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Energy Efficiency Evaluation of China's "Belt and Road" Node Cities Based on Super Efficiency SBM and Malmqusit Index

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Abstract

Taking 16 node cities in China's "Belt and Road" from 2013 to 2022 as the research object, this paper evaluates the total factor energy efficiency of each city from a static perspective by using the super-efficiency SBM model with unexpected output. At the same time, with the help of Malmquist index, we further analyze the changes of total factor energy efficiency in these cities from a dynamic perspective. It is found that the overall total factor energy efficiency of each node city is low, and there is a big difference between cities, which leads to unbalanced energy development; The malmquist index values of "Belt and Road" areas are both greater than 1, and the changes of technical efficiency and technical progress index are also greater than 1, which are the factors that jointly promote the growth of total factor productivity. The influence of technological progress on the change of total factor energy efficiency in the "One Road" area is slightly higher than that in the "One Belt" area, but the technical efficiency is the opposite.

Keywords

"Belt and Road"; Super efficient SBM; Malmquist index

1. Introduction

In today's era of deepening globalization, the "Belt and Road" initiative, as a core platform for promoting international cooperation and common prosperity, has opened up unprecedented development opportunities for countries and regions along the route participating in the initiative. Under this framework, such as Shanghai, Ningbo, Xiamen, Qingdao, Shenzhen, Chengdu, Xining and other Belt and Road node cities play a key role in this initiative and are important hubs connecting domestic and foreign economic, cultural and technological exchanges. Energy, as the cornerstone of modern social development, is crucial to the stable operation and sustainable development of the Belt and Road node cities. These cities are not only the highlands of economic development, carrying huge industrial systems and population scales, but also their energy consumption is at a high level. From industrial production to residents 'lives, from transportation to commercial activities, stable energy supply is the prerequisite for ensuring the normal operation of various functions of cities. According to the data of China Energy Statistics Yearbook 2023, China's total energy consumption continues to grow, reaching more than 5.5 billion tons of standard coal in 2023, with significant energy consumption pressure. Against this background, the Belt and Road node cities are facing the challenge of balancing economic growth and energy consumption. On the one hand, the rapid development of cities requires sufficient energy support; On the other hand, reducing energy consumption intensity, reducing environmental pollution and realizing green and low-carbon transformation are also urgent tasks. Energy efficiency evaluation is of great significance in this context. It can not only objectively measure the relationship between economic development and energy consumption in these node cities, but also reveal the advantages and disadvantages in the process of energy utilization. It can also provide powerful data support for the government to formulate scientific and reasonable energy policies. Through energy efficiency evaluation, it is helpful to tap the energy saving potential and promote the efficient use of energy, thus helping the Belt and Road node cities to move forward steadily on the road of realizing green and low-carbon development, playing a greater leading and driving role in the Belt and Road Initiative, and promoting the prosperity and sustainable development of regional economy. In this study, 16 node cities of "One Belt and One Road" in China from 2013 to 2022 are taken as research objects, and the total factor energy efficiency of each node city is calculated from static and dynamic angles by using super efficiency SBM model and Malmquist.

