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Research on the Evaluation of Green Innovation Efficiency of Listed Thermal Power Enterprises in China

-- Based on the Super-SBM-GML Index Model

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Abstract

In order to promote the dual coordination of the efficient development of China's listed thermal power enterprises and environmental protection, the principle of green innovation and development in China is practiced. Based on the super-efficient SBM model considering undesirable output and the GBL index, this paper statically and dynamically measures and analyzes the green innovation efficiency of seven listed thermal power companies in China from 2017 to 2021. The results show that: most of China's listed thermal power enterprises have achieved effective green innovation efficiency, but the development of green innovation efficiency is not balanced, and the overall growth is continuous, but many of them have inverted "U" type changes. Based on the GML dynamic efficiency measurement, it can be seen that the main reason for the current increase in the efficiency of green innovation is efficiency improvement rather than technological progress. Finally, according to the empirical conclusions, targeted policy suggestions are put forward for the improvement of the green innovation efficiency of listed thermal power enterprises in China.

Keywords

Green Innovation Efficiency; China's Listed Thermal Power Enterprises; Super-SBM; GML.

1. Introduction

Since China's reform and opening up, in just three decades, the economy has taken off. But the price of this rapid economic development is the excessive consumption of resources and the excessive destruction of the environment. China has experienced three decades of rapid economic development, but this rapid growth has come at a huge resource and environmental cost. In the "Twelfth Five-Year Plan", China has clearly proposed that scientific and technological innovation should promote economic growth. In March 2019, the Ministry of Industry and Information Technology and the National Development Bank of China issued the Notice on Accelerating Industrial Energy Conservation and Green Development, which emphasizes that the energy-saving and green development of industry is an important measure to achieve industrial transformation and upgrading and promote supply-side structural reform. In 2015, the total emissions of sulfur dioxide (SO2) and soot in the thermal power industry accounted for 3.9% and 13.4% of the country's industrial emissions, respectively, is an important source of air pollution. Therefore, the thermal power industry is a key industry of national environmental governance, and energy conservation and emission reduction of thermal power enterprises have always been an important goal of government environmental governance. Therefore, studying the green innovation efficiency of listed thermal power enterprises and how to improve the green innovation efficiency of thermal power enterprises

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is an important issue that needs to be solved urgently for thermal power enterprises to achieve green development.

2. Literature Review

In the context of global warming, the international community has paid more and more attention to ecological and environmental issues and green innovation research. Among them, especially in the evaluation of the efficiency of green innovation, scholars continue to focus on all aspects of the field and have achieved certain results. Zhao Lu et al. (2020) used the super-efficiency SBM model considering undesirable output to measure the green innovation efficiency of Chinese industries from 2006 to 2017, and conducted a spatial effect analysis, pointing out that the green innovation efficiency of the east and west showed a big difference[1]. Chen Haiyan (2021) adopted the SBM-Malmquist index method, and grouped the static and dynamic measurements of China's listed pharmaceutical manufacturing industry, and the measurement results showed that there is still a lot of room for improvement in the green innovation efficiency of China's listed pharmaceutical manufacturing industry[2] Cao Jingying et al. (2021) calculated the green innovation efficiency of the automotive industry based on the super-efficiency SBM model, and analyzed the influencing factors of the green innovation efficiency of the automotive industry using the Tobit regression model. The intensity of environmental regulations and government support are the main influencing factors[3]. Suriguga and Ma Zhanxin (2021) used super-efficient SBM and GML indices to measure 12 league cities in Inner Mongolia from both dynamic and static aspects The overall green factor productivity of inner Mongolia is low[4]. Based on panel data from 11 provinces and cities in the Yangtze River Economic Belt, Yan Huafei et al. (2022) measured the efficiency of green innovation and tested its spatial correlation with the super-efficiency SBM model and ML index The results show that the midstream has made the greatest progress, and there is a regression trend in the upstream[5]. Liu Dan et al. (2022) used the network SBM model and GML index to study the green total factor productivity of the economic development systems of 33 cities in Jiangsu, Zhejiang and Fujian. It is pointed out that the decline in green total factor productivity in most cities is related to the irrational industrial structure and the low effectiveness of innovation-driven[6]. Guo Haoran (2022) measured the green innovation efficiency of China's counter mining enterprises with three wastes as unintended output, pointed out that the technological progress of enterprises in the departmental year has regressed significantly, and found that the scale of enterprises is significantly positively correlated with the green innovation efficiency of enterprises through Tobit regression[7]. Cao Huizhong et al. (2022) used the super-efficiency DEA model to measure the green innovation efficiency of high-tech industries in 28 provinces in China, and found that there was a "U" trend. Spatially, there is a phenomenon of high east and low west[8].

