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Study on environmental performance of electric power industry based on super-efficiency three-stage DEA model

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ABSTRACT

By means of constructing the super-efficiency three-stage DEA model, this paper conducts a study on the environmental performance of electric power industry in 30 cities, provinces and municipalities of China. Firstly, in consideration of the undesired output, this paper takes advantage of super-efficiency one-stage DEA model (Super-SBM) to evaluate and analyze the environmental performance of China's electric power industry. Secondly, this paper makes a regression analysis on the macro-factors influencing environmental performance of electric power industry of China, by dint of super-efficiency two-stage DEA model (Tobit model). At last, this paper calculates the macro impact factors, as well as includes them in the super-efficiency DEA model to empirically analyze the third stage. The findings show that in consideration of the influence of macro-factors, this paper works out that the regions such as Shanghai, Hainan, Beijing, Zhejiang, and Hubei achieve comparatively high comprehensive environmental performance, as well as puts forward the policy suggestions on the improving environmental performance of China's electric power industry.

KEYWORDS

Super-efficiency three-stage DEA model;
Electric power industry;
Environmental performance.

INTRODUCTION

Electric power industry is the most important energy industry of the national economic development On one hand, the structure of electric power industry is not well balanced, with a high energy consumption and low efficiency in resources utilization; on the other hand, a large number of pollutant emissions including SO_2 and NO_x are coursing severe environmental pollution problems, which violates the principle of "Energy Saving, Emission Reduction, Green Development, Low Carbon".

There are various research papers at home and abroad the environmental performance of electric power industry., But very few of them is on environmental performance of electric power industry. Most of scholars only consider economic output factor, they did not consider environmental factors which are closely connected with electric power industry, such as the undesired output SO_2 [8,9]. Therefore, in order to be more comprehensive and scientific in environmental performance of electric power industry in China, this paper, based on the original DEA model, build the Super efficiency DEA

3 phase model, at the same time it effectively disposed the Super - SBM model to the expectation.

RESEARCH METHODS AND MODELS

In performance evaluation with super efficiency DEA method, it requires minimum input for maximum output. However, different industries have their own characteristics, for example, in the process of production, electric power enterprises realized the economic value of electricity, on the other hand, it inevitably produce a lot of environmental pollutants, these environmental pollutants are not desired, collectively known as the undesired output. Based on the radial Angle of SBM model, at the same time, in dealing with undesired output, this thesis effectively solved the problem of the slacking relation between input and output. Essentially speaking, it can reflect the essence of the performance evaluation than other methods.

Based on SBM model, we can obtained the undesired output of the Super efficiency DEA model which is Super - SBM model, on the one hand, it can effectively solve the decision-making unit scheduling problems; On the other hand, it also considered the issue of the undesired output of the electric power industry in this thesis. Super - SBM model is as follows:

$$\begin{cases} \min \rho = \dfrac{1-\dfrac{1}{m}\sum_{i=1}^{m}\dfrac{s_i^-}{x_{i0}}}{1+\dfrac{1}{s}\sum_{r=1}^{s}\dfrac{s_r^+}{y_{r0}}} \\ s.t. \\ \sum_{i=1}^{n}\lambda_j x_{ij} + s_i^- = x_{i0} \\ \sum_{i-1}^{n}\lambda_j y_{rj} - s_r^+ = y_{r0} \end{cases} \quad (1)$$

ρ is efficiency value, S-and S+ respectively means deficiency and excess output.

VARIABLE SELECTION AND DATA SOURCES

Selection of decision-making unit and data sources

This paper uses cross-sectional data research method on environmental performance of electric power industry in China's 30 provinces and autonomous regions (except Tibet). 30 provinces and cities autonomous regions are taken as samples for empirical research. Data is mainly from *China Power Yearbook*, *China Environment Yearbook*, *China Energy Statistical Yearbook*, *China Statistical Yearbook* and *China Labor Statistical Yearbook*.

