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Carbon Emission Reduction of Power Enterprises in Subtropical and Temperate Regions of China

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Abstract

China's power enterprises consume a large amount of energy and emit a high quantity of carbon dioxide. To reduce carbon emissions and save energy, China has implemented various energy-saving and emission reduction (ESER) policies in the power industry. The purpose of this study is to analyze the carbon emission reduction (CER) performance and the ESER performance of China's power enterprises. The data envelopment analysis was applied to obtain the CER efficiency and the ESER efficiency of power enterprises in subtropical and temperate regions of China. The research findings are as follows. First, the average ESER efficiency of Chinese power enterprises is lower than their CER efficiency. Second, only 30% of Chinese power enterprises have both high CER and ESER efficiency. Most power enterprises in China need to take measures to further reduce carbon emissions and improve the efficiency of resource utilization. Third, due to their high economic development and advanced use of technology, the CER efficiency of power enterprises in subtropical regions is higher than that in temperate regions. Based on empirical results, specific policy recommendations are provided for Chinese power enterprises.

Keywords

power enterprises, subtropical and temperate regions of China, carbon emission reduction performance

Introduction

The rapid development of Chinese modern industry requires a large amount of electric energy (Liu, Chu, Yin, & Sun, 2017). The electricity generated by power enterprises mainly relies on fossil energy such as coal, oil, and natural gas, which emit large quantities of carbon dioxide into the atmosphere (K. Wang, Wei, & Huang, 2018), thereby accelerating the "greenhouse effect" (Li, Zheng, Ji, & Li, 2018; Sun, Wang, & Li, 2018). In addition, due to the consumption of a large amount of energy, China's power industry is facing the problem of energy shortages (Sun, Li, & Wang, 2018). The problems of excessive carbon emissions and energy shortages have adversely affected the long-term development of China's economy (Mi et al., 2017). Together with the growth in environmental awareness and the transformation of the economic structure, the Chinese government has realized the importance of environmental protection and energy conservation (Ji, Li, & Wang, 2017). Therefore, it is necessary for the Chinese government and the power companies to reduce both fossil energy consumption for thermal power generation and carbon dioxide emissions.

To save energy and reduce emissions, China has made many efforts, for example, setting targets for reducing energy intensity (Q. Wang & Chen, 2015), setting targets for reducing carbon emissions (Q. Wang, Su, Sun, Zhou, & Zhou, 2015), and enforcing Top-1000 enterprises to participate in energy-saving action (Wei, Löschel, & Liu, 2015). The issue of energy-saving and emission reduction (ESER) of power enterprises has attracted the attention of a number of scholars. Studies have been performed evaluating the performance of power companies, most of

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which employed the data envelopment analysis (DEA) method (Sueyoshi & Goto, 2001; K. Wang, Lee, Zhang, & Wei, 2018). The main feature of the DEA method is that it does not require decision makers to provide subjective information (Sun, Yuan, Yang, Ji, & Wu, 2017). In addition, DEA can also consider undesirable indicators to analyze the environmental performance of the evaluated units (Q. Wang et al., 2015). Golany, Roll, and Rybak (1994) used the basic model of DEA to measure the operational efficiency of Israeli power generation enterprises, analyzing also the importance of input and output variables. Chitkara (1999) used the DEA method to calculate the efficiency of Indian thermal power plants from 1991 to 1995 and proposed improvement suggestions by analyzing the slack variables. Park and Lesourd (2000) used the DEA model and the stochastic frontier analysis method to evaluate the efficiency of 64 traditional fuel power plants in Korea. Through the statistical analysis of the calculation results, the author found that the evaluation results of the DEA method are more accurate than those of the stochastic frontier analysis method. Goto and Tsutsui (1998) applied the DEA to compare the technical efficiency of 9 Japanese power enterprises and 14 U.S. power enterprises. The authors found that Japanese power enterprises have an overinvestment tendency and recommended that Japan should open its markets to reduce electricity prices. Lo, Chien, and Lin (2001) applied the DEA to analyze the relative effectiveness of 22 power enterprises in Taiwan. The authors recommend that 11 inefficient power enterprises should take measures to improve their efficiency. Pahwa, Feng, and Lubkeman (2003) applied the DEA to evaluate the performance of the 50 largest power enterprises in the United States, suggesting improvements. You and Jie (2016) used the DEA model to evaluate the operation efficiency of China's power enterprises from the perspective of dynamic evaluation. The authors found that the level of local economic development is positively related to the operation performance of local enterprises. K. Wang, Lee, et al. (2018) evaluated China's power industry from the two perspectives of efficiency and utility. The authors draw the conclusion that efficiency and utility are not equivalent and not always positively related.

