Hindawi
Mathematical Problems in Engineering
Volume 2018, Article ID 3605024, 16 pages
https://doi.org/10.1155/2018/3605024

Research Article

A Dynamic Approach to Measuring China's Provincial Energy Supply Security along "the Belt and Road"

Pin Li,[1,2] Jin-suo Zhang ,[3] Jian Xu ,[2] and Ping Wang[2]

[1] *School of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an 710054, China*
[2] *Research Center for Energy Economy and Management, Xi'an University of Science and Technology, Xi'an 710054, China*
[3] *School of Economics and Management, Yan'an University, Yan'an 716000, China*

Correspondence should be addressed to Jin-suo Zhang; mark56zhang@163.com

Received 28 December 2017; Accepted 2 May 2018; Published 31 May 2018

Academic Editor: Quanxin Zhu

Using a dynamic model from 2005 to 2015, this study assessed China's energy supply security in the provinces along "the Belt and Road". Energy supply security was conceptualized across four dimensions: availability, affordability, acceptability, and energy technology and efficiency. A dynamic model was used to calculate the dynamic weights for each indicator and to examine the variation laws. It was found that the acceptability dimension indicator weights had rapidly increased, indicating that energy supply security had been widely accepted. Smooth weights were found for the availability dimension indicators, indicating that the resources needed to protect basic energy supplies were available. A synthetical energy supply security evaluation index was also analyzed for each "Belt and Road" province using a "quadratic weighting" method, which showed that the index was different in the same provinces in different years and different for different provinces in the same year. For 14 "Belt and Road" provinces, the overall energy supply security was found to have a "V" shape and a general dynamic upward trend, with the trends in the northwest and southeast provinces and along the whole "Belt and Road" found to be consistent. The energy supply security differences between these provinces were analyzed deeply in this paper; it will help us to understand the strengths and weaknesses of energy supply security levels in these provinces. The result will make it easier to cooperate with other provinces or countries along the "Belt and Road" in energy supply.

1. Introduction

China is currently promoting its "Belt and Road" initiative, which involves the promotion of economic restructuring and economic upgrading in the provinces along the "Belt and Road". Of these, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang are aligned with the ancient land-based Silk Road; Fujian, Guangdong, Zhejiang, Hainan, and Shanghai are aligned with the maritime Silk Road; Inner Mongolia, Heilongjiang, Jilin, and Liaoning are aligned with both rail and water transportation to the Russian Far East; and Yunnan and Guangxi link the Road and the Belt. As energy cooperation is one of the core drivers of the "the Belt and Road" initiative, and as there are different energy distribution characteristics and spatial differences between the "Belt and Road" provinces, the individual strengths of each province are important to China's overall energy supply security. Northwest provinces such as Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, and Inner Mongolia are major coal-producing areas in China; these provinces totally have produced more than 65% of China's national coal output production, since 2010. The northeast provinces (Heilongjiang, Jilin, and Liaoning) are major oil producing areas in China, with the crude oil production at the Daqing Oilfield producing around 47% of China's total onshore oil production for the past 8 years. However, as there are few natural energy sources in the southwest and southeast provinces (Yunnan, Guangxi, Fujian, Guangdong, and Zhejiang), there has been a rapid development in clean energy resources in recent years, with nuclear power plants having been put into operation in Daya Bay and Qinshan. To promote "the Belt and Road" initiative and realize optimal energy allocations, China is factoring in the respective comparative advantages of these provinces to encourage provincial energy cooperation as well as energy cooperation with the other " Belt and Road" countries.

As regional economies grow in the "Belt and Road" provinces, there have been significant challenges associated with guaranteeing energy supply security. First, as regional energy supply structures are affected by local resource conditions and energy supplies, transport distances, and freight costs, many provinces have inadequate energy supply structures. Further, as there are significant spatial differences in the different provinces, the northwest and northeast provinces have abundant natural energy reserves, and therefore a relatively high degree of energy self-sufficiency, while the southwest and southeast provinces have poor natural energy reserves and therefore, as these regional economies develop, the gaps in energy supply are growing. Second, energy supply has had an adverse effect on the Chinese environment. China's energy structure has been based on coal for many years, with coal fired energy being the main supply for the "Belt and Road" provinces; however, this has had a severe effect on the ecological environment and depleted environmental capacities, which in turn has seriously threatened energy supplies and adversely affected sustainable regional development. Even relatively "clean" hydropower projects have had a severe negative impact on the surrounding ecosystems. Third, China has a high external dependence on oil. While China's own crude oil output is low and stable, further exploitation has been limited by resource endowments, technical conditions, and other factors. As a result, China's dependence on oil and gas imports has continued to rise and, as forecast by the IEA, is not controlled; China's foreign oil dependence could reach 80% by 2040 [1], further exacerbating energy supply security issues in "the Belt and Road" provinces. Fourth, China's energy price management system may possibly have an adverse effect on the "Belt and Road" provinces as it could lead to low energy prices in some regions, which would stimulate a rise in energy consumption, possibly defer local energy investment, and ultimately result in restricted energy supplies. Fifth, energy supply technology is undeveloped in China. Although all "Belt and Road" provinces have increased their energy technology investments and energy supplies, compared to the requirements of the world's energy technology powerhouses that are leading the energy revolution, there remains a significant gap between the energy supply technological levels in each province. On the whole, the unbalanced energy supply structure, the overcapacity in some energy sectors, the negative impact on the supply environment, the imperfect energy supply system, and the low technology supply levels have all restricted economic, social, and ecological sustainable development in the "Belt and Road" provinces. China has been gradually adjusting its energy structure to reduce the use of coal, increase clean energy development efforts, and improve energy efficiency, with the "National Energy Development 13th Five-Year Plan" highlighting that energy supply structural reform was necessary to accelerate energy supply system development and improve quality and efficiency. However, to achieve these aims requires solutions to be found to several key issues: improving energy supply security in the "Belt and Road" areas; encouraging economic growth while constraining energy consumption; and reducing the negative impacts of greenhouse gas emissions in the region. The determination of viable solutions to these issues requires a thorough understanding of the key drivers behind provincial energy supply security and a detailed study of the current energy supply security conditions in these "One Belt and Road" provinces.

2. Literature Review

While most energy security research has highlighted energy supply security as a key aspect, in general, energy supply has been the core focus. Depending on the research background, subjects, or samples, energy security has been differently defined in different periods, and various index systems and assessment methods developed. As the most common definition for energy security has been to obtain an adequate energy supply at a reasonable price (IEA [2, 3], the Asia Pacific Energy Research Center (APERC) [4]), most energy security research has been based on this definition (Yergin [5], Vander Linde C [6], Le Coq [7], Sovacool BK [8], and Winzer C [9]). However, David [10] pointed out that the above concept has become less salient to policy formation due to increasingly global, diverse energy markets combined with emerging energy-related local, regional, national, and transnational issues, including climate change, local air pollution, acid rain, and water quantity and quality issues, as now many energy security facets need be considered, environment, technology, demand-side management, social and cultural factors, and post–Cold War international relations, when developing comprehensive energy security plans. Based on a meta-analysis of 104 studies, Ang [11] claimed that as energy security has become inherently dynamic and is continuing to expand in scope to embrace environmental sustainability and energy efficiency, major oil importing countries such as China need to pay more attention to energy supply continuity [12]. However, choosing appropriate evaluation indicators has proven difficult as different research objects have had different valuation systems in different periods. Vivoda [13], believing that energy security was transformable, evaluated the Asia Pacific regional energy security using 11 dimensions such as energy supply security, energy efficiency, and the environment and technology and proposed 44 indicators for these dimensions. Månsson [14], however, believing energy security to be dynamic and requiring an assurance of energy supply continuity, developed 13 energy security indicators within five dimensions: energy supply, upstream markets and imports, domestic markets and infrastructure, economic vulnerability, and comprehensive perspectives. Xue [15] evaluated China's energy supply security using 13 indicators within the four key dimensions of availability, affordability, efficiency, and technological research and development, and based on China's energy supply and demand statistics, Geng [16] studied China's energy supply security using 6 indicators under the four dimensions of energy resource availability, importable energy affordability, energy technology and energy efficiency, and energy resource reserves. Lucas [17] used 15 indicators to assess European energy security from the three dimensions of supply security, the environment, and competitiveness. Erahman [18] developed a 14-indicator system to evaluate energy safety performance in 71 countries across five dimensions: availability, affordability, accessibility, acceptability, and efficiency. While there have been significant differences in the number of dimensions and indicators, on the whole, availability, affordability, technology, efficiency, and the environment have been the most common in energy security studies.