Selection of Input and output indicators

the thesis selected indicators as follows:

Capacity (KW) represents an important index of electric power industry investment; it mainly shows the sum of active power in actual installation of generator.

Labor (person). The total number of employees of electric power industry in all provinces is difficult to get, we will adopt the labor force of thermal power production and supply which is highly closed to electric power industry.

Desulfuration Equipment Units (Set). As China's electricity industry is mainly coal-fired power, the major emission pollutant is so2, from the perspective of environmental protection, we select desulfurization equipment units.

Electricity Generation Coal Consumption (g/kwh). In view of the practical situation of energy saving in electric power industry, we mainly calculate from the fuel consumption indicators, it stands for the variable cost of electric power industry.

The consumption rate of power station (%). It reflects the power station's own power consumption level in the process of generating electricity.

Two major indicators were selected, output and the undesired output emissions of SO_2respectively.

Selection of macro-affecting factors index

This paper selects major influential factors as follows: GDP mainly reflect a region's gross domestic production, it affects the development of electric power industry and offers certain support from all sides. Region's population reflects the level of electricity consumption, it directly affects the overall operation of electric power industry; The electricity consumption reflects regional economic development; Raw coal production volume reflects the regional resources endowment.

EMPIRICAL RESULTS

Empirical results of Super efficiency DEA Stage-I

To evaluate Electric power industry environmental performance for 2009 in 30 provinces and autonomous regions in China (exclude Tibet) with software DEA-Solver Pro5.0, we compared and analyzed results of Super efficiency DEA model without considering the undesired output and Super - SBM model with undesired output.

(1) Technical efficiency analysis

we can conclude the following result: under the condition of not considering undesired output, the average technical efficiency is 1.718; there are 19 provinces and regions reached efficient frontier level. 18 provinces and regions reached efficient frontier level; the technical efficiency of considering the undesired output is lower than that of not considering undesired output; only Jiangsu and Shandong provinces remain the same level. It shows that in environmental performance evaluation, in electric power industry research, environmental emissions of pollutants has a great influence on efficiency, Super - SBM model can deal with the undesired output more effectively and reflects the real situation.

(2) Analysis on decision-making unit

The biggest advantage of Super efficiency DEA model is to sort decision-making units according to the efficiency of units. Through the above two types of model calculation and analysis, without considering the undesired output, Under the condition of considering the undesired output, the top five are Qinghai, Shanghai, Hubei, Hainan and Beijing. Shanxi was decreased from No. 22^{nd} to No. 29^{th}. Through the above comparison, we find that provinces and regions with high coal consumption and severe environmental pollution have comparatively low technical efficiency considering the undesired output.

(3) Projection analysis

To improve the technical efficiency less than 1 is very important. After an analysis of the effectiveness of 30 provinces and regions in China with Super - SBM model, we find that there are12 decision-making units in the invalid state; it can further draw input redundancy and output deficiency, which contribute to solutions for improving environmental efficiency in provinces and regions. For instance, in Inner Mongolia, if the installed

TABLE 1 : Analysis on Slacks of Ineffective decision-making units

DMU	Input Redundancy					Output Insufficiency	
	S_1^-	S_2^-	S_3^-	S_4^-	S_5^-	S_1^+	S_2^+
Jilin	0.037	23	0	0	1.523	0	0
Tianjin	0	0	1.387	0	1.228	0	43.803
Guizhou	0	2228	117.397	0	0	85.471	0
Anhui	0	7731	72.5	0	1.263	0	0
Yunnan	0	11527	198.82	0	1.065	65.89	0
Sichuan	293.896	45984	12.278	30.968	0.359	0	0
Gansu	0	1479	325.565	0	4.713	0	0
Jiangxi	0	32380	59.87	0.294	1.548	56.27	0
InnerMongolia	796.96	4157	298	2.234	0	0	0
Xinjiang	1215.26	1887	1389	0	0	0	0
Shanxi	128.453	2910	1500	51.89	1.89	0	0
Hunan	134.292	0	38.792	24.084	0	10.39	0