Bi et al. (2014) measured both the efficiency and the environmental efficiency of China's power industry in the period 2007–2009. The authors pointed out that the environmental efficiency of China's power industry was lower than the expected efficiency. Munisamy and Arabi (2015) employed the slack-based measure DEA model to measure the environmental efficiency of Iran's power industry during the period from 2003 to 2010. The authors found that the environmental efficiency of Iran's power industry was increasing during that period, and that the efficiency of thermal power enterprises was higher than that of gas power enterprises. Cook, Du, and Zhu (2017) added consumer preference factors to the DEA model to evaluate the environmental efficiency of the U.S. power industry. The empirical results show that the main reason for the inefficiency of most U.S. power generation enterprises lies in their excessive pollutant emissions. Wu, Xia, Zhu, and Chu (2018) proposed an equilibrium-game DEA model and used it to evaluate the environmental performance of China's power enterprises. The authors found that half of China's electric power enterprises have low environmental efficiency.

The above review shows that existing research on either the performance or the environmental performance of power enterprises still suffers from two major inadequacies. First, there has been a large number of studies on carbon emission reduction (CER) performance or on the ESER performance at the regional level in China (Meng & Xiong, 2018). However, research on the CER performance or on the ESER performance of China's power industry is insufficient. Second, few studies consider the impact of regional differences (such as between subtropical and temperate regions in China) on the efficiency of the CER or the ESER of power enterprises.

In view of these shortcomings, this study evaluated the CER and the ESER efficiency of Chinese power enterprises and explored the impact of regional differences (such as between subtropical and temperate regions) on their efficiency. More specifically, this study addressed the following research questions: (a) Which model should be selected to assess the CER efficiency or the ESER efficiency of China's power enterprises? (b) Is the performance of Chinese power enterprises in the subtropical region better than that of power enterprises in the temperate region? And (c) How can an inefficient power enterprise improve its performance?

To respond to these questions, Q. Wang et al.'s (2015) model was first decomposed into the CER performance evaluation model and the ESER evaluation model. Then, these two models were applied to the empirical analysis of Chinese power enterprises. Finally, based on the results of the empirical analysis, specific policy recommendations were formulated.

The following findings have been obtained by this study. First, from 2010 to 2015, both the CER and the ESER performance of each power enterprise have not changed significantly. Second, for each power enterprise, the average ESER efficiency was lower than the average CER efficiency. Therefore, to improve their ESER efficiency, power enterprises must first improve their CER performance. Third, due to a higher economic development and a more advanced use of technology, the CER efficiency of the power enterprises in subtropical regions was higher than that in temperate regions. Finally, all power enterprises were classified into three categories on the basis of their CER and ESER efficiency. It was found that only 30% of Chinese power companies had both a high CER efficiency and a high ESER efficiency. This means that most power enterprises in China need to take measures to further reduce carbon emissions and improve the efficiency of their resource utilization.

This article is organized as follows. "Methods" section introduces the CER performance evaluation model and the ESER efficiency evaluation model. "Results" section presents an empirical study of China's power enterprises using data from 2010 to 2015. "Discussion" section provides the main findings. Finally, "Implications for Conservation" section presents the conclusions and the policy recommendations.

Methods

The CER and ESER Models

The DEA method was first developed by Charnes et al. (1978) on the basis of the concept of "relative efficiency evaluation." It is usually applied to the determination of the relative efficiency of a same type of decision-making units (DMUs) with multiple inputs and outputs (Sun, Wu, Liang, Zhong, & Huang, 2014). As a nonparametric analysis method, the DEA has the following advantages. First, the units of the input and output indicators do not need to be unified (Mardani, Zavadskas, Streimikiene, Jusoh, & Khoshnoudi, 2017). Second, no prior assumption is necessary on the weights of inputs and outputs; this has the advantage of avoiding subjective factors in the artificial determination of the weights (Sun, Yuan, et al., 2017). Third, there is no complicated function relationship between inputs and outputs (Song, An, Zhang, Wang, & Wu, 2012; Sun, Li, & Wang, 2018). Fourth, the DEA may provide improvement suggestions for inefficient DMUs (Sun, Wang, et al., 2017). In view of these advantages, this study employed the DEA method to study the efficiency of Chinese power enterprises.