Energy security research has experienced a dynamic progression from qualitative to quantitative evaluation methods, with quantitative methods being the principal research method in recent years. Wu [19] used a weighted average model to assess China's energy security and proposed some corresponding strategies. Malavika [20] verified the principal concerns of China's energy users using survey research methods, the results of which found that fossil fuel supply security was the greatest concern as well as soil erosion, air pollution, and water pollution factors. Cohen [21] developed a country-specific index based on oil and natural gas supply diversification to measure energy security. Cao and Bluth [22] analyzed the critical characteristics of China's energy policy related to energy supply security. Manley [23], from a survey of 884 members of professional membership organizations, found there was a need for the U.S. to prioritize energy policy across energy supply security, the environment and climate, and economic goals. Zhang [24] conducted a comprehensive evaluation of the safe, green, and efficient development levels for coal resources in three mining areas of Shaanxi Province based on a fuzzy membership method. Ren [25] investigated the factors that most influenced China's energy security using a fuzzy AHP method. Nie [26] examined conventional energy supply diversity based on economic methods and demonstrated that energy supply shocks yielded energy diversity and high energy prices. Lu [27] introduced an ecological network analysis (ENA) into an energy security assessment, based on which a model of the crude oil supply network in China was established. Narula [28] assessed sustainable energy security (SES) in India using a sensitivity analysis. Table 1 gives a brief comparison of previous studies as well as the present study.

Because energy security is dynamic, issues related to energy supply security have attracted significant research attention, with different scholars applying different meanings to the concept, indexing, and research methods. As the depth of these studies has increased, the scope has also expanded. However, most previous studies have based the analysis on a static research method, with the weights of all indicators or the weight of one indicator being the same in the time series. However, as the system is dynamic, the same energy supply security indicator changes over time, and therefore this needs to considered for accurate assessments. Therefore, the contributions of this study are as follows:

(1) Based on energy supply development in China's new era and the need for energy security on "the Belt and Road", this paper proposes an index system for China's provincial energy supply security.

(2) A dynamic energy supply security evaluation model is creatively established. Using this model, it is easy to calculate the dynamic weights for each indicator in each year and then determine the energy supply security index for each province in each year. Compared to traditional static research methods, as the results are more precise, it is possible to analyze in depth the dynamic evolutionary trends for energy supply security in China's "Belt and Road" provinces.

(3) A fixed effects model is established to study the key energy supply security drivers to fully understand the reasons for the provincial energy supply security variations, which can assist the 14 provinces to integrate their local conditions based on the supply and the demand situations in the countries along the "Belt and Road".

The remainder of this paper is organized as follows: Section 3 constructs two dynamic models for the energy supply security research: a dynamic synthetic Double Weighting Method model to evaluate energy supply security and a panel data model to explore the energy supply security influencing factors. Section 4 describes the proposed indicators and data sources that influence energy supply security. Section 5 analyzes the results and gives the main findings, and Section 6 highlights the main conclusions.

3. Methodologies

In this paper, a dynamic method is used to study energy supply security in China's "Belt and Road" provinces. First, a dynamic "quadratic weighting" model is used to evaluate energy supply security and analyze the dynamic evolutionary energy supply security trends in each province, after which a fixed effects model is used to explore the key drivers affecting energy supply security in each province.

3.1. Dynamic Synthetical Energy Supply Security Evaluation. Dynamic synthetical evaluation, which is a part of multi-attribute decision-making, is a more scientific assessment method; however, little research has been conducted using this evaluation method in China. Professor Guo Yajun [33] conducted pioneering research on dynamic synthetical evaluations, with the results having been widely cited. Guo proposed dynamic synthetical evaluation principles to allow for the development of "vertical and horizontal" methods that could be used to optimize dynamic synthetical evaluations as they had uncomplicated principles, were easy to calculate, and were reliable. Subsequently, extensive applications in China such as Qu [34] and Tian [35] have verified the applicability of this method.

Data from 2005 to 2015 for 14 "Belt and Road" provinces were taken as the experimental data. Based on Guo's "vertical and horizontal" method, a Doubly Weighting Method was used for the dynamic synthetical evaluation of the energy supply security of "the Belt and Road" provinces. The first weight was used to calculate the energy supply security level in province S_i $(i = 1, 2, \ldots, n)$ each year, after which the changes in the energy supply security level in province S_i in different years were analyzed and the differences in the energy supply security in n provinces in the same year compared. A second weight was then used for the time period in each year, which was used to calculate the energy supply security

Table 1: Comparison between previous studies and present study.

No.	Source	Themes	Dimension	No. of countries	Time frame	No. of indicators	Assessment method Normalization	Weighting	Model	Provide rank
1	Coq C L [7]	Energy supply security	Oil, Gas, Coal	24	1	3	—	—	Aggregation	√
2	Sovacool B K [8]	Energy security, Energy supply	Availability, Affordability, Technology development, Sustainability and regulation	10	5	20	—	—	Subjective scoring	√
3	Ang B W [11]	Energy security, Energy supply	Economic, Energy supply chain, Environment	1	5	22	—	Subjective Weight	Aggregation	√
4	XueJingjing [15]	Energy supply security	Availability, Affordability, Efficiency, Technology	1	12	13	Min-Max	Entropy method	Set Pair Analysis	√
5	Geng J B [16]	Energy supply security	Availability, Affordability, Energy technologies and energy efficiency, Energy resource reserves	1	8	7	Min-Max	—	Aggregation	√
6	Lucas J N V [17]	Energy security, Energy supply	Energy supply, Environment	22	1	12	—	—	Econometrics	—
7	Erahman Q F [18]	Energy security	Availability, Affordability, Accessibility, Acceptability and efficiency.	71	6	14	Min-Max	PCA	Aggregation	√
8	WuChuguo [19]	Energy security, Energy supply	Energy supply, International market, Environment	1	21	10	—	combined weight	Aggregation	—
9	Malavika [20]	Energy security, Energy supply	Security of energy supply, Climate change, Energy efficiency, Research and innovation of new energy technologies, Self-sufficiency and trade.	1	—	16	—	—	Questionnaire survey	√
10	ZhangJinsuo [24]	Coal security	Safe, Green and Efficient.	—	—	22	Min-Max	AHP	Aggregation	√
11	Ren J [25]	Energy security	Availability, Accessibility, Affordability, Acceptability	1	1	24	—	—	Fuzzy DEMATEL	—
12	Narula [28]	Energy security, Energy supply	Availability, Affordability, Acceptability, Efficiency	1	3	16	Min-Max	Subjective Weight	Multi-objective decision model	—
13	Vivoda V [13]	Energy security, Energy supply	Energy supply, Demand management, Efficiency, Economy, Technology, and so forth.	10	1	44	—	—	—	—

Table 1: Continued.

No.	Source	Themes	Dimension	No. of countries	Time frame	No. of indicators	Assessment method: Normalization	Assessment method: Weighting	Assessment method: Model	Provide rank
14	Hippel D V [29]	Energy security, Energy supply	Security of supply, Economy	1	—	29	—	—	Forum discussion	—
15	Sovacool B K [30]	Energy security, Energy supply	Availability, Affordability, Technology development, Sustainability	1	—	320	—	—	Questionnaire survey, Literature review	—
16	Li Y [31]	Energy security	Vulnerability, Efficiency, Sustainability	4	13	9	—	Equal weight	Aggregation	√
17	Cohen G [21]	Energy security, Energy supply	Diversification	27	—	—	—	—	Aggregation	√
18	Brown M A [32]	Energy security, Energy supply	Availability, Affordability, Efficiency, Environment	22	40	10	—	—	Aggregation	—

synthetic index in each province in each year. The evaluation function used was

$$\begin{aligned} R_i &= F\left(\left\langle t_1, y_i\left(t_1\right)\right\rangle, \left\langle t_2, y_i\left(t_2\right)\right\rangle, \ldots \left\langle t_k, y_i\left(t_k\right)\right\rangle\right) \\ &= \sum_{k=1}^{T} V_k y_i\left(t_k\right) \end{aligned} \quad (1)$$

$$\begin{aligned} y_i\left(\mathrm{t}_k\right) &= \mathrm{f}\left(\left\langle \mathrm{w}_1\left(\mathrm{t}_k\right), \mathrm{w}_2\left(\mathrm{t}_k\right), \ldots, \mathrm{w}_m\left(\mathrm{t}_k\right); \mathrm{x}_{i1}\left(\mathrm{t}_k\right), \mathrm{x}_{i2}\left(\mathrm{t}_k\right), \right.\right. \\ &\quad \left.\left. \ldots, \mathrm{x}_{im}\left(\mathrm{t}_k\right)\right\rangle\right) = \sum_{j=1}^{m} \mathrm{w}_j\left(\mathrm{t}_k\right).x_{ij}\left(\mathrm{t}_k\right) \\ &\quad \mathrm{i} = 1, \ldots, \mathrm{n};\ \mathrm{k} = 1, 2, \ldots, \mathrm{T};\ \mathrm{j} = 1, 2, \ldots, \mathrm{m}. \end{aligned} \quad (2)$$

$y_i(\mathrm{t}_k)$ is the energy supply security level in province $\mathrm{S_i}$ in year k, R_i is the energy supply security synthetic index in each province ($\mathrm{S_i}$) each year, $\mathrm{w}_j(\mathrm{t}_k)$ is the first weight, that is, the weight of indicator j in year k, $x_{ij}(\mathrm{t}_k)$ is the indicator for j in year k after normalization in $\mathrm{S_i}$ province, and $\mathrm{V_k}$ represents the second weight for the time period in each year.

