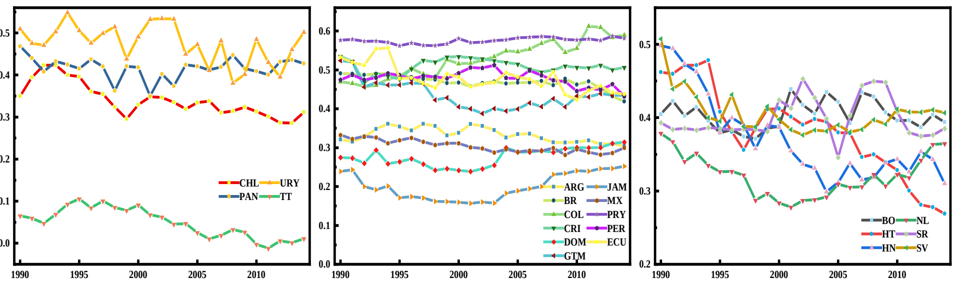

Figure 3: Trends in composite energy security scores for three different income countries.

4.3.2. Characterization of the spatial evolution pattern of energy resources

Based on the ArcGIS 10.7 software to select the natural breakpoint method, the energy security situation in Latin America was categorized into four classes: hazardous, more hazardous, transitional, and safer according to the composite scores, drawing on the approach of Jun Su et al. [9] . As can be seen from Figure 4: (1) In 1990, only the Dominican Republic, Jamaica, and Trinidad and Tobago were in the energy hazardous type class; countries belonging to the energy safer type were Guatemala, Costa Rica, Ecuador, and Paraguay. The ratio of the number of the four classes is 3:6:8:4, with more countries in the intermediate class, revealing that these countries are in the middle of the scale in terms of energy supply, sustainability, and economic level, indicating that Latin American countries have the potential to improve their energy security situation. (2) In 2002, Chile, Argentina, Honduras, Haiti, and Mexico shifted from the more hazardous energy type to the hazardous type; Uruguay and Colombia improved their energy situation to the more secure type. The ratio of the number of the four classes is 8:3:6:4, revealing the urgent need to improve the situation of Latin American countries in terms of energy security. (3) In 2014, Chile, Argentina, Honduras, and Haiti re-entered the energy more dangerous type class; Guatemala and El Salvador fell into the energy more dangerous type class; and Suriname and Bolivia were among those that entered the transitional type class. The ratio of the number of the four grades is 5:6:5:5, indicating the diversity of the energy security situation in Latin American countries, reflecting the concern of Latin American countries about energy security and their active improvement of the energy security situation through the adoption of positive measures.

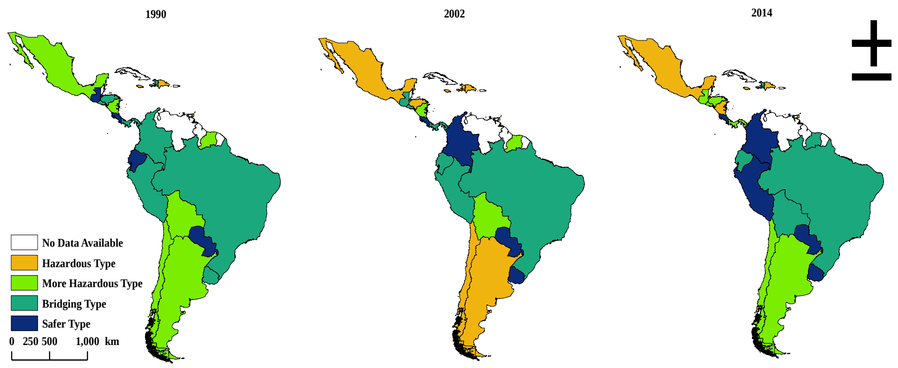

Figure 4: Evolution of the spatial distribution of energy security in Latin America.

5. Conclusions

The results of the analysis of energy security trends in Latin America from 1990-2014 through the construction of the Latin American Energy Security Evaluation Model show that:

(1) The fluctuating downward trend in the energy security of high-income countries indicates that such countries have a high economic level but rely on imported energy and have not fully developed renewable energy, resulting in a lack of stability in energy security.

(2) The energy security of high and middle-income countries shows a "one" shaped evolutionary trend, indicating that such countries are less dependent on imported energy and that the development of renewable energy is more mature, which contributes to relatively stable energy security.

(3) The continuing deterioration of the energy security situation in low and middle-income countries shows that the low utilization of renewable energy, insufficient energy supply and lagging economic level of such countries have led to the deterioration of energy security.