Suppose that there are N power enterprises in total; then, it can be considered that there are N DMUs. For each DMU_j, there are J types of energy inputs $\left(E^j, j = 1, \cdots, J\right)$ and K types of nonenergy inputs $\left(NE^k, k = 1, \cdots, K\right)$. These inputs are used to produce P types of desirable outputs $(Y^p, p = 1, \cdots, P)$ and Q types of undesirable outputs $(B^q, q = 1, \cdots, Q)$. According to Fare, Grosskopf, and Whittaker (2007) and Zhou, Ang, and Han (2010), the possible production set of DMUs is the following:

$$T = \left\{\left(E^j, NE^k, Y^p, B^q\right) : \left(E^j, NE^k,\right)\text{produce}(Y^p, B^q)\right\} \tag{1}$$

To reduce both the excess input and the undesirable output in the production process, as well as to find the possibility of expanding the desirable output, Q. Wang et al. (2015) defined the nonradial output distance function (2):

$$\begin{aligned}&\vec{D}^k\left(E^j, NE^k, Y^p, B^q : g\right)\\&= \sup\left\{w^T\beta : \left(E^j + g_{E^j}, NE^k + g_{NE^k}, Y^p + g_{Y^p}, B^q + g_{B^q}\right) \in T\right\}\end{aligned} \tag{2}$$

In Equation (2), $w = \left(w_{E^j}, w_{NE^k}, w_{Y^p}, w_{B^q}\right)$ represents the improvement weights of energy input, nonenergy input, desirable output, and undesirable output, respectively. $g = \left(-g_{E^j}, -g_{NE^k}, g_{Y^p}, -g_{B^q}\right)$ is a set of direction vectors, indicating the reduction in input and in undesirable output, and the increase in desirable output. The improvement ratio of both inputs and outputs is expressed as $\beta = (\beta_{E^j}, \beta_{NE^k}, \beta_{Y^p}, \beta_{B^q})$. If $\beta = (\beta_{E^j}, \beta_{NE^k}, \beta_{Y^p}, \beta_{B^q}) = 0$, then the power enterprise is on the frontier and does not need improvement. The purpose of this study was to calculate and analyze the CER efficiency and the ESER efficiency of power enterprises, by adopting and extending Q. Wang et al.'s (2015) nonradial output distance function.

To measure the ESER efficiency of power enterprises, the direction variable was defined as $g = (-g_{E^j}, 0, 0, -g_{B^q})$, while the weight was defined as $w = (w_{E^j}, 0, 0, w_{B^q}) = (1/2J, 0, 0, 1/2Q)$. Based on the variable conditions of scale returns, Q. Wang et al. (2015) proposed the following linear programming (3):

$$\begin{aligned}
CEP_h = \max : \frac{1}{2}\left(\frac{1}{J}\sum_{j=1}^{J}\beta^h_{E^j} + \frac{1}{Q}\sum_{q=1}^{Q}\beta^h_{B^q}\right)\\
s.t. \sum_{n=1}^{N}\lambda_n E^j_n \le \left(1 - \beta^h_{E^j}\right)E^j_n \quad j = 1, \cdots, J\\
\sum_{n=1}^{N}\lambda_n NE^k_n \le NE^k_n \quad k = 1, \cdots, K\\
\sum_{n=1}^{N}\lambda_n Y^p_n \ge Y^p_n \quad p = 1, \cdots, P\\
\sum_{n=1}^{N}\lambda_n B^q_n = \left(1 - \beta^h_{B^q}\right)B^q_n \quad q = 1, \cdots, Q.\\
\sum_{n=1}^{N}\lambda_n = 1 \quad n = 1, \cdots, N\\
0 \le \beta^h_{E^j}, \quad {}^{B^q h}_{\beta} < 1, \quad \lambda_n \ge 0
\end{aligned} \tag{3}$$

Then, the ESER efficiency of DMU_h was defined as:

$$ESER^h_n = 1 - CEP^h_n \tag{4}$$

Model (3) calculates the efficiency of a power enterprise from the perspective of energy conservation and carbon emissions. Therefore, the ESER efficiency obtained by the Model (3) can reflect, to a certain extent, the resource utilization rate of a power enterprise.