First, the nondimensional quantities of the original data are assessed. To ensure consistency and comparability of data sizes, the synthetical evaluation value depends not only on the weight coefficient but also on the type of nondimensional method chosen [36]. The advantage of the "vertical and horizontal" method is that the evaluation results are significantly different for the valuation subjects; when applied by previous scholars, noise disturbance was not considered; therefore, for comparison purposes, this article uses a linear scale transformation method for the dimensionless data [37–39], as shown in

$$\mathrm{x}_{ij}^{*} = \frac{x_{ij}}{x_j'} \quad (3)$$

where x_j' is special data represented by m_j, M_j, $\overline{x_j}$, or $\sum_{i=1}^{n} x_{ij}$ and x_j' should be greater than 0.

Second, the first weight $\mathrm{w}_j(\mathrm{t}_k)$ is calculated. Calculating the weight of indicator j in year k is a central issue in the dynamic synthetical evaluation. The principle of this step is that it should show a significant difference in the valuation subjects. In this step, the purpose is to calculate the different $y_i(\mathrm{t}_k)$ in the energy supply security in "the Belt and Road" provinces $(\mathrm{S}_1, \mathrm{S}_2, \ldots, \mathrm{S}_\mathrm{n})$, which can be calculated using $e^2 = \sum_{k=1}^{T}\sum_{i=1}^{n}(\mathrm{y}_i(\mathrm{t}_k) - \overline{y})^2$ [37], in which

$$\overline{y} = \frac{1}{T}\sum_{K=1}^{T}\left(\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m}\mathrm{w}_j x_{ij}\left(\mathrm{t}_k\right)\right) = 0 \quad (4)$$

$$\begin{aligned} e^2 &= \sum_{k=1}^{T}\sum_{i=1}^{n}\left(\mathrm{y}_i\left(\mathrm{t}_k\right) - \overline{y}\right)^2 = \sum_{k=1}^{T}\sum_{i=1}^{n}\left(\mathrm{y}_i\left(\mathrm{t}_k\right)\right)^2 \\ &= \sum_{k=1}^{T}\left[\mathrm{w}^T \mathrm{H}_k \mathrm{w}\right] = \mathrm{w}^T\sum_{k=1}^{T} H_k w = \mathrm{w}^T \mathrm{Hw} \end{aligned} \quad (5)$$

In the above formula, $W = (\mathrm{w}_1, \mathrm{w}_2, \ldots, \mathrm{w}_m)^T$, $H = \sum_{K=1}^{T} H_k$ is a symmetric matrix, $H_k = X_k^T X_k$ (k = 1, 2, ..., T), and

$$X_k = \begin{bmatrix} x_{11}\left(\mathrm{t}_k\right) & \cdots & x_{1m}\left(\mathrm{t}_k\right) \\ \cdots & \cdots & \cdots \\ x_{n1}\left(\mathrm{t}_k\right) & \cdots & x_{nm}\left(\mathrm{t}_k\right) \end{bmatrix} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{T}) \quad (6)$$

If $\mathrm{w}^T\mathrm{w} = 1$, then the maximal eigenvalue is $\lambda_{\max}(\mathrm{H})$, the corresponding eigenvector is W, e^2 has a maximum value, and $\max_{\|w=1\|}\{e^2\} = \lambda_{\max}(\mathrm{H})$.

According to Frobenius' theorem, when H is a positive matrix, the maximal eigenvalue and the corresponding eigenvector are positive. W satisfies the following restrictions:

$$\begin{aligned} \max \quad & W^T H W \\ \text{s.t.} \quad & \|W\| = 1 \\ & W > 0 \end{aligned} \quad (7)$$

Third, $y_i(\mathrm{t}_k)$ is directly obtained by substituting the first weight $\mathrm{w}_j(\mathrm{t}_k)$ into (2).

Fourth, the second weight $\mathrm{V_k}$ is calculated. The normalization method has been widely used in dynamic evaluations [35]; the nearer the present, the greater the weight, the farther from now, the smaller the weight. In time intervals $[\mathrm{t}_1, \mathrm{t}_\mathrm{T}]$, the time weight $\mathrm{t_k}$ is

$$v_k = \frac{k}{\sum_{k=1}^{N} k} \quad \mathrm{k} = 1, 2, \ldots, \mathrm{T}. \quad (8)$$

Fifth, the dynamic evaluation index $\mathrm{R_i}$ is calculated.

The dynamic evaluation value $\mathrm{R_i}$ in each province in the time interval $[\mathrm{t}_1, \mathrm{t}_\mathrm{T}]$ is obtained by substituting $\mathrm{V_k}$ into (1).

3.2. Energy Supply Security Dynamic Change Drivers. The provincial energy supply security indicators are assumed to be the explanatory variables and the energy supply security comprehensive index $\mathrm{R_i}$ is the explained variable; therefore, the fixed effects model can be built as

$$\begin{aligned} \ln R_{d,it_k} &= \alpha_{d0} + \alpha_{d1}\ln \mathrm{x}_{R_p d,it_k} + \alpha_{d2}\ln \mathrm{x}_{P_d d,it_k} \\ &\quad + \alpha_{d3}\ln \mathrm{x}_{S_u d,it_k} + \alpha_{d4}\ln \mathrm{x}_{E_p d,it_k} \\ &\quad + \alpha_{d5}\ln \mathrm{x}_{C_d d,it_k} + \alpha_{d6}\ln \mathrm{x}_{E_i d,it_k} + \alpha_{d7}\ln \mathrm{x}_{S_d d,it_k} \\ &\quad + \alpha_{d8}\ln \mathrm{x}_{W_d d,it_k} + \alpha_{d9}\ln \mathrm{x}_{F_c d,it_k} \\ &\quad + \alpha_{d10}\ln \mathrm{x}_{P_p d,it_k} + \alpha_{d11}\ln \mathrm{x}_{D_l d,it_k} + \lambda_{d,it_k} \end{aligned} \quad (9)$$

where d is the different regions in which the provinces are located, i is the different provinces, $\mathrm{t_k}$ is the year, α_{d0} is the unobservable regional effect used to control the various provinces in the same region, $\lambda_{\mathrm{d,it}}$ is the unobservable time effect to explain any time effects not included in the model, and α_{d1}-α_{d11} are the regression coefficients for each influencing factor. This paper mainly considered the cross-sectional differences in the total sample of provinces along "the Belt and Road" and four regional samples where the provinces are located; however, it does not consider the individual variations within the regions; therefore, a variable coefficient model was not included.

4. Indicators and Data Sources

4.1. Energy Supply Security Dimensions and Metrics. A greater number of dimensions or indicators do not necessarily result in a better tool; however, when there are too few indicators, the index is overly sensitive to indicator changes, and when there are too many indicators, any indicator changes would have no effect if the other indicators remain unchanged [12]. Therefore, the indicator and dimension selection need to represent the complexities inherent in energy supply security and account for the special problems in China's "Belt and Road" provinces. Therefore, to determine the dimensions and indicators as accurately as possible, data was collected from research interviews, a focus workshop, an extensive literature review, and available data, from which four dimensions, availability, affordability, acceptability, and technology and efficiency, and 11 indicators (Table 2) were identified.

(1) Availability. If the energy resources from the region are developed and energy supply diversification is promoted, an adequate and stable energy supply security system is ensured. While fossil fuels are being phased out, the cheapest fuel is usually used first [40], and after this source is depleted, another fossil fuel or renewable energy resource must be available to replace it to ensure an adequate energy supply. Alternatively, another fossil fuel or renewable energy may replace those that are more expensive or less acceptable [41]. In other words, energy reserves and resources are fundamental to guaranteeing energy supply security [42]. Therefore, the first dimension in the energy security concept in this study is resource availability, which includes energy resources and energy production. This dimension was represented by reserve and production ratios, a production diversity index, and energy self-sufficiency.

(2) Affordability. A reliable and adequate energy supply at reasonable prices is required for energy supply security, which means reasonable, steady energy prices and affordable energy supplies. The volatile prices associated with fossil fuels can result in problems in energy supply security and affect capacity expansion plans and other shorter-term measures. Most studies have emphasized the importance of energy prices as part of the energy security supply equation [43, 44]. This dimension is represented by an energy price index, which is specifically referred to as the provincial purchase price index for fuel power products.