2. literature review

At present, scholars at home and abroad have carried out in-depth research on energy efficiency, and have made a lot of research results. Among them, NastaranNajkar[1] uses spatial Bayesian panel model to evaluate provincial energy efficiency, and finds that industrial agglomeration can not only promote technology and knowledge spillover, but also have a positive impact on regional energy efficiency. Thomas Zaragoza et al.[2] conducted systematic mapping studies based on software-based energy consumption optimization strategies and found that information and communication technologies can be used to improve energy efficiency, especially in residential and commercial environments. Khan Baz et al.[3] analyzed energy use in OECD member countries using Westrend cointegration test and Granger causality test techniques, emphasizing the importance of environment-related technologies in improving energy efficiency and economic productivity. JosephJr.Aduba et al.[4] derived a multi-factor learning model to study the energy data of manufacturing industry for 20 years and found that the industry that is good at "learning" is also an energy efficient industry. António L.Amaral et al.[5] used data envelopment analysis, statistical analysis and multiple linear regression to find that the driving factors identified by MLR can effectively estimate the energy consumption of water supply and wastewater treatment SP, thus improving the overall energy efficiency. In terms of domestic research, Wen Linhong [6] constructed a threshold effect model and an intermediary effect model, and found that different types of environmental regulations can improve energy efficiency to a certain extent, and there is an intermediary effect. Jiang Dewei et al.[7] selected the super-efficiency SBM model and the Malmquist index to build an energy efficiency evaluation index system and found that the key to improving energy efficiency in Heilongjiang Province lies in technological innovation. Zhang Yabing [8] uses the improved social network method to point out that most small and medium-sized cities can promote energy efficiency by improving polycentricity, and large cities should strengthen functional links among centers. Li Yingchun [9] constructs error-corrected spatial Dobbin model to analyze influencing factors, and through spatial econometric model analysis, finds that pure technology and scale efficiency of energy industry should be improved according to local conditions, so as to improve energy efficiency. Qu Danlei [10] found that green energy efficiency in China provinces has significant spatial positive correlation by means of Super-SBM model and spatial correlation test. In summary, scholars focus on energy efficiency measurement methods and their application, and empirical analysis of factors affecting energy efficiency. These studies lay a foundation for energy efficiency related problems. However, existing studies still have certain limitations. In view of the coverage of the research area, the number of in-depth studies on specific areas is relatively small. In view of this, this paper focuses on the Belt and Road node cities, closely combining the actual situation of energy input and output of each city, and carefully constructs an evaluation index system applicable to each city's energy efficiency. On this basis, the super-efficiency SBM-Malmquist model is used to comprehensively measure the static and dynamic energy efficiency of each city. Through this research, the current situation and changing trend of energy efficiency of each node city are analyzed in depth, and practical suggestions are put forward based on the research results, aiming to provide powerful theoretical support and practical guidance for improving the energy efficiency of the node cities of the Belt and Road Initiative.

3. Research Methods and Variable Selection

（一）Super-SBM Model with Unexpected Outputs

Data Envelopment Analysis (DEA) is usually used to calculate efficiency involving multiple decision making units (DMUs), but it has some defects, such as it can only measure efficiency from a single angle, radial measurement error and variable slack problems are not consistent with the actual situation, in contrast, in order to solve efficiency problems involving unexpected outputs, Super-efficiency SBM model can not only measure efficiency from multiple angles, but also distinguish the difference between effective DMUs. In view of this, this study adopts the super efficiency SBM model incorporating unexpected outputs to evaluate the total factor energy efficiency of 16 "Belt and Road" node cities in China. The specific model is constructed as follows:

$$\text{S.t. } \rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^{-}}{x_{ik}}}{1-\frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1}\frac{s_r^{+}}{x_{rk}}+\sum_{r=1}^{q_2}\frac{s_t^{b-}}{b_{rk}}\right)} \tag{1}$$

$$\sum_{j=1,\neq k}^{n} x_{ij}\lambda_j - s_i^{-} \leq x_{ik}$$

$$\sum_{j=1,\neq k}^{n} x_{ij}\lambda_j - s_i^{-} \leq x_{ik}$$

$$\sum_{j=1,\neq k} b_{rj}\lambda_j - s_t^{b-} \leq b_{rk}$$

$$\sum \lambda_j = 1$$

$$\lambda,\ s^{-}, s^{+} \geq 0$$

$$\mathrm{i} = 1,2,\ldots,m; t = 1,2,\ldots,q_2$$

$$t = 1,2,\ldots,q_2;$$

$$j = 1,2,\ldots,n(j \neq \mathrm{k});$$

where: ρ is the target efficiency evaluation value; n represents the total number of decision units (DMUs);m represents the number of input variables;q1 represents the number of expected output variables, and q2 represents the number of undesired output variables; x represents the specific value in the input matrix, yr represents the value in the expected output matrix, bt is the value in the undesired output matrix; s-represents input redundancy, s+ represents expected output deficiency, sb-represents undesired output excess; λ is the weight distribution coefficient for each DMU.

