Research Study on Energy Efficiency in Various Municipalities in Guizhou Province

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Abstract. Using the data envelopment analysis (DEA) method, the total factor energy efficiency and total factor electricity efficiency in various cities and municipalities in Guizhou Province are analyzed from five input indicators: the number of on-the-job workers, science and technology expenditures, energy conservation and environmental protection expenditures, comprehensive energy use and electricity consumption, and the correlation between the distribution of industries and the development trend of energy efficiency in various cities and municipalities is also explained. It is found that:(1) for the total factor energy efficiency and total factor electricity efficiency, except for Liupanshui City, the efficiency of other municipalities shows a good growth trend, especially Guiyang City being the most significant;(2) among the municipalities with similar industry structure, their industrial efficiency level may have high similarity, or the efficiency development trend may be similar but the level varies, or the trend varies considerably, for which multiple reasons may account for their heterogeneity. Based on the results of the above study, suggestions for industrial development in Guizhou Province are put forward, including increasing communication, developing diversified industries, and strengthening technological investment.

Keywords: Guizhou Province; total factor energy efficiency; total factor electricity efficiency; DEA

1 Introduction

After the dual-carbon target was proposed, the "1+N" policy system was gradually built, deepened and improved. In the entire energy consumption system, the industrial sector in particular accounts for the highest proportion of energy consumption and has the greatest impact on the transformation of energy consumption in society as a whole. In July of 2022, the Ministry of Industry and Information Technology of the People's Republic of China, the Development and Reform Commission and the Ministry of Ecology and the Environment jointly issued the "Implementation Plan for Peak Carbon Performance in the Industrial Sector", which builds a top-level framework for energy-saving and carbon-reducing development in the industrial sector.

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According to the results of the third Chinese National Land Survey, 61.01% of the land in Guizhou province has a slope of more than 25 degrees, and the area of towns, villages and industrial and mining land accounts for only 4.4% of the total, so that the space for urban development is relatively limited and the space suitable for industrial development is even more narrow. In different municipalities in Guizhou Province, on the one hand, the differences in industrial distribution, location conditions, resource endowment and management level of each city have led to differences in the industrial output efficiency of each city; on the other hand, the dominant industrial sectors in different municipalities have subjective and objective differences in process benchmarks, technological levels, management levels, etc., which have led to uneven production efficiency among industries.

Efficiency is the way of evaluating inputs and outputs, including single-factor efficiency evaluation and multi-factor efficiency evaluation. Single-factor efficiency evaluation evaluates only one input, while multi-factor efficiency evaluation is used to evaluate the overall efficiency level of multiple inputs and multiple outputs, and commonly used measurement methods include Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA).

Wang et al.[1] uses DEA-Banker-Charnes-Cooper (BCC) model and DEA-Malmquist model to conducts a provincial comparative study with the panel data of ten representative provinces from 2011 to 2020, finding that the rapid number increase of high-tech enterprises in most provinces (cities) is accompanied by an ineffective input–output efficiency. NguyenNhuY et al.[2] proposes using the SBM-I-C DEA model to examine and suggest partners for Vietnamese logistics firms to form strategic alliances, finding that integrating technology in managing strategic alliances will foster companies in the alliance to formulate a better strategy with up-to-date information on policies. Choi et al. [3] uses slacks-based DEA to investigate investment performance at the local government level in Korea and reveals that the average score for R&D investment performance in Korea is 64%. Cui et al. [4] uses SFA and kernel density function to evaluate Green Total Factor Productivity growth trend for 36 China's industrial sectors during 2000–2016 to explore their key driving factors. Osuagwu et al. [5] applies both non-parametric DEA and SFA, using the Malmquist Productivity Index, and error component production function respectively, to ascertain if any significant variation in efficiency exists on a sample of 12 banks covering over 80 percent of total bank assets in Nigeria. Besides, to explore the prediction and improvement of energy efficiency, especially that related to electricity, there are also studies adopting big data and random forest algorithm [6], hybrid data-model driven optimization [7], Yalmip optimization [8] and improved fireworks algorithm [9].

The geographic location and environment differences of the cities in Guizhou Province are obvious, and the development level of industry is uneven. This study plans to use the DEA model to analyze the differences in total factor energy efficiency among the nine municipalities (including three autonomous prefectures) in Guizhou Province, to study the differences in spatial development, and to evaluate the correlation with the industrial structure of each region. This study aims to analyze the development level of cities in Guizhou Province from multiple perspectives, such as temporal development, industry differences and spatial distribution, so as to play a positive role in promoting energy conservation and emission reduction as well as industrial transformation and coordinated development in Guizhou Province.