To measure the CER efficiency of power enterprises and to explore their potential for improvement, the direction variable was defined as $g = (-g_{E^j}, 0, 0, 0)$ and the weight was defined as $w = (w_{E^j}, 0, 0, 0) = (1/2J, 0, 0, 0)$. Then, the model of Q. Wang et al. (2015) was extended into the following model:

$$
\begin{aligned}
ERP_h = \max \frac{1}{Q}\sum_{q=1}^{Q}\beta_{B^q}^h \\
s.t. \sum_{n=1}^{N}\lambda_n E_n^j \leq E_n^j \quad j = 1, \cdots, J \\
\sum_{n=1}^{N}\lambda_n NE_n^k \leq NE_n^k \quad k = 1, \cdots, K \\
\sum_{n=1}^{N}\lambda_n Y_n^p \geq Y_n^p \quad p = 1, \cdots, P \\
\sum_{n=1}^{N}\lambda_n B_n^q = \left(1 - \beta_{B^q}^h\right) B_n^q \quad q = 1, \cdots, Q \\
\sum_{n=1}^{N}\lambda_n = 1 \quad n = 1, \cdots, N \\
0 \leq \beta_{B^q}^h < 1, \lambda_n \geq 0
\end{aligned}
\tag{5}
$$

After solving Model (5), the CER efficiency of DMU_h was defined in the following way:

$$CER_h = 1 - ERP_h \tag{6}$$

In Models (3) and (5), N represents the number of power enterprises; λ_n indicates the weight of inputs and outputs; $\beta_{E^j}^h$ represents the potential for improvement in energy consumption; and $\beta_{B^q}^h$ represents the potential for improvement in undesirable output (e.g., carbon dioxide emissions). These two models are linear programming models and can be solved by computing software. Compared with Model (5), the direction variable and the weight of Model (3) requires to reduce both the energy input and the undesirable output, while maintaining current output levels.

Sampling and Data Collection

This study included the China's listed thermal power enterprises from 2010 to 2015; data came from Xu (2017). For each power enterprise, there are five inputs and outputs. The inputs include the installed capacity, labor, and coal consumption. These three inputs were also select by Bi et al. (2014) to study the environmental performance of Chinese Power enterprises. The installed capacity of the power system is an indicator of the power generation capacity; it represents the sum of the rated and the effective power of the generating units actually installed in generating systems. Generally, the greater the total capacity, the higher the power generation capacity of a power enterprise (Bi et al., 2014). Labor represents the total number of employees in a power enterprise. To a certain extent, labor reflects the scale of a power enterprise (Wei et al., 2015). The high quantity of coal consumption in the production process of power generation companies generates a considerable amount of carbon dioxide emissions. Therefore, this study considered also coal as an input. As the power enterprises did not disclose their coal consumption data, these were obtained by multiplying the standard coal consumption of a power enterprise by its power generation.

The outputs of China's thermal power enterprises include the desirable output and the undesirable output. Power generation is an important indicator of the output of a power enterprise. Therefore, this study considered power generation as an important desirable output (Bi et al., 2014) and carbon dioxide as an indicator of undesirable output (Wei et al., 2015). As carbon emissions of power enterprises have not been disclosed, this study referred to the methods of Yu and Choi (2015) and Emrouznejad and Yang (2016) to obtain carbon dioxide data. The statistical data of inputs and outputs are shown in Table 1.

Table 1. Inputs and Outputs Statistical Data.