(3) Acceptability. Energy and the environment are closely connected as fossil fuel combustion directly pollutes the environment, and even environmentally clean energy resources can damage the environment [45]. The support for eco-innovation can also improve the ecological environment. As environmental protection has become a major concern in the international community, it has also become a focus for building a more beautiful China. To ensure that the energy supply is safer and more reliable, a spatial structure related to resource conservation and environmental protection needs to be built. This dimension is represented by a consumption diversity index, GDP energy intensity, GDP sulfur dioxide emissions, GDP waste water emissions, and forest coverage.

(4) Energy Technology and Efficiency. This refers to obtaining the same services or useful output for less energy input. As the energy efficiency of a country reflects the development level of its energy technologies, improvements in energy efficiency can reduce energy consumption. Therefore, adequate energy technologies are important for the development of multilevel energy supplies [46–48], as improved energy technologies, systems, and practices can reduce energy needs and improve energy supply security. From a dynamic perspective, people pay more attention to the level of technological diversity, which indicate technological transitions, and taking account of technological transitions is an imperative when evaluating energy supply security. In China, however, technological diversity especially eco-innovations often needs support in policy, for example, China's desulfurization price subsidies for the power plants and energy infrastructure. From a social/cultural perspective, the impact of large infrastructure projects can be highly variable depending on the areas the pipelines and power lines pass through and how developers handle the interactions with those living in these areas [49]. As the Chinese government has been mainly concerned with energy infrastructure that supports large state-owned energy enterprises, data is available only for national time series, while similar statistics are not available from provincial governments; therefore, this dimension is represented by power generation equipment utilization time and distribution losses.

4.2. Data Sources. After establishing the metrics shown in Table 2, associated data from 2005 to 2015 was collected for the 14 provinces examined in this study: Shaanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Xinjiang, Heilongjiang, Jilin, Liaoning, and Yunnan, Guangxi, Fujian, Guangdong, and Zhejiang. The reserve and production ratios, production diversity index, energy self-sufficiency, energy price index, and the consumption diversity index were taken from the respective Statistical Yearbooks from the 14 provinces (2006–2016), and the GDP energy intensity, GDP sulfur dioxide emissions, GDP waste water emissions, and forest coverage data were taken from the China Statistics Yearbook (2006–2016), and the power generation equipment utilization times and distribution losses data were taken from the Wind Database. The primary energy sources were coal, crude oil, natural gas, and other new and renewable energy production.

5. Results and Main Findings

5.1. Energy Supply Security Calculations. Based on the method in Section 3.1, the first weight $w_j(t_k)$ and the second weight V_k were calculated using MATLAB (Table 3). From Table 3, it can be seen that the indicator weights changed dynamically over time. Each energy supply security indicator weight also

Table 2: Indicators used in the present study.

Dimension	Indicator	Unit	Equation	Variable description	Indicator source
Availability	Reserve and production ratio (x_{R_p})	%	$\sum_i r_i p_i$	r_i: reserve and production ratio of energy i p_i: proportion of energy i produced in energy source production	[8, 16, 18, 30, 50]
	Production diversity index (x_{P_d})	HHI	$\sqrt{\sum_{i=1}^{n} {p_i}^2}$	p_i: proportion of energy i produced in energy source production	[11, 13, 17, 29, 30, 50, 51]
	Energy self-sufficiency (x_{S_u})	%	e_{pro}/e_{con}	e_{pro}: total energy production e_{con}: total energy consumption	[8, 25, 30, 31, 50]
Affordability	Energy price index (x_{E_p})	--			[11, 12, 25, 30, 32, 50]
Acceptability	Consumption diversity index (x_{C_d})	SWI	$SWI = -\sum_i c_i \ln c_i$	c_i: consumption of energy i in total energy source consumption	[7, 13, 18, 29, 50, 51]
	GDP energy intensity (x_{E_i})	tce/104 CNY	e_{con}/gdp	e_{con}: total energy consumption gdp: gross domestic product	[8, 11, 13, 17, 18, 30–32]
	GDP sulfur dioxide emissions, (x_{S_d})	Tons/104 CNY	d_{so_2}/gdp	d_{so_2}: total sulfur dioxide emissions	[8, 11–13, 17, 29–32, 51]
	GDP waste water emissions (x_{W_d})	Tons/104 CNY	d_{wat}/gdp	d_{wat}: total waste water emissions	[8, 11, 25, 29, 30, 51]
	Forest coverage (x_{F_c})	%			[8, 11, 25, 29, 30, 51]
Energy technology and efficiency	Utilization time of power generation equipment (x_{P_p})		t_{power}/h_{total}	t_{powe}: power generation equipment utilization time each year, h_{total}: total hours in the year	[8, 11, 12, 18, 25, 31]
	Distribution loss (x_{D_l})				[8, 11, 12, 18, 31]

Table 3: Dynamic weights for energy supply security in China's "Belt and Road" provinces from 2005 to 2015.

Dimension	Indicators	First weight										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Availability	Reserve and production ratio	0.0760	0.0757	0.0710	0.0645	0.0627	0.0708	0.0408	0.0568	0.0555	0.0707	0.0691
	Production diversity index	0.1221	0.1226	0.1196	0.1216	0.1150	0.1173	0.1176	0.1157	0.1107	0.1103	0.1098
	Energy self-sufficiency	0.0642	0.0650	0.0627	0.0582	0.0524	0.0518	0.0486	0.0467	0.0464	0.0440	0.0430
Affordability	Energy price index	0.1225	0.1237	0.1219	0.1177	0.1138	0.1211	0.1164	0.1168	0.1185	0.1164	0.1135
Acceptability	Consumption diversity index	0.1524	0.1533	0.1654	0.1591	0.1478	0.1378	0.1404	0.1492	0.1451	0.1451	0.1405
	GDP energy intensity	0.0798	0.0787	0.0769	0.0787	0.0745	0.0758	0.0879	0.0845	0.0811	0.0784	0.0770
	GDP sulfur dioxide emissions	0.0653	0.0591	0.0606	0.0663	0.0705	0.0753	0.0632	0.0607	0.0609	0.0491	0.0614
	GDP waste water emissions	0.0795	0.0820	0.0717	0.0690	0.0760	0.0808	0.1205	0.1094	0.1167	0.1224	0.1158
	Forest coverage	0.0831	0.0826	0.0815	0.0822	0.0880	0.0902	0.0911	0.0894	0.0872	0.0877	0.0842
Energy technology and efficiency	Utilization time of power generation equipment	0.1274	0.1255	0.1299	0.1323	0.1406	0.1245	0.1272	0.1316	0.1274	0.1265	0.1300
	Distribution loss	0.0276	0.0319	0.0389	0.0504	0.0587	0.0546	0.0465	0.0391	0.0505	0.0494	0.0554
	Second times weight	0.015	0.030	0.045	0.061	0.076	0.091	0.106	0.121	0.136	0.152	0.167

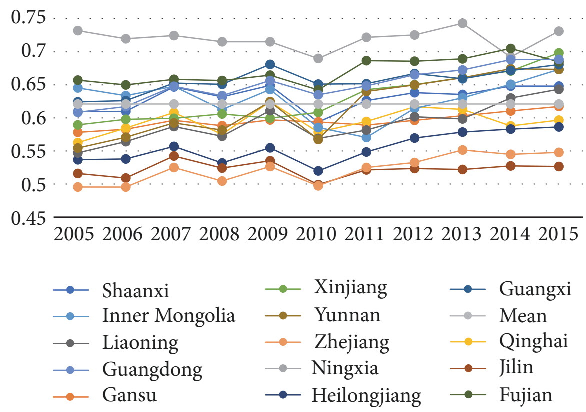

Figure 1: Dynamic evolutionary trends for energy supply security in China's "Belt and Road" provinces from 2005 to 2015.

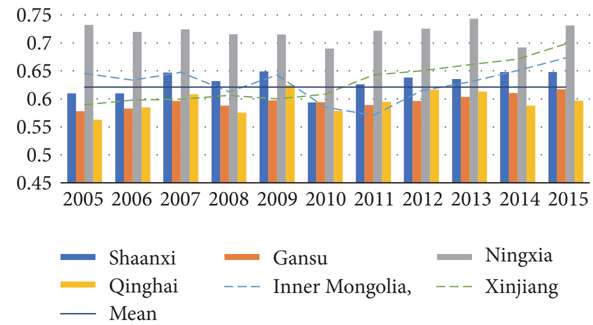

Figure 2: Dynamic evolutionary trends for energy supply security in the northwest region.

