Impact of industrialization on China’s regional energy security in the New Era

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Abstract
This research is one of the very few studies that seeks to examine the association between China’s industrial development and its energy sustainability. It does so by discussing the impact of industrialization on energy security in the new era, during which the focuses of industrialization and energy security in China have changed. The former has shifted from quantity-based expansion to quality-based growth, while the latter has shifted from supply security to comprehensive security, including matching security. Since researchers have paid little attention to evaluations of industrialization and energy security from the perspective of the new era, this study aims to address this gap. An empirical study on the impact of industrialization on energy security is conducted, taking 30 provinces in China as research objects. The findings show that China’s energy supply security and consumption security have improved but that its matching security has deteriorated, which will eventually lead to an overall deterioration in energy security. Industrialization, however, can improve levels of energy security, supply security, and consumption security. Moreover, green technology efficiency and the capital–labor ratio both can improve levels of energy security and supply security, the former can also improve the level of consumption security and the latter can also improve the level of matching security. In contrast, an increase in GDP per capita inhibits energy security, supply security, consumption security, and matching security. This study will be helpful for policymakers seeking to resolve the issue of energy sustainability in the context of industrialization in China’s new era.

Keywords New era · Industrialization · Energy security · Quality-based growth

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1 Introduction

As the world’s largest energy-consuming and energy-producing country, China views energy security as the core issue of sustainable development and utilization of resources in the twenty-first century. Meanwhile, industrialization has had a significant impact on energy security through supply and demand. Entering the new era, the focuses of energy security and industrialization have therefore changed.

The term “new era” was introduced at the 19th National Congress of the Communist Party of China (CPC) to refer to the new historical orientation of China’s development. Before the new era, energy security policy emphasized supply security (Creti & Fabra, 2007). As China enters the new era, its energy supply capacity has improved significantly, but extensive energy consumption has led to an increasingly prominent imbalance between energy supply and energy demand. The ratio of energy consumption to production per capita increased from 1.16 in 2008 to 1.25 in 2017. Moreover, there is increased dependence on imports of primary energy (such as oil and natural gas), and the environmental impact of this is significant. Therefore, the theme of energy security in the new era has shifted from supply security to comprehensive security, including matching security.

More than 70 years of industrialization in China have promoted rapid economic growth (Franck & Galor, 2019), but associated problems include shortages and exhaustion of natural resources, environmental pollution, and ecological crises. The supply imbalance in the industrial structure makes traditional industrial development unsustainable (Li et al., 2019). With the acceleration of the industrialization process, enterprises are being asked to mitigate the adverse effects of industrialization on resources and the environment by actively practicing corporate social responsibility (CSR), which is conducive to improving corporate performance and achieving high-quality development (Abbas et al., 2019a, b). This approach is in line with the theme of industrialization in the new era, where the focus has shifted from quantity-based expansion produced by increased proportion of industrial structure in GDP, expansion of assets, and more outputs in industry to quality-based growth produced by more innovations, higher quality of employment, and increasing profitability of enterprises (King, 2007).

Since the focuses of energy security and industrialization have changed in the new era, three research questions present themselves. First, previous studies have often measured the level of industrialization in quantitative terms, such as industrial added value, output per capita, and the number of industrial enterprises in a region. What evaluation of industrialization can better reflect the emphasis in the new era on quality-based growth? Second, the imbalance between supply and demand plays a prominent role in energy security. How can this imbalance be evaluated reasonably for a given research object? Third, most studies have focused on the evaluation of energy security (Hendiani et al., 2019), avoiding the controversial issue of whether industrialization can increase supply security, reduce energy consumption, and mitigate the negative impact on the regional environment (Cherniwchan, 2012). What then is the relationship between industrialization and energy security in the new era?

There are substantial differences among China’s provinces in labor and energy resources, degree of economic development, and flow of energy fuels and services (Li et al., 2010). However, previous studies have tended to consider the country as a whole (Afonso et al., 2021; Ang et al., 2015b; Augutis et al., 2020), rather than taking regions within the country as research objects. In this paper, we take China’s 30 provinces as research objects in order to study the impact of industrialization on the country’s regional energy security in the new
era, which will help to achieve synchronous development of industrialization and energy security.

This paper makes three main contributions. First, it adopts the perspective of the new era to study the impact of industrialization on energy security and to make up for the lack of consideration given to the development stage of the research object. Second, it constructs a new index to evaluate the level of industrialization in a way that reflects the speed of development of quality-based growth relative to quantity-based expansion. Third, energy supply–demand matching security is introduced as an element of energy security and evaluated from the perspectives of energy self-sufficiency, external dependence, and environmental impact. This development enriches the meaning of energy security and enables analysis of the consistency of energy supply and energy demand.