（二）Malmquist Index

Malmquist index is an index proposed by Malmquist[11] to measure the dynamic change of efficiency.Its model form is as follows:

$$TFPCH_{\mathrm{c}} = TC \times EC = \sqrt{\frac{D^{t}{}_{c}(x^{t+1}, y_r^{t+1}, b_t^{t+1})D^{t+1}{}_{c}(x^{t+1}, y_r^{t+1}, b_t^{t+1})}{D^{t}{}_{c}(x^{t}, y_r^{t}, b_t^{t})D^{t+1}{}_{c}(x^{t}, y_r^{t}, b_t^{t})}} \tag{2}$$

where: Dt denotes the distance function; TFPCHc is Malmquist index under the assumption of constant return to scale, indicating the change of total factor energy efficiency under this state. If TFPCHc is greater than 1, it means that total factor energy efficiency increases, equal to 1 means that it remains unchanged, and less than 1 means that it decreases. EC indicates the change of technical efficiency, greater than 1 means that the contribution of economic factors to total factors increases, equal to 1 means that it remains unchanged, and less than 1 means that it decreases. TC indicates the change of technological progress. When this value is greater than 1, it means that technology has played a positive role in improving total factor energy efficiency; when it is equal to 1, it indicates that technology remains unchanged without significant change; and when it is less than 1, it reflects that technology has regressed compared with before.

In Fare[12], the application of Malmquist index is deepened and refined into technical efficiency change index (EC) and technical progress index (TC). Technical efficiency change index (EC) reveals the dynamic position change of decision-making unit relative to production frontier, i.e., the fluctuation of efficiency. EC can be decomposed into scale efficiency change index and pure technical efficiency change index. The pure technical efficiency change index reflects the specific effect of management and technological innovation on efficiency improvement, while the scale efficiency change index shows how the adjustment of production scale affects efficiency level. The calculation form is as follows:

$$TFPCH_{\mathrm{v}} = TC \times PEC \times SEC = \frac{D^{t+1}{}_{v}(x^{t+1}, y^{t+1})}{D^{t}{}_{v}(x^{t}, y^{t})} \sqrt{\frac{D^{t}{}_{v}(x^{t}, y^{t}) D^{t}{}_{v}(x^{t+1}, y_{r}^{t+1})}{D^{t+1}{}_{v}(x^{t}, y^{t}) D^{t+1}{}_{v}(x^{t+1}, y^{t+1})}} \times \sqrt{\frac{D^{t}{}_{v}(x^{t+1}, y^{t+1}) / D^{t}{}_{v}(x^{t+1}, y^{t+1})}{D^{t}{}_{v}(x^{t}, y^{t}) / D^{t}{}_{v}(x^{t}, y^{t})} \times \frac{D^{t+1}{}_{v}(x^{t+1}, y^{t+1}) / D^{t+1}{}_{v}(x^{t+1}, y^{t+1})}{D^{t+1}{}_{v}(x^{t}, y^{t}) / D^{t+1}{}_{v}(x^{t}, y^{t})}} \quad (3)$$

where: TFPCHc is an index to measure the change of total factor energy efficiency under the premise of variable return to scale; PEC is obtained by comparing the difference of management and technical efficiency at different time nodes on the same production frontier, which reflects the influence of management and technology application level on the change of total factor energy efficiency;SEC is calculated by comparing the distance between actual production point and optimal production frontier (or efficiency frontier), reflecting the influence of scale factor on total factor energy efficiency.

（三）Selection of variables and data sources

This paper measures the energy efficiency of China's Belt and Road node cities from 2013 to 2022, including Chengdu, Guangzhou, Hefei, Lanzhou, Ningbo, Qingdao, Xiamen, Shantou, Shanghai, Shenzhen, Tianjin, Wuhan, Xi'an, Xining, Changsha and Chongqing (The key data of other cities are excluded due to lack of them). The data come from EPS statistical database, China urban statistical yearbook and statistical yearbook of each node city. In terms of the selection of input-output indicators, refer to the research of Jiang Huaiyin (2022), Lv Zhouyang (2023) and other scholars. This study regards labor force, capital and energy as input factors, takes the actual GDP of the region as expected output, and regards industrial sulfur dioxide emission and industrial wastewater emission as non-expected output. The details are as follows:

(1) Labor input, which is measured by the employment population data at the end

of each node city from 2013 to 2022.