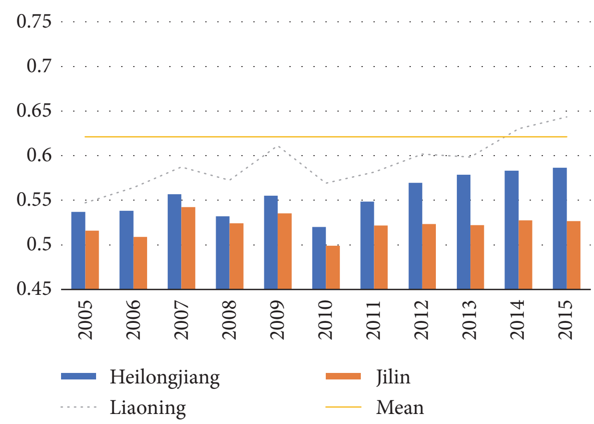

Figure 3: Dynamic evolutionary trends for energy supply security in the northeast region.

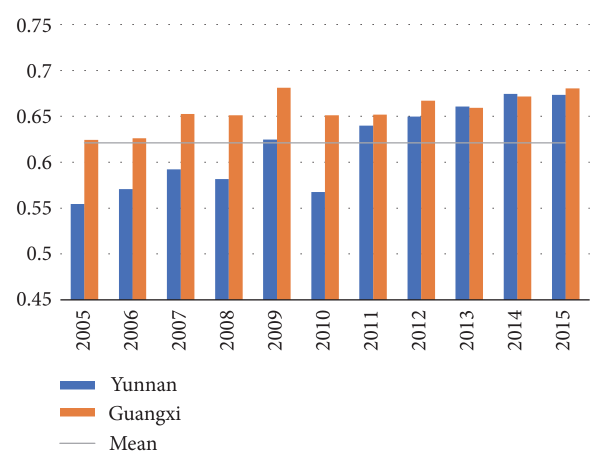

Figure 4: Dynamic evolutionary trends for energy supply security in the southwest region.

changed regularly, with the variation laws found to have three main characteristics.

(1) The availability indicator weight increased. The consumption diversity index had the largest weight, which declined from 2007 and then increased continually from 2010. The GDP energy intensity weight was stable before 2010 and then increased steadily. The GDP sulfur dioxide emissions increased year on year before 2010 but decreased from then on and reached the lowest point in 2014, after which they increased significantly in 2015. The GDP waste water emissions index had the largest weight increase, with the annual increase being 0.04 after 2010, indicating that GDP waste water emissions were becoming more important to energy supply security. The forest coverage weight increased steadily at an annual increase of about 0.05 after 2008. In recent years, as the Chinese government has focused more on energy safety and environmental problems, energy supply security has received increased attention.

(2) Energy technology and energy efficiency are important for energy supply security. The power generation equipment utilization time weight was high and remained stable, and the distribution weight was small and then increased sharply at an annual increase of 0.03, which was a similar speed to the GDP waste water emissions.

(3) The availability dimension index weight, which indicated the basic resource relationships to energy supply security, was stable. There was a gradual decline in the reserve and production ratio weight before 2011, after which it began to increase. The production diversity index weight remained stable, and the energy self-sufficiency weight decreased.

Based on the first energy supply security weight for China's "Belt and Road" provinces from 2005 to 2015 (Table 3), using formula (2), the energy supply security index was obtained for each year, and using formula (1), the energy supply security synthetical index for each province was determined, as shown in Table 4. To fully understand the energy supply security level in each province, the results are shown using six separate figures: Figure 1 shows the dynamic evolutionary trends for energy supply security from 2005 to 2015 in China's "Belt and Road" provinces; Figure 2 shows the dynamic evolutionary trends for energy supply security from 2005 to 2015 in the northwest "Belt and Road" region; Figure 3 shows the dynamic evolutionary trends for energy supply security from 2005 to 2015 in the northeast "Belt and Road" region; Figure 4 shows the dynamic evolutionary trends for energy supply security from 2005 to 2015 in the southwest "Belt and Road" region; Figure 5 shows the

Table 4: Energy supply security index for China's "Belt and Road" provinces from 2005 to 2015.

Province	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	e^2	Comprehensive evaluations	Grade
Shaanxi	0.6097	0.6098	0.6471	0.6318	0.6492	0.5937	0.6263	0.6383	0.6357	0.6481	0.6482	0.0004	0.6353	II
Gansu	0.5782	0.5829	0.5963	0.5882	0.5971	0.594	0.5891	0.5964	0.6034	0.6104	0.6173	0.0001	0.6008	II
Ningxia	0.7321	0.7198	0.7247	0.7154	0.7153	0.6899	0.722	0.7254	0.7431	0.6922	0.7313	0.0003	0.7187	II
Qinghai	0.5626	0.5848	0.6081	0.5752	0.6245	0.5787	0.5947	0.6169	0.6128	0.5879	0.5966	0.0004	0.5986	III
Inner Mongolia	0.6453	0.6337	0.6478	0.6127	0.643	0.5855	0.5705	0.6144	0.6305	0.6509	0.6734	0.0009	0.6293	II
Xinjiang	0.5895	0.598	0.5994	0.6061	0.5998	0.6085	0.6426	0.6503	0.6611	0.6709	0.6983	0.0013	0.647	II
Heilongjiang	0.5368	0.5381	0.5569	0.5321	0.5549	0.5198	0.5487	0.5697	0.5785	0.5833	0.5863	0.0005	0.5635	III
Jilin	0.516	0.509	0.5424	0.5242	0.5352	0.4991	0.5216	0.5234	0.5221	0.5273	0.5265	0.0001	0.5232	III
Liaoning	0.5471	0.5642	0.5871	0.5723	0.6112	0.569	0.5815	0.6017	0.5984	0.6301	0.6434	0.0008	0.6037	II
Yunnan	0.5544	0.5707	0.5924	0.5818	0.6246	0.5674	0.6399	0.6499	0.6608	0.6744	0.6735	0.002	0.638	II
Guangxi	0.6243	0.6262	0.6526	0.651	0.681	0.6511	0.6517	0.6671	0.6592	0.6717	0.6805	0.0004	0.6634	II
Fujian	0.6573	0.6499	0.6585	0.6565	0.6646	0.6424	0.6867	0.6857	0.6892	0.7051	0.685	0.0004	0.6791	II
Guangdong	0.6085	0.6171	0.6477	0.6336	0.6565	0.6349	0.6484	0.6653	0.6726	0.6881	0.6884	0.0007	0.6633	II
Zhejiang	0.4957	0.4955	0.5252	0.5045	0.5267	0.4974	0.5252	0.5325	0.5516	0.5448	0.548	0.0005	0.5314	III

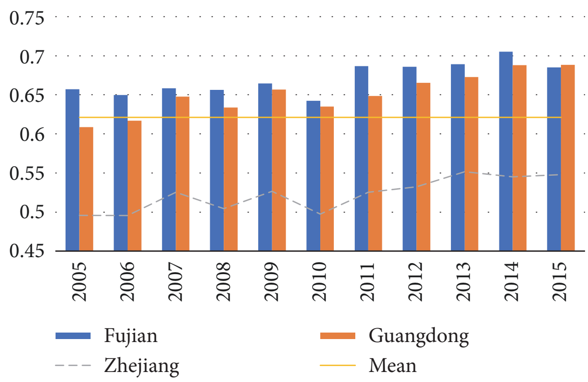

Figure 5: Dynamic evolutionary trends for energy supply security in the southeast region.

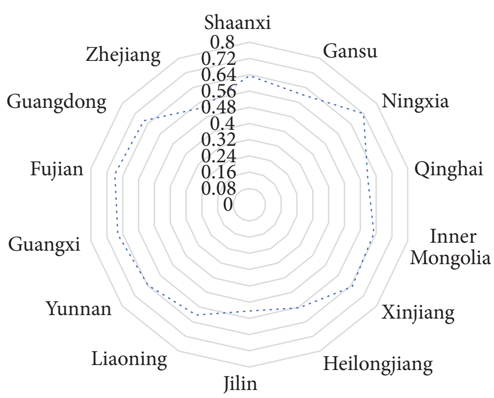

Figure 6: Energy supply security synthetical index for China's provinces along "the Belt and Road".

dynamic evolutionary trends for energy supply security from 2005 to 2015 in the southeast "Belt and Road" region; and Figure 6 shows the energy supply security synthetical index for all 14 "Belt and Road" provinces.