	Installed capacity (MWh)	Labor	Coal (10,000 tons)	Power generation (TWh)	Carbon dioxide (10,000 tons)
Max	82,331.00	42,039.00	9,804.34	320.53	19,392.01
Min	990.50	127.00	140.95	4.22	278.79
Mean	13,900.48	9,430.52	2,015.88	64.17	3,987.22
Median	6,147.00	5,086.00	920.02	29.21	1,819.69
Standard deviation	17,045.69	10,161.90	2,415.09	77.89	4,776.81

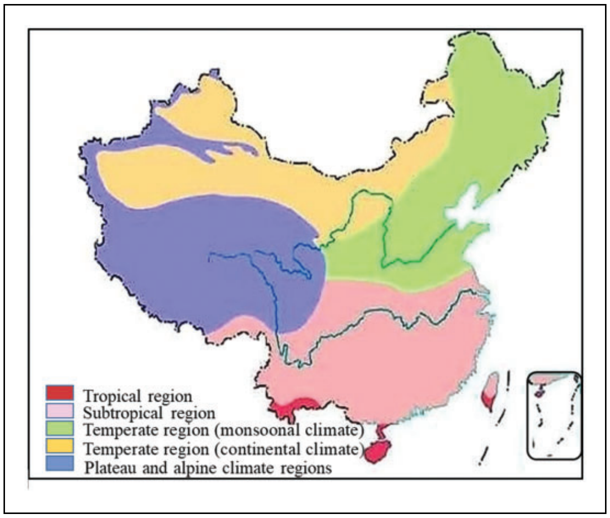

Figure 1. China's climatic regions.

As shown in Table 1, there are differences in development among Chinese power enterprises. For example, the maximum installed capacity recorded is 83 times its minimum recorded value. Similar cases have been recorded for other indicators.

China has a vast territory, with different levels of economic development and electricity consumption among regions (Yang & Zhang, 2018; Zhu, Wu, Li, & Xiong, 2017). This study classified all power enterprises based on climate regions. The reason for this classification is that China is usually divided into southern China and northern China according to temperature factors. Southern China mainly corresponds to the subtropical regions, while northern China mainly corresponds to the temperate regions. The division of China's climate regions is shown in Figure 1. Accordingly, all Chinese power enterprises were classified in a different climatic region (see Table 2). As shown in Table 2, all power enterprises are located in subtropical and temperate regions of China.

Results

The Matlab software was used to calculate the CER efficiency and the ESER efficiency of the 20 power enterprises investigated during the period from 2010 to 2015. Figures 2 and 4 show the CER efficiency and ESER efficiency of each power generation enterprise. Based on these results, it is possible to obtain two main findings.

First, Figure 2 shows that there is a small change in CER efficiency (or ESER efficiency) for each power enterprise in the period from 2010 to 2015, and the CER efficiency gap (or ESER efficiency gap) between power enterprises is not clear. The main reasons for the small difference in efficiency of China's power

Table 2. Number of Chinese Power Enterprises by Climatic Region.

Climatic region	Number of power enterprises
Tropical region	0
Subtropical region	10
Temperate region (Monsoonal climate)	9
Temperate region (Continental climate)	1
Plateau and alpine climate regions	0

enterprises are as follows. Recently, the Chinese government has realized the importance of developing a low-carbon economy and increased its support for innovation in energy conservation, emission reduction, and energy technology. In the past 10 years, the Chinese government has forced the closure of small power generation enterprises and eliminated high-energy-consuming and technologically backward power generation enterprises. In addition, the Chinese government's subsidies to the renewable power industry have also stimulated traditional power enterprises to increase their environmental protection investment, to further reduce emissions and improve productivity.

Second, as illustrated in Figure 3, it was found that the average ESER of all power enterprises is lower than their average CER efficiency. The CER efficiency represents the carbon emission performance of a power enterprise, while the ESER efficiency considers its energy inputs and undesirable outputs, including carbon emissions. Therefore, the average ESER efficiency of a power enterprise is lower than its average CER efficiency. This finding also indicates that if a power enterprise emits a high amount of carbon dioxide, its ESER efficiency will not be high.

Discussion

Analysis of Regional Differences in CER Efficiency

After classifying the location of the 20 power enterprises analyzed into the subtropical or temperate regions, the following findings were obtained.