The structure of this paper is as follows: Sect. 2 provides a review of related research. In Sect. 3, we set out the methods and data used to evaluate industrialization and energy security and impact research. In Sect. 4, we discuss the evolution of industrialization and energy security and discuss the impact of industrialization on energy security in the new era. Section 5 presents our conclusions and policy implications.

2 Literature review

There have been few studies on the impact of industrialization on energy security, and the relevant literature focuses mainly on evaluations of industrialization and energy security.

2.1 Evaluations of industrialization

Previous studies have evaluated industrialization from the perspective of quantity-based expansion. The measure indicators used include income per capita (Chenery, 1960), output per capita, added value from industry or manufacturing (Nasir et al., 2021), the number of industrial enterprises in a region (Sejati, 2020), the ratio of value added by industry to GDP (Pan et al., 2019), and the proportion of manufacturing exports to total merchandise exports (Demiral et al., 2021). Issues such as the unbalanced development of regional economies (Li et al., 2020) and CO₂ emissions (Demiral et al., 2021) have generated an immense multidimensional literature on the sustainability of industrialization. Thus, there is a strong body of evidence that economic indicators, such as income per capita, industrial structure rationalization, and manufacturing added value, as well as non-economic factors such as sustainable organizational innovation, knowledge sharing, and urbanization, are widely acknowledged indices of industrialization evaluation (Abbas et al., 2019a, b, 2020; Hussain et al., 2019).

2.2 Evaluations of energy security

Research on energy security has focused on energy supply security. In 1974, the International Energy Agency (IEA) was the first to recommend basing energy security on stability of the supply and price of crude oil. Subsequently, environmental problems caused by energy consumption have been of great concern to the public, and the connotations of energy security have expanded to include environmental and social factors (Ang et al., 2015a). Therefore, the definition of energy security has developed from an initial emphasis on supply security toward a more comprehensive evaluation.
There are two kinds of evaluation methods for energy security, namely the single index and the comprehensive index. The most common examples of a single index are the Shannon–Wiener index and the Herfindahl–Hirschman index, which measure the diversity of energy supply (Ozcan, 2019). In contrast, a comprehensive index constructs an evaluation system to measure the overall level of energy security. For example, the Asia–Pacific Energy Research Center (APERC, 2006) considers energy security in four dimensions: availability, accessibility, affordability, and acceptability. As the meaning of energy security has gradually been enriched, more and more scholars agree that an evaluation system should contain even more dimensions, such as reliability, efficiency, and environment-friendliness (Purwanto et al., 2019).

In general, most scholars study energy security from the perspective of energy supply and consumption, paying less attention to imbalances in supply and demand. Nevertheless, the matching security of energy is important for overall energy security, because it determines both a region’s dependence on external energy in terms of quantity and the stability of its energy security in relation to the environmental impact of energy production and consumption. Moreover, although industrialization in the new era puts more emphasis on quality-based growth than on quantity-based expansion, relatively little attention has been paid to this change in how industrialization is evaluated. Since the indices mentioned above were developed, the relationship between industrialization and energy security has undergone numerous changes, and this necessitates a fresh empirical analysis of the impact of industrialization on energy security that takes China’s new stage of development into account.

3 Research methodology and data

3.1 Evaluation of industrialization

3.1.1 Evaluation index system

Industrialization is not only the expansion of industrial scale but also the improvement of the quality (Döschter et al., 2021). Accordingly, industrialization is here divided into the two aspects of quantity-based expansion and quality-based growth. Taking account of the availability of data, the above aspects are measured as follows:

1. Quantity-based expansion. This aspect covers the indices of assets per unit, outputs per unit of industrial enterprises, and the ratio of added value to GDP (Pan et al., 2019). The first two indices represent asset scale (Steinfeld, 2004) and output scale, respectively, and the last one represents industrial structure.

2. Quality-based growth. This aspect covers the indices of overall labor productivity, the number of full-time-equivalent R&D personnel, and the ratio of total assets to industrial output value. The above indices represent employment quality, technology R&D level (Opoku & Boachie, 2020), and the profitability of enterprises, respectively.

Thus, this study constructs a regional industrialization evaluation system consisting of two dimensions and six indices. See Table 1 for the evaluation system used for regional industrialization.
Table 1  Evaluation system for regional industrialization

