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Impact of Industrialization on China's Regional Energy Security in the New Era

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Abstract: Ensuring industrialization and energy security in a positive direction at the same time is significant to achieve high-quality development of the regional economy. This study attempts to provide two evaluation index systems for industrialization and energy security in the new era and discuss the impact of industrialization on energy security in the new era. In doing so, industrialization in the new era is evaluated by the ratio of quality expansion and quantity improvement during industrial development, then the evaluation system of energy security is put forward which has a total of 18 indexes in three dimensions, including energy supply security, energy consumption security, and energy supply-demand matching security. Entropy weight is used to evaluate industrialization and energy security levels of 30 provinces in China, then we compare respectively the changes of industrialization and energy security before and after the new era. Next, we examine the impact of industrialization on energy security in the new era for 30 provinces in China during the period from 2008 to 2017 by using the panel Tobit model. The study shows that: in the new era, the industrialization is pursuing high-quality development at a faster pace but energy security is threatened by deteriorated supply-demand matching security; there is an positive relationship between industrialization and energy security, and also supply security and consumption security,but the positive relationship between industrialization and matching security is not statistically significant; GDP per capita can inhibit energy security, green technology efficiency and the ratio of capital to labor will improve energy security. Finally, some suggestions are put forward from four aspects: building

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an environment-friendly development model, encouraging green technological innovation, optimizing the input structure of factors, and building a dynamic balance of energy supply and demand.

Keywords: The New Era; Industrialization; Energy Security; Evaluation System; Influencing Factors

1. Introduction

Since the Industrial Revolution, energy has provided an inexhaustible power for the economic development of all countries in the world. In the 21st century, fossil fuels are still the primary energy consumption in most countries. Threatened by international politics and wars, the availability and stability of energy supply have been challenged. Simultaneously, problems such as lack of motivation for energy technology innovation, carbon emissions, and environmental pollution in consumption have also attracted widespread attention from all over the world. Therefore, enhancing energy security and achieving sustainable development has become all APEC members' common goals in the 21st century (IEA, 2015; APERC, 2007). As a member of APEC, China is also facing severe energy security issues in deepening industrialization. In the new era, the themes of energy security has shifted from supply security to the comprehensive security including consumption security and environmental impact and others by time period. The total energy consumption (calorific value calculation) in China increases from 3.064 billion tons in 2008 to 4.161 billion tons in 2017 (CESY, 2018), with an annual growth rate of 3.46%. Primary energy production increased from 2.630 billion tons in 2008 to 3.259 billion tons in 2017, with an annual growth rate of 2.41% (CESY, 2018). When the growth rate of supply is lower than the growth rate of consumption, and the contradiction between energy supply and demand has become increasingly prominent. Particularly, the energy sector is undergoing profound changes in the new era, such as traditional methods of energy production and consumption are facing constraints on resources and the environment. In contrast, new energy, electric vehicles, and energy storage technology applications provide more opportunities for energy production and consumption. As the world's largest energy-consuming and producing country, China views energy security as the core issue of sustainable development and utilization of resources in the 21st century and also thinks of it as the key to sustainable economic and social development.

The industry is an energy consumption sector and also a supply sector of energy products. Therefore, industrialization will have a significant impact on energy security through supply and demand. More than 70 years of industrialization in China has promoted rapid economic growth (Franck and Galor, 2019), but the problems including the shortage and exhaustion of natural resources, environmental pollution and ecological crisis, and the supply imbalance in industrial structure make the traditional industrial development unsustainable (Li et al., 2019; Xu et al., 2020).With China's economy entering into the new era, depeening industrialization is coming. Industrialization in the new era means the focus of industrialization has shifted from quantity expansion produced by increasing proportion of industrial structure in GDP,expansion of assets and outputs in industry to the quality growth produced by innovation, improvements of employment quality and profitability (King, 2007). Whether depeening industrialization can increase the level of supply security, reduce energy consumption and negative impact on the regional environment is still a controversial topic (Cherniwchan, 2012; Opoku and Boachie, 2020). Furthermore, there are great differences in endowments of labor and energy, degree of economy development and flows of energy fuels and services among China's provinces (Li et al., 2020). But there is few studies on the synthetic development of industrialization and energy security from the perspective of China's provinces. Taking China's 30 provinces as research object under the condition of the availability of data,we aim to study the impact of industrialization on China's regional energy security in the new era, which will help to achieve both goals of new industrialization and effectively ensuring regional energy security.

The contributions of this paper are three points. Firstly, the industrialization in the new era is evaluated from the quality-quantity ratio during industrial development, in which the quality and quantity of industrial development are evaluated by multi-index method respectively. Secondly, energy supply-demand matching security is introduced into the energy security evaluation system, which enriches the meaning of energy security and can analyze the consistency of energy supply to energy demand. Thirdly, it is based on the perspective of the new era to study the impact on energy security, to make up for the inadequacy of previous research those do not fully consider the development stage of the research object when studying on the environmental impact of industrialization.

It is essential to point out that "the new era" means the new era of socialism with Chinese characteristics. This term appeared firstly in the 19th National Congress of the Communist Party of China (CPC), referring to the new historical orientation of China's development. In the new era, the meanings of industrialization and energy security have changed.Specifically,industrialization cannot follow the old road of extensive development, and the focus of energy security cannot emphasize supply security. The new era started from the 18th National Congress of CPC (CPC CCDI, 2017), which was held in November 2012. Under the premise of annual statistics, we define 2013 and subsequent years as the new era. This paper aims to examine the impact of industrialization on energy security in the new era based on the above scenario. The remaining structure of this paper is as follows. Section 2 is a literature review of related research. In Section 3, we show the methods and data used to evaluate industrialization and energy security and impact research. In Section 4, we present the evolution trend of industrialization and energy security in the new era and discuss the impact of industrialization on energy security in the new era. Section 5 presents some conclusions and policy recommendations.

2. Literature Review

There are few studies on the impact of industrialization on energy security, and the relevant literature mainly focuses on industrialization evaluation, the definition of energy security, and its index evaluation.

2.1. Evaluation of industrialization

The evaluation method of regional industrialization is divided into two types: a single index and a comprehensive index. A single index is mainly expressed by indicators such as income per capita (Chenery, 1960), output per capita (Mahmood et al., 2020), the added value of industry or manufacturing (Wang et al., 2019; Nasir et al., 2021; Opoku and Boachie, 2020), the ratio of industrial value or added value to GDP (Deng et al., 2008; Pan et al., 2019; Li et al., 2018), number of industrial enterprises in the region (Sejati, 2020), the deviation between economic structure and employment structure (Yang and Shao, 2018). While the comprehensive index is mainly based on the comprehensive evaluation of multiple aspects of industrialization development. Hao and Cao (2019) believe that the core characteristics of the post-industrialization stage include three aspects, which include innovation has become the primary source of economic growth in terms of factor endowments, the tertiary industry occupies a dominant position in terms of economic structure and consumption has the highest contribution to economic growth in terms of growth drives. Then, they conclude that China's current industrialization level is in the initial stage of post-industrialization. Li et al. (2019) comprehensively evaluated China's industrialization level from five aspects: per capita GDP, the proportion of urban population, industrial structure, proportion of non-agricultural employees, and proportion of manufacturing added value.

2.2. Definition of energy security

In terms of defining energy security, the International Energy Agency (IEA) is the first to propose energy security centered on stabilizing the supply and price of crude oil in 1974. Previous research mainly focus on energy supply security. Scholars believe that energy security is the loss of economic welfare caused by fluctuations in energy prices or interruptions in energy supply (Bohi and Toman,1996). During deepening industrialization, energy must be guaranteed at reasonable prices and continuous supply (Yan et al., 2018). With the occurrence of the "911" terrorist incident in the United States in 2001 and the two hurricanes in the United States in 2005, energy supply security has extended to the fields of energy infrastructure, supply chain security and use security (Yergin, 2006).

Subsequently, environmental problems caused by energy consumption are highly concerned by the public, and the connotation of energy security evaluation has further expanded to environmental and social levels. The Asia-Pacific Energy Research Center (APERC, 2007) summarizes energy security into four dimensions,namely availability, accessibility, affordability, and acceptability, in which "acceptability" reflects the environmental and social factors that affect energy security. Ang et al. (2015a) introduce the environmental impact of energy into the index system and construct a comprehensive energy security evaluation index system from seven aspects: energy availability, infrastructure, energy prices, social effects, environmental governance and energy efficiency. Kucharski and Unesaki (2015) believe that energy security is a strategy for managing energy system risks. So far, the definition of energy security has realized the transition from considering only supply security at the beginning to a comprehensive evaluation of energy security.

2.3 Quantitative evaluation of energy security

In the process of making policy, how to quantitatively evaluate energy security is a challenge. Previous studies about the evaluation method of energy security have changed from a single index to a comprehensive index. The single evaluation index method is mainly represented by Shannon Wiener Index and Herfindahl-Hirschman Index, which measure the diversity of energy security (Ozcan, 2019; Shakya and Shrestha, 2011). Additionally, Coq and Paltseva (2009) use the share of EU countries' energy imports in the EU's total imports as a weight to evaluate the EU's external energy supply risk level. The comprehensive index method is to select suitable indexes from the influencing factors of energy security to construct an evaluation index system, and weighted sum of them through a particular weight method to obtain the overall level of energy security.