First, the CER efficiency of power enterprises in subtropical regions was higher than that of power enterprises in temperate regions. Usually, due to industrial underdevelopment, emissions in backward areas are lower than in economically developed areas, while the environmental quality is higher. However, this study obtained the opposite conclusion. In fact, the power enterprises in subtropical regions are superior to the power enterprises in temperate regions not only economically but also in terms of their CER performance. Looking at regional environmental policies, it was found that differentiated environmental policies have

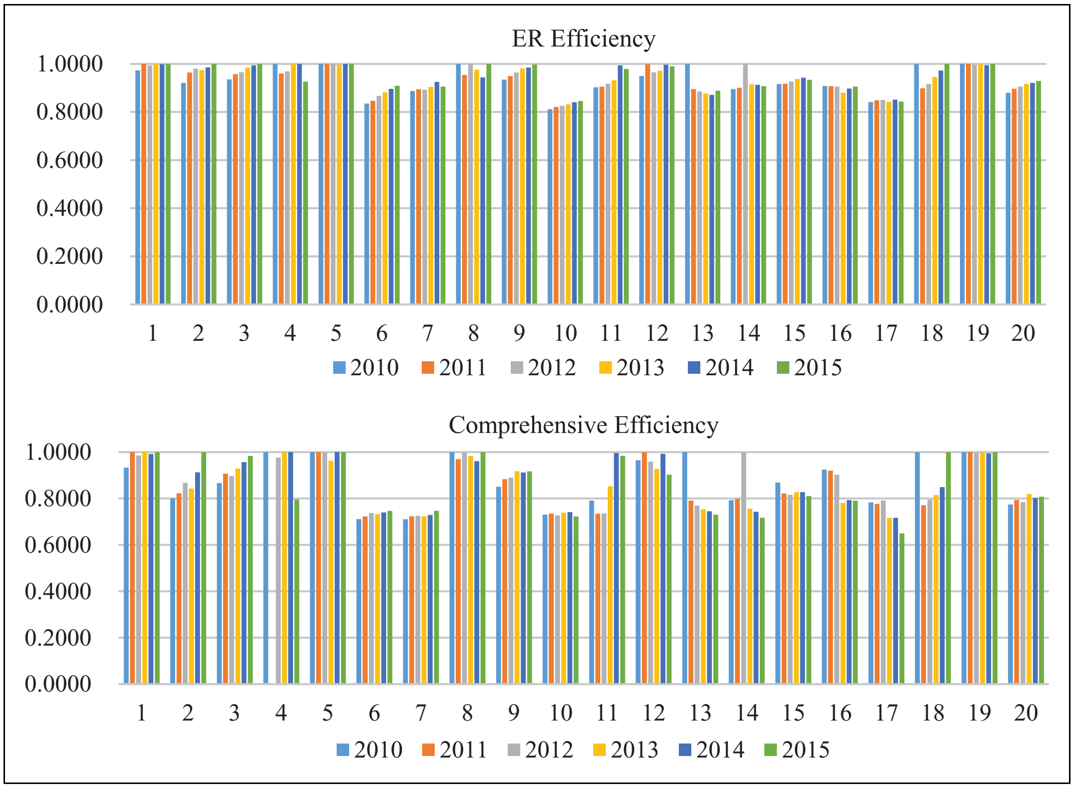

Figure 2. The CER efficiency and ESER efficiency of each power generation enterprise from 2010 to 2015. ER = emission reduction.

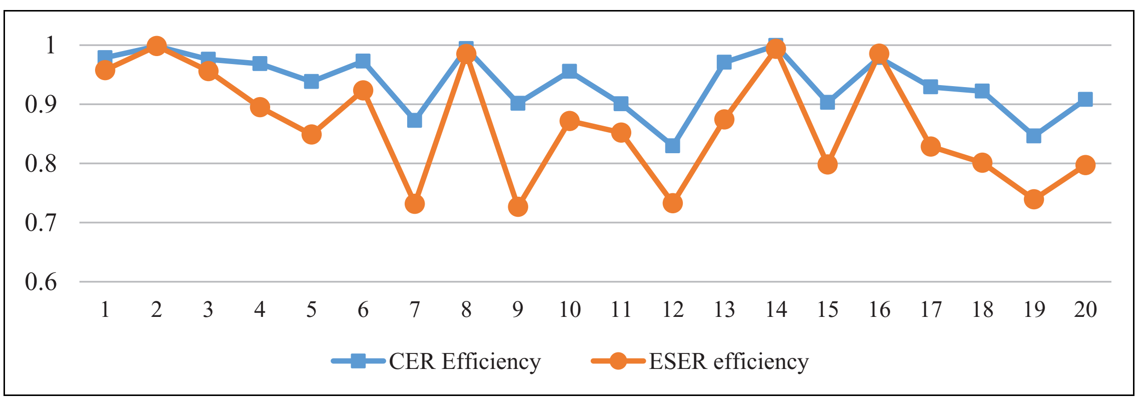

Figure 3. Average CER efficiency and ESER efficiency of each power generation enterprise. CER = carbon emission reduction; ESER = energy-saving and emission reduction.