| Dimension                  | Index                                | Calculation method                                                                 | Unit       | Meaning                                                                 | Index type |
|----------------------------|--------------------------------------|------------------------------------------------------------------------------------|------------|-------------------------------------------------------------------------|------------|
| Quantity-based expansion   | Assets per unit of industrial enterprises | $X_1 = \frac{\text{Total assets of industrial enterprises above designated size}}{\text{Number of industrial enterprises}}$ | $10^4$yuan/unit | Reflecting the asset expansion of industrial enterprise                  | Positive   |
|                            | Output per unit of industrial enterprises | $X_2 = \frac{\text{Industrial added value of industrial enterprises above designated size}}{\text{Number of industrial enterprises}}$ | $10^4$yuan/unit | Reflecting the output increase in industrial enterprise                 | Positive   |
|                            | Ratio of added value in industry to GDP | $X_3 = \left(\frac{\text{Industrial added value of industrial enterprises above designated size}}{\text{GDP}}\right) \times 100\%$ | %          | Reflecting the level of industry to gross regional production            | Positive   |
| Quality-based growth       | Overall Labor Productivity            | $X_4 = \frac{\text{Industrial added value of industrial enterprises above designated size}}{\text{Annual average employees}}$ | $10^4$yuan/person | Reflecting employment quality                                           | Positive   |
|                            | Full-time Equivalent of R&D Personnel | $X_5 = \frac{\text{number of full-time staff} + \text{number of part-time staff converted by workload}}{\text{person year}}$ | person year | Reflecting the technology R&D level                                     | Positive   |
|                            | Ratio of Total Assets to Industrial Output Value | $X_6 = \left(\frac{\text{total profit} + \text{total taxes} + \text{interest expense}}{\text{average total assets}}\right) \times 100\%$ | %          | Reflecting the profitability of enterprises                              | Positive   |

All indexes adopt the statistical caliber of industrial enterprises above designated size
3.1.2 Entropy-weight method

The entropy-weight method is used here to determine the weight of each index. It objectively describes the salient characteristics of the aspect under evaluation, making the weighting more objective (Liu et al., 2020; Rani et al., 2019). The method consists of the following steps.

First, a standardized evaluation matrix is constructed. The initial evaluation matrix for regional industrialization including the six indices is thus established and represented as $X = (x_{ij})_{m \times n}$, here, $i$ 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 indices need to be min–max standardized. The processing formula is shown in Eqs. (1) and (2), and the standardized evaluation matrix is represented as $R = (r_{ij})_{m \times n}$.

Forward standardization:

$$ r_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1) $$

Reverse standardization:

$$ r_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2) $$

Second, the weight of each index is determined by entropy weight. The proportion of the index value of the $i$th evaluation object in the $j$th index is calculated using formula (3).

$$ p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (3) $$

The $j$th index’s entropy value ($e_j$) and redundancy ($d_j$) are calculated using formulas (4) and (5), where $k = 1/ \ln (m)$, $e_j \geq 0$, and $\ln 0 = 0$.

$$ e_j = -\frac{k}{m} \sum_{i=1}^{m} p_{ij} \ln (p_{ij}) \quad (4) $$

$$ d_j = 1 - e_j \quad (5) $$

The weight of each indicator is calculated according to formula (6).

$$ w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6) $$

Lastly, based on the standardized evaluation matrix $R$, combined with the entropy weight $w_j$, a standardized evaluation matrix $Y_{mn}$ with the entropy-weight method is constructed. The calculation process is shown in formula (7).

$$ Y_{mn} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} = \begin{bmatrix} r_{11} \cdot w_1 & r_{12} \cdot w_2 & \cdots & r_{1n} \cdot w_n \\ r_{21} \cdot w_1 & r_{22} \cdot w_2 & \cdots & r_{2n} \cdot w_n \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} \cdot w_1 & r_{m2} \cdot w_2 & \cdots & r_{mn} \cdot w_n \end{bmatrix} \quad (7) $$
where $Y_{mn}$ is a matrix with 300 rows and six columns, and the sum of $Y_{mn}$’s first to third columns and fourth to sixth columns are the scores for quantity-based expansion and quality-based growth, respectively.

In the new era, methods for evaluating industrialization must pay more attention to quality-based growth. Accordingly, we use the ratio of quality to quantity to reflect the level of industrialization in the new era, as follows:

$$IND_{qqr_{at}} = \frac{IND_{quality_{at}}}{IND_{quantity_{at}}}$$  \hspace{1cm} (8)

where $IND_{qqr_{at}}$ represents the ratio of quality to quantity, $a$ represents the province, and $t$ represents the year. $IND_{qqr_{at}} > 1$ indicates that the emphasis of regional industrialization is on quality-based growth, while $IND_{qqr_{at}} \leq 1$ indicates that the emphasis of regional industrialization is on quantity-based expansion.

### 3.2 Evaluation of energy security

#### 3.2.1 Construction of a regional energy security evaluation system

Regional energy security involves reducing regional energy system risks through effective energy supply, moderate consumption growth, and an overall balance between supply and demand based on interactions among countries and regions in terms of supply security, consumption security, and supply–demand matching security.

The following evaluation indices were selected for use in this paper.