2 Research Methodology

This study will firstly use DEA method to analyze the trend of social development efficiency changes in recent years in various cities of Guizhou Province, then apply the concept of total factor efficiency to the two key factors of energy inputs and electricity inputs to conduct in-depth analysis, and finally interpret the results of the data analysis by combining with the structure of industrial development in various cities.

2.1 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA), a non-parametric technical efficiency analysis method, was first proposed in 1978. Since then, the theoretical and practical methods of DEA have developed rapidly, and the scope of application has been expanding. The commonly used basic models include Constant Returns to Scale (CRS, also known as CCR model), as shown in Equation (1), and Variable Returns to Scale (VRS, also known as BCC model), as shown in Equation (2).

$$
\begin{aligned}
& min\theta(CRS) \\
& s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{ik} \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \\ \lambda, s^-, s^+ \geq 0 \\ i = 1,2,\ldots,m; j = 1,2,\ldots,n; r = 1,2,\ldots,q \end{cases}
\end{aligned} \tag{1}
$$

where θ denotes the efficiency value of the decision unit, x denotes inputs, y denotes outputs, λ denotes the weight coefficient, and s^- and s^+ are the input slack and output slack variables, respectively.

$$
\begin{aligned}
& min\theta(VRS) \\
& s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{ik} \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda, s^-, s^+ \geq 0 \\ i = 1,2,\ldots,m; j = 1,2,\ldots,n; r = 1,2,\ldots,q \end{cases}
\end{aligned} \tag{2}
$$

Eq. (2) adds the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ compared to Eq. (1) to construct a pure technical efficiency frontier after removing scale efficiency.

Both the CCR model and the BCC model are radial DEA models, whose measure of the degree of inefficiency includes only the proportion of all inputs that shrink or increase in equal proportion to their outputs, and excludes slack improvements. In order to consider the slack improvement component in the measurement of efficiency value, Tone et al. [10] proposed Slack Based Measure (SBM). In a radial model, efficiency is measured by the proportion of all inputs that increase or decrease in equal proportion to their outputs. While in the SBM method, efficiency is measured by the average proportion of increases or decreases in each of the inputs and outputs. The θ in CRS indicates the Technical Efficiency (TE) while in VRS it indicated the Pure Technical Efficiency (PTE), eliminating the effect of scale. Thus, with considering both CRS and VRS model in SBM method, the Scale Efficiency (SE) could be calculated by θ(CRS) dividing θ(VRS).

2.2 Total Factor Efficiency

Energy efficiency includes a variety of meanings such as physical efficiency, which indicates the ratio of energy inputs to energy outputs, and economic efficiency, which considers energy as one of the factors of production and analyses the impact and correlation between energy inputs and economic outputs. Total Factor Energy Efficiency (TFEE) is generally defined as the ratio of the theoretical optimal value to the actual value of energy use within a certain time frame in a region or system[11], and its value is less than or equal to 1, and the closer it is to 1, the more energy is fully utilized. TFEE looks at various inputs, including labor, capital, and materials, in addition to energy. This approach acknowledges that energy efficiency is influenced not just by how energy is used, but also by how effectively other resources are utilized. The output is often measured in terms of economic value, such as gross domestic product (GDP) or other relevant metrics. For both CRS and VRS could be used in a view of input orientation, that is, to adjust the x to make θ reach 1. Thus, when we adjust the energy consumption input to make θ reach 1, the energy number is the theoretical optimal value. With the actual number divided by the optimal value, TFEE could be calculated. Same rule could work for electricity factor in our analysis case when we treat electricity as an independent input like energy, so that total factor electricity efficiency (TFEE of electricity) could be calculated in similar way as TFEE of energy.

Compared with single-factor energy efficiency (e.g. energy intensity of 10,000 yuan output value), total factor energy efficiency takes into account the synergies and constraints of capital, labor, energy, scientific and technological inputs, environmental inputs, etc., and is more capable of evaluating the energy use situation under a comprehensive perspective, which is more adaptable to the development needs of regional or industrial energy conservation assessment in the future. Alajmi [12] estimates the total factor energy efficiency using the DEA–Malmquist method to explore the current energy efficiency situation in the Gulf countries. Feng et al. [13] focuses on the measurement of the total factor energy efficiency with establishing the Gray Weight Slack-Based Measure. Ohene-Asare et al. [14] presents a total factor energy efficiency assessment of 46 African countries and analyzes possible bidirectional relationship between energy efficiency and economic development within a three-stage framework consisting of SBM, bootstrapped truncated regression and two-stage least squares.