The four-dimensional energy security evaluation model proposed by the Asia Pacific Energy Research Center (APERC, 2007) is a comprehensive evaluation method. However, Sovacool (2011) believes that an evaluation system including more dimensions is needed to understand whether a region can provide accessible, affordable, reliable, efficient and environment-friendly energy services. This view has been agreed upon by more and more scholars and has become a standard method for evaluating energy security in the past decade. Ang et al. (2015b) evaluate Singapore's energy security from three dimensions of economy, energy supply chain, and environment, in which the energy supply chain is divided into three aspects of energy supply, energy consumption and energy transportation. Purwanto et al. (2019) used a causal loop mapping to construct a regional energy security model from the economy, society, population, energy, and industrial development. Song et al. (2019) construct a new comprehensive energy evaluation model from three dimensions of energy supply, economy-technology and environment to evaluate China's energy security in six critical years from 2000 to 2014, and find that China's energy security level presents an "N" curve relationship. Wang et al. (2020) construct an evaluation system containing 17 sub-indexes from three dimensions of energy supply, energy consumption and environmental impact to evaluate the trend of energy security changes in China's energy security from 2000 to 2018, and conclude that it presents a "W" curve.

Even in small differences in the comprehensive evaluation index system, the conclusions drawn for the same research object are not the same, which has a lot to do with the determining method of the index weight. The common methods for determining weight indexes in the existing literature include the subjective procedure and objective method. The subjective procedure is that the decision-maker combines the actual situation of the evaluation object to determine the weight of each dimension index through survey, interview and Delphi method (Baloch, 2019; Augutis et al., 2009; Ang et al., 2015b; Song, et al., 2019). This method can fully reflect the focus of the decision maker, but it is also limited by the subjective judgment of the researcher. The objective methods include principal component analysis (Gnansounou, 2008), data envelopment analysis (Zhang et al., 2013), analytic hierarchy process (Wu et al., 2012), fuzzy analytic hierarchy process (Ren and Dong et al., 2018), equal weights method (Sovacool and Brown, 2010), correlation analysis (Zhang et al., 2017), entropy weight (Rani et al., 2019; Liu et al., 2020), functional entropy weighting method (Wang et al., 2020). The entropy method uses the original data information to analyze the index relevance and determine the index weight according to the amount of information carried by each index. It can objectively describe the salient characteristics of the evaluation object, thereby making the determination of the weight more objective and is used in comprehensive evaluation (Delgado and Romero, 2016; Rani et al., 2019).

In general, most scholars study energy security from the perspective of energy supply and consumption, but pay less attention to an imbalance of energy supply-demand matching. The problem of energy supply-demand matching determines the external dependence of regional energy in terms of quantity and determines the stability of energy security from the environmental impact in the process of energy production and consumption. Therefore, it is an important factor of energy security. Moreover, the existing literature mostly focus on the comprehensive evaluation of energy security and rarely analyze the impact of specific economic activities on energy security. The industry is both an energy demand sector and the supply sector. The process of deepening industrialization will inevitably have a significant impact on regional energy security in terms of supply and demand, but few studies have been done on the impact of industrialization on energy security. Lastly, economic development in the new era makes a new requirement for industrialization, and energy policies also present new characteristics, so the impact of industrialization on energy security has also undergone new changes due to different development stages. It needs to be combined with China's new economic development characteristics to do an empirical analysis of the impact of industrialization on energy security.

3. Research Methodology and data

There are three key issues in the process of evaluating the impact of industrialization on energy security in the new era: firstly, constructing a comprehensive evaluation index of industrialization, then constructing a reasonable and feasible comprehensive evaluation index system for energy security, lastly selecting appropriate variables and empirical models to do empirical research.

3.1 Evaluation of Industrialization Index

3.1.1 Evaluation index system of industrialization

Industrialization is not only the expansion of industrial scale, but also the improvement of the quality of development (Dscher et al., 2021). Based on the design idea, industrialization is divided into two aspects: quantity expansion and quality improvement. Under the rationality of index as well as availability of data, the selection of the evaluation indexes in this paper is as follows:

(1) Quantity expansion. It includes assets per unit industrial enterprise, outputs per unit industrial enterprise, the ratio of added value in industry to GDP (Wang et al.,2018; Pan et al., 2019). The first two represent asset scale (Steinfeld, 2004) and output scale repectively, and the last represents industrial structure level.

(2) Quality improvement. It includes overall labor productivity, full-time equivalent of R&D personnel and ratio of total assets to industrial output value, which reflect employment quality (Yang et al., 2018), technology R&D level (Opoku and Boachie, 2020) and the profitability of enterprises respectively.

Therefore, this paper constructs a regional industrialization evaluation system consisting of 2 dimensions and 6 indexes. See Appendix 1 for the evaluation system of regional industrialization.

3.1.2 Evaluation of industrialization in the new era based on entropy-weight method

This paper uses the entropy-weight method to determine the index weight, and an evaluation matrix is constructed to evaluate regional industrialization,which include two dimensions namely quantity expansion and quality improvement.

(1) Construction of standardized evaluation matrix

The initial evaluation matrix of regional industrialization including 6 indexes is established, which is represented as $X = \left(x_{\mathrm{ij}}\right)_{m\times n}$, where i is the evaluation object, j is the evaluation index, and x_{ij} is the initial value of the j-th index of the i-th evaluation object. To eliminate the deviation caused by each index, all of the indexes need to be standardized. Common standardization methods include min-max standardization (Cabalu, 2010), z-score standardization (Martchamadol, 2012), and classification standardization (Ang et al., 2015a, b), among which the min-max standardization method is the most common（Song, 2019). The processing formula is shown in equations (1) and (2). After the process, the standardized evaluation matrix is represented as $R = \left(r_{\mathrm{ij}}\right)_{m\times n}$.

Forward standardization:

$$r_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}\text{-}\min(x_{\mathrm{ij}})}{\max(x_{\mathrm{ij}})\text{-}\min(x_{\mathrm{ij}})} \tag{1}$$

Reverse standardization

$$r_{\mathrm{ij}} = \frac{\max(x_{\mathrm{ij}})\text{-}\mathrm{x}_{\mathrm{ij}}}{\max(x_{\mathrm{ij}})\text{-}\min(x_{\mathrm{ij}})} \tag{2}$$

(2) The index weight with entropy-weight method

There are three steps to determine the index weight by entropy-weight method. Firstly, the proportion of the index value of the i-th evaluation object in the j-th index is calculated by formula (3).

$$p_{\mathrm{ij}} = \frac{r_{\mathrm{ij}}}{\sum_{i=1}^{m} r_{\mathrm{ij}}} \tag{3}$$

Secondly, the j-th index's entropy value (e_j) and redundancy (d_j) are calculated by the formula (4) and formula (5), where $k = 1/\ln(m)$, $e_j \geq 0$, and $\ln 0 = 0$.

$$e_j = \text{-}k \sum_{i=1}^{m} p_{\mathrm{ij}} \ln(p_{\mathrm{ij}}) \tag{4}$$

$$d_j = 1\text{-}\mathrm{e}_j \tag{5}$$

Finally, the weight of each indicator is calculated by the formula (6).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

(3) Construction of evaluation matrix with entropy-weight method

Based on the standardized evaluation matrix R, combined with the entropy weight w_j, a standardized evaluation matrix Y with the entropy-weight method is constructed. The calculation process is shown in formula (7).

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1\mathrm{n}} \\ y_{21} & y_{22} & \cdots & y_{2\mathrm{n}} \\ \vdots & \vdots & \vdots & \vdots \\ y_{\mathrm{m}1} & y_{\mathrm{m}2} & \cdots & y_{\mathrm{mn}} \end{bmatrix} = \begin{bmatrix} r_{11} \cdot w_1 & r_{12} \cdot w_2 & \cdots & r_{1\mathrm{n}} \cdot w_n \\ r_{21} \cdot w_1 & r_{22} \cdot w_2 & \cdots & r_{2\mathrm{n}} \cdot w_n \\ \vdots & \vdots & \vdots & \vdots \\ r_{\mathrm{m}1} \cdot w_1 & r_{\mathrm{m}2} \cdot w_2 & \cdots & r_{\mathrm{mn}} \cdot w_n \end{bmatrix} \tag{7}$$

Where Y is a matrix with 300 rows and 6 columns, the sum of Y's 1st to 3th columns, 4th to 6th columns are respectively the scores of quantity expansion and quality improvement.

In the new era, the focus of China's industrialization has shifted from pursuing quantity expansion to quality improvement (Li et al., 2021).To adapt to this change, the evaluation method of industrialization should also pay more attention to quality improvement.We use the ratio of quality to quantity to reflect the level of industrialization in the new era.Formula is as follows:

$$IND\_qqr_{at} = \frac{IND\_quality_{at}}{IND\_quantity_{at}} \tag{8}$$

where IND_qqr_{at} represents the ratio of quality to quantity, *a* represents the province, *t* represents the year. $IND\_qqr_{at} > 1$ indicates that the emphasis of regional industrialization is quality improvement, while $IND\_qqr_{at} \leq 1$ indicates that the emphasis of regional industrialization is quantity expansion.

