An Empirical Analysis of China's Energy Security Based on TOPSIS Model

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Abstract. Within the last twenty years, China has become a net importer of coal, oil and natural gas. China's energy security becomes increasingly important. The paper analysed the energy production and consumption of China, and described the change of China's energy security strategy. This research constructed an evaluation system from five dimensions of reserve security, production and transmission security, trade security, consumption security and sustainability. By adopting the grey related TOPSIS model, the research examined the energy security level of China from 2005 and 2019. The paper proposed countermeasures and suggestions to improve energy security level of China.

1. Introduction

Energy is one of the most important resources for economic development in the world. However, the uneven global distribution of energy and the rapid increase of energy consumption to support the global development have made energy as a key strategic resource (Li, 2020; Lu et al., 2019; Yan, 2016; Wei, 2012). Consequently, energy security is a key component of national security with strategic attributes.

Energy security involves many disciplines and the academic community has not reached a consensus on its concept. The traditional concept was based on the reliable and adequate supply of energy at reasonable prices (Maull, 1984; International Energy Agency (IEA), 1985; Chang and Lee, 2008; Yao and Chang, 2014). As environment and ecological sustainability has been increasingly drawing public attention, the environment sustainability has been added to the energy security concept (Li, 2020; Lu et al., 2019; Yao and Chang, 2014). For example, according to Wei et al. (2012) the energy security was a reliable, affordable and sustainable energy supply that meets the needs of economic development without damaging ecological sustainability. There had been many attempts in the energy economics literature to construct evaluation index system for energy security. Shannon-Wiener Index (SWI) and Herfindahl-Hirschman Index (HHI) were two main indexes. The former measured the diversification of energy varieties and the latter measured the concentration of markets. Gupta (2008) incorporated factors such as political risks on the basis of HHI to get a new composite index. The Asia Pacific Energy Research Center developed the 4A framework with international influence, which included the availability, accessibility, acceptability and affordability (Yao and Chang, 2014).

Within the last twenty years, China has become a net importer of coal, oil and natural gas (Odgaard and Delman, 2014; Yan and Xu, 2018). Due to the strategic nature of energy, prominent ecological damage, and geopolitical reasons, China's energy security becomes increasingly important (Leung, 2011; Lu et al., 2019; Yan, 2018). Therefore, a comprehensive evaluation of China's energy
security has an important theoretical and practical significance. The purpose of this research aims to construct an evaluation system from five dimensions, which including reserve security, production and transmission security, trade security, consumption security and sustainability. By adopting the grey related TOPSIS model, the research aims to examine the energy security level of China in the new normal era.

2. Current Situation of China's Energy Security

2.1 The energy production and consumption of China

China's energy production and consumption has grown rapidly during the last twenty years following its economic growth. From 2005 to 2019, China's energy production increased from 66.37EJ to 115.83EJ, with an average growth rate of 4.60%. In 2019, China's output of oil, gas, coal, nuclear energy and renewable energy were 8.57EJ, 6.39EJ, 79.82EJ, 3.11EJ and 17.95EJ respectively. Renewable energy grew rapidly, the production share had increased from 5.95% in 2005 to 15.49% in 2019 (BP, 2020). China's energy self-sufficiency had fallen from 87.02% in 2005 to 78.56% in 2019, due to the decreasing of self-sufficiency rates of oil and natural gas.

As a major energy importer, China is directly affected by international energy prices, especially international oil prices. In 2019, the average global crude oil spot price was US$62.40 per barrel, a year-on-year decrease of 10.37% (BP, 2020). In addition, due to political reasons, the price of crude oil imported from Middle East countries by China and other Asian countries is generally higher than that of European and American countries, known as the “Asia premium”. China imports a large amount of oil and natural gas, and the sources are relatively concentrated. The Middle East and West African countries were China's main sources of crude oil, accounting for 44.41% and 15.35% of China's imports in 2019 respectively. Australia and Qatar were China's main sources of LNG, accounting for 46.95% and 13.49% of China's imports in 2019 respectively. Although China is rich in coal resources, the cost of mining and transportation is high. Therefore, the domestic price is generally higher than import price, so that a small amount of coal is imported every year. Indonesia and Australia were China's main sources of coal, accounting for 34.21% and 32.27% of China's imports in 2019 respectively.

China's energy demand increased from 2005 to 2019 at an average growth rate of 5.22%, which had shown a downward trend as the economy has shifted into the "new normal". Green development is an inevitable choice for China's economic and social transformation and development. It’s worth noting that China's energy consumption had grown rapidly from 2010 to 2019, with an average annual growth rate of 7.43%. Among the different types of energy, the consumption of renewable energy grew rapidly, with the proportion of consumption rising from 5.22% in 2005 to 12.66% in 2019. Nevertheless, the excess demand for power generation still needed to be met by coal, resulting in a year-on-year growth of 2.31% in coal consumption in 2019, and the fuel structure for power generation had not been significantly optimized.