3 Municipalities Analysis in Guizhou

3.1 Data Source

The input data is based on the panel data of Guizhou Province by prefecture and city from 2013-2022, with the input variables being the number of on-the-job workers, science and technology expenditures, energy conservation and environmental protection expenditures, comprehensive energy utilization and electricity consumption, and the output variable being the Gross Regional Product. All data were obtained from the Guizhou Provincial Statistical Yearbook.

3.2 Technical Efficiency

The study numbers for each city are as follows: G1 Guiyang City, G2 Liupanshui City, G3 Zunyi City, G4 Anshun City, G5 Bijie City, G6 Tongren City, G7 Qianxinan Buyi and Miao Autonomous Prefecture, G8 Qiandongnan Miao and Dong Autonomous Prefecture, and G9 Qiannan Buyi and Miao Autonomous Prefecture. The results of their pure technical efficiency and scale efficiency analyses are shown in Figure 1.

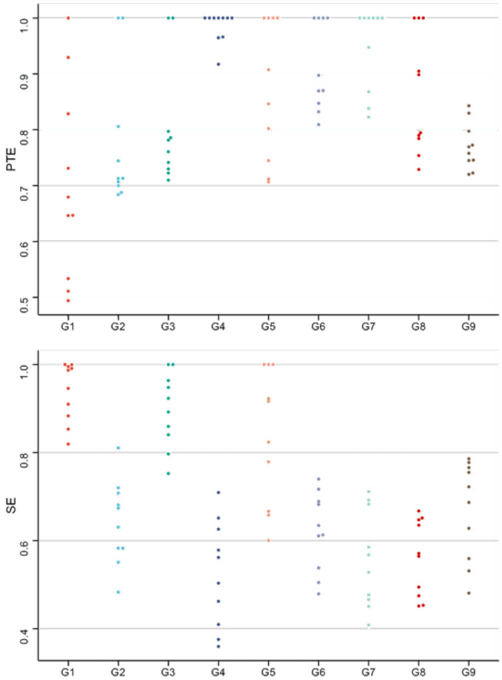

Fig. 1. Distribution of Pure Technology and Scale Efficiency of Industry by Municipalities in Guizhou Province, 2013-2022

At the pure technical efficiency (PTE) level, Anshun, Bijie, Tongren, Qianxinan and Qiandongnan are at a high level, especially led by Anshun, whose pure technical efficiency of industrial output has remained above 0.9. Guiyang City maintains a good growth trend in pure technical efficiency, gradually increasing from 0.51 in 2013 to 1.0 in 2022, reflecting the continuous iterative upgrading of Guiyang City's industrial development. The pure technical efficiency of Liupanshui City and Zunyi City, on the other hand, shows a certain range of volatility, varying between 0.7 and 1.0. On the other hand, the pure technical efficiency of Qiannan Autonomous Prefecture has remained relatively stable, staying in the level range of 0.7 to 0.8 for a long time, showing no obvious progress or regression.

At the scale efficiency (SE) level, the more prominent ones are Guiyang City, Zunyi City and Bijie City, in which Guiyang City and Zunyi City show year-on-year improvement in scale efficiency, reflecting the increasingly better scale fitness of the industry. The scale efficiency of the remaining cities is at a similar level (0.5~0.7), showing a good trend of increasing year by year, but due to the poor foundation in the early years, their scale efficiency in 2022 still has not reached a high level.

As shown in Fig. 2, in terms of the average level of each city, the average pure technical efficiency level shows volatility in the range of 0.8 to 0.9, while the average scale efficiency gradually improves from 0.6 to 0.8. As a result, the overall efficiency level shows an upward trend amidst fluctuations, gradually increasing from around 0.5 in the early years to around 0.75. It can be seen that the efficiency improvement of the industry in Guizhou Province is mainly driven by the improvement of scale efficiency, and in the development of the industry, the level of scale allocation has gradually improved, which strongly supports the good development of their industry.

