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Total Factor Energy Efficiency Analysis Based on Empirical Analysis of Super Efficiency DEA Method

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Abstract: Energy is the basis of people's life and the normal operation of economic activities, and plays an important role in our daily life. However, with the rapid economic development(ED), energy problems and ecological environment problems are becoming more and more(MAM) obvious, attracting more and more attention of the society. Problems such as lack of energy, high energy cost but low utilization rate, and environmental pollution have also had a negative impact on people's lives and ED. It is urgent to improve energy efficiency(EE) and reduce pollution. This paper studies the current situation of energy consumption in province A, and uses the super-efficiency(SE) DEA method to measure the total factor energy efficiency(TFEE) of province A, and compares their TFEE values with three cities in province A as representatives space for improvement, and put forward a path for improving TFEE. By improving energy efficiency, it has certain practical significance for promoting the coordinated development of economy and environment.

1. Introduction

With the development of research, the DEA method is MAM widely used in the field of EE research, and the application of this method also makes it possible to consider the comprehensive efficiency research of multi-input and multi-output. MAM attention has been paid to the problem of environmental pollution, and more and more people have incorporated undesired output into the DEA model, which makes the measurement and evaluation of EE more in line with the actual situation, and avoids the overestimation of EE. In this paper, the SE DEA model is used to analyze TFEE, which can give play to the advantages of this model in measuring energy efficiency.

At present, the research on TFEE analysis based on the empirical analysis of the SE DEA method has achieved good results. For example, a scholar studied and considered TFEE under the influence of natural disasters, and concluded that technological change will have a two-way impact on TFEE, and the negative impact is greater [1]. A scholar studied the relationship between inter-industry structure and industrial energy efficiency base on SBM model, and found that industrial structure efficiency is the determinant of industrial energy efficiency in various provinces [2]. Because the non-parametric method has stronger applicability and does not require a preset model, it has been well applied and promoted [3]. At the same time, scholars creatively proposed some new DEA models. For example, consider the redundant non-radial SBM-DEA model, the DDF-DEA model that can effectively deal with the energy saving problem, etc. [5]. A scholar used super-efficiency DEA to measure my country's total factor energy efficiency, and concluded that my country's energy efficiency level is low, the situation is severe, and there are large differences between regions and provinces [5]. Some researchers have used the DEA method to calculate the EE of sewage treatment plants in Western countries. The results show that the energy efficiency of the analyzed sewage treatment plants is very low, only 10% is effective [6]. Although the DEA method is widely used in EE analysis, the SE DEA model still has a lot of room for improvement in TFEE analysis.

This paper first introduces the concept of TFEE, and proposes a super-efficiency DEA method on the basis of traditional DEA. Then, it analyzes the energy consumption and industrial pollutant emissions in province A, and then uses the SE DEA method to calculate the TFEE value of province A, and finally puts forward countermeasures to improve TFEE.

2. TFEE and Super Efficiency DEA

2.1. Total Factor Energy Efficiency

EE is measured as a technical efficiency, that is, using as little input (energy input) as possible to obtain as much effective output as possible, and using total factor energy efficiency to measure [7]. Furthermore, the definitions of productivity and efficiency are further differentiated. Referring to the three-factor model, adding energy to the production function, we get:

$$Y = A \cdot f(X_i) = A \cdot f(M, N, L) \tag{1}$$

Among them, Y represents effective output, Xi represents input factors, and factors M, N, and L represent capital resources, human resources, and energy consumption, respectively. Then, Y/Xi is used to express the productivity of energy, and TFEE productivity is to add up the input factors according to a certain weight w to obtain the input-output relationship, namely:

$$\frac{Y}{X} = \frac{Y}{\sum w_i x_i} = \frac{Y}{\sum w_1 M + w_2 N + w_3 L} \tag{2}$$

2.2. Super-Efficient DEA

DEA takes the index importance of each decision-making unit(DMU) as a variable, and compares and analyzes the input and output of each DMU to achieve its optimization. Under a certain input level, the DMU with the largest output has the highest production efficiency, which constitutes the production frontier [8]. The effective DMUs for DEA are those that fall on the production frontier, on the contrary, other DMUs are ineffective [9]. The EE value measured by the basic DEA model ranges from [0, 1]. If the efficiency of many DMUs is 1, the evaluation ability of the DEA model will be greatly reduced. The SE DEA model can make the efficiency exceed 1 and better evaluate the effective DMU [10]. The SE DEA method is an improved model of traditional DEA, which overcomes the shortcomings of the traditional DEA DMUs evaluation ability under the condition of variable scale returns [11].