The energy supply security levels in China's "Belt and Road" provinces were dynamic and different. As shown in Figure 1, there were obvious differences in the energy supply security in each province each year; however, the V shape indicates that the energy supply security in all 14 provinces has improved. An inflection point was noticeable in 2010, indicating that the energy supply security level in each province changed after 2010. As the inflection point was in 2010, this may have been due to the international market as there were significant differences between the Brent and WTI oil prices in 2010, which resulted in energy cost advantages in America and other countries including China. The foreign oil dependence is high in the "Belt and Road" provinces, which could have led to decrease in the energy supply security levels in this year. Before 2010, about two-thirds of the provincial energy supply security was below the average energy supply security in "the Belt and Road" provinces; however, energy supply security began to improve and by 2015, about 1/2 of the provincial energy supply security was above average. This improvement was closely related to China's energy policy during the "Twelfth Five" year period when the Chinese government introduced policies to actively promote energy supply security improvements. The Chinese government has made full use of its domestic resource advantages and has continued to encourage innovation through its promotion of energy efficient and renewable energy technologies. Due to these proactive energy policies, the energy supply capacity in China's "Belt and Road" provinces have expanded; therefore, the application results are objective and reasonable.

The energy supply security in the northwest region is shown in Figure 2. The V shape indicates that the energy supply security has been improving. From Figure 2, it can be seen that Ningxia province performed the best from 2005 to 2015, with Gansu, and Qinghai increasing slowly, but remaining lower than average. The energy supply security in Xinjiang was the fastest growing in the northwest region, especially after 2009, when the annual increase went up sharply to 0.0164.

From Figure 3, it can be seen that the energy supply security in the three northeast provinces was lower, and the original level was low. Energy supply security was lower than average in all provinces except Liaoning, which surpassed the average after 2014. Heilongjiang and Jilin provinces also showed a general "V" shape, and both had an inflection point in 2010, with Heilongjiang improving faster than Jilin after 2010.

As shown in Figure 4, the southwest energy supply security in Yunnan and Guangxi provinces was good, with both being higher than average after 2010. Energy supply security in Yunnan increased the most rapidly of all "Belt and Road" provinces; the energy supply security had been far below average before 2010, after which it increased to the same level as Guangxi over the following 3 years. As shown in Figure 5, the energy supply security in the southwest provinces had a general "V" shaped trend; however, while Fujian and Guangdong were far better than average after 2007, Zhejiang performed the worst.

It can be seen from the synthetical evaluation index in Figure 6 that the greater the value, the safer the energy supply. There were significant differences between "the Belt and Road" provinces, as shown in the following results: Shaanxi (0.6353), Gansu (0.6008), Ningxia (0.7187), Qinghai (0.5986), Inner Mongolia (0.6293), Xinjiang (0.647), Heilongjiang (0.5635), Jilin (0.5232), Liaoning (0.6037), Yunnan (0.638), Guangxi (0.6634), Fujian (0.6791), Guangdong (0.6633), and Zhejiang (0.5314).

Based on the risk rank method criteria in Wu [52], the energy supply security was divided into five grades: grade I from 1 to 0.8 indicated that there were some unsafe factors, but overall it was in a basically secure state; grade II from 0.8 to 0.6 indicated that there were many unsafe factors and an overall weak secure state; grade III from 0.6 to 0.4 indicated that the safety factor was close to or exceeded half and overall was not in a safe state; grade IV from 0.4 to 0.2 indicated that there was a majority of unsafe factors and overall it was in a very unsafe state; and grade V at below 0.2 indicated that there were a majority of unsafe factors and overall it was in a seriously insecure state. Figure 7 shows that the energy supply security in China's "Belt and Road" provinces was not high, with the overall evaluation results being between 0.52

Table 5: Regression results for the key drivers affecting energy supply security.

Variable	Total for 14 provinces	Northwest	Northeast	Southwest	Southeast
C	-1.1640^{***} (-3.2652)	-1.6273^{**} (-2.7991)	-1.8768^{*} (-2.14245)	-0.7396^{*} (-2.2688)	-0.1476^{*} (-2.1791)
αd1	0.1940^{*} (2.1433)	0.1255^{*} (2.1602)	0.0194^{**} (3.0201)	0.0081^{**} (2.5404)	0.0101^{***} (3.5112)
αd2	0.1285^{**} (2.9011)	0.3468^{*} (2.1124)	0.1526^{**} (2.7258)	0.0092^{***} (5.4797)	0.0737^{***} (3.9796)
αd3	0.1283^{***} (3.3730)	0.0851^{***} (3.3603)	0.1650^{***} (3.5989)	0.0238 (2.0333)	0.0212^{***} (3.6892)
αd4	0.1243^{***} (3.4984)	0.0519^{**} (2.3728)	0.1280^{***} (4.0961)	0.1425^{**} (3.0561)	0.0273^{**} (2.3035)
αd5	0.0088^{***} (3.9717)	0.0752^{**} (2.9861)	0.2374^{***} (5.3084)	0.2536^{**} (2.6849)	0.1794^{*} (2.1721)
αd6	-0.0585^{***} (-5.5902)	-0.0597^{***} (-3.3775)	-0.2186^{*} (-2.0447)	-0.1884^{**} (-3.1646)	-0.1507^{***} (-6.4653)
αd8	-0.0392^{**} (-2.3665)	-0.0339^{**} (-2.9515)	-0.0895^{**} (-2.5085)	-0.0911^{***} (-5.0034)	-0.0427^{***} (-4.3981)
αd10	0.0349^{*} (2.0880)	0.0239^{**} (2.8395)	0.0821^{***} (3.5971)	0.1463^{***} (5.0034)	0.2573^{**} (2.2479)
αd11	-0.0288^{**} (-2.5389)	-0.0409^{**} (-2.3480)	-0.0183^{***} (-3.5998)	-0.0964^{**} (-2.7866)	-0.0295^{***} (-3.3811)
R2	0.9162	0.8998	0.9357	0.8969	0.9861
AdjR2	0.9021	0.8354	0.9020	0.8032	0.9789
F	62.1158	49.3251	27.7837	19.571	136.077
Sample number	154	66	33	22	33

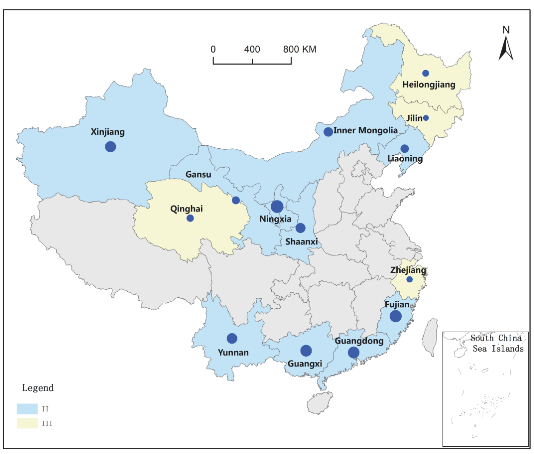

Figure 7: Average energy security performance in the fourteen provinces along "the Belt and Road".

and 0.72. Ningxia, Fujian, Guangxi, Guangdong, Xinjiang, Yunnan, Shaanxi, Inner Mongolia, Liaoning, and Gansu provinces were classified as grade II, indicating their energy supply security was weak, and Qinghai, Heilongjiang, Zhejiang, and Jilin were classified as grade III, indicating that their energy supply security was unsafe.

5.2. Key Drivers Affecting Energy Supply Security. Using the weights and energy supply security evaluation results presented in Section 5.1, the fixed effects model was used to explore the drivers for the dynamic changes in energy supply security in China's "Belt and Road" provinces. First, using an econometrics joint hypotheses test and the Hausman test, the unreasonable variable GDP sulfur dioxide emissions (S_d) and forest coverage (F_c) were eliminated. Then, a cross-section weighted generalized least squares (GLS) was used for a panel data regression analysis of model (9), the results of which are shown in Table 5. From Table 5, it can be seen that the fitness of the regression model was higher than 0.8 in both the overall sample and the classified sample, indicating that the model was available. The specific results were as shown in Table 5.

In Table 5, the data without parentheses are the regression coefficients, the data with $***$ indicate that $p < 0.01$, the data with $**$ indicate that $p < 0.05$, the data with $*$ indicate that $p < 0.1$, and the data in parentheses are the T values.