3.2 Energy Security Evaluation

3.2.1 Definition and theoretical framework of regional energy security

Regional energy security refers to reducing regional energy system risks through effective energy supply, moderate demand growth, and overall supply-demand balance based on considering the interaction between countries and regions, including energy supply security, energy consumption security, and energy supply-demand matching security. Energy supply security lies in controlling regional risks caused by unstable energy supply, which is reflected in energy independent production capacity, supply price stability, supply variety, energy industry performance, etc.. Energy consumption security lies in controlling regional unsustainable risks of economic and social development caused by excessive energy consumption, which is reflected in energy consumption intensity and the diversity of consumption types. Energy supply-demand matching security lies in controlling the risk of regional energy supply-demand imbalance based on the mutual influence among countries and regions to achieve the overall energy supply-demand matching and environment-friendly development, which is reflected in the regional energy self-sufficiency, energy dependence on foreign and provincial imports, and the environmental impact of supply-demand matching. The conceptual framework of regional energy security is shown in Figure 1.

Figure 1 Conceptual framework of regional energy security

3.2.2 Construction of regional energy security evaluation system

Regional energy security is a comprehensive concept including the factors of energy industry, economy, society, environment, etc. According to the conceptual framework of regional energy security, the selection of the evaluation indexes in this paper is as follows:

(1) Supply security.It includes four metrics referring to regional independent production capacity,fluctuations in energy supply prices (Belgin et al, 2020), energy supply diversity (Onamics, 2005) and energy industry profitability. Regional energy independent production capacity is an important support to cope with energy supply shortfalls (Greenleaf et al., 2009), which is measured by energy production per capita and elasticity of energy production in this paper.The fluctuations of energy supply prices are measured by relative changes in producer price index of energy industries. The energy supply diversity is measured by Shannon-Wiener index of energy supply

(Chalvatzis et al., 2017). And the energy industry profitability is measured by energy industry asset profit rate.

(2)Consumption security. It includes two metrics referring to energy consumption and energy consumption diversity. The energy consumption is measured by energy consumption per capita, energy consumption intensity (Institute for 21st Century Energy, 2012) and elasticity of energy consumption. And the energy consumption diversity is measured by Shannon-Wiener index of energy consumption (Juozas et al., 2020).

(3) Matching security. It includes four metrics referring to energy self-sufficiency level, energy import dependence, energy dependence outside of the province and environmental impact of energy supply and demand. The energy self-sufficiency level is measured by energy self-sufficiency rate. The energy import dependence is measured by percentage of net imports in available energy for consumption. The energy dependence outside of the province is measured by proportion of net transfer from other provinces in available energy consumption. The environmental impact of energy, such as global warming and air pollution, has attracted extensive attentions from government and scholars (Green, 2001; Pasqualetti et al., 2012). And the environmental impact of energy supply and demand is measured by emissions of sulfur dioxide and nitrogen dioxide,concentration of PM_{10} in the air and proportion of good weather in provincial city.

To sum up,the energy security evaluation system includes three dimensions and 18 specific measurement indexes. See Appendix 2 for the evaluation system of energy security.

3.2.3 Regional energy security evaluation based on entropy-weight method

The calculation steps of entropy-weight method in energy security are similar to those of industrialization. However, since there are 18 indexes in the evaluation of energy security, the standardized evaluation matrix Y is 300*18 dimension matrix. The sum of matrix Y by row is the regional energy security score and the sum of Y's 1st to 7th columns, 8th to 11th columns, and 12th to 18th columns are respectively the scores of supply security, consumption security and matching security.

3.3 Empirical research based on Tobit model

This paper uses empirical research to illustrate the specific impact of industrialization on energy security in the new era. Since the value of energy security lies between 0 and 1, it is a restricted dependent variable. If the ordinary least squares (OLS) method is still used, it will cause bias and inconsistency of parameter estimates.

While the panel Tobit model can achieve regression statistics on part of the continuously distributed dependent variables, it can solve restricted dependent variables (Brown et al.,2015). Therefore, we take energy security as the explained variable, industrialization as the core variable, introducing the year dummy variable, and constructing a panel Tobit model of the impact of industrialization on energy security to study the impact of industrialization on energy security in the new era.

The specific form of the Tobit model is as follows:

$$S_{at} = \begin{cases} \beta^T Z_{at} + \varepsilon_{at}, & \beta^T Z_{at} + \varepsilon_{at} > 0 \\ 0, & \text{other} \end{cases} \tag{9}$$

where S_{at} is the restricted dependent variable, which refers to energy security and its three sub-indexes; Z_{at} is the column vector of independent variables, which refers to the explanatory variables including industrialization and year dummy variable; β^T is the row vector of the parameter to be estimated; ε_{at} is a random interference term, $\varepsilon_{at} \sim N(0, \sigma^2)$.

3.4 Data sources

Data required for the above indexes are obtained from *China Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Price Index Yearbook*, *China Environmental Statistics Yearbook*, *China Population and Employment Statistical Yearbook*, *China Industrial Statistics Yearbook,* and provincial statistical yearbooks over the period from 2009 to 2018. Considering the availability of data, Tibet is excluded from the econometric analysis. The other 30 provinces of China Mainland are the research objects.

4.Results and discussion

4.1. Evolution trend of regional industrialization in the new era

To compare the performance differences of industrialization levels before and after the new era, the data from 2008 to 2012 and from 2013 to 2017 are analyzed respectively. The results are shown in figure 2 and 3. Each province in the figures is colored by the average annual growth rate of industrialization. The two bar charts on each province represent the level of industrialization in the starting and ending years in the the survey period respectively.

Figure 2 Comparison of the industrialization in China's 30 provinces in 2008 and 2012

Figure 3 Comparison of the industrialization in China's 30 provinces in 2013 and 2017

In terms of the average annual growth rate of industrialization between 2008 and

2012, there are 22 provinces increasing year by year. Jiangsu has grown fastest with annual growth rate of 12.402%,which is because Jiangsu,located in the easten of China,has a solid industrial foundation and the technology investment and profitability increased significantly from 2008 to 2012.There are 8 provinces declining year by year. Beijing has declined with a most negative rate of -7.754%, which is mainly due to the significant declination of industrial enterprises' profitability associated with a structural transformation from an industrial economy to a service economy(Li et al.,2019).In terms of industrialization level, the scores of Jiangsu, Guangdong, and Zhejiang are in top 3 both in 2008 and 2012, which is mainly because their excellent performance in R&D investment and profitability.While Qinghai, Ningxia, and Shanxi are in bottom 3 in the corresponding years, which is mainly due to their poor performance in profitability, as well as the lack of R&D investment in Qinghai and Ningxia.

In terms of the average annual growth rate of industrialization between 2013 and 2017, there are 24 provinces increasing year by year,more than the numbers of provinces between 2008 and 2012. The results show that the high-quality industrial development of China's provinces in the new era speed up. Guizhou has grown with a fastest annual growth rate of 14.717%, which is because the industrial foundation in Guizhou is weak and it has achieved rapid industrial growth through promoting vigorously infrastructure construction in the survey period.There are 6 provinces declining year by year. Liaoning has declined with a fastest negative rate of -13.963%, which is mainly due to poor profitability. In terms of industrialization level, the scores of Zhejiang, Jiangsu, and Guangdong are in top 3 both in 2013 and 2017, while the scores of Qinghai, Shanxi and Ningxia are in bottom 3 in the corresponding years, the ranking reasons of the top and bottom 3 provinces are as same as the period from 2008 to 2012.

On the whole, the industry in the new era is pursuing high-quality development at a faster pace. China is a large country with a large population and a vast territory, which means that securing a decisive victory in building a moderately prosperous society in all respects neither rely on individual industry like a small country,nor weakening industry to shift to non-manufacturing industry as other developing countries (Carmignani et al., 2014). Moreover, China has a relatively complete industrial system with a more reasonable layout. In the new era, China's industrialization process should continue to accelerate the transformation from quantity expansion to quality improvement, promote continuously the positive role of labor and technology on the profitability of industrial enterprises to achieve high-quality development.

4.2 Evolution trend of regional energy security in the new era

The entropy-weight method is used to evaluate the energy security, supply security, consumption security and supply-demand matching security levels of China's 30 provinces from 2008 to 2017. Especially, the results of four years in 2008, 2012and 2017, as well as its annual growth rates of energy security and its three sub-indexes between 2008 and 2012, between 2013 and 2017, are reported respectively in Table 1.

In general, the energy security levels of Inner Mongolia, Shanxi, and Shaanxi, which are abbreviated as MJS, rank the top three in 2008, 2012 and 2017, and their performances are stable. However, the reasons for the high level of energy security in MJS are not the same. Inner Mongolia's outstanding advantage is sufficient energy supply, such as its security level of energy supply in 2017 was top 1 in China. The high levels of energy security in Shanxi and Shaanxi are attributed to good performance in supply-demand matching. Meanwhile, the eastern provinces represented by the Beijing-Tianjin-Hebei region have low energy security scores, which is due to minimal energy supply and continuously high energy demand.

In addition, the energy security scores of 30 provinces are highly differentiated. The energy security scores of MJS have been higher than those of other provinces for a long time. The differentiation level trends between MJS and remaining provinces are expanding at first and slightly shrinking then. In particular, the energy security scores of MJS in 2008 are above 0.48, and those of other provinces are all below 0.37, the lag is 0.11; the energy security scores of MJS in 2012 increase to above 0.59, and those of others are below 0.43, the lag is 0.16; the energy security score of MJS in 2017 increase to above 0.54, and those of others are below 0.39, the lag is 0.15.