During the period of rapid industrialization and urbanization, China's energy activities have brought ecological problems. The ecological problems were reflected in the high energy intensity and high carbon emissions. In 2019, the average energy consumption per 10,000 US dollars of GDP was 122.82 GJ, a decrease of 42.13% compared with that of 2005 (BP, 2020). The emission of carbon dioxide was 9,825.80 million tons, an increase of 61.13% compared with that of 2005. Total of 8.52 tons of CO₂ were emitted per 10,000 dollars of GDP in 2019, with the decrease of 50.25% compared to that of 2005(BP, 2020). In 2019, China pledged to reduce its carbon emissions per unit of GDP by 40% to 45% by 2020 compared to that of 2005 at the Copenhagen Climate Conference.

2.2 China's energy security strategy

In July 2006, Chinese government put forward a new energy security concept featuring mutually beneficial cooperation, diversified development, and coordinated guarantee. In 2014, Chinese
government proposed the "Four Revolutions, One Cooperation" energy security strategy to prevent various energy security risks.

China has adjusted its energy consumption structure and improved energy efficiency, setting "carbon neutrality" as a strategic goal. In September 2020, China announced that it would strive to reach its peak carbon emissions by 2030 and achieve carbon neutrality by 2060. In response to this, China has adhered to the basic national policy of conserving resources and protecting the environment, and adopted a series of measures such as the development of clean energy and the establishment of a unified carbon market. On the other hand, China has promoted the diversification strategy of energy foreign relations and established energy security dialogue and cooperation mechanisms with other countries. China has maintained friendly energy relations with many countries, such as Russia, Saudi Arabia, Angolan, Iran, etc. In March 2021, China and Iran signed a 25-year comprehensive cooperation agreement including oil purchases. In recent years, China and Russia have had close energy relations and increased cooperation in the construction of oil and gas pipelines. In addition, China actively has participated in various bilateral and multilateral energy cooperation and dialogues. For example, China regularly holds regular energy cooperation conferences with the EU, established an energy cooperation committee with Russia and established an energy forum with Indonesia.

3. Development of An Empirical Model to analyze China's Energy Security

3.1 Evaluation index system designing

In terms of index selection, this research follows six design principles of comprehensive evaluation index system, including maneuverability, independence, dynamics, intentionality, significance and completeness. The paper takes energy security as the target layer, establishes a three-level system, screens out 13 indicators, as shown in Table 1. The time span was 2005-2019. Data sources are adopted from BP, EIA, World Bank, UNCTAD, UN Comtrade and International Country Risk Guide.

| Metric          | Index                                | Unit  | Type  |
|-----------------|--------------------------------------|-------|-------|
| Reserve security| Proved reserves of oil, coal and natural gas | EJ    | Positive |
|                 | Production of key minerals /total world production | %     | Positive |
| Production transmission security | Production/consumption of oil, natural gas and coal | %     | Positive |
|                 | Production diversity in the form of SWI |       | Positive |
|                 | Power loss/total power generation    | %     | Negative |
| Trade security  | Import concentration in the form of HHI |       | Negative |
|                 | Energy consumption/total population  | J/person | Positive |
| Consumption security | Population with electricity/total population | %     | Positive |
|                 | Consumption diversity in the form of HHI |       | Positive |
|                 | Clean energy consumption/total consumption | %     | Positive |
| Sustainability  | Renewable energy power /total power generation |       | Positive |
|                 | CO2 emissions / GDP                  | t/ USD | Negative |

3.2 Evaluation method

Assuming the initial sample $X=(x_{ij})_{m\times n}$, $x_{ij}$ is the value of the year i under the index j, $i=\{1,2,...,m\}$, $j=\{1,2,...,n\}$. Firstly, the data was pre-processed by calculating the correlation coefficient and VIF by using extreme method to keep the independence and comparability. Secondly, this paper used entropy, gray relational and TOPSIS to construct an evaluation model. Entropy method was used for index
weight evaluation, and gray relational analysis method and TOPSIS were used for comprehensive evaluation. The main steps were as follows:

Calculating the proportion of the evaluation year under the evaluation index:
$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Calculating the entropy value of the indicator:
$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij}$$

Calculating the coefficient of variance of the index:
$$\gamma_j = 1 - e_j$$

Calculate the weight of each indicator:
$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

Calculating the weighted normalization matrix:
$$z_{ij} = w_j \times x_{ij} \quad i = \{1, 2, ..., m\}, j = \{1, 2, ..., n\}$$

Calculating the gray correlation coefficient matrix and $\rho$ was 0.5:
$$R^+ = (r_{ij}^+)_{m \times n}, R^- = (r_{ij}^-)_{m \times n}, r_{ij}^+ = \min_i \min_j \frac{\max_j z_i^+ - z_{ij}}{\max_j z_i^+} + \rho \max_j \max_i |z_i^+ - z_{ij}|$$
$$r_{ij}^- = \min_i \min_j \frac{\max_j z_i^- - z_{ij}}{\max_j z_i^-} + \rho \max_j \max_i |z_i^- - z_{ij}|$$