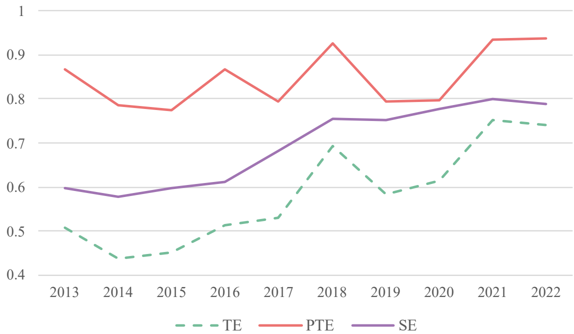

Fig. 2. Average efficiency of municipalities in Guizhou Province, 2013-2022

3.3 Total Factor Efficiency Analysis

Comprehensive energy use and electricity consumption were used as pointer to analyze the total factor energy efficiency and total factor electricity efficiency in each city, respectively, and the results are shown in Figure 3.

In terms of total factor energy efficiency, there is a general upward trend, with the average efficiency of all municipalities fluctuating from 0.84 in 2013 to 0.94 in 2022. Among the municipalities, Guiyang and Zunyi have seen the most significant increase in efficiency, from 0.43 and 0.56 in 2013 to 1.0 in 2022, respectively. Anshun City, Tongren City, and Qianxinan Autonomous Prefecture have long maintained a high level of energy use efficiency, while Bijie City, Qiandongnan Autonomous Prefecture and Qiannan Autonomous Prefecture have fluctuated up and down within a certain range, with no obvious trend of increasing or decreasing efficiency. Among the cities, only Liupanshui City has maintained a low level of total factor energy efficiency for a long period of time, with only a few years of outstanding performance.

In terms of total factor electricity efficiency, the level of utilization efficiency is generally high and the average efficiency level of each city fluctuates from 0.9 in 2013 to 0.98 in 2021, followed by a slight decline in 2022. Among the cities, similar to the total factor energy efficiency, Guiyang city has the most significant increase in efficiency, from 0.62 in 2013 to 1.0 in 2022, while Anshun city, Bijie city, Tongren city, Qianxinan Autonomous Prefecture, and Qiandongnan Autonomous Prefecture maintain high efficiency levels over the long term. For Liupanshui City, Zunyi City and Qiannan Autonomous Prefecture, their total factor electricity efficiency fluctuates more, but Zunyi City has seen a more pronounced efficiency improvement since 2019. In 2022, similar to the case of total factor energy efficiency, Liupanshui city's total factor electricity efficiency remains at the lowest level among all municipalities.

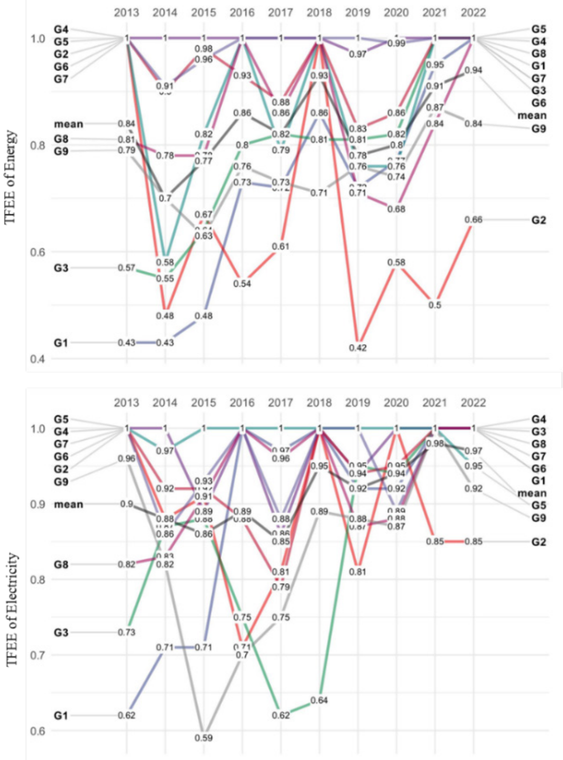

Fig. 3. Total Factor Comprehensive Energy Efficiency and Total Factor Electricity Efficiency in municipalities of Guizhou Province, 2013-2022

3.4 Explanation on Industry Structure and Efficiency

As the industrial sector is the mainstay of energy and power consumption in each region, the distribution and development trend of each industrial sector is coupled with the development trend of each city.