Note: S_1^- is adjustment value for installed capacity, S_2^- is adjustment value for the labor force, S_3^- is adjustment value for desulfurization equipment, S_4^- is adjustment value for standard coal consumption, S_5^- is adjustment value for electricity consumption rate of power stations, S_1^+ is adjustment value for power generating amount, S_2^+ is adjustment value for SO_2 emission.

capacity is reduced to 796.96, labor force to 4157, desulfurization equipment to 298 and standard coal consumption to 2.234, and then the effective frontier level can be achieved.

See TABLE 1:

By analyzing the projection theorem, we analyzed the input redundancy ratio and output insufficiency ratio;. From Figure 1, we can see the room for improvement for Labor and desulfurization equipment decrease is big. It shows the labor personnel qualities and skills in electric power industry need to improve; at the same time, the desulfurization equipment operation ability shall be improved through technological improvement.

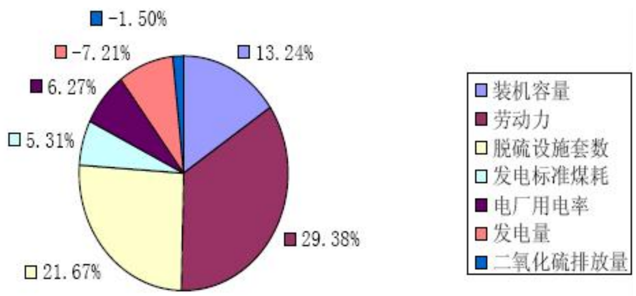

Figure 1 : Potential Improvement for Inefficient Decision-making unit Diagram Input and Output

Empirical results of Super efficiency DEA Stage-2

According to the characteristics of electric power industry, the macro factors affecting environmental performance Tobit model of electric power industry is as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (2)$$

In the formula: y refers to efficiency values of the super efficiency DEA model; x_1 is regional GDP; x_2 is the region's population; x_3 is the proportion of electricity consumption of the second industry; x_4 is the regional raw coal production volume; β_0 is the constant term; ε is stochastic term.

TABLE 2 : Result of Tobit Model Regression Analysis

Explanatory variable	Coefficient estimates	Standard error	Z	P
C	0.4843	0.0975	4.5315	0.0000
x_1	0.5095	0.1927	6.3709	0.0184
x_2	-0.2036	0.3419	-2.4015	0.0293
x_3	0.0095	0.0055	1.7327	0.0053
x_4	-8.3006	3.6619	-2.2687	0.0233

Note: the entire above variable coefficient have passed through significance test

Using Eview6.0 to handle Tobit model truncation type and make the maximum likelihood estimation of the program, results after Tobit regression are shown in TABLE 2

By analyzing TABLE 2, we can see that regional GDP and electricity consumption of the second industry are positively related to the environmental performance; the region's population and regional raw coal production is negatively related to the environmental performance.

All in all, that different macro factors affect different parts of the electric power industry, the macro fac-

TABLE 3 : Calculation result for environmental impact factors

Region	Environmental Impact Factors	Region	Environmental Impact Factors	Region	Environmental Impact Factors
Beijing	201	Zhejiang	9798	Hainan	553
Tianjin	-2629	Anhei	-93421	Chongqing	-36712
Hebei	-60783	Fujian	-14725	Sichuan	-74099
Shanxi	-532556	Jiangxi	-25002	Guizhou	-93028
InnerMongolia	-413432	Shandong	-100152	Yunnan	-64666
Liaoning	-47932	Henan	-169385	Shannxi	-197834
Jilin	-30319	Hubei	-4296	Gansu	-32301
Heilongjiang	-77558	Hunan	-45858	Qinghai	-10355
Shanghai	2777	Guangdong	16153	Ningxia	-35466
Jiangsu	-6289	Guangxi	-1070	Xinjiang	-54196

tors should be considered in the evaluation system which can really reflect the environmental performance of electric power industry in China

Empirical results of Super efficiency DEA Stage-3

According to the former analysis on macro influencing factors, the result can be further calculated on the influence degree of various areas, so that the electric power industry environmental performance in China can be more comprehensively analyzed. Through the calculation of environmental impact factor of each region, $C_i = \sum_{j=1}^{m} \beta_j x_{ij}, (i = 1, 2, ..., n; j = 1, 2, ..., m)$ and then further analyze the environmental performance of electric power industry in China.