By analyzing the differences of energy security levels in the periods from 2008 to 2012 and from 2013 to 2017, it can be found that the energy security levels of 76.67% of the provinces from 2008 to 2012 have improved, and Inner Mongolia, Qinghai, and Ningxia rank in the top three for annual growth rate. Meanwhile, the energy security levels of the remaining provinces except for Shaanxi have been declined in varying degrees from 2013 to 2017. Through the analysis of the three sub-indexes, it can be found that 66.67%, 86.67% and 66.67% of the provinces have improved in supply security, consumption security and matching security from 2008 to 2012, and those corresponding proportions during the period from 2013 to 2017 have become 83.33%, 90%, and 0% respectively. It can be concluded that the levels of China's energy supply security and consumption security have been improved in the new era. However, the overall energy security level has been declined due to the apparent deterioration of energy supply-demand matching security. The work to ensure energy security from the perspective of mitigating the contradiction between supply and demand is still a long way to go.

4.3 Empirical analysis of industrialization on energy security in the new era

4.3.1 Variables selection and descriptive statistics

On the basis of previous studies, combined with the availability of data and the quantification of indicators, we select the following influential variables for empirical analysis.

1. Energy Security. As the dependent variable of empirical analysis, energy security is the key observation object in this paper. As mentioned above, energy security includes its security and the security of three sub-indexes. We regress energy security, supply security, consumption security, and matching security as dependent variables respectively.

2. IND_qqr.It represents quality to quantity ratio of industrialization, which can reflect high-quality industrial development in the new era.The energy industry belongs to industry,so high-quality industrial development means greater profitability in the energy industry and energy supply security is promoted.At the same time, high-quality industrial development means that output depend less on scale expansion and more on labor and technology, which helps to reduce energy intensity and improve energy consumption security. Therefore, an increase in IND_qqr will improve energy security in general.

3. GDP per capita. The increase in GDP per capita increases energy purchasing power and stimulates energy consumption, which will augment the external dependence of regional energy. Moreover, it is bad for the reduction of energy consumption intensity. GDP per capita is expressed as the ratio of the GDP of each province to the permanent population of the region at the end of the year.

4. Green technology efficiency. Green technology efficiency represents the regional green technological innovation capability. Technological innovation will expand the variety of energy supply and raise independent energy production quantity. Simultaneously, it is beneficial to reduce energy consumption intensity and ease the contradiction between energy supply and demand. Therefore, green technology innovation will promote regional energy security. The super-efficiency EBM model is used here to measure the efficiency of green technology. The hybrid distance function of this model is considered to be a more realistic measurement method because it has two distance functions of both radial and SBM (Wu et al., 2020). Moreover, the super-

efficiency method of this model can solve the incomparable problem when the unit efficiency value is 1. The input variables of green technology efficiency include: (1) fixed capital stock at the end of the year, which uses the perpetual inventory method and its unit is 100 million RMB; (2) number of employees at the end of the year, its unit is 10,000 people; (3) water per capita, its unit is cubic meters per capita; (4) sum of the area of agricultural land and construction land, its unit is 1000 hectares; (5) energy consumption, it is converted into 10,000 tons of standard coal based on the conversion coefficient of various types of energy. The expected output is the total output value of each region over the years by GDP deflator, and its unit is 100 million RMB. The variables of unexpected output include (1) CO_2 emissions, it is calculated according to the IPCC (2006) carbon emission coefficient, carbon dioxide is released by the sum consumption of nine kinds of fossil energy including coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas and natural gas, the unit is 10,000 tons; (2) wastewater discharge, the unit is 10,000 tons; (3) solid waste emissions, the unit is 10,000 tons; (4) SO_2 in exhaust gas emissions, the unit is 10,000 tons; (5) emissions of smoke and dust in the exhaust gas, the unit is 10,000 tons.

5. Capital-to-labor ratio. This index is used to analyze the impact of input factor endowments on energy security. A higher capital-to-labor ratio indicates that regional economic development depends more on capital rather than labor. Capital-intensive areas are more motivated to conduct research and development on the technologies of energy-saving and emission-reduction, which is beneficial to improve the level of energy security. Capital in this variable is calculated using the method of year-end fixed capital stock, which is used to deflate by a fixed asset price index, and the number of labors is the number of employees at the end of the year.

6.Dummy variable. To reflect the difference in energy security changes in the new era, the year dummy variable is introduced, and the years before 2013 are set to 0, while in 2013 and later years are set to 1.

The descriptive statistics of each variable are shown in Table 2.

Table 2 Summary statistics and data source

4.3.2 Stationarity of Variables

In order to ensure the stationarity of each variable to avoid spurious regression, each variable is checked for unit root. There are some common methods of unit root tests, such as LLC-T, ADF-FCS, PP-FCS, etc., which represent Levin, Lin&Chu test statistics, Fisher-ADF test statistics and Fisher-PP test statistics, respectively. Here, the results of the unit root test based on LLC-T. Since there are only 10 years of data, a zero-lag period is selected, and zero averaging (“demean” option) is used to alleviate the cross-sectional correlation. The results are shown in Table 3.

Table 3 Results of unit root test

It can be seen that each variable rejects the null hypothesis at the significance level of 1%, indicating that it does not have a unit root, and is a stationary sequence. The results indicate that the long-term trend of each variable can reach its expected value, which can be empirically tested.

4.3.3 Analysis of Empirical Results

Considering energy security, supply security, consumption security, and matching security as the explained variables, IND_qqr, GDP per capita, green technology efficiency, capital-to-labor ratio, and dummy variable are used as the explanatory variables for panel Tobit regression. The regression results are reported in Table 4. The log-likelihood ratio indicates that the Xttobit model could provide a statistically better fit of the sample data at the 99% level of confidence (Huang,et al., 2013).

Table 4 Empirical Results

The results of Model 1 show that there is a positive relationship between IND_qqr and energy security.The coefficient of IND_qqr is 0.0736 and it passes the significance test of 10%,which shows that the process of industrialization will promote energy security. The coefficient of GDP per capita is -0.0516,which means that increasing in GDP per capita can reduce energy security. The coefficient of green technology efficiency is 0.0557,which means that improvement of green technology efficiency can improve energy security. The coefficient of capital-to-labor ratio is 0.1410 and it passes the significance test of 1% , which shows that the higher the capital-to-labor ratio,the more dependent the regional economy development on capital rather than energy.

Comparing the results of models 2, 3, and 4, we find that the coefficients of IND_qqr in model 2 and 3 are positive and both pass the significance test of 10%,which means IND_qqr can impove supply security and consumption security significantly (Kander et al., 2017). The coefficient of IND_qqr in model 4 is positive but it can’t pass the significance test of 10%. Since energy self-sufficiency and environmental impact are important to matching security, the insignificant coefficient of supply-demand matching is probably because industrialization has not solved completely the problem of external dependence on energy and also industrialization has not affect the environment (Opoku and Boachie, 2020; Nasir et al., 2021). The coefficients of GDP per capita in these three models are negative significantly,which show that GDP per capita has reduced energy independent productivity by increasing energy purchasing power,stimulated energy consumption and increased external dependence on energy.In the new era,China needs to experience energy-related transitions at lower levels of income than developed countries (Marcotullio et al., 2007). Green technology efficiency is very significant to improving both supply security and consumption security, indicating that green technology innovation can promote supply security through increasing both energy independent production and supply varieties probably,also promote consumption security through reducing consumption intensity(Pan et al., 2019) and increasing diversity of consumption types (Ang, 2015a). But this variable is not significant to improving matching security,which is because cross-province convergence in air pollutants (Cherniwchan, 2012). The capital-labor ratio reflects regional factor endowment, which has improved supply security and matching security but worsened consumption security.That indicates that all regions need to carry out reasonable industrial planning when expanding capital to avoid from entering high energy consumption and high pollution industries.Its insignificant coefficient in model 3 is mainly because the energy consumption characteristics of neighboring provinces are similar affected by the similar factor endowment levels.

The year dummy variable analysis shows that regional energy security is generally deteriorating in the new era. From three sub-indexes of energy security, it can be seen that both supply security and consumption security in the new era have increased significantly. However, matching security has decreased significantly, which leads to the deterioration of energy security overall. For example, increased demand for electricity in some countryside due to busy farming or returning home in Spring Festival could cause the seasonal overload of power supply network. It can be concluded that the overall deterioration of regional energy security in the new era is mainly due to the deterioration of energy supply-demand matching security.

5. Conclusions and policy recommendations

The industry in China has a solid foundation for development and is also facing new challenges in the new era. One of the challenges is to achieve coordinated development of industrialization and energy security.This paper aims to study on the impact of deepening industrialization on energy security. Firstly ,we construct the evaluation index system of industrialization from two dimensions including the quantity expansion and quality improvement and the evaluation index system of energy security from three dimensions including supply security, consumption security, and matching security.Then,taking the data of China’s 30 provinces from 2008 to 2017, entropy-weight method is used to evaluate and contrast the changes of industrialization and energy security for 30 provinces before and after the new era. Further, the Tobit model for panel data is selected to conduct empirical research on the impact of industrialization on energy security in the new era. The results show that China's energy supply security and consumption security have improved in the new era, but matching security has deteriorated, which eventually leads to the overall deterioration of energy security. According the empirical results, some policy suggestions are given to advance industrialization and ensuring energy security in the same direction in the new era.