(4) The energy security rating of the Latin American region shows a spatial pattern in which the center is safer and the ends are more dangerous. The Amazon River provides water resources for the central region, which contributes to the relatively safe energy situation in the central region, while the two ends of the region are more dependent on other energy sources, resulting in a more dangerous energy security situation.

The conclusions of the study are of great practical significance for promoting the sustainable development of Latin American countries, and also provide useful reference for China's energy security. In order to improve energy security in Latin American countries in the future, it is recommended that breakthroughs be made in energy supply, diversified energy sources, energy policy, green investment and cooperation.

References

[1] Bazilian M, Bradshaw M, Goldthau A, et al. Model and manage the changing geopolitics of energy. Nature, 2019, 569(7754): 29-31.
[2] Yang Y, Zheng X, Sun Z. Coal Resource Security Assessment in China: A Study Using Entropy-Weight-Based TOPSIS and BP Neural Network. Sustainability, 2020, 12(6): 2294.
[3] Iqbal W, Fatima A, Yumei H, et al. Oil supply risk and affecting parameters associated with oil

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supplementation and disruption. Journal of Cleaner Production, 2020, 255: 120187.
[4] Tao Ran, Cai Yunze, Lou Zhenfei, et al. Comprehensive research of domestic and foreign energy forecast model and energy safety appraisal systems. Shanghai Energy Conservation, 2012(1): 16-21.
[5] Huang B, Zhang L, Ma L, et al. Multi-criteria decision analysis of China's energy security from 2008 to 2017 based on Fuzzy BWM-DEA-AR model and Malmquist Productivity Index. Energy, 2021, 228: 120481.
[6] Wu TH, Chung YF, Huang SW. Evaluating global energy security performances using an integrated PCA/DEA-AR technique. Sustainable Energy Technologies and Assessments, 2021, 45: 101041.
[7] Shittu W, Adedoyin FF, Shah MI, et al. An investigation of the nexus between natural resources, environmental performance, energy security and environmental degradation: Evidence from Asia. Resources Policy, 2021, 73: 102227.
[8] Meng Chao,Hu Jian.A research on China' s coal mine safety evaluation based on BP neural network.Science Research Management,2016,37(8):153-160.
[9] Su Jun, Wang Yongxun, Wang Qiang. Pattern evolution of global energy security and the geopolitical game. Journal of Natural Resources, 2020, 35(11): 2613-2628.
[10] Liang Jinqiang, Liu Danzhu, Xu Shuliang, et al. Quantitative evaluation method of energy security under dual carbon target. Chemical Industry and Engineering Progress, 2022, 41(3): 1622-1633.
[11] Ang BW, Choong WL, Ng TS. Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews, 2015, 42: 1077-1093.
[12] Šprajc P, Bjegović M, Vasić B. Energy security in decision making and governance-Methodological analysis of energy trilemma index. Renewable and Sustainable Energy Reviews, 2019, 114: 109341.
[13] Shi, D, Xue, Q. Influencing Factors, Evaluation and Outlook of Primary Energy Security in China. Econ. Rev,2021, 1, 31–45.
[14] Mahlknecht J, González-Bravo R, Loge FJ. Water-energy-food security: A Nexus perspective of the current situation in Latin America and the Caribbean. Energy,2020, 194: 116824.
[15] Balza L, Espinasa R, Serebrisky T. Lights On?: Energy Needs in Latin America and the Caribbean to 2040. 2016.
[16] Le TH, Chang Y, Taghizadeh-Hesary F, et al. Energy insecurity in Asia: A multi-dimensional analysis. Economic Modelling, 2019, 83: 84-95.
[17] Alemzero DA, Sun H, Mohsin M, et al. Assessing energy security in Africa based on multi-dimensional approach of principal composite analysis. Environmental Science and Pollution Research, 2021, 28(2): 2158-2171.
[18] Abdullah FB, Iqbal R, Hyder SI, et al. Energy security indicators for Pakistan: An integrated approach. Renewable and Sustainable Energy Reviews, 2020, 133: 110122.
[19] Hock D, Kappes M, Ghita B. Entropy-Based Metrics for Occupancy Detection Using Energy Demand. Entropy, 2020, 22(7): 731.
[20] TIAN Shuicheng,SHEN Zhangjin. Safety evaluation of coal mine flooding based on entropy method and catastrophe theory. Journal of Xi'an University of Science and Technology,2022,42(6) : 1064-1070.
[21] Tian Fujin, Ma Qingshan, Zhang Ming, Tang Zhimin. Evaluation of water quality in Xin'anjiang River Basin based on principal component analysis and entropy weight method. Geology in China, 2023, 50(2): 495-505.