At a 10% confidence level, (1) first, as can be seen from the regression results for the overall sample, the reserve and production ratios were the largest single factors affecting energy supply security, followed by the production diversity index and the energy self-sufficiency index. These results suggested that energy storage and production capacity are very important to China's energy supply security, the higher the production, the stronger the production capacity, the stronger the energy self-satisfaction ability, and the higher the energy supply security. (2) In the "Belt and Road" northwest area, the production diversity index was the largest single factor affecting energy supply security, followed by the reserve and production ratio and the energy self-sufficiency index. Energy production in the northwest area is high and therefore it has high energy self-sufficiency and good conditions for renewable energy development. As one of the 13 large coal bases planned for development, Ningxia has rich coal resources and is also a wind and solar energy enriched area, with the 4th highest ranked production of solar power in China. Therefore, Ningxia province has better energy availability, a higher degree of energy diversity, better renewable energy utilization, and a wind power discard rate of only 0.73% in 2014, all of which makes Ningxia the province with the best energy supply security of all "the Belt and Road" provinces. (3) In the northeast "Belt and Road" region, the top three drivers affecting energy supply security are the consumption diversity index, GDP energy intensity, and energy self-sufficiency. This area has high coal production and high energy self-sufficiency; however, there are many problems such as "supply and demand dislocation", low consumption diversity and energy efficiency, and serious environmental pollution. In comparison, the energy efficiency in Liaoning was better than in the other provinces in this area, all of which had slightly higher energy supply security. (4) In the southwest area along “the Belt and Road”, the top three drivers affecting energy supply security were the consumption diversity index, GDP energy intensity, and power generation equipment utilization time. This area is rich in water resources; therefore, as the hydraulic electrical system power proportion is larger, the power generation equipment utilization time is longer, the energy efficiency better, and the pollution lower. For example, in Guangxi province [53], the energy acceptability is high and the energy industry policy support has balanced energy supply and demand; therefore, the energy supply security level in Guangxi province was higher than in the other provinces in this area. (5) In the southeast “Belt and Road” area, the top three drivers affecting energy supply security are power generation equipment utilization time, the consumption diversity index, and GDP energy intensity and diversity. The common energy characteristics in this area are traditional energy scarcity and high energy efficiency; however, clean energy has been developing rapidly. Fujian has been designated a “Clean Energy Powerful Province”, with their wind power generation equipment utilization time from 2013 to 2015 and the tidal energy installed capacity being the highest in China, resulting in the high-quality clean energy proportion rising gradually from 19.8% in 2010 to 24.9% in 2015. The high energy acceptability and efficiency in this province has improved energy supply security. Guangdong province has been constantly improving its technological level and has also been rapidly developing renewable clean energy; as a result, energy supply security has improved rapidly and energy consumption has climbed from 1006.24 million tonnes of standard coal in 1990 to 2.96 billion tonnes in 2014. In all, the high-quality energy resources, the diverse energy supply, and the technological advances have ensured a coordinated development of the energy supply and the environment in Guangdong province. In comparison, the domestic energy supply gap has expanded rapidly in Zhejiang, from 2415.68 million tonnes of standard coal in 1990 to 17271.42 million tonnes in 2014. An increased dependence on foreign energy and a low primary energy self-sufficiency rate has adversely affected Zhejiang’s energy supply security. During the “Twelfth Five” year period, the self-sufficiency rate was only 5.3%, indicating that Zhejiang’s energy supply security was far lower than in the other “Belt and Road” provinces.

In conclusion, the key drivers affecting energy supply security in the different areas varied widely, with the influences in the four regions being quite different. The energy resource endowment influence in northwest and northeast China was higher than in the southwest and southeast, with the reserve and production ratio as well as the production diversity factors having a greater influence in the northwest region, energy price impacts in the northeast and southwest regions being higher than in the northwest and southeast, energy acceptability having a greater impact in the northeast, southwest, and southeast regions, and the energy efficiency indicators having a greater impact in the southwest and southeast regions.

6. Conclusions

Energy supply security is dynamic. This paper reviewed domestic and foreign literature and the practical situation in China to construct a provincial energy supply security index system across four dimensions. Panel data from 2005 to 2015 from fourteen “Belt and Road” provinces in China were used as the research sample. This paper used the Doubly Weighting Method for a dynamic synthetical evaluation of the energy supply security in China’s “Belt and Road” provinces and then used fixed effects to explore the key drivers behind the dynamic changes in energy supply security, all of which provide new methods for energy supply security studies in China. This paper had better, more accurate, and more discriminating results than those from conventional static evaluation methods as this new method allowed for dynamic weights to be calculated for each index each year. This paper could assist the 14 provinces in China to better integrate their local conditions with the supply and the demand situations in the other provinces and countries along the “Belt and Road” and allow for more coordinated cooperation.

As energy supply security is affected by many factors such as energy resource endowment, economics, environmental issues, and technology, the energy supply security level in each province was different and dynamic. The key drivers behind the dynamic energy supply security changes varied across the provinces. It was found that energy storage and production capacity were the basic energy supply security factors in every province, both of which were found to be affected by energy prices and technology. The main conventional energy source in China is coal, the use of which has resulted in many environmental problems and adversely influenced the development of green energy supplies and continuous social development. Because of the abundant fossil fuel energy supply in northeast and northwest China, Ningxia province was found to have the highest energy security level because of its energy diversity and energy efficiency. Therefore, increased focus needs to be given to the development of renewable and alternative energy sources to improve energy supply security.

Energy efficiency was seen to be the major threat to energy supply security in “the Belt and Road” provinces. Energy efficiency was found to be higher in east China and lower in west and middle China. The southwest and southeast “Belt and Road” areas, in contrast, were found to have higher energy efficiency, which was in accordance with their actual conditions. By strengthening technological energy developments, developing rational energy development and transportation systems, and improving the cooperation between “the Belt and Road” nations and provinces, complementarity and comprehensive utilization could be realized, which could resolve energy supply problems and enhance energy supplies. Ningxia province in China is making use of its photovoltaic energy advantages and is investing in a 1000 MW photovoltaic power station and a photovoltaic module production plant in Iran in 2018. Gansu province has been involved in new energy education and training since 1991, with trainees from Zimbabwe, Panama, Eritrea, Jordan, and other countries participating every year, which could contribute to a New Energy Industry for "the Belt and Road" nations. Inner Mongolia, as a cross-border energy transit station, has obvious geographical advantages; therefore, enhancing cooperation with Mongolia and Russia could bridge China's energy gaps and optimize bilateral energy supply security. Northeast China could take advantage of its geographical location by enhancing cooperation with Russia's Natural Gas Resources, which could increase the overall green energy supply. Yunnan province in southwest China produces excess hydroelectric resources, with the surplus electricity being transferred to provinces with relatively higher development in eastern China as well as energy poor countries such as Vietnam, Laos, and Burma. Guangxi, as a linking province on the Belt and Road, plans to build an international passage to other ASEAN countries. Fujian is an important province that exported 4.72 million tonnes of oil in 2017, which was 8.19% of China's total oil exports. To sum up, energy supply security is a dynamic and complex issue that is restricted by many factors; however, when there is an energy supply shortage in one region, this can be offset by other regions. Therefore, collaboration across the "Belt and Road" region could help improve overall energy supply security, resolve energy supply problems, and enhance energy supplies. This paper creatively applied a dynamic model to assess China's energy supply security and enriched the energy security research field. However, because of the many provinces studied in this article and the difficulties with such multi-index evaluations, it is difficult to accurately forecast the energy supply security levels in each province [54]. Future research needs to correct the possible noise disturbances in the data processing to allow for accurate assessments and reliable forecasting.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (NSFC) under Grant nos. 71273206 and 71704140, the National Soft Science Plan Program (no. 2013GXS4D151), the Soft Science Research Major Program of Shaanxi Province (no. 2012KR2-01), and Philosophy and Social Sciences Prosperous Development Project of Xi'an University of Science and Technology (2018SY03).

References

[1] IEA, *Gas Pricing and regulation: China's Challenges and IEA Experience*, International Energy Agency, Paris, France, 2014.

[2] I. E. A. IEA, "Towards a Sustainable Energy Future," Paris: OECD/IEA, 2001.

[3] I. E. A. IEA, "World Energy Outlook," Paris: OECD/IEA, 2007.

[4] A. P. E. R. APERC, *Energy Security Initiative: Some Aspects of Oil Security*, Institute of Energy Economics, 2003.

[5] D. Yergin, "Energy Security in the 1990s," *Foreign Affairs*, vol. 1, no. 67, pp. 110–132, 1988.

[6] C. Van der Linde, "Study on energy supply security and geopolitics," *Final Report*, 2004.

[7] C. Le Coq and E. Paltseva, "Measuring the security of external energy supply in the European Union," *Energy Policy*, vol. 37, no. 11, pp. 4474–4481, 2009.

[8] B. K. Sovacool, I. Mukherjee, I. M. Drupady, and A. L. D'Agostino, "Evaluating energy security performance from 1990 to 2010 for eighteen countries," *Energy*, vol. 36, no. 10, pp. 5846–5853, 2011.

[9] C. Winzer, "Conceptualizing energy security," *Energy Policy*, vol. 46, pp. 36–48, 2012.

[10] D. Von Hippel, "Energy security (East Asia)," *Berkshire Encyclopedia of Sustainability: China, India, and East and Southeast Asia: Assessing Sustainability*, pp. 143–150, 2012.

[11] B. W. Ang, W. L. Choong, and T. S. Ng, "Energy security: definitions, dimensions and indexes," *Renewable & Sustainable Energy Reviews*, vol. 42, pp. 1077–1093, 2015.