1. **Supply security index.** This controls regional risks caused by unstable energy supply. It contains four metrics: regional independent production capacity, fluctuations in energy supply prices (Belgin et al., 2020), energy supply diversity (Chuang, 2013), and energy industry profitability.
2. **Consumption security index.** This controls regional unsustainable risks of economic and social development caused by excessive energy consumption. It contains two metrics: quantity and diversity of energy consumption.
3. **Matching security index.** This controls the risk of regional energy supply–demand imbalance based on mutual influences among countries and regions to achieve an overall match between energy supply and demand as well as environment-friendly development. Its metrics are regional energy self-sufficiency, energy dependence on foreign and provincial imports, and the environmental impact of supply–demand matching.

Thus, the energy security evaluation system includes three dimensions and 18 specific measurement indices. See Table 2 for the evaluation system for energy security.

#### 3.2.2 Evaluation of regional energy security

We also use the entropy-weight method to determine the index weights. The steps are similar to those used for industrialization. However, since there are 18 indices in the evaluation of energy security, the standardized evaluation matrix $Y_{mn}$ is a $300 \times 18$ dimension matrix. The sum of matrix $Y_{mn}$ by row is the regional energy security score, and the sum of $Y_{mn}$’s
| Dimension            | Metric                                      | Index                                                                 | Calculation method                                                                 | Unit                                      | Index type |
|----------------------|---------------------------------------------|----------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------|------------|
| Supply security      | Regional independent production capacity    | Energy production per capita                                         | $X_1 = \text{Primary energy production/number of resident population}$             | Tons of standard coal equivalent/person   | Positive   |
|                      |                                              | Elasticity of energy production                                      | $X_2 = \text{Growth rate of energy production/Growth rate of the national economy}$ | %                                         | Positive   |
| Fluctuations in energy supply prices | Relative change in producer price index of petroleum processing, coking and nuclear fuel processing | X3 = $\text{Producer price index for petroleum processing, coking and nuclear fuel processing/producer price index for industrial products}$ | %                                                                                   | Negative     |
|                      | Relative change in producer price index of production and supply of electricity and heat | X4 = $\text{Producer price index of production and supply of electricity and heat/producer price index for industrial products}$ | %                                                                                   | Negative     |
|                      | Relative change in producer price index of production and supply of gas | X5 = $\text{Producer price index of production and supply of gas/producer price index for industrial products}$ | %                                                                                   | Negative     |
| Energy supply diversity | Shannon–Wiener index of energy supply | X6 = $-\sum s_k \ln s_k$, 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 = $\text{Industrial profits of petroleum processing, coking and nuclear fuel processing, production and supply of electricity, heat, and gas/average assets of the above industries}$ | %                                                                                   | Positive     |
| Dimension                | Metric                          | Index                                                      | Calculation method                                                                 | Unit                                      | Index type |
|--------------------------|---------------------------------|------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------|------------|
| Consumption security     | Energy consumption              | Energy consumption per capita                              | \( X_8 = \frac{\text{Total energy consumption}}{\text{number of resident population}} \) | Tons of standard coal equivalent/person   | Negative   |
|                          |                                 | Energy consumption intensity                                | \( X_9 = \frac{\text{Total energy consumption}}{\text{GDP}} \)                    | Tons of standard coal equivalent/ten thousand yuan | Negative   |
|                          |                                 | Elasticity of energy consumption                           | \( X_{10} = \frac{\text{Growth rate of energy consumption}}{\text{Growth rate of the national economy}} \) | %                                         | Negative   |
|                          | Energy consumption diversity    | Shannon–Wiener index of energy consumption                 | \( X_{11} = - \sum c_k \ln c_k \), where \( c_k \) indicates the ratio of the k-th energy consumption to the total supply | %                                         | Positive   |
| Dimension                          | Metric                                | Index                           | Calculation method                                                                 | Unit        | Index type |
|-----------------------------------|---------------------------------------|---------------------------------|------------------------------------------------------------------------------------|-------------|------------|
| Matching security                 | Energy self-sufficiency level          | Energy self-sufficiency rate    | $X_{12} = \frac{\text{Primary energy production}}{\text{total energy consumption}}$ | %           | Positive   |
|                                   | Energy import dependence              | Percentage of net imports in available energy for consumption | $X_{13} = \frac{\text{Net energy import}}{\text{energy available for consumption}}$ | %           | Negative   |
|                                   | Energy dependence outside of the province | Proportion of net transfer from other provinces in available energy consumption | $X_{14} = \frac{\text{Net energy transfer from other provinces}}{\text{available energy consumption}}$ | %           | Negative   |
| Environmental impact of energy supply and demand | Sulfur dioxide emission               | Sulfur dioxide concentration in the air of provincial capital city | $X_{15} = \frac{\text{Sulfur dioxide concentration}}{\text{air of provincial capital city}}$ | $\mu g/m^3$ | Negative   |
|                                   | Nitrogen dioxide emission             | Nitrogen dioxide concentration in the air of provincial capital city | $X_{16} = \frac{\text{Nitrogen dioxide concentration}}{\text{air of provincial capital city}}$ | $\mu g/m^3$ | Negative   |
|                                   | Concentration of $\text{PM}_{10}$ in the air | Average concentration of $\text{PM}_{10}$ of provincial capital city | $X_{17} = \frac{\text{Average concentration of $\text{PM}_{10}$}}{\text{provincial capital city}}$ | $\mu g/m^3$ | Negative   |
|                                   | Proportion of good weather            | Proportion of days of air quality equal to or above grade 2 of provincial capital city in one year | $X_{18} = \frac{\text{Proportion of days of air quality equal to or above grade 2}}{\text{provincial capital city in one year}}$ | %           | Positive   |
first to seventh columns, eighth to eleventh columns, and twelfth to eighteenth columns are the scores for supply security, consumption security, and matching security, respectively.