2.3. Related Theories

(1) Energy-Economy-Environment Theory

The energy crisis has made people aware of the limited and scarce energy resources, and a series of issues such as rational use of energy, development of new energy, and energy security have attracted more and more global attention. Energy resources provide material support for economic development to a certain extent, and can also meet the energy needs of people's social life [12]. Environmental problems brought about by energy consumption have become increasingly prominent, such as haze weather and the greenhouse effect, which have negatively affected people's lives. People have begun to realize the importance of protecting the ecological environment and green development, and some scholars have begun to study the relationship between(RB) energy, environment and economy(3E). It is not difficult to find that there is a close RB 3E. Energy is the material basis of ED, and in turn, rapid economic development will promote the transformation and development of energy. The environment is the external condition of economic development. A good environment is conducive to sound and rapid economic development. On the contrary, a bad environment will be detrimental to economic development [12-13]. In turn, the high-quality development of the economy is also conducive to the development of the environment, which can provide an economic foundation for environmental governance. Energy comes from the environment, but the pollutants generated in the process of energy consumption will cause damage to the ecological environment, and may cause ecosystem imbalance in severe cases [14]. As shown in Figure 1, it reflects the relationship between energy, environment, and economic sustainable development.

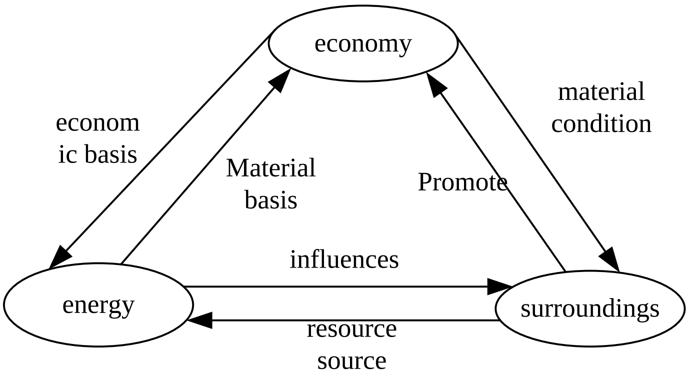

Figure 1. The relationship between energy, environment and economy

(2) Sustainable Development Theory

When environmental problems become more and more prominent, sustainable development is more and more popular. Sustainable development calls us to develop our economy without sacrificing the environment. Not only economic interests, but also changes in the ecological environment must be considered. In economic development, pollution should be minimized, and the damaged environment should be treated and repaired. In addition to paying attention to environmental issues, it is also necessary to recognize that natural resources are not unlimited, and to use resources appropriately to achieve the goal of sustainable development [15-16].

3. A provincial Energy Usage

3.1. Status Quo of Energy Consumption

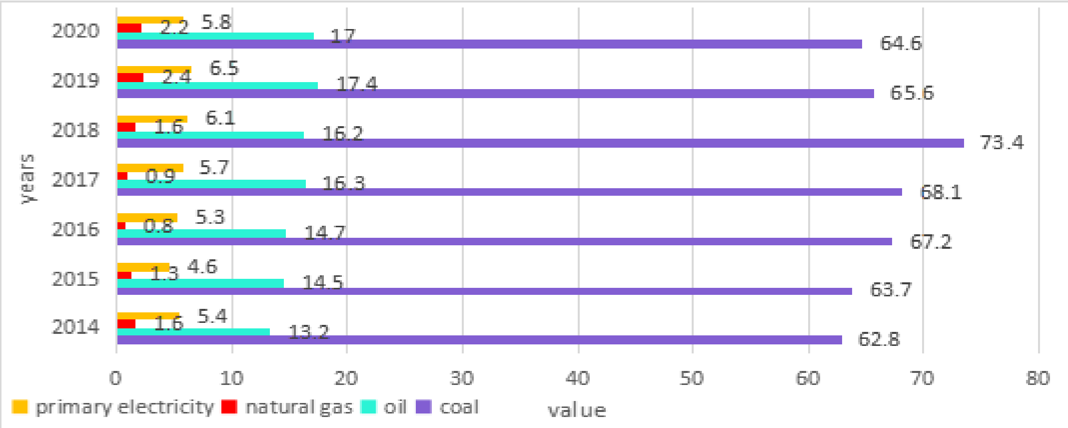

Figure 2. A province energy consumption structure

From Figure 2, it can be found that the energy consumption of province A focuses on coal. In the past seven years, the coal consumption ratio of this province has exceeded 60%. Followed by oil, the proportion of oil consumption is roughly between 13% and 18%. In contrast, primary electricity and natural gas consumption accounted for a relatively small proportion, both accounting for less than 10%. It can also be found that in the past few years, the composition ratio of various energy sources has not changed much, and the energy structure is relatively simple. The energy development of Province A is facing great challenges, the energy consumption structure needs to be further improved, and the economic development mode also needs to be transformed.