Firstly, there is a positive relationship between industrialization and energy security, and this similar relationship also lies in supply security and consumption security. That means the deepening of industrialization in the new era requires more attention to the improvement of "quality" rather than the growth of "quantity". This requires to abandon old development concept of scale expansion and build an environment-friendly development model. This new development model consists of two aspects at least. The first is to enhance the role of technology and human capital in industrial development by building a team of R&D people and increasing vocational training.The second is to cultivate new industries with energy and resource savings by promoting the application of green manufacturing model to various industries under the premise of ensuring product quality (Li et al., 2021).

Secondly, green technology efficiency can improve energy consumption security significantly, which means that the encouragement of capable enterprises to make great innovations in green manufacturing design and energy production efficiency is very necessary (Wu et al., 2020). Simultaneously, ensuring energy safety also needs to promote efficient and clean energy use by increasing the diversity of energy supply when the economic cost is feasible.

Thirdly, the capital-to-labor ratio will improve the regional energy security. That needs optimizing the input structure of factors. For one hand, increase the investments of capital and guide capital into industries with the factors of low energy consumption, pollution and emissions.For the other, reduce labor inputs by improving labor productivity and reduce industrial development dependence on labor (Sovacool et al., 2010).

Finally, matching security has dramatically inhibited the improvement of energy security. That needs to build a dynamic balance of energy supply and demand.On the one hand, it is necessary to improve the energy supply system's adaptability to the energy demand among different regions by optimizing the structure of energy supply.

On the other hand, the distributed energy system should strive to reduce transmission and distribution costs and environmental pollution by flexible policy tools based on regional factor endowments(Coq et al.,2009). Moreover, internet of things technology and the energy industry should be integrated deeply by using market mechanisms to break the information barriers between energy supply and consumption.

One of the limitations in the paper is few sample size which is partly because taking 30 provinces as research objects. From a more detailed perspective, industrialization and energy security levels are greatly different among cities even in the same province. Will these differences among cities have an impact on the research results? With access to data, future studies can take Chinese cities as research objects to expand the sample size and carry out deeper empirical research. Additionlly, digital economy,which is a new driver for China's economic development in the new era, changes the industrial modes of production and consumption to a large extent (Ahmad, etc., 2018). With access to adequate data, future studies may consider digital economy in evaluation of industrialization in the new era.

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Author’s contributions Jun Zhang: Methodology, Writing - Original Draft; Jiangquan Wang: Investigation; Linling Zhang: Conceptualization, Formal analysis; Lei Zhao: Writing - Review & Editing.

Data Availability The data analyzed during the current study are available in the Appendix.

Ethical approval and consent to participate Not applicable.

Conflict of interest The authors declare that they have no conflict of interest.

Consent for publication Not applicable.

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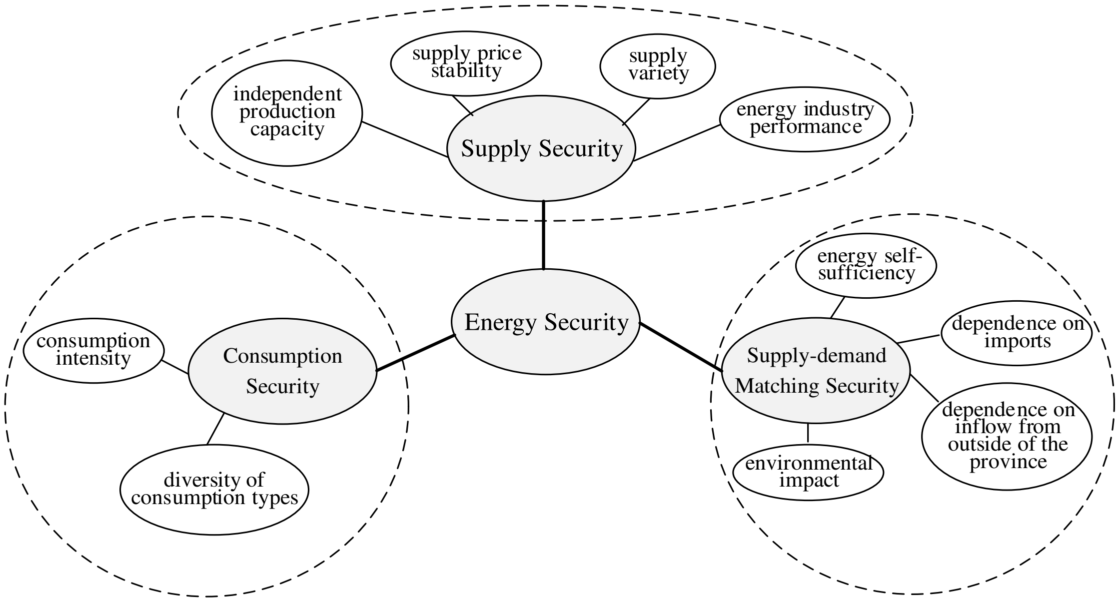

Figure 1 Conceptual framework of regional energy security

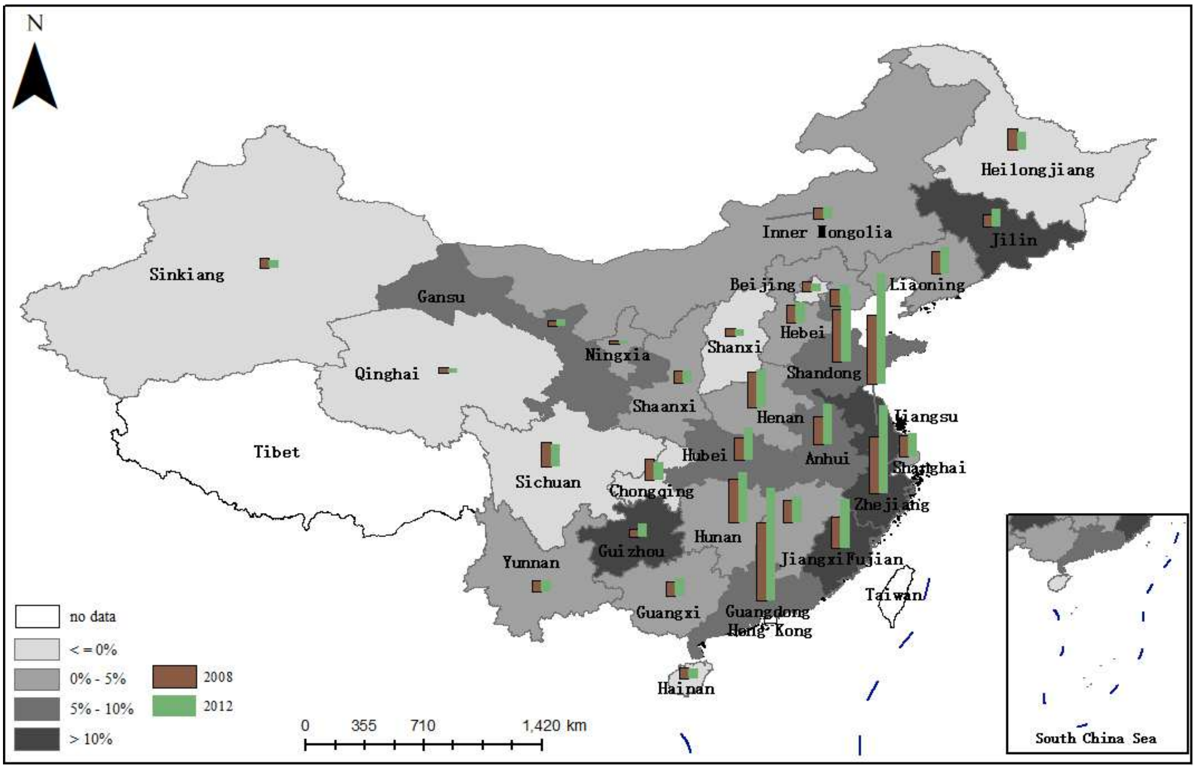

Figure 2 Comparison of the industrialization in China’s 30 provinces in 2008 and 2012