led to differentiated CER efficiency results. The subtropical region (such as the Yangtze River Delta and the Pearl River Delta regions), which was the first to implement the air pollution prevention and joint control mechanism, has been controlling strictly their carbon emissions. Therefore, the power enterprises in this region demonstrated a superior CER performance. The temperate regions mainly include Central China, Northeast China, and Northwest China. The economic development level of these areas is relatively low. To stimulate economic development, environmental policies in these regions are relatively “moderate.”

In addition to policy factors, the level of economic development in a region may also affect the CER performance of its power enterprises. The economic development model of the subtropical region (e.g., the Yangtze River Delta Region and the Pearl River Delta Region) is relatively mature. Power enterprises in this region have higher production technology levels and pollution control investments, making them more efficient

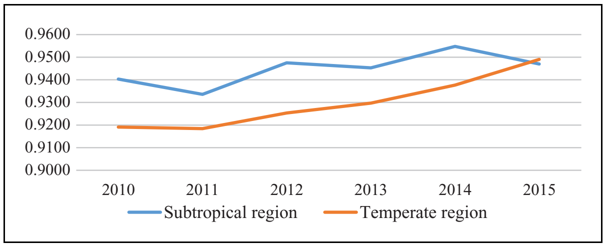

Figure 4. Regional differences in CER efficiency.

to use the resources in the production process. Therefore, the power enterprises in this region show a better CER performance. In temperate regions (e.g., Shanxi, Jilin, and Inner Mongolia), the levels of economic development and of production technology are relatively lower than those in the subtropical region. Therefore, compared with the subtropical region, the power enterprises in the temperate region are weaker in terms of energy consumption and emission reduction, and their CER performance needs further improvement.

Second, as shown in Figure 4, it was found that the CER efficiency gap of power enterprises between the two regions in 2010 is high, and that the CER efficiency in the subtropical region is better. However, over time, the CER efficiency gap between the two regions gradually narrowed. This means that the Chinese government recognized the importance of environmental protection and has imposed strict controls on the carbon emissions of power enterprises in all regions.

Third, the CER efficiency of thermal power companies in the subtropical and temperate regions showed a small decline around 2011. The reason for this result is that in 2011 China promulgated the "Emission Standards for Thermal Pollutants in Thermal Power Plants." After the emission standards were promulgated, the power enterprises that failed to meet the standards had to invest capital for the construction of energy conservation and emission reduction, with a short-term degradation in the CER performance.

Classification of Power Enterprises

To improve the efficiency of China's power enterprises, these were further divided into three categories, on the basis of their CER efficiency and ESER efficiency. The strategy for improving the efficiency of each category is different. The information and efficiency enhancement strategies of the three categories of power enterprises are shown in Figure 5.

Category 1 is composed of the power enterprises with both a high CER efficiency and a high ESER efficiency; it includes 6 power enterprises (3 in the subtropical region and 3 in the temperate region). Both the CER efficiency and the ESER efficiency of these power

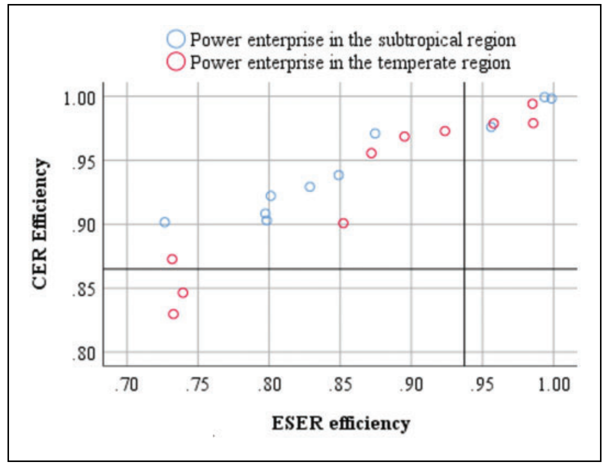

Figure 5. The three categories of power enterprises. CER = carbon emission reduction; ESER = energy-saving and emission reduction.

enterprises are higher than the national average; this means that these enterprises have a higher level of resource saving and environmental protection. In view of this, these power enterprises should maintain their current advantages, and communicate with other electric power enterprises on resource conservation and environmental protection technology. This can increase the spillover effect of the power enterprises in Category 1.