Calculating the gray correlation degree:
$$r_i^+ = \frac{1}{n} \sum_{j=1}^{n} r_{ij}^+$$
$$r_i^- = \frac{1}{n} \sum_{j=1}^{n} r_{ij}^-$$

Calculating the euclidean distance:
$$d_i^+ = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_{ij}^+)^2}$$
$$d_i^- = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_{ij}^-)^2}$$

Dimensionless processing of grey relational degree and euclidean distance and merge together:
$$T_i^+ = \alpha R_i^+ + \beta D_i^+, \quad T_i^- = \alpha R_i^- + \beta D_i^-$$

Calculating the close degree, the greater the degree, the better the energy security system in the year:
$$S_i^+ = \frac{T_i^+}{T_i^+ + T_i^-}$$

The greater the value of the degree of closeness finally obtained, the better the status of the energy security system in the evaluation year, and vice versa.

4. Evaluation Results Analysis and Implications

4.1 Empirical result analysis

The static driving mechanism of China's energy security could be analyzed from the weight. Assuming that the weight of the target layer was 1, the weight of each evaluation index was determined according to the entropy method. In the indicator layer, the weight of production and consumption diversity, reserves and clean energy share were all greater than 0.1000, which were
were greater than 0.2000, which were 0.2581, 0.2436 and 0.2145 respectively. Thus the three important dimensions together accounted for 71.62%. If the first three dimensions in the measurement layer were regarded as energy supply-side security and the latter two dimensions were regarded as energy use-side security, the energy supply-side security was slightly higher than the energy use-side securities which were 0.5275 and 0.4725 respectively. It could find that China's energy security was based on supply, and stressed the importance of sustainability, production-transmission. In addition, renewable energy generation had become an important development area that affected energy security level of China.

China energy security evaluation results are shown in the Table 2. As shown in the table, the energy security evaluation result was 34.5 in 2005, but fell to dangerous and relatively level with grade of 30.0 in 2006. Since then, the China's energy security had improved and achieved an increase of 100.94% from 2005 to 2019. The dynamic driving mechanism of China's energy security could be analyzed from the dimension evaluation. Sustainability, consumption safety and production-transmission safety increased by 38.82 %, 22.10% and 15.30% respectively from 2005 to 2019, with sustainability being the most prominent. The rapid improvement of China's energy security was mainly due to the rapid improvement of the diversification of production and consumption, as well as the greatly reduced carbon intensity. Although China's energy security improved in the past fifteen years, it reached relatively safety level. Thus more measures were needed to adopt to improve energy security level of China.

Table 2 China Energy Security Evaluation Results

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Score | 34.5 | 30.0 | 31.5 | 35.2 | 34.0 | 41.7 | 41.4 | 44.9 | 49.6 | 55.7 | 61.9 | 64.6 | 66.8 | 67.9 | 69.4 |

4.2 Implications to improve China’s energy security

In view of the supply side, China should establish a diversified and stable energy supply system. Firstly, it needs to enhance the diversification of energy consumption and production for China. This requires greater efforts in the exploration of traditional energy resources, as well as the development of new energy resources. On the other hand, China should increase import diversification. This requires expanding overseas markets and reducing market concentration. Secondly, China need to stabilize energy prices, give full play to the role of the market mechanism and promote the formation of an energy price mechanism in the Asian market. Asian energy consuming countries should strengthen cooperation, jointly adjust crude oil reserves, actively participate in the price setting of Asian energy markets, and jointly resist the risks of international energy price fluctuations.

In view of the demand side, China should optimize the energy consumption structure and promote the low-carbon transformation of the energy system. China could set “red lines” for total consumption and encourage enterprises to research and develop energy-efficient technologies through subsidies and other preferential policies. On the other hand, the government should promote to use clean energy. In terms of institutional design, China can implement a renewable energy quota system and a green certificate trading mechanism. In terms of concrete operation, the government should promote a distributed renewable energy power generation model which is connected to the grid and consumed nearby.

China should actively carry out relevant international cooperation, establish a multilateral dialogue and cooperation mechanism and deepen the reform of the cooperation mechanism. Firstly, China should increase energy development cooperation with neighboring countries, step up cooperation on exploration of traditional energy, promote the construction of cross-border pipelines and the interconnection of power grids. Secondly, China can rely on the “B&R” initiative to build a regional energy supply and demand sharing platform where countries carry out technological exchanges and
uniform trading rules, and form a community with a shared future on energy security. This will help increase China's voice in global energy security governance.

5. Conclusions
China's energy security issues become increasingly important with the rapidly growing economy. The fast growing consumption of energy has made China increasingly dependent on imports of energy. This research constructed an evaluation system from five dimensions of reserve security, production and transmission security, trade security, consumption security and sustainability. By adopting the grey related TOPSIS model, the research examined the energy security level of China in the 21st century. The research showed that China's energy security level stood at 69.39 in 2019 and was at a safe level. The energy security level increased 100.94% over 2005. The improvement of China's energy security was mainly due to the diversification of energy production and consumption, as well as the development of renewable energy.

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