(2) Capital input, which is measured by the total fixed asset investment of each node city from 2013 to 2022.

(3) Energy input, which is measured by the total energy consumption of each node city during the above period.

(4) Expected output, expressed as the actual GDP of each node city.

(5) Unexpected output, referring to previous studies, considering that energy consumption may cause environmental pollution problems such as waste water and exhaust gas, this study selects the amount of sulfur dioxide and industrial waste water emitted by each node city over the years as measurement indicators.

4. Empirical Analysis

（一）Static Efficiency Analysis Based on Super-SBM Model

The division of "One Belt and One Road" cities in China is mainly based on geographical location, economic development level and strategic consideration of participating in the construction of "One Belt and One Road". Among the 16 cities studied in this paper,"One Belt" node cities cover Chengdu, Hefei, Lanzhou, Wuhan, Xi'an, Xining, Changsha and Chongqing; while "One Road" node cities include Guangzhou, Ningbo, Qingdao, Xiamen, Shantou, Shanghai, Shenzhen and Tianjin. Based on the panel data of 16 node cities of "One Belt and One Road" from 2013 to 2022, this paper uses Dearun software tool to evaluate the total factor energy efficiency of each node city.

The results are shown in

Table 1. below:Table 12013-2022 Total Factor Energy Efficiency of "One Belt and One Road" Node Cities

region	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	mean value	Grouping/sorting
Chengdu	0.529	0.535	0.624	0.669	0.656	0.723	0.877	0.959	1.024	1.033	0.763	Medium 5
hefei	0.402	0.374	0.391	0.430	0.446	0.429	0.394	0.410	0.406	0.398	0.408	Low 8
lanzhou	0.223	0.258	0.214	0.209	0.226	0.217	0.31	0.221	0.228	0.225	0.233	Low 14
wuhan	0.355	0.348	0.340	0.458	0.460	0.512	0.557	0.543	0.567	0.552	0.469	Low 7
xian	0.434	0.480	0.738	1.108	0.544	0.548	0.667	1.086	1.104	0.677	0.739	Medium 6
xining	0.157	0.155	0.173	0.184	0.196	0.193	0.205	0.214	0.222	0.227	0.193	Low 16
changsha	1.093	0.896	0.805	1.027	1.008	1.160	1.012	0.925	1.005	1.075	1.001	High 4
chongqing	0.212	0.210	0.208	0.226	0.258	0.263	0.283	0.316	0.379	0.403	0.276	Low 13
“belt”	0.429	0.409	0.436	0.536	0.470	0.501	0.533	0.579	0.612	0.569	0.507	-
guangzhou	1.056	1.042	1.083	1.055	1.032	1.027	1.022	1.011	1.005	1.008	1.034	Low 1
ningbo	0.310	0.316	0.313	0.320	0.360	0.395	0.394	0.416	0.433	0.428	0.369	Low 11
qingdao	0.356	0.354	0.350	0.387	0.436	0.441	0.419	0.432	0.446	0.445	0.407	Low 9
xiamen	0.349	0.350	0.348	0.355	0.372	0.389	0.384	0.392	0.401	0.406	0.375	Low 10
shantou	0.335	0.338	0.329	0.325	0.321	0.319	0.315	0.308	0.310	0.311	0.321	Low 12
shanghai	0.845	1.024	1.031	1.036	1.043	1.049	1.052	1.05	1.053	1.055	1.024	High 2
shenzhen	1.010	1.013	1.049	1.010	1.037	1.032	0.861	1.171	1.003	1.028	1.021	High 3
tianjing	0.193	0.184	0.174	0.170	0.225	0.255	0.249	0.253	0.282	0.332	0.232	Low 15
“"All the way”	0.557	0.578	0.585	0.582	0.603	0.613	0.587	0.629	0.617	0.627	0.598	-