- Guiyang City and Anshun City both account for about 21% of local GDP in terms of industrial added value in 2022, and the structure of industrial industries is relatively balanced, with no single industry accounting for more than 20% of the industrial industry's output value. Guiyang's dominant industries include computer communications and other electronic equipment manufacturing, electric power and heat production and supply, tobacco products, non-ferrous metal smelting and rolling processing, and chemical raw materials and chemical products manufacturing. The advantaged industries in Anshun City include railway, shipbuilding, aerospace and other transport equipment manufacturing, computer communications and other electronic equipment manufacturing, pharmaceutical manufacturing, electric power and heat production and supply, and non-metallic mineral products. Based on the results of the TFEE analysis, it can be seen that Anshun City has maintained a high level of energy and power efficiency under a balanced industrial layout; whereas Guiyang City has continued to improve its own energy and power efficiency through continuous technological iteration and upgrading of its industrial structure as it does not rely on a single industry. From the analysis result, it can be also inferred that action programme for the revitalization of industrial sectors and action plan for high quality development of the manufacturing industry work better in Guiyang than other cities, pushing the high-speed increase of its industry technical efficiency and TFEE.
- The leading industries of Tongren City and Qiannan Autonomous Prefecture include chemical materials and chemical products manufacturing, non-metallic mineral products industry and agricultural food processing industry, and the first two leading industries are high energy-consuming industries, with the combined output value reaching more than 40% of their own industrial output value. In terms of their efficiency, Tongren City shows a higher level of technology and industry management, and its TFEE are significantly better than that of Qiannan Autonomous Prefecture, given the similarity of its industrial structure. The scale efficiency of both cities is low, and there is some room for optimization in terms of industrial scale.
- The leading industries in Qianxinan and Qiandongnan Autonomous Prefectures both include electric power and heat production and supply, non-ferrous metal smeltin, non-metallic mineral products and ferrous metal smelting. The four leading industries are all energy-intensive, and the sum of their output values is greater than 60% of their own industrial output value. The two states are similar in terms of pure technical efficiency, scale efficiency, and TFEE, reflecting the similar technical and managerial level of the industries in the two states.

- Liupanshui City and Bijie City are both large coal-producing cities, with the output value of the coal mining and washing industry accounting for more than 40% of the industrial output value. However, the industrial output value of Liupanshui City accounts for about 40% of the GDP, which is about twice as much as that of Bijie City. From the analysis, it can be seen that Bijie City is significantly better than Liupanshui City in terms of both pure technical efficiency and scale efficiency. Thus, while the coal mining and washing industry shows fluctuation characteristics, Bijie City's industrial development is not completely limited to the decline or progress of a single industry due to its relatively low industrial share and higher technical and scale efficiency. As for Liupanshui City, where the coal industry accounts for a large proportion of the total and low efficiency, and TFEE are at the lowest level in the province, is suitable for promoting industrial diversification and industrial upgrading to achieve better economic robustness.
- Zunyi is a big city of Chinese baijiu, and the structure of industrial output value is different from that of all other cities in Guizhou Province, with the output value of the alcoholic beverages and refined tea manufacturing industries accounting for nearly half of the industrial output value, and the industrial output value accounting for more than 40% of the regional GDP. As the steady progress of alcoholic beverages and refined tea industry over the long term, it strongly pushes Zunyi's TFEE to maintain the same trend growth pattern over the same period as well. However, it should also be noted that it is difficult for any industry to maintain long-term sustained positive development. A strong tie to a single industry may bring higher uncertainty and risk to the region's economic development in the future.

4 Conclusions

The DEA model approach is used to analyze the output efficiency as well as the total factor energy use efficiency of nine municipalities (including three autonomous prefectures) in Guizhou Province from 2013 to 2022. The results of the study found that, at the level of pure technical efficiency of industries, all cities except Liupanshui City and Qiannan Autonomous Prefecture have maintained a high level or shown a good growth trend for a long period of time; whereas at the level of scale efficiency, Guiyang City, Zunyi City and Bijie City have performed better, while the rest of the cities are at the same level. An analysis of TFEE shows that electricity use efficiency is generally higher than energy use efficiency, and that, with the exception of Liupanshui City, all other cities and municipalities show a good growth trend, especially Guiyang City, which is the most significant.