3.3 Empirical research

This study uses empirical research to identify 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. A panel Tobit model can solve restricted dependent variables (Brown et al., 2015), and we use this method to obtain regression statistics for the continuously distributed variables. To study the impact of industrialization on energy security in the new era, we introduce the year into the panel Tobit model as a dummy variable.

The specific form of the Tobit model is as follows:

\[
S_{at} = \begin{cases} 
 \beta^T Z_{at} + \epsilon_{at}, & \beta^T Z_{at} + \epsilon_{at} > 0 \\
0, & \text{other} 
\end{cases}
\]

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

3.4 Data sources

Data 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 for the period 2009 to 2018. Because of data availability considerations, Tibet is excluded from the econometric analysis and the other 30 provinces of China Mainland are the research objects.

4 Results and discussion

4.1 Evolution of regional industrialization in the new era

The new era started with the 18th National Congress of the CPC (CPC CCDI, 2017), which was held in November 2012. Because the statistics are annual, we define 2013 and subsequent years as the new era. To compare differences in industrialization before and since the beginning of the new era, the data from 2008 to 2012 and from 2013 to 2017 are treated separately in the analysis. The results are shown in Figs. 1 and 2, where each province is colored according to its average annual growth rate in industrialization. The two bar charts for each province represent the level of industrialization in the start and end years of the survey period.

Between 2008 and 2012, 22 provinces grew year on year. Jiangsu grew fastest, with an annual growth rate of 12.402%, because it has a solid industrial foundation and its technology investment and profitability increased significantly over the period. Eight provinces declined year on year. Beijing declined the most, with a negative growth rate of −7.754%, which is mainly due to the significant reduction in the profitability of its industrial
enterprises associated with the structural transformation from the industrial economy to the service economy (Li et al., 2019). In terms of level of industrialization, Jiangsu, Guangdong, and Zhejiang scored highest in both 2008 and 2012, mainly because of their excellent performances in R&D investment and profitability. In the same years, Qinghai,
Ningxia, and Shanxi scored lowest, because of their poor performances in terms of profitability, as well as a lack of R&D investment in Qinghai and Ningxia.

Between 2013 and 2017, 24 provinces grew year on year, more than between 2008 and 2012. This indicates that more provinces have improved the quality of the industrialization in the new era. Guizhou grew fastest, with an annual growth rate of 14.717%. Its industrial foundation was weak at the start of the period, but it achieved rapid industrial growth by vigorously promoting infrastructure construction. Six provinces declined year on year, with Liaoning declining fastest at −13.963%, mainly because of poor profitability. In terms of level of industrialization, the top scores in both 2013 and 2017 were those for Zhejiang, Jiangsu, and Guangdong, while the lowest scores were those for Qinghai, Shanxi, and Ningxia, as in the period from 2008 to 2012.

4.2 Evolution of regional energy security in the new era

The evaluation results for energy security and its three subindices in 2008, 2012, 2013, and 2017 are reported in Figs. 3, 4, 5, 6, respectively. The evolution trends for energy security from 2008 to 2012 and from 2013 to 2017 are reported in Figs. 7 and 8, respectively.

Analysis of Figs. 3, 4, 5, 6 indicates that Inner Mongolia, Shanxi, and Shaanxi (abbreviated as MJS) were the top three provinces for energy security levels in 2008, 2012, 2013, and 2017, with stable performances. However, their levels of energy security are high for different reasons. Inner Mongolia’s outstanding advantage is its self-sufficient energy supply; in 2017, the province was ranked first in China for security of energy supply. In contrast, the high levels of energy security in Shanxi and Shaanxi can be attributed to good performance in supply–demand matching. Meanwhile, the Beijing–Tianjin–Hebei region had low energy security scores, mainly because of limited energy supply and continuously high demand. In addition, the extent of the difference between MJS and the other provinces increased at first before decreasing later in the period, with the gap widening from 0.113 in 2008 to 0.201 in 2013 and then narrowing to 0.158 in 2017.
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By analyzing annual rates of energy security, we find that 23 provinces improved their energy security levels from 2008 to 2012, with Inner Mongolia, Qinghai, and Ningxia as the top three provinces. From 2013 to 2017, although 21 provinces improved their energy security levels, the number of provinces with improved energy security decreased a little comparing with the period 2008 to 2012.