As can be seen from the table, overall, the total factor energy efficiency of 16 node cities is between 0.155 and 1.171. During 2013-2022, only Guangzhou and Shenzhen have reached DEA efficiency. In addition, during this period, the average energy efficiency of all factors in the "One Belt" node cities is lower than that in the "One Road" node cities, but the energy efficiency of Tianjin and Shantou in the "One Road" node cities is very low, only 0.232 and 0.321 respectively. At the same time, during the period from 2013 to 2022, although the energy efficiency of the "Belt" node cities and the "One Road" node cities fluctuated, compared with 2013, in 2022, the energy efficiency of the "Belt" node cities and the "One Road" node cities increased by 32.6% and 12.6% respectively, and the "Belt" node cities increased significantly. From the regional point of view, there are big differences in total factor energy efficiency among node cities. The cities in the high efficiency group are Changsha, Guangzhou, Shanghai and Shenzhen, among which Guangzhou, Shanghai and Shenzhen belong to the "One Road" node cities, Changsha belongs to the "One Belt" node cities; the cities in the medium efficiency group are composed of Chengdu and Xi'an, and all belong to the "One Belt" node cities, and there is no case in the "One Road" node cities. In the low efficiency group, Hefei, Lanzhou, Wuhan and Chongqing belong to the category of "One Belt" node cities, while Ningbo, Qingdao, Xiamen, Shantou and Tianjin belong to "One Road" node cities, and the last five cities are "One Road" node cities. It can be found that the reason for the higher average total factor energy efficiency of "One Road" node cities is that Guangzhou, Shanghai and Shenzhen are higher, while the cities in the low efficiency group of "One Road" node cities are the same as "One Belt" node cities, indicating that there are obvious differences in total factor energy efficiency between cities, and there is unbalanced development of energy efficiency.

（二）. Dynamic Efficiency Analysis Based on Malmquist Index

1. Time Dimension Analysis

Through the collected panel data of each node city, Dearun software is used to calculate the malmquist index change, technology progress index and efficiency change index of China's "One Belt" and "One Road" node cities from 2013 to 2022. The results are shown in Table 2. From the perspective of total factor productivity changes, the total factor energy efficiency of the "Belt" region has increased significantly in 11 years, with an average increase of 4.8%. The "One Road" region has also increased significantly during this period, with an average increase of 4.7%. Among them, the impact of technical efficiency changes on the total factor energy efficiency of the "Belt" region is slightly higher than that of the "One Road" region. However, The influence of technological progress on TFP of "One Road" region is slightly higher than that of "One Belt" region.

From the perspective of technical efficiency change, the average change value of technical efficiency index in "One Belt" region and "One Road" region is 1.019 and 1.016 respectively; according to the decomposition results, the pure technical efficiency of "One Belt" region has increased by 0.7 percentage points, and the scale efficiency has increased by 1.3 percentage points; in contrast, the pure technical efficiency of "One Road" region has increased by 0.9 percentage points, while the scale efficiency has increased by 0.7 percentage points; At the same time, the technical efficiency change of the "One Belt" region is less than 1 in three time periods, namely 2015-2016, 2017-2018 and 2020-2021, and the technical efficiency change of the "One Road" region is less than 1 in 2015-2015, 2015-2016 and 2020-2021, and the technical efficiency of the "One Road" region increases in other years. Judging from the change of technological progress index, the technological progress index of the "Belt and Road" region was less than 1 in 2013- 2014,2014 -2015 and 2019-2020, and was greater than 1 in the rest of the years. Moreover, during 2015-2016, the technological progress index changed the most, increasing by 10.3%, and the total factor productivity also increased significantly by 7.1%; At the same time, the technological progress index of the "One Road" region was less than 1 in 2014-2015 and 2019-2020, and greater than 1 in the rest of the years. Moreover, during 2015-2016, the technological progress index changed the most, increasing by 10.5%. Although the technical efficiency decreased during this period, the total factor productivity still increased by 5.1%.