A correlation consideration between industry and city reveals that there may be high similarity in energy efficiency levels between cities with similar industrial structures (Guiyang and Anshun, Qianxinan and Qiandongnan), similar structure but different energy efficiency development trends (Tongren and Qiannan), and also large differences in energy development trends (Liupanshui and Bijie). The source of the heterogeneity comes from both the technical efficiency level and the scale efficiency level, while the deeper reason behind the data reflects the impact of the differences in the development balance of primary, secondary and tertiary industries, the transformation and upgrading of the old and new industries, the introduction and iteration of new technologies in the production processes and procedures, and the optimization and improvement of the management level of the government and enterprises in the different cities and municipalities on the local economic and industrial development.

In response to the findings of this study, the following recommendations are made: (1)Strengthening communications between industries, localities and municipalities, especially exchanges and learning between regions with similar resource endowments and industry structures, such as Tongren City and Qiannan Autonomous Prefecture; (2) Optimizing the scale of industry and promoting industrial diversification to increase resilience to risk and enhance the economic robustness of the region, such as Liupanshui City, Bijie City and Zunyi City; (3) Increasing industrial investment in technological upgrading and training more specialized management personnel to promote the continuous optimization and upgrading of the entire industry chain, which could be useful for all cities to maintain good trend or adjust to rising path.

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References

1. Wang Liwei,and Tang Tianbo.Evaluation of innovation efficiency of high-tech enterprise based on DEA and Malmquist index under the background of sustainable development.Asia Pacific Journal of Innovation and Entrepreneurship 18.4(2024):340-354.
2. Ho NguyenNhuY,Nguyen Phuong Mai,Luu ThiMinhNgoc,Tran ThiThuyAnh.Selecting Partners in Strategic Alliances: An Application of the SBM DEA Model in the Vietnamese Logistics Industry.Logistics 6.3(2022):64-64.
3. Yongrok Choi,Siyu Li,and Hyoungsuk Lee.Korean Paradox of Public Support for the Research and Development Investment in the Sustainable Performance of the Regional Economy.Land 13.6(2024):759-759.
4. Herui Cui,Haoran Wang,Qiaozhi Zhao.Which factors stimulate industrial green total factor productivity growth rate in China? An industrial aspect.Greenhouse Gases: Science and Technology 9.3(2019):505-518.
5. Eze Simpson Osuagwu,Wakeel Atanda Isola,and Isaac Chii Nwaogwugwu.Measuring Technical Efficiency and Productivity Change in the Nigerian Banking Sector: A Comparison of Non-parametric and Parametric Techniques.African Development Review 30.4(2018):490-501.
6. Bai Liang,Guo Xingyin,Pan Xudong,Yedeli Bolati,Guzainuer Aizaizi.Artificial Intelligence Prediction Method of Information System Resource Utilization Based on Big Data.Power Systems and Big Data 25.6(2022):43-48.

7. Fan Hong,Xu Tao,Jia Qingshan.Review of Optimization Scheduling for Integrated Energy Systems with Data Centers Based on Hybrid Data-Model Driven.Southern Power System Technology (2024):1-14.
8. Wu Difan,Zhang Nan,Han Yu,Chen Yun,Xu Tinging,Yu Haibin.Optimal Dispatching Strategy for Multi-microgrid Integrated Energy System Based on the Efficiency of Cascade Utilization of Energy. Power Systems and Big Data 26.4(2023):19-27.
9. Liu Jie,Zhao Xiaojun,Jia Yuchen,Li Yanan,Bai Muke,Zhang Limei.Dynamic Reconstruction of AC/DC Distribution Network with High Proportion of New Energy Based on Improved Fireworks Algorithm.Southern Power System Technology 18.10(2024):64-72.
10. Kaoru Tone,and Biresh K. Sahoo.Scale, indivisibilities and production function in data envelopment analysis.International Journal of Production Economics 84.2(2003):165-192.
11. Jinli Hu,Shihchuan Wang. Total-factor energy efficiency of regions in China.Energy Policy 34.17(2006):3206-3217.
12. Reema Gh. Alajmi.Total-Factor Energy Efficiency (TFEE) and CO2 Emissions for GCC Countries.Sustainability 16.2(2024).
13. Ren Feng,Zhang Jiayue,Yu Xin,Long Dinghong.Measurement and influencing factors of TFEE, and potentials of energy conservation and emission reduction in china based on GW-SBM and bootstrap model.Energy Reports 11.(2024):745-753.
14. Kwaku Ohene-Asare,Eric Nuertey Tetteh,Evelyn Lamisi Asuah. Total factor energy efficiency and economic development in Africa.Energy Efficiency 13.6(2020):1177-1194.