Fig. 4 Energy security of China’s 30 provinces in 2012. Note: Energy security is the sum of supply security, consumption security, and matching security.

Fig. 5 Energy security of China’s 30 provinces in 2013. Note: Energy security is the sum of supply security, consumption security, and matching security.
By analyzing the growth rates of the provinces, we find that 20, 26, and 19 provinces had a positive growth rate for supply security, consumption security, and matching security, respectively, during the period 2008 to 2012; for the period 2013 to 2017, the numbers were 22, 18, and 19, respectively. This shows that more provinces improved their supply security and fewer improved their consumption security in the new era. Specifically, during the period 2008 to 2012, Inner Mongolia had the fastest growth rates for supply security and matching security, and Shanghai had the fastest growth rate for consumption security. During the period 2013 to 2017, Hebei had the fastest growth...
rates for supply security and matching security, and Qinghai had the fastest growth rate for consumption security.

4.3 Impact of industrialization on energy security in the new era

4.3.1 Selection of variables and descriptive statistics

Drawing on previous studies, and taking account of the availability of data and the quantifiability of indicators, we selected the following variables for our empirical study.

Energy security. This is the key observation object in this paper. As mentioned above, it covers the security of energy itself and the security of the three subindices. We therefore regress energy security, supply security, consumption security, and matching security as dependent variables.

IND_qqr. This represents the quality-to-quantity ratio for industrialization, which reflects high-quality industrial development in the new era. As with any other industry, high-quality development in the energy industry means greater profitability, which promotes energy supply security. At the same time, high-quality development means that output depends more on quality-based growths, and this helps to reduce energy intensity and improve energy consumption security. Therefore, our main hypothesis is that an increase in IND_qqr improves energy security in general.

GDP per capita. This represents regional income level, which is expressed as the ratio of GDP to the permanent population of the region at the end of the year. An increase in GDP per capita increases energy purchasing power and stimulates energy consumption, which augments dependence on external energy and makes it difficult to reduce energy consumption intensity. Therefore, in theory, GDP per capita is an important factor in reducing energy security.

Green technology efficiency. This represents regional green technological innovation capability. Technological innovation broadens the variety of the energy supply and increases independent energy production. Simultaneously, it is beneficial for reducing energy consumption intensity and for resolving tensions between energy supply and demand. Therefore, in theory, green technology innovation promotes regional energy
security. Green technology efficiency is measured by the super-efficiency EBM model. The hybrid distance function of this model is considered to be a realistic measurement method because it has two distance functions, radial and SBM. Moreover, the super-efficiency method can solve the incomparability problem when the unit efficiency value is 1.1

*Capital–labor ratio.* This index is used to analyze the impact of input factor endowments on energy security. A higher capital–labor ratio indicates that regional economic development depends more on capital than on labor. Intensive capital generates economies of scale and increases R&D capability, which is beneficial for improving energy security. But intensive capital boosts energy consumption at the same time, which results in reducing energy security. Thus, the impact of capital-labor ratio on energy security is unknown, which needs to be judged based on empirical results. Capital in this variable is calculated from year-end fixed capital stock, which is used to deflate a fixed asset price index, and labor is measured by the number of employees at the end of the year.

*Dummy variable.* To reflect the changes of energy security in the new era, the year dummy variable is introduced, with the years before 2013 set to 0 and the years from 2013 onward set to 1.

The descriptive statistics for each variable are shown in Table 3.

### 4.3.2 Stationarity of variables

To ensure the stationarity of each variable and avoid spurious regression, the unit root for each variable is checked. Common unit root tests include LLC-T, ADF-FCS, and PP-FCS.