3. Research Methodsresearch Methodology, Data Sources and Descriptive Statistics

3.1. Research Methods

3.1.1. Static Efficiency Evaluation Model - Super-SBM Model that Considers Undesirable Output

Tone (2001) proposed the non-angle non-radial DEA method, that is, the SBM model, which overcomes the defects of the traditional DEA model and solves the problem of element relaxation. Bias due to radial and angular problems is eliminated, and further comparisons can be made when multiple valid decision units exist compared to traditional DEA methods (Tone Cited Pages, A slacks-based measure of efficiency in data envelopment analysis)[9]. Tone (2004)

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introduces undesirable outputs into this model and proposes an SBM model that considers undesirable outputs (Tone Cited Pages, Dealing with undesirable outputs in DEA: a Slacks-Based Measure (SBM) approach)[10]. Compared with the traditional DEA model, it needs to first use the SBM model to evaluate the effective decision-making unit and properly handle the undesirable output;Then the super-efficient SBM is used to further evaluate the effective decision units and consider n decision units, each decision unit includes input m and expected output S1 utput S2 for a total of 3 elements. The Super-SBM model with undesirable outputs is shown below.

$$\rho = \min \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{S_i^{x}}{x_{i0}}}{1-\frac{1}{S1+S2}\left(\sum_{k=1}^{S1}\frac{S_k^{y}}{Y_{k0}}+\sum_{l=1}^{S2}\frac{S_l^{z}}{Z_{l0}}\right)}$$

$$s.t.\quad x_{i0} \geq \sum_{j=1,\neq 0}^{n}\lambda_j x_j - S_i^{x},\quad \forall i;$$

$$y_{k0} \leq \sum_{j=1,\neq 0}^{n}\lambda_j y_j + S_k^{y},\quad \forall k;$$

$$z_{l0} \geq \sum_{j=1,\neq 0}^{n}\lambda_j z_j - S_l^{z},\quad \forall l;$$

$$1-\frac{1}{S1+S2}\left(\sum_{k=1}^{S1}\frac{S_k^{y}}{Y_{k0}}+\sum_{l=1}^{S2}\frac{S_l^{z}}{Z_{l0}}\right) > 0;$$

$$s_i^{x} \geq 0,\ s_k^{y} \geq 0, s_l^{z} \geq 0, \lambda_j \geq 0, \forall i,j,k,l;$$

3.1.2. Dynamic Efficiency Evaluation Model Globalmalmquist-luenberger Exponential Model

Matlab was used to measure the Green Innovation Efficiency (GML), Green Innovation Technology Efficiency Improvement (BPC) and Green Innovation Technology Progress (GEC) in each province from 2010 to 2017. The super-efficiency SBM-DEA model measures the static efficiency value of different listed thermal power companies in a certain year from the perspective of static evaluation, while the GBL index provides the dynamic changes in the green innovation efficiency of thermal power enterprises in a period of time, in order to provide more comprehensive suggestions for the long-term development of green innovation of listed thermal power enterprises. Different from the traditional M index and ML index, the GML index based on SBM can effectively overcome the problem of no solution to linear programming that may exist in intertemporal measurement by constructing a global production technology set, so that the decision-making units in different periods can be compared, avoiding the "passive" improvement of production efficiency and " Emergence of the phenomenon of technological regression". This article represents the GML index as follows.

$$M_C^G = EC_c * BPC_c$$

$$M_C^G = (x^t, y^t, x^{t+1}, y^{t+1}) = \frac{E_C^G(x^{t+1}, y^{t+1})}{E_C^G(x^t, y^t)}$$

$$EC_c = \frac{E_C^{t+1}(x^{t+1}, y^{t+1})}{E_C^{t}(x^t, y^t)}$$

$$BPC_c = \left[\frac{E_C^G(x^{t+1}, y^{t+1}) / E_C^{t+1}(x^{t+1}, y^{t+1})}{E_C^G(x^t, y^t) / E_C^{t}(x^t, y^t)}\right]$$

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3.2. Data Sources and Descriptions

According to the research objectives and the availability of data, this paper selects the input and output of 7 enterprises listed in Shanghai and Shenzhen in China from 2017 to 2021 with the main business of thermal power for the measurement of green innovation efficiency, and the sulfur dioxide and soot emission or emission rate indicators are derived from the annual reports, annual social responsibility reports and sustainable development reports of listed thermal power enterprises. The annual reports, social responsibility reports and sustainability reports of China's listed thermal power companies are from the Shanghai Stock Exchange, Shenzhen Stock Exchange and the company's official website.