Table 2. 2013-2022 Malmquist Index and Decomposition of "One Belt" and "One Road" Regions

region	"Belt" area					"One Road" Area				
	EC	TC	PEC	SEC	TFEE	EC	TC	PEC	SEC	TFEE
2013-2014	1.015	0.994	1.003	1.013	1.008	0.994	1.012	0.992	1.003	1.007
2014-2015	1.048	0.993	1.004	1.045	1.039	1.044	0.994	1.021	1.022	1.036
2015-2016	0.973	1.103	0.986	0.988	1.071	0.952	1.105	0.976	0.977	1.051
2016-2017	1.031	1.035	1.048	0.985	1.067	1.053	1.037	1.058	0.997	1.092
2017-2018	0.990	1.067	0.999	0.993	1.055	1.001	1.058	1.009	0.993	1.059
2019-2020	1.084	0.962	1.010	1.073	1.034	1.052	0.980	1.009	1.043	1.029
2020-2021	0.996	1.070	0.994	1.003	1.065	0.989	1.040	0.992	0.996	1.027
2021-2022	1.039	1.035	1.014	1.025	1.073	1.030	1.044	1.011	1.018	1.075
mean value	1.019	1.031	1.007	1.013	1.048	1.016	1.033	1.009	1.007	1.047

2. Spatial Dimension Analysis

It can be seen from Table 3 that the total factor energy efficiency of China's "One Belt and One Road" node cities shows an upward trend to varying degrees, and the malmquist index of all node cities is greater than 1, among which the node city with the largest increase is Xining, with an increase of 10.9%. The technical progress index of 16 node cities is greater than 1, and the technical efficiency index is only less than 1 in Shan Tou City, while the other node cities are greater than 1. Among them, Guangzhou, Hefei, Lanzhou, Ningbo, Qingdao, Xiamen, Shanghai, Shenzhen, Tianjin, Wuhan, Xi'an, Xining, Changsha and Chongqing belong to the "double high type". The pure technical efficiency and scale efficiency are greater than or equal to 1, indicating that the technological innovation and development and construction of energy projects in these cities in the energy field are effective; Chengdu's pure technical efficiency is less than 1 and scale efficiency is greater than 1, belonging to "high and low type", which requires improving resource allocation rate and accelerating technological innovation to improve pure technical efficiency; Shantou's pure technical efficiency is equal to 1 and scale efficiency is less than 1, belonging to "low and high type", indicating that it is necessary to expand the scale of energy projects to improve scale efficiency.

Table 3. Malmquist Index and Decomposition of "One Belt and One Road" Node Cities

region	EC	TC	PEC	SEC	TFEE
chengdu	1.000	1.020	0.987	1.018	1.019
hefei	1.036	1.032	1.011	1.025	1.061
lanzhou	1.033	1.044	1.000	1.033	1.078
wuhan	1.021	1.026	1.000	1.021	1.047
xian	1.051	1.029	1.008	1.042	1.069
xining	1.074	1.055	1.000	1.074	1.109
changsha	1.000	1.008	1.000	1.000	1.008
chongqing	1.024	1.039	1.023	1.005	1.064
guangzhou	1.003	1.036	1.002	1.002	1.038
ningbo	1.000	1.048	1.008	0.992	1.047
qingbo	1.024	1.040	1.024	1.000	1.060
xiamen	1.009	1.043	1.000	1.009	1.053
shantou	0.981	1.027	1.000	0.981	1.007
shanghai	1.007	1.024	1.000	1.007	1.030
shenzhen	1.000	1.002	1.000	1.000	1.002
tianjing	1.041	1.031	1.042	1.000	1.072

5. Conclusion

Based on the panel data of China's "Belt and Road" node cities from 2013 to 2022, taking industrial sulfur dioxide and industrial wastewater emissions as unexpected outputs, this paper constructs a super efficiency SBM model and malmquist index method to conduct static and dynamic analysis on the total factor energy efficiency of China's "Belt and Road" node cities. The following conclusions are obtained: From a static point of view, the total factor energy efficiency of China's "Belt and Road" node cities generally shows a rising trend, but the overall total factor energy efficiency is still low, regional energy efficiency is low, and there are large differences among node cities. In the research scope of this paper, the total factor energy efficiency of "One Road" node cities is higher than that of "One Belt" node cities, but the gap between the two is narrowing continuously. The number of cities in low efficiency in "One Belt" node cities is the same as that of "One Road" cities. From a dynamic point of view, the malmquist index values of the "Belt" region and the "One Road" region are greater than 1, increasing by 4.8% and 4.7% respectively, and the changes in the technical efficiency index and the technical progress index are greater than 1. The two factors jointly promote the growth of total factor energy efficiency.

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