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**Table 3** 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 eff   | 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 | –          |

1 The inputs of the super-efficiency EBM model are included as follows: (1) fixed capital stock at the end of the year, measured using the perpetual inventory method, unit 100 million RMB; (2) number of employees at the end of the year, unit 10,000 people; (3) water consumption per capita, unit cubic meters per capita; (4) sum of the area of agricultural land and construction land, unit 1,000 hectares; and (5) energy consumption, converted into 10,000 tons of standard coal based on the conversion coefficient of various types of energy, expected output the total output value of each region over the years by GDP deflator, unit 100 million RMB. The following variables of unexpected output are included: (1) CO2 emissions, calculated according to the IPCC (2006) carbon emission coefficient, whereby carbon dioxide released is the total consumption of nine kinds of fossil energy (coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas, and natural gas), unit 10,000 tons; (2) wastewater discharge, unit 10,000 tons; (3) solid waste emissions, unit 10,000 tons; (4) SO2 in exhaust gas emissions, unit 10,000 tons; and (5) emissions of smoke and dust in exhaust gas, unit 10,000 tons.
which represent the Levin–Lin–Chu test statistic, the Fisher–ADF test statistic, and the Fisher–PP test statistic, respectively. Here, the results of the unit root test are based on LLC-T. Since there are only 10 years of data, a zero-lag period is selected, and zero averaging (the “demean” option) is used to alleviate the cross-sectional correlation. The results are shown in Table 4.

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. This shows 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

Taking energy security, supply security, consumption security, and matching security as the explained variables, IND_qqr, GDP per capita, green technology efficiency, capital–labor ratio, and the dummy variable are used as the explanatory variables for the panel Tobit regression. The regression results are reported in Table 5. The log-likelihood ratio indicates that the Xttobit model provides a statistically better fit for the sample data at a 99% level of confidence (Huang et al., 2013).

The results of model 1 show a positive relationship between IND_qqr and energy security. The coefficient of IND_qqr is 0.074, significant at the 10% level, indicating that the process of industrialization promotes energy security. The coefficient of GDP per capita is -0.052, which means that an increase in GDP per capita reduces energy security. The coefficient of green technology efficiency is 0.056, which means that an improvement in green technology efficiency increases energy security. The coefficient of the capital–labor ratio is 0.141, significant at the 1% level, which shows that the higher the capital–labor ratio, the more dependent the development of the regional economy is on capital rather than on energy.

Comparing the results of models 2, 3, and 4, we find that the coefficients of IND_qqr in models 2 and 3 are positive at the 10% level of significance, which means that IND_qqr can improve supply security and consumption security (Kander et al., 2017). The coefficient of IND_qqr in model 4 is positive but not significant. Since energy self-sufficiency and environmental impact are important for matching security, the insignificant coefficient for supply–demand matching is probably due to the failure of industrialization to solve the problem of external dependence on energy and to improve the environment (Nasir et al., 2021; Opoku & Boachie, 2020).
The coefficients for GDP per capita in the three models are significantly negative, which shows that GDP per capita reduces independent energy production, stimulates energy consumption, and increases external dependence on energy by increasing energy purchasing power (Abbasi et al., 2021). Green technology efficiency is very significant for improving both supply security and consumption security, mainly because green technology innovation improves the capability for independent energy production, increases the variety of the supply, and reduces the intensity of consumption (Ang, 2015a; Pan et al., 2019). However, this variable is not significant for improving matching security, mainly because of cross-province convergence in air pollutants (Cherniwchan, 2012).

The capital–labor ratio reflects regional factor endowment, which improves supply security and matching security significantly. This may be because of the combination of a rise in the price of labor and a decline in capital in recent years in China. A large number of industrial enterprises respond strategically to control production costs by using more capital and less labor (Liu et al., 2021). Such an increase in invested capital is conducive to the improvement of enterprise scale, and the scale effect is very important for the development of energy enterprises such as hydropower (Xin et al., 2020). Moreover, capital-intensive areas are more motivated to conduct R&D work on new energy and on reducing emissions of pollutants. These measures can increase the diversity of the energy supply, lower energy consumption, and reduce environmental pollution. However, the impact of

| Table 5 Empirical results |
|---------------------------|
| Variables                | Model1 Energy Security | Model2 Supply Security | Model3 Consumption security | Model4 Matching security |
| IND_qqr                  | 0.074* (0.040)         | 0.085* (0.045)         | 0.180* (0.100)              | 0.622 (0.517)            |
| GDP per capita           | −0.052*** (0.016)      | −0.052*** (0.019)      | −0.084*** (0.039)           | −0.489*** (0.204)        |
| Green Technology Efficiency | 0.056** (0.027)      | 0.076** (0.031)      | 0.223*** (0.065)           | 0.224 (0.345)            |
| Capital-labor ratio     | 0.141*** (0.046)       | 0.153*** (0.051)      | −0.004 (0.118)              | 1.826*** (0.599)        |
| Dummy variable          | −0.065*** (0.007)      | 0.028*** (0.008)      | 0.046*** (0.016)           | −2.310*** (0.086)       |
| $\sigma_u$              | 0.252*** (0.035)       | 0.192*** (0.027)      | 0.604*** (0.091)           | 5.946*** (0.780)        |
| $\sigma_e$              | 0.037*** (0.002)       | 0.045*** (0.002)      | 0.092*** (0.004)           | 0.480*** (0.021)        |
| Log likelihood          | 465.531 (0.035)        | 425.978 (0.027)       | 197.523 (0.091)            | −315.617 (0.780)        |
| Prob > chi2             | 0.000 (0.002)          | 0.000 (0.002)         | 0.000 (0.004)              | 0.000 (0.021)           |
| rho                     | 0.979 (0.977)          | 0.949 (0.977)         | 0.977 (0.994)              | 0.994 (0.994)           |
| Observations            | 300 (30) 300 (30) 300 (30) 30 (30) |