Environment impact factor Calculation

This paper calculated the region environmental impact factors With Tobit model, the calculation formula is: $C_i = \sum_{j=1}^{m} \beta_j x_{ij,} (i = 1,2, \ldots n, j = 1,2 \ldots, m)$, see the result as follows:

Results analysis of super efficiency DEA stage-3

According to calculation result of TABLE 3, environmental impact factors in some regions are negative. So data conversion is needed here. After process, the minimum environment factor is Zero. The calculation results of Super efficiency DEA Stage-3 model are shown in TABLE 4. The contrastive analysis with TABLE 1 super-efficient DEA Stage-1 model is made at the same time.

Through the contrast drawn from above, we can see that rank for regions are also changed. The top five are Shanghai, Hainan, Beijing, Zhejiang and Hubei. Efficiency values in Zhejiang, Guangdong and some other regions are elevated, the ranks are also higher compared with last stage. It shows that local GDP and power consumption of the second industry give, to some extent, supports to the development of the regional electric power industry. In the calculation of stage-3, both environmental indicators and other technical indexes of electric power industry are taken into consideration, along with other macro factors which human being cannot change.

TABLE 4 : Contrastive analysis of Super-efficient DEA Stage-I (SE-DEA-1) mode land Stage-3(SE-DEA-3) Model

Region	SE-DEA-1	Rank	SE-DEA-3	Rank
Beijing	1.337	5	1.346	3
Tianjin	0.990	20	0.924	10
Hebei	1.015	12	0.907	11
Shanxi	0.792	29	0.665	30
Inner Mongolia	0.810	27	0.706	28
Liaoning	1.010	13	0.856	18
Jilin	0.991	19	0.812	21
Heilongjiang	1.002	16	0.833	19
Shanghai	2.012	2	1.874	1
Jiangsu	1.000	17	1.016	6
Zhejiang	1.075	8	1.287	4
AnHui	0.893	22	0.800	22
Fujian	1.003	15	0.872	14
Jiangxi	0.832	26	0.799	23
Shandong	1.000	17	0.866	15
Henan	1.036	10	0.865	16
Hubei	1.554	3	1.157	5
Hunan	0.744	30	0.733	26
Guangdong	1.024	11	0.975	8
Guangxi	1.262	6	0.933	9
Hainan	1.389	4	1.602	2
Chongqing	1.121	7	0.889	13
Sichuan	0.868	24	0.797	24
Guizhou	0.949	21	0.815	20
Yunnan	0.875	23	0.740	25
Shannxi	1.007	14	0.860	17
Gansu	0.845	25	0.722	27
Qinghai	4.013	1	0.998	7
Ningxia	1.039	9	0.905	12
Xinjiang	0.806	28	0.670	29

Note: SE - DEA - 1 refers to performance value of Super Efficiency DEA Stage-I, SE - DEA - 3 refer to performance values of Super Efficiency DEA Stage-3.

SUGGESTIONS ON HOW TO IMPROVE THE ENVIRONMENTAL PERFORMANCE OF ELECTRIC POWER INDUSTRY IN CHINA

From the above analysis, we can see that unbalanced regional development gap of electric power industry in China is big, power generation and energy consumption for the industry itself are big with serious environmental pollution. we should strengthen carbon technology research and use of electric power industry, to enhance people's mentality through low-carbon education, to construct a system of production-teaching-research of low carbon development system, to make more efforts to learn the international advanced technology.

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