3.2.1. Input Indicators

Green innovation and production are inseparable from the investment of human and financial resources in research and development, so the number of R&D personnel and R&D are selected Internal expenditures are used as indicators. According to the input-output analysis theory and production function model of economic economic growth analysis, the net value of fixed assets is selected as the input index. In addition to the above three main indicators, since the biggest feature of green innovation is to reduce environmental pollution and reduce energy consumption, and thermal power enterprises mainly consume coal, the annual coal consumption of enterprises is further introduced as an input indicator.

3.2.2. Expected Output Indicators

The number of patents granted and the amount of electricity on the Internet are selected as the expected output indicators. In terms of green innovation, the number of patent authorizations can best reflect the efforts made by enterprises in R&D investment and pollution prevention and control in that year, so the number of patent authorizations is selected as the main expected output indicator. The key to measuring whether power grid enterprises can achieve low coal consumption and high power generation is also the online electricity of enterprises in that year, so they choose online electricity as the second input indicator.

3.2.3. Indicators of Undesirable Outputs

In terms of environmental benefits, thermal power enterprises as a heavy polluting industry, its main pollutants are soot and sulfur dioxide, green innovation is also intended to reduce soot and sulfur dioxide emissions. Therefore, these two pollutant emissions are selected as undesirable output indicators, and the unpublished pollution emission data of enterprises in some years is treated proportionally. This paper uses SPSS25.0 to conduct descriptive statistics on various indicators, and the descriptive statistics of green innovation efficiency inputs and outputs are shown in the following table.

Table 1. Descriptive statistics of green innovation efficiency indicators

Indicators/units	Number of cases	minimum	maximum	mean	standard deviation
Number of R&D personnel (m1) piece	35	56	12387	1788	3420
Total R&D investment (m2)Million yuan	35	1017	133431	26325	36810
Net fixed asset value (m3) 100 million yuan	35	262	2892	1231	974
Coal consumption for power supply (m4) ton	35	9929752	132002200	51058917	43253291
Number of patents granted (s1) item	35	1	2400	152	405
Internet power (s2)Billion kWh	35	290	4404	1651	1440
Soot emissions (s3) ton	35	210	6365	1804	1666
Sulfur dioxide emissions (s4) ton	35	1217	43393	11936	10643

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4. Empirical Analysis

4.1. Static Efficiency Evaluation based on the Super-SBM Model of Undesirable Output

From Table 2, it can be seen that the overall level of green innovation efficiency of listed thermal power enterprises in China has exceeded 1, and all have reached the DEA effect; Only the average efficiency of Guodian Power in 2017-2021 is less than 1, which may be related to the excessive R&D investment of Guodian Power in 2017, while the actual output is reflected in the following year, with a significant increase in green innovation efficiency. From the perspective of the overall efficiency changes of each enterprise, 4 companies have shown an "inverted U" change trend of increasing the efficiency of green innovation first and then decreasing, and the other 3 have maintained continuous growth, which may also be related to factors such as the level of environmental regulation in the location of their enterprises. From the overall ranking, Guodian Electric Power, Guangdong Electric Power and other enterprises still need to implement improvements in green innovation management and technological innovation level.

Table 2. Static green innovation efficiency of 7 listed thermal power enterprises

The name of the listed company	2017	2018	2019	2020	2021	average value
Guangdong Electric Power A	1.01	1.14	1.01	1.04	1.07	1.05
Shenzhen Energy	1.05	1.13	1.12	1.04	1.05	1.08
Huaneng International	0.78	1.15	1.14	0.90	1.48	1.09
Guodian Electric Power	0.29	1.14	1.09	1.15	1.21	0.98
Shanghai Electric Power	1.50	1.49	1.02	1.07	1.08	1.2
Datang Power Generation	1.06	1.60	1.20	1.04	1.07	1.2
Inner Mongolia Huadian	1.48	1.05	1.01	1.01	1.01	1.1
average value	1.024	1.24	1.08	1.04	1.14	1.1