Before we do empirical test, all variables are standardized to make them dimensionless

Standard errors in parentheses

$**p < 0.01$, $*p < 0.05$, $^*p < 0.1$
the capital–labor ratio on consumption security is insignificant, as intensive capital also consumes more energy. Therefore, it is very important to carry out careful industrial planning when expanding capital to avoid entry by industries that have high energy consumption and high pollution.

The year dummy variable analysis shows that regional energy security is generally deteriorating in the new era. From the three subindices of energy security, it can be seen that both supply security and consumption security have increased significantly. However, matching security has decreased significantly, which is detrimental to energy security overall. These results indicate that the external dependence of regional energy has increased, and that the environmental impact of energy remains prominent.

5 Conclusions and policy implications

5.1 Conclusions

This study investigates the impact of industrialization on energy security in the new era, during which the focuses of industrialization and energy security have changed. The focus of industrialization has shifted from quantity-based expansion to quality-based growth, and the focus of energy security has shifted from supply security to comprehensive security. On this basis, we constructed an evaluation index system for industrialization with two dimensions (quantity-based expansion and quality-based growth) and an evaluation index system for energy security with three dimensions (supply security, consumption security, and matching security). Then, taking China’s 30 provinces from 2008 to 2017 as research objects, we evaluated and compared the changes in industrialization and energy security before and after the new era. The Tobit model for panel data was used to conduct empirical research on the impact of industrialization on energy security in the same period.

The following conclusions can be drawn.

1. There have been improvements in China's energy supply security and consumption security in the new era, but matching security has deteriorated, which will eventually lead to an overall deterioration of energy security.
2. Industrialization can improve the level of energy security in relation to supply security and consumption security. However, it cannot significantly improve the level of matching security.
3. In addition to industrialization, green technology efficiency and the capital–labor ratio can improve levels of energy security and supply security. The former also improves consumption security, while the latter improves matching security.
4. GDP per capita inhibits energy security, supply security, consumption security, and matching security.

5.2 Policy implications

The results of this study have the following implications.

1. It is important to achieve a dynamic balance of energy supply and demand. On the one hand, it is necessary to improve the energy supply system’s adaptability to demand from different regions by optimizing its structure. On the other hand, the distributed
energy system should aim to reduce transmission and distribution costs and environmental pollution, using flexible policy tools based on regional factor endowments. Internet of things technology and the energy industry should be fully integrated, using market mechanisms to break the information barriers between energy supply and consumption.

(2) The increase in industrialization in the new era depends more on quality than on quantity, and this requires abandonment of the old development path of scale expansion in favor of a new model of quality-based growth. This new model must take account of two main aspects. The first is the need to enhance the role of technology and human capital in industrial development by building a team of R&D staff and increasing vocational training. The second is the need to cultivate new industries with energy and resource savings by promoting the application of green manufacturing in various industries under the premise of ensuring product quality.

(3) For innovation in developing new energy, research on energy storage technology and energy efficiency is indispensable. At the same time, the input structure of these factors should be optimized. On the one hand, capital and guide capital investment should be increased for industries that are low in energy consumption, pollution, and emissions. On the other hand, labor inputs should be reduced by improving labor productivity and reducing the dependence of industrial development on labor.

(4) The use of efficient and clean energy should be widely encouraged as the purchasing power of energy increases. Meanwhile, the general public should be educated in green and low-carbon energy consumption to reduce energy waste and achieve a decoupling of income growth and energy consumption.

One of the limitations of this study is the small sample that results from taking 30 provinces as research objects. From a more detailed perspective, industrialization and energy security levels differ greatly between cities, even within a single province. The impact of these differences among cities on the results of this study remains unclear. With access to more data, future studies can take individual cities as research objects to increase the sample size and carry out deeper empirical research. Furthermore, the digital economy, which is a driver of China’s economic development in the new era, has changed the industrial modes of production and consumption to a great extent. Future studies should therefore include the digital economy in their evaluations of industrialization in the new era.

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Author contribution Jun Zhang contributed to methodology, writing—original draft; Jiangquan Wang contributed to investigation; Linling Zhang contributed to conceptualization, formal analysis; Lei Zhao contributed to writing—review & editing.

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

Declarations

Conflict of interest The authors declare that they have no conflict of interest. This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to the Publisher.
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