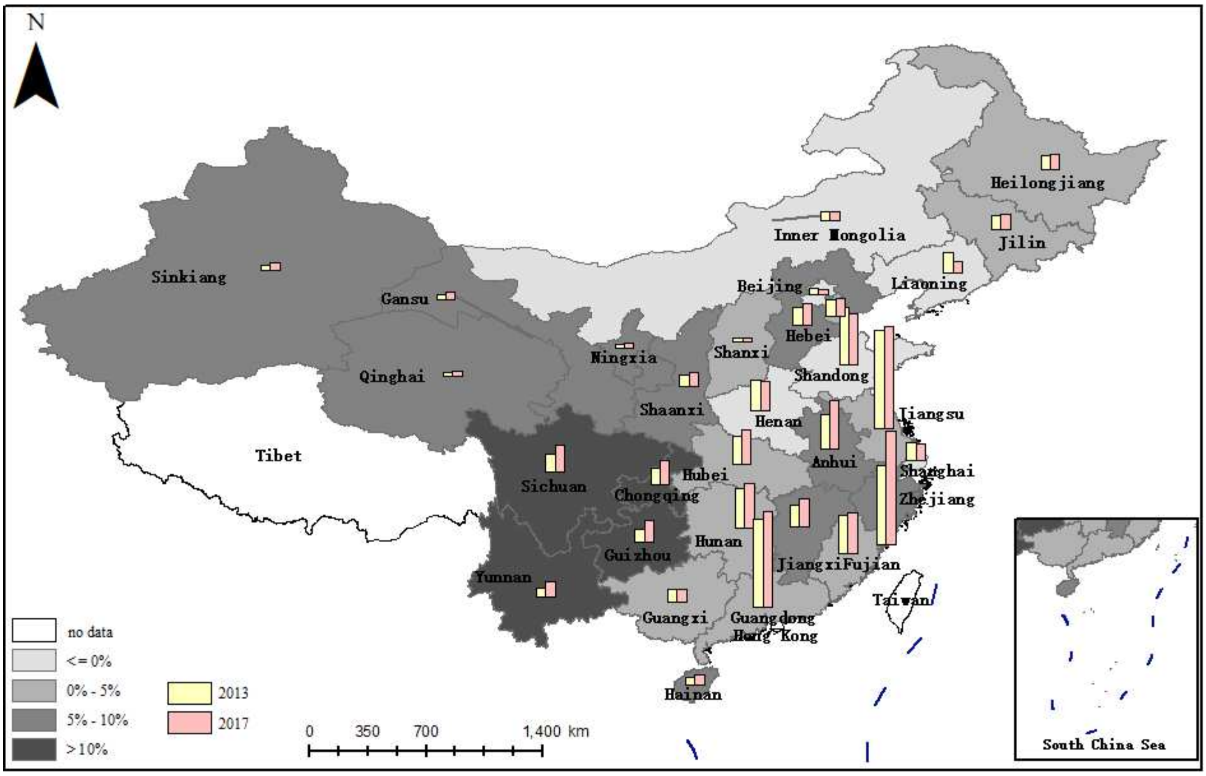

Figure 3 Comparison of the industrialization in China's 30 provinces in 2013 and 2017

Table 1 Energy security and sub-indices scores of 30 provinces in China in 2008, 2012 and 2017

Regions	2008				2012				2017				Annual growth rate between 2008 and 2012(%)				Annual growth rate between 2013 and 2017(%)			
	Energy security	Supply security	Consumption security	Matching security	Energy security	Supply security	Consumption security	Matching security	Energy security	Supply security	Consumption security	Matching security	Energy security	Supply security	Consumption security	Matching security	Energy security	Supply security	Consumption security	Matching security
Beijing	0.18	0.05	0.03	0.11	0.21	0.07	0.03	0.11	0.19	0.10	0.03	0.06	3.53	9.43	5.64	0.08	-2.09	9.90	0.02	-13.32
Tianjin	0.22	0.07	0.02	0.13	0.26	0.09	0.03	0.14	0.24	0.11	0.03	0.09	3.71	5.77	9.12	1.53	-2.24	5.82	3.27	-10.41
Hebei	0.24	0.09	0.02	0.12	0.24	0.08	0.03	0.13	0.20	0.12	0.02	0.05	-0.61	-2.82	1.95	0.47	-4.70	9.75	-6.26	-19.33
Shanxi	0.53	0.21	0.02	0.30	0.61	0.26	0.02	0.33	0.54	0.26	0.03	0.26	3.23	4.60	3.74	2.19	-2.73	0.60	3.12	-6.08
Neimenggu	0.54	0.23	0.02	0.28	0.83	0.43	0.02	0.37	0.69	0.38	0.03	0.28	11.24	16.42	0.72	7.18	-4.43	-2.85	1.86	-6.83

Liaoning	0.27	0.11	0.03	0.14	0.25	0.09	0.03	0.13	0.22	0.12	0.03	0.08	-2.25	-3.60	0.66	-1.80	-2.72	5.84	1.80	-12.21
Jilin	0.25	0.10	0.02	0.13	0.29	0.11	0.03	0.15	0.24	0.12	0.03	0.08	3.63	3.23	8.63	3.05	-4.92	1.86	3.36	-13.69
Heilongjiang	0.36	0.13	0.03	0.20	0.34	0.13	0.03	0.18	0.29	0.14	0.03	0.11	-1.53	-0.35	-0.55	-2.51	-3.95	2.09	0.87	-10.32
Shanghai	0.22	0.10	0.02	0.11	0.23	0.09	0.03	0.11	0.22	0.12	0.03	0.07	0.39	-2.94	19.88	-0.42	-0.70	9.50	0.41	-12.08
Jiangsu	0.23	0.09	0.03	0.12	0.26	0.11	0.03	0.12	0.23	0.13	0.03	0.06	2.58	5.35	3.45	0.00	-3.35	3.76	0.25	-13.63
Zhejiang	0.20	0.06	0.03	0.11	0.23	0.09	0.03	0.11	0.21	0.11	0.03	0.07	3.44	9.35	1.23	0.47	-2.70	5.09	0.50	-11.44
Anhui	0.27	0.08	0.03	0.16	0.28	0.08	0.03	0.17	0.21	0.08	0.03	0.09	0.48	-0.08	0.18	0.80	-6.59	2.36	1.26	-13.86

Fujian	0.24	0.08	0.03	0.13	0.24	0.08	0.03	0.12	0.24	0.11	0.03	0.10	-0.11	-0.29	1.07	-0.30	-0.30	6.91	0.99	-6.47
Jiangxi	0.23	0.06	0.03	0.13	0.22	0.06	0.03	0.13	0.21	0.10	0.03	0.08	-0.37	-0.21	1.09	-0.80	-1.53	12.84	0.31	-11.84
Shandong	0.26	0.10	0.03	0.13	0.27	0.11	0.03	0.14	0.23	0.12	0.03	0.08	1.16	0.36	4.42	1.12	-4.40	2.84	2.71	-13.68
Henan	0.28	0.08	0.03	0.16	0.25	0.07	0.03	0.14	0.18	0.08	0.04	0.07	-2.51	-3.79	2.00	-2.78	-7.61	1.31	1.54	-16.29
Hubei	0.25	0.11	0.02	0.12	0.26	0.11	0.03	0.12	0.20	0.10	0.03	0.07	0.64	0.49	3.51	0.15	-6.32	-1.67	0.49	-13.72
Hunan	0.23	0.07	0.03	0.13	0.24	0.07	0.03	0.14	0.19	0.08	0.03	0.07	1.28	1.39	2.12	1.04	-5.78	3.27	1.17	-14.26
Guangdong	0.24	0.10	0.03	0.12	0.27	0.11	0.03	0.12	0.22	0.12	0.04	0.07	2.44	3.34	5.35	0.92	-4.66	1.09	0.45	-13.10

Guangxi	0.24	0.09	0.03	0.12	0.26	0.10	0.03	0.12	0.24	0.12	0.03	0.09	1.59	3.78	-0.10	0.34	-1.72	4.03	1.12	-8.41
Hainan	0.28	0.13	0.03	0.12	0.26	0.11	0.03	0.11	0.24	0.10	0.03	0.10	-1.60	-2.87	1.00	-0.96	-2.00	-2.78	1.00	-2.11
Chongqing	0.24	0.07	0.03	0.14	0.26	0.10	0.03	0.13	0.24	0.12	0.03	0.08	1.76	6.58	2.28	-1.21	-2.31	6.21	2.30	-11.65
Sichuan	0.27	0.09	0.03	0.15	0.29	0.12	0.03	0.14	0.25	0.13	0.03	0.09	2.40	7.28	1.77	-0.81	-3.51	2.91	2.06	-11.76
Guizhou	0.29	0.09	0.02	0.18	0.32	0.11	0.02	0.19	0.27	0.10	0.03	0.15	2.50	5.33	0.02	1.40	-4.14	-1.42	2.57	-6.66
Yunnan	0.29	0.09	0.03	0.17	0.29	0.10	0.03	0.16	0.26	0.11	0.03	0.12	0.56	2.36	0.84	-0.50	-2.59	3.63	2.35	-8.13
Shaanxi	0.48	0.15	0.03	0.30	0.59	0.23	0.03	0.33	0.60	0.25	0.03	0.31	4.87	10.80	-0.88	2.14	0.48	2.74	2.27	-1.33
Gansu	0.26	0.10	0.02	0.14	0.28	0.10	0.03	0.15	0.24	0.12	0.03	0.09	1.55	-0.03	7.42	1.70	-3.10	5.59	3.23	-12.30

Qinghai	0.31	0.14	0.02	0.15	0.38	0.18	0.02	0.18	0.30	0.17	0.02	0.11	5.44	7.08	3.51	4.08	-5.63	-1.50	4.19	-12.06
Ningxia	0.31	0.12	0.01	0.17	0.38	0.16	0.02	0.20	0.29	0.16	0.01	0.11	5.19	6.75	4.61	4.09	-6.57	0.33	-8.41	-13.14
Xinjiang	0.37	0.16	0.02	0.19	0.43	0.19	0.02	0.21	0.39	0.22	0.02	0.14	3.73	4.92	-2.10	3.39	-2.66	3.21	-0.80	-9.41

Table 2 Summary statistics

Variable name	Mean	St. Deviation	Min.	Max.	Unit
Energy Security	0.288	0.120	0.132	0.829	--
Supply Security	0.125	0.063	0.046	0.431	--
Consumption Security	0.029	0.005	0.012	0.037	--
Matching security	0.134	0.690	0.020	0.374	--
IND_qqr	1.583	1.557	0.1848	7.7003	--
GDP per capita	3.964	2.070	0.930	11.320	10^4 per capita
Green Technology Efficiency	0.627	0.227	0.294	1.102	--
Ratio of Capital to Labor	24.473	10.501	8.070	59.190	10^4 per capita
Dummy Variable	0.500	0.500	0.000	1.000	--

Table 3 Results of unit root test

Variables	LLC-T	Conclusions	Variables	LLC-T	Conclusions
Energy Security	-6.779***	Stationary	IND_qqr	-4.216***	Stationary
Supply Security	-8.065***	Stationary	GDP per capita	−18.785***	Stationary
Consumption Security	-10.754***	Stationary	Green Technology Efficiency	-2.918***	Stationary
Mathcing Security	-3.642***	Stationary	Capital-to-labor Ratio	-2.431***	Stationary

Notes:1.Before we do the unit root test,all of variables are standarded.