4.2. Dynamic Efficiency Evaluation based on GML Index Model

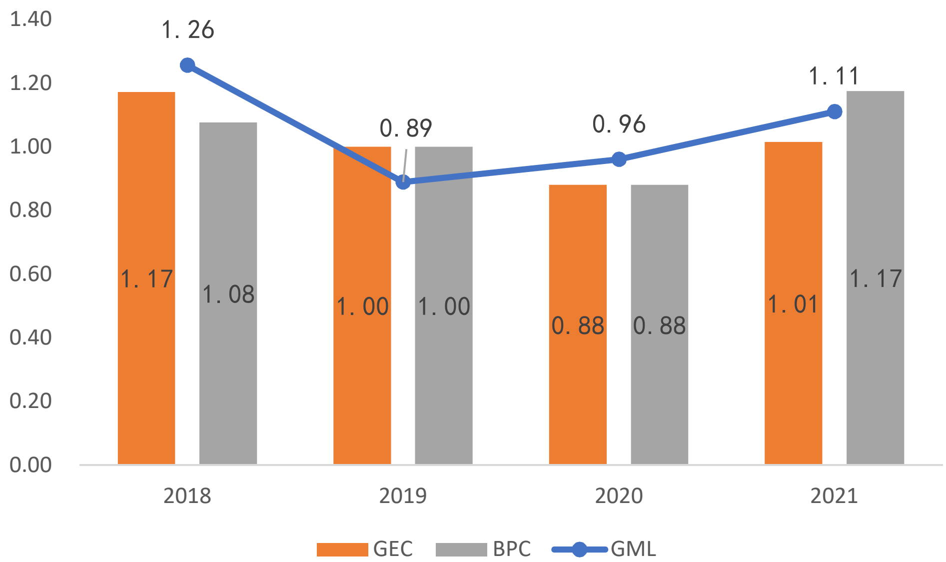

Figure 1. Trends of GML index and its decomposition index in 2018-2021

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Figure 1 depicts the GML index of 7 listed thermal power companies in China and the annual average of each decomposition index (2017 as the base period), and after the overall observation, it can be seen that only 2018 and 2021 GML values are greater than 1s, showing an overall downward trend, mainly due to a sharp decline in technological progress values, a decline of 23%. Both the GEC (Technological Advancements) and BPC (Efficiency Improvement) indices reached effectiveness in 2021, contributing to the growth of GML, From 2018 to 2019, the GML index declined significantly, mainly due to a significant regression in the technological progress index; By comparing the values of GEC and BPC, it can be seen that BPC as a whole shows an upward trend, indicating an improvement in efficiency (BPC) is the internal driving force for the improvement of green innovation efficiency of listed thermal power enterprises in China.

5. Research Conclusions and Recommendations

5.1. Conclusions of the Study

(1) 2017-2021, on the whole, China's listed thermal power companies have shown that the DEA is effective, but the changes during the period are showing phased fluctuations rising or falling, and the overall situation is not stable, which may be related to changes in environmental regulatory policies; Its China Power has still not reached the DEA effectiveness, which is related to the excessive relaxation of its input indicators in 2017.

(2) The difference in the green innovation efficiency of different listed thermal power enterprises still has obvious differences, according to the empirical analysis results of green innovation efficiency, the green innovation efficiency of listed thermal power enterprises in 2017-2021 still has room for improvement, and inefficient enterprises usually cannot solve the problem of the amount and structure of R&D investment.

(3) The dynamic research results of the green innovation efficiency of 7 listed thermal power enterprises from 2017 to 2021 show that efficiency improvement is the main reason for the change in the green innovation efficiency of enterprises. Overall, the GML index shows a U-shaped change, and companies should further balance technological progress and efficiency improvement.

5.2. Policy Recommendations

(1) Increase investment in green technology research and development

Based on empirical analysis, we found that there is a redundancy in R&D funds and personnel investment in inefficient enterprises, especially in the measurement of green efficiency. This is mainly because the R & D funds are mainly used to improve production efficiency, and there is no research and development of green technology, so the R & D management department of the enterprise should pay attention to the research and development of green technology, pay attention to the impact of green factors on technological innovation, and adopt the R & D management development strategy of attaching equal importance to economic benefits and green benefits.

(2) Improve the level of environmental management and actively respond to environmental regulations

At present, the low green efficiency hinders the improvement of the green technology innovation efficiency of papermaking enterprises. Although the listed thermal power enterprises are relatively large, they are also facing great pressure from national environmental regulations. Enterprises should clarify the responsibilities of their own pollution control entities, cooperate with environmental protection departments to conduct self-inspection and self-correction of their own pollution prevention and control facilities, and take the initiative to improve the level of environmental protection facilities of enterprises.

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(3) Continue to promote technological innovation activities of thermal power enterprises.

The government should create a good institutional environment for enterprises, and use policies to guide and encourage enterprises to carry out R&D and innovation activities, so as to give play to the strengthening and regulating effect of technological innovation of enterprises. For non-state-owned enterprises, they should be given more support in project development policies, improve the business environment, promote the real and effective transformation of their R&D investment into R&D output, and give play to the role of technological innovation in promoting the efficiency of green innovation.

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