Category 2 includes 12 power enterprises with a high CER efficiency and a low ESER efficiency (7 in the subtropical region and 5 in the temperate region). These power enterprises have a high performance in CER; however, their performance in resource saving is low. Therefore, the strategic focus of these power enterprises should be to save resources.

Category 3 is composed of power enterprises with a low CER efficiency and a low ESER efficiency. It includes 2 power enterprises in the temperate regions. These power enterprises have serious problems of resource waste and excessive carbon emissions in the production process. Therefore, they should increase their efficiency level in both these two aspects (i.e., resources and emissions) simultaneously.

Implications for Conservation

As environmental issues become more prominent, China is paying increasing attention to environmental protection. The power enterprises, which are related to the lifeblood of China's economic development, consume a large amount of energy and emit a high quantity of carbon dioxide, which in turn have caused serious energy shortages and environmental pollution. In response to these problems, the Chinese government has taken specific measures to reduce the energy consumption and the emissions of power enterprises. The main purpose of this study was to calculate and analyze the ESER efficiency of China's power enterprises. To this purpose, Q. Wang et al.'s (2015) model was further decomposed into the CER efficiency evaluation model and the ESER efficiency model. These models were then applied to the empirical study of Chinese listed power enterprises. Finally, based on the empirical results, this study provided specific policy recommendations.

The main findings of this study are as follows. First, both the CER performance and the ESER performance of each power enterprise have not changed significantly from 2010 to 2015. Second, the average ESER efficiency of power enterprises was lower than their average CER efficiency. Third, after classifying all power enterprises by region, it was found that the CER efficiency of the power enterprises in the subtropical region is higher than that of the power enterprises in the temperate region. Finally, this study classified all power enterprises into three categories on the basis of their CER efficiency and ESER efficiency. A total of 12 power enterprises (7 in the subtropical region and 5 in the temperate region) were included in category 2, characterized by both a high CER efficiency and a low ESER efficiency.

Based on these results, this study suggests the following policy recommendations. First, to narrow the differences in CER performance between regions, power enterprises in the temperate regions should learn from the experience of the power enterprises in the subtropical region, and for example introduce advanced technologies and develop low-carbon development plans. Moreover, power enterprises in the subtropical region should use their technological advantages and experience to help other regions' enterprises improve their environmental performance. Power enterprises with poor technology should perform dynamic technology updates, instead of blindly introducing the most advanced technologies. The introduction of the most advanced technology is expensive and requires the corresponding technical talents; as such, it is difficult to implement it in the short term. Therefore, power enterprises should select technologies that are appropriate to their economic development levels, to improve both their CER performance and the utilization efficiency of the advanced technologies.

Second, the achievement of both CER efficiency and ESER efficiency may be a long and arduous process for Chinese enterprises. However, this study found that the ESER efficiency of power enterprises was lower than their CER efficiency, and that the prerequisite for improving the ESER efficiency lays in the improvement of the CER efficiency. Therefore, inefficient power enterprises should improve their efficiency in both the short- and long term. In the short term, ineffective enterprises should focus on low carbon development to improve their CER performance. Once the short-term goal is achieved, then the ineffective enterprises should conduct long-term resource/energy conservation efforts to improve their ESER performance.

Third, it is true that China's coal-based energy structure will not change in the short term. Hence, the power industry, especially thermal power enterprises, should vigorously promote clean coal power generation technologies, improve the application level of low-carbon technologies, and actively seek different cooperative CER methods to achieve long-term sustainable development. The Chinese government is currently constructing a national carbon emissions trading market, in which the power industry should be included. In the case of marketization of carbon trading, power enterprises with lower marginal CER costs should become the mainstay of low carbonization in the power industry. This can better achieve an optimal allocation of resources and the sustainable development of the Chinese society.

Declaration of Conflicting Interests

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