2.***p < 0.01, **p < 0.05, *p < 0.1

Table 4 Empirical Results

Variables	Model1：Energy Security	Model2：Supply Security	Model3：Consumption Security	Model4：Matching security
IND_qqr	0.074*	0.085*	0.180*	0.622
	(0.040)	(0.045)	(0.100)	(0.517)
GDP per capita	-0.052***	-0.052***	-0.084**	-0.489**
	(0.016)	(0.019)	(0.039)	(0.204)
Green Technology Efficiency	0.056**	0.076**	0.223***	0.224
	(0.027)	(0.031)	(0.065)	(0.345)
Capital-to-labor ratio	0.141***	0.153***	-0.004	1.826***
	(0.046)	(0.051)	(0.118)	(0.599)
Dummy variable	-0.065***	0.028***	0.046***	-2.310***
	(0.007)	(0.008)	(0.016)	(0.086)
σ_u	0.252***	0.192***	0.604***	5.946***
	(0.035)	(0.027)	(0.091)	(0.780)
σ_e	0.037***	0.045***	0.092***	0.480***
	(0.002)	(0.002)	(0.004)	(0.021)
Log likelihood	465.531	425.978	197.523	-315.617
Prob > chi2	0.000	0.000	0.000	0.000
rho	0.979	0.949	0.977	0.994
Observations	300	300	300	300
	30	30	30	30

Notes: 1.Before we do empirical test, all variables are standardized to make them dimensionless.

2.Standard errors in parentheses.

3.***p < 0.01, **p < 0.05, *p < 0.1.

Appendix 1 Evaluation index system of regional industrialization

Dimension	Index	Calculation method	Unit	Meaning	Index type
Quantity expansion	Assets per unit of industrial enterprises	X1=Total assets of industrial enterprises above designated size/Number of industrial enterprises	10^4 yuan/unit	Reflecting the asset expansion of industrial enterprise	positive
	Output per unit of industrial enterprises	X2= Industrial added value of industrial enterprises above designated size /Number of industrial enterprises	10^4 yuan/unit	Reflecting the output increase of industrial enterprise	positive
	Ratio of added value in industry to GDP	X3=(Industrial added value of industrial enterprises above designated size/GDP)×100%	%	Reflecting the level of industry to gross regional production	positive
Quality improvement	Overall Labor Productivity	X4=Industrial added value of industrial enterprises above designated size/Annual average employees	10^4 yuan/person	Reflecting employment quality	positive
	Full-time Equivalent of R&D Personnel	X5=number of full-time staff+number of part-time staff converted by workload	person year	Reflecting the technology R&D level	positive
	Ratio of Total Assets to Industrial Output Value	X6=((total profit + total taxes + interest expense)/average total assets)×100%	%	Reflecting the profitability of enterprises	positive

Note: All indexes adopt the statistical caliber of industrial enterprises above designated size.

Appendix 2 Evaluation index system of regional energy security

Dimension	Metric	Index	Calculation method	Unit	Index type
Supply security	Regional independent	Energy production per capita	X1=Primary energy production/number of resident population	Tons of standard coal equivalent/person	positive

	production capacity	Elasticity of energy production	X2= Growth rate of energy production /Growth rate of the national economy	%	positive
	Fluctuations in energy supply prices	Relative change in producer price index of petroleum processing, coking and nuclear fuel processing	X3= Producer price index for petroleum processing, coking and nuclear fuel processing /producer price index for industrial products	%	negative
		Relative change in producer price index of production and supply of electricity and heat	X4= Producer price index of production and supply of electric and heat/producer price index for industrial products	%	negative
		Relative change in producer price index of production and supply of gas	X5= Producer price index of production and supply of gas/producer price index for industrial products	%	negative
	Energy supply diversity	Shannon-Wiener index of energy supply	X6= $-\sum_k s_k ln s_k$,where s_k indicates the ratio of the k-th energy supply to the total supply	%	positive
	Energy industry profitability	Energy industry asset profit rate	X7=Industrial profits of petroleum processing, coking and nuclear fuel processing, production and supply of electricity, heat, and gas /average assets of the above industries	%	positive
Consumption security	Energy consumption	Energy consumption per capita	X8=Total energy consumption/ number of resident population	Tons of standard coal equivalent/person	negative

		Energy consumption intensity	X9=Total energy consumption/GDP	Tons of standard coal equivalent/ten thousand yuan	negative
		Elasticity of energy consumption	X10= Growth rate of energy consumption /Growth rate of the national economy	%	negative
	Energy consumption diversity	Shannon-Wiener index of energy consumption	X11= $-\sum_k c_k ln c_k$,where c_k indicates the ratio of the k-th energy consumption to the total supply	%	positive
Matching security	Energy self-sufficiency level	Energy self-sufficiency rate	X12= Primary energy production/total energy consumption	%	positive
	Energy import dependence	Percentage of net imports in available energy for consumption	X13= Net energy import/energy available for consumption	%	negative
	Energy dependence outside of the province	Proportion of net transfer from other provinces in available energy consumption	X14= Net energy transfer from other provinces/available energy consumption	%	negative
	Environmental impact of energy supply and demand	Sulfur dioxide emission	X15=Sulfur dioxide concentration in the air of provincial capital city	μg/m^3	negative
		Nitrogen dioxide emission	X16=Nitrogen dioxide concentration in the air of provincial capital city	μg/m^3	negative
		Concentration of PM_{10} in the air	X17=Average concentration of PM_{10} of provincial capital city	μg/m^3	negative
		Proportion of good weather	X18=Proportion of days of air quality equal to or above grade 2 of provincial capital city in one year	%	positive