[12] B. Ang, W. Choong, and T. Ng, "A framework for evaluating Singapore's energy security," *Applied Energy*, vol. 148, pp. 314–325, 2015.

[13] V. Vivoda, "Evaluating energy security in the Asia-Pacific region: a novel methodological approach," *Energy Policy*, vol. 38, no. 9, pp. 5258–5263, 2010.

[14] A. Månsson, B. Johansson, and L. J. Nilsson, "Assessing energy security: an overview of commonly used methodologies," *Energy*, vol. 73, pp. 1–14, 2014.

[15] X. Jingjing, L. Shen, L. Litao et al., "Energy supply security assessment of China and the influence factor based on set pair analysis," *Geographical Research*, no. 05, pp. 842–852, 2014.

[16] J.-B. Geng and Q. Ji, "Multi-perspective analysis of China's energy supply security," *Energy*, vol. 64, pp. 541–550, 2014.

[17] J. N. Valdés Lucas, G. Escribano Francés, and E. San Martín González, "Energy security and renewable energy deployment in the EU: Liaisons dangereuses or virtuous circle?" *Renewable & Sustainable Energy Reviews*, vol. 62, pp. 1032–1046, 2016.

[18] Q. F. Erahman, W. W. Purwanto, M. Sudibandriyo, and A. Hidayatno, "An assessment of Indonesia's energy security index and comparison with seventy countries," *Energy*, vol. 111, pp. 364–376, 2016.

[19] W. Chuguo, H. Xianjie, and S. Chang, "Comprehensive evaluation methods of energy security," *Journal of Natural Resources Policy Research*, no. 6, pp. 964–970, 2011.

[20] M. J. Bambawale and B. K. Sovacool, "China's energy security: the perspective of energy users," *Applied Energy*, vol. 88, no. 5, pp. 1949–1956, 2011.

[21] G. Cohen, F. Joutz, and P. Loungani, "Measuring energy security: trends in the diversification of oil and natural gas supplies," *Energy Policy*, vol. 39, no. 9, pp. 4860–4869, 2011.

[22] W. Cao and C. Bluth, "Challenges and countermeasures of China's energy security," *Energy Policy*, vol. 53, pp. 381–388, 2013.

[23] D. K. Manley, V. A. Hines, M. W. Jordan, and R. E. Stoltz, "A survey of energy policy priorities in the United States: energy supply security, economics, and the environment," *Energy Policy*, vol. 60, pp. 687–696, 2013.

[24] Z. Jinsuo, L. Chunguang, Z. Wei et al., "On comprehensive evaluation of safe, green and efficient development of coal resources," *China Coal*, no. 01, pp. 15–19, 2014.

[25] J. Ren and B. K. Sovacool, "Quantifying, measuring, and strategizing energy security: determining the most meaningful dimensions and metrics," *Energy*, vol. 76, pp. 838–849, 2014.

[26] P.-Y. Nie, "Analysis of conventional energy supply resource diversity," *Applied Thermal Engineering*, vol. 89, pp. 663–668, 2015.

[27] W. Lu, M. Su, B. D. Fath, M. Zhang, and Y. Hao, "A systematic method of evaluation of the Chinese natural gas supply security," *Applied Energy*, vol. 165, pp. 858–867, 2016.

[28] K. Narula, B. Sudhakara Reddy, S. Pachauri, and S. Mahendra Dev, "Sustainable energy security for India: An assessment of the energy supply sub-system," *Energy Policy*, vol. 103, pp. 127–144, 2017.

[29] D. Von Hippel, T. Suzuki, J. H. Williams, T. Savage, and P. Hayes, "Energy security and sustainability in Northeast Asia," *Energy Policy*, vol. 39, no. 11, pp. 6719–6730, 2011.

[30] B. K. Sovacool and I. Mukherjee, "Conceptualizing and measuring energy security: a synthesized approach," *Energy*, vol. 36, no. 8, pp. 5343–5355, 2011.

[31] Y. Li, X. Shi, and L. Yao, "Evaluating energy security of resource-poor economies: a modified principle component analysis approach," *Energy Economics*, vol. 58, pp. 211–221, 2016.

[32] M. A. Brown, Y. Wang, B. K. Sovacool, and A. L. D'Agostino, "Forty years of energy security trends: A comparative assessment of 22 industrialized countries," *Energy Research and Social Science*, vol. 4, no. C, pp. 64–77, 2014.

[33] G. Yajun, Y. Yuan, and Y. Pingtao, "A method and application of dynamic comprehensive evaluation," *System Engineering-Theory & Practice*, vol. 27, no. 10, pp. 154–158, 2007.

[34] Qu. Xiaoe, "China' s provincial environment assessment: an empirical analysis based on the years from 1990 to 2009," *China Population Resources and Environment*, vol. 22, no. 5, pp. 158–163, 1990.

[35] T. Shizhong and Z. Pengda, "Dynamic evaluation and empirical study on haze pressure in six provinces of central China," *Statistics & Information Forum*, vol. 31, no. 09, pp. 56–61, 2016.

[36] L. Lingyu, G. Yajun, and Y. Pingtao, "Analyzing the principles for choosing dimensions methods," *Journal of Systems & Management*, no. 06, pp. 1040–1045, 2016.

[37] W. Sun and L. Peng, "Observer-based robust adaptive control for uncertain stochastic Hamiltonian systems with state and input delays," *Nonlinear Analysis: Modelling and Control*, vol. 19, no. 4, pp. 626–645, 2014.

[38] Q. Zhu, F. Jiang, H. Wangand, and B. Wang, "Comment on Stability analysis of stochastic differential equations with Markovian switching," *Systems & Control Letters*, vol. 102, pp. 102-103, 2017.

[39] Q. Zhu and H. Wang, "Output feedback stabilization of stochastic feedforward systems with unknown control coefficients and unknown output function," *Automatica*, vol. 87, pp. 166–175, 2018.

[40] H. Hotelling, "Economics of exhaustible resources. I. The peculiar problems of mineral wealth," in *Economics of Exhaustible Resources*, pp. 281–312, Edward Elgar Publishing, 1931.

[41] L. Cervini, R. Farinato, and L. Loreto, "Security of supply and renewable energy in the light of the opening of electricity markets to competition," *M.C. Escher: Art and Science*, pp. 269–284, 1986.

[42] B. Stefanova, "European strategies for energy security in the natural gas market," *Journal of Strategic Security*, vol. 5, no. 3, pp. 51–68, 2012.

[43] L. Yao and Y. Chang, "Energy security in China: a quantitative analysis and policy implications," *Energy Policy*, vol. 67, pp. 595–604, 2014.

[44] B. Kruyt, D. P. van Vuuren, H. J. M. de Vries, and H. Groenenberg, "Indicators for energy security," *Energy Policy*, vol. 37, no. 6, pp. 2166–2181, 2009.

[45] F. Wirl, "The exploitation of fossil fuels under the threat of global warming and carbon taxes: a dynamic game approach," *Environmental & Resource Economics*, vol. 5, no. 4, pp. 333–352, 1995.

[46] D. P. Harris, "Mineral resource stocks and information," *Handbook of Natural Resource and Energy Economics*, vol. 3, no. C, pp. 1011–1076, 1993.

[47] J. P. Dorian, H. T. Franssen, and D. R. Simbeck, "Global challenges in energy," *Energy Policy*, vol. 34, no. 15, pp. 1984–1991, 2006.

[48] H. Turton and L. Barreto, "Long-term security of energy supply and climate change," *Energy Policy*, vol. 34, no. 15, pp. 2232–2250, 2006.

[49] D. Von Hippel, R. Gulidov, V. Kalashnikov, and P. Hayes, "Northeast Asia regional energy infrastructure proposals," *Energy Policy*, vol. 39, no. 11, pp. 6855–6866, 2011.

[50] D. K. Jonsson, B. Johansson, A. Månsson, L. J. Nilsson, M. Nilsson, and H. Sonnsjö, "Energy security matters in the EU energy roadmap," *Energy Strategy Reviews*, vol. 6, pp. 48–56, 2015.

[51] D. Von Hippel, T. Savage, and P. Hayes, "Introduction to the asian energy security project: project organization and methodologies," *Energy Policy*, vol. 39, no. 11, pp. 6712–6718, 2011.

[52] H. Xianjie, L. Zengjie, W. Chuguo, and J. Qingsu, "Evaluation and suggestion of China's petroleum safety," *Land and Resources Information*, no. 10, pp. 2–7, 2012.

[53] Z. Changgen and H. Xinxin, "Evaluation of Guangxi energy security based on entropy method," *Land and Resources Information*, no. 07, pp. 32–39, 2017.

[54] Y. Wang, A. Gu, and A. Zhang, "Recent development of energy supply and demand in China, and energy sector prospects through 2030," *Energy Policy*, vol. 39, no. 11, pp. 6745–6759, 2011.