Figures

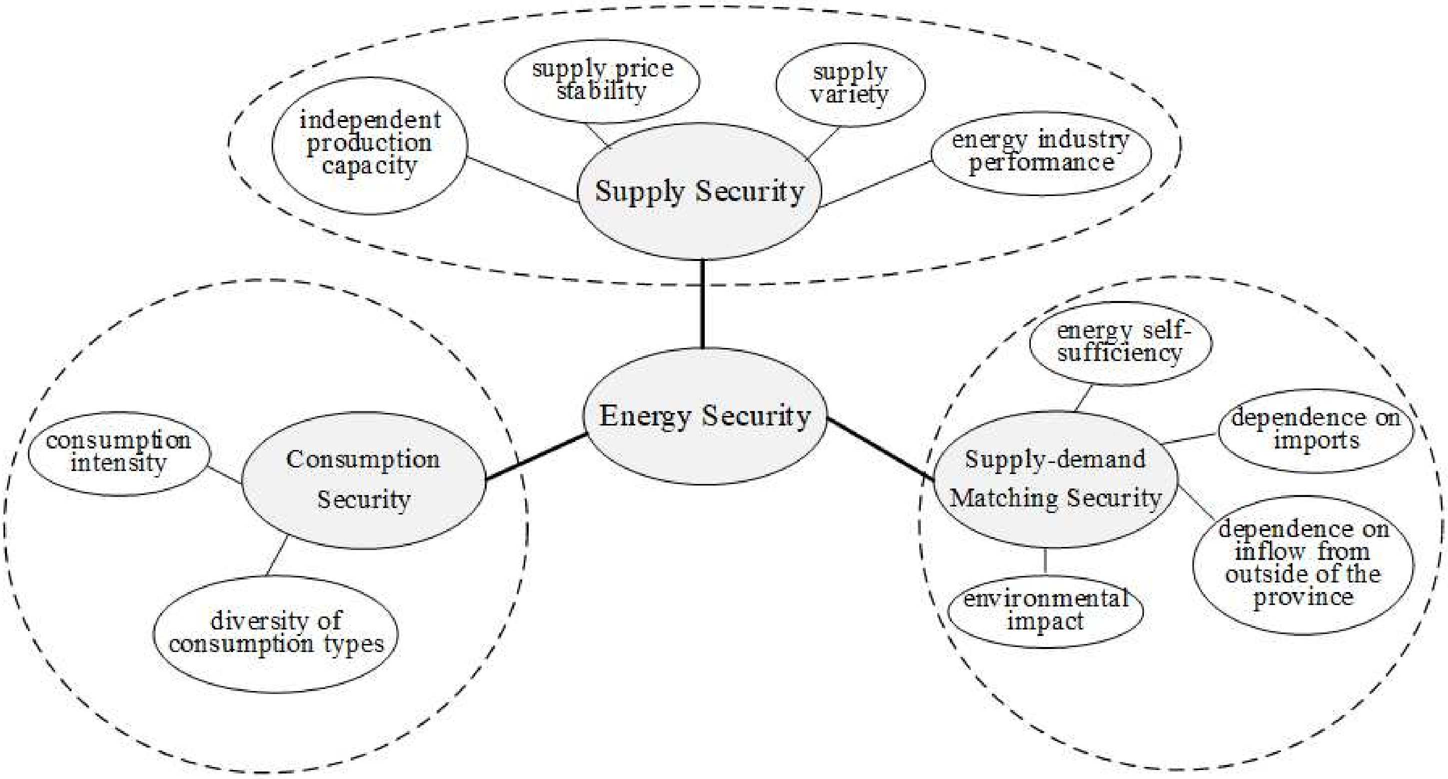

Figure 1

Conceptual framework of regional energy security

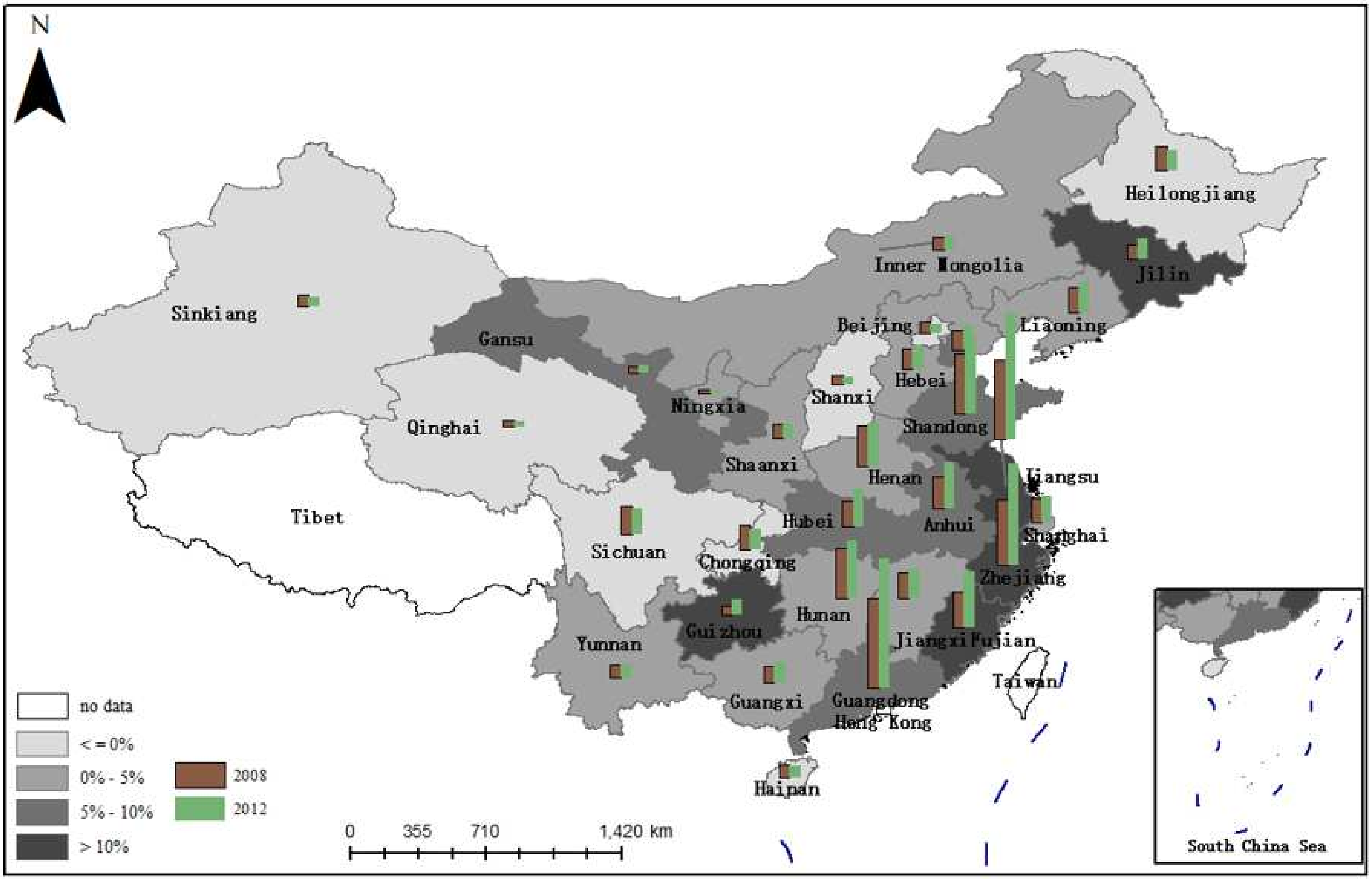

Figure 2

Comparison of the industrialization in China's 30 provinces in 2008 and 2012 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

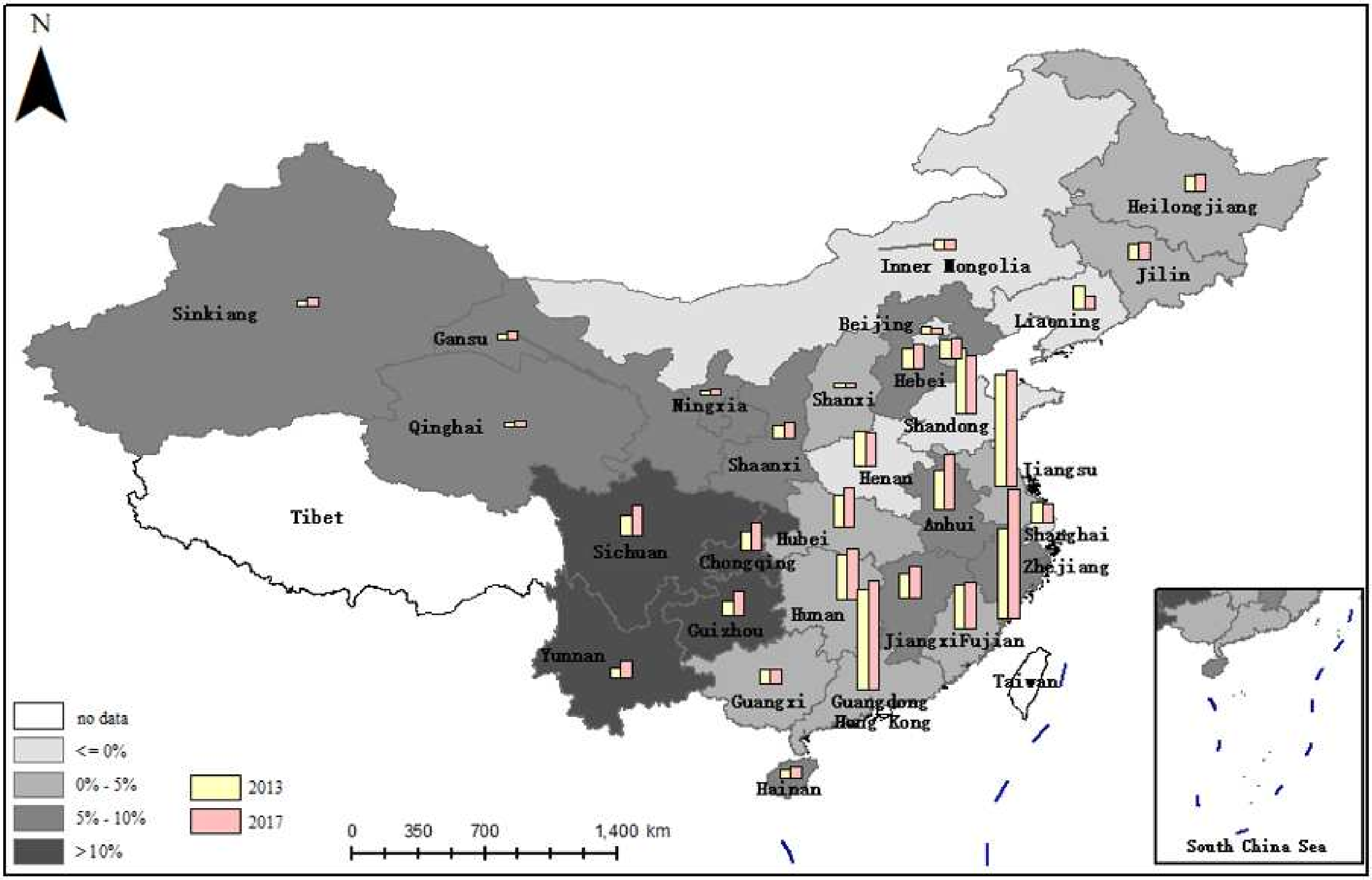

Figure 3

Comparison of the industrialization in China's 30 provinces in 2013 and 2017 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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- Appendix.docx