3.2. Status Quo of Environmental Pollution

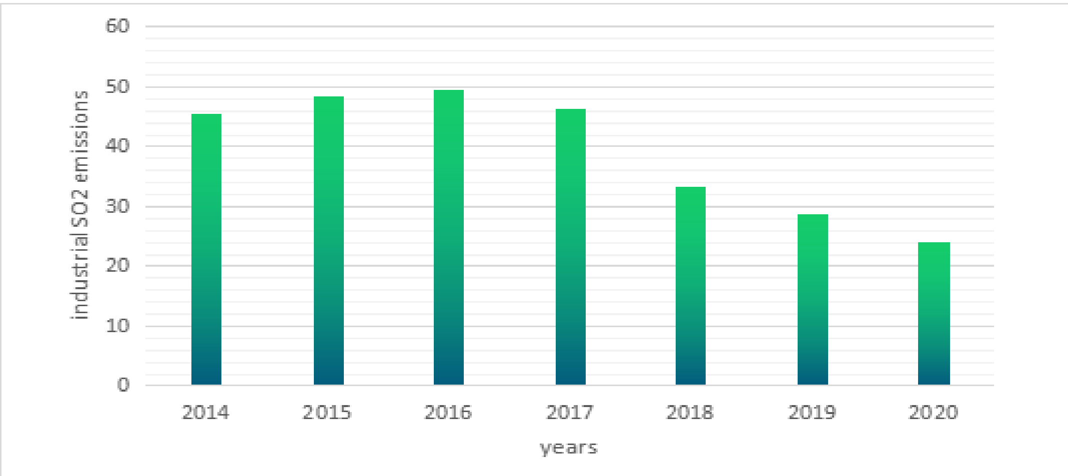

Figure 3. Industrial sulfur dioxide emissions in province A

As can be seen from the changes in Figure 3, the industrial sulfur dioxide emissions in Province A showed a trend of increasing first , then decreasing, from 362,800 tons in 2014 to 455,300 tons in 2017, and then decreasing to 241,200 tons in 2020. On the whole, industrial sulfur dioxide emissions have been reduced by about 33.52%, indicating that province A has paid more and more attention to ecological environmental protection in recent years, and environmental pollution emissions have also been controlled to a certain extent.

4. Empirical Analysis of TFEE Based on SE DEA Method

4.1. Calculation of TFEE

Table 1 and Table 2 show the TFEE represented by the prefecture-level cities(PLC) and three cities in A province based on the SE DEA model.

Table 1. Overall situation of EE in PLC in province A

	Mean	Min	Max
2014	0.673	0.058	1
2015	0.684	0.046	1
2016	0.689	0.124	1
2017	0.701	0.108	1
2018	0.715	0.145	1
2019	0.711	0.157	1
2020	0.694	0.092	1

Table 1 shows the EE usage of all PLC in province A. First of all, it can be seen that the overall level of EE in Province A is not high, and there is still some room for improvement. From 2014 to 2020, the average value of the efficiency value increased first, reaching the maximum value of 0.715 in 2018, an increase of only 0.038, about 5.6 percentage points, and the increase was very small. This may be due to the province's large-scale "shutdown and transfer" of high-polluting, high-energy-consumption small and medium-sized enterprises, and the short-term effect of improving dividends after this. However, this direct measure has not really solved the fundamental problem of low energy utilization efficiency from the root, that is, it has a downward trend. In terms of the minimum value, the city with the lowest efficiency was only 0.046 in 2015, and the minimum value is 0.092 in 2020, a slight improvement, but the efficiency is still very low. It shows that the areas with low energy use efficiency in Province A still exist and have not been well improved. The maximum efficiency is 1.

Table 2. TFEE values of three cities in province A

	D	E	F
2014	0.77	0.53	0.47
2015	0.76	0.55	0.47
2016	0.75	0.58	0.47
2017	0.79	0.59	0.47
2018	0.80	0.61	0.47
2019	0.86	0.64	0.42
2020	0.83	0.65	0.41

Table 2 shows the EE values calculated by the super-efficiency DEA method in three representative cities of A province. The analysis of each city is as follows:

The efficiency value of City D has been the highest in Province A from 2014 to 2020, with an average efficiency value(AEV) of 0.88. The AEV value of the entire region remains between 0.75-0.85. The EE value of the D city area first decreased, then increased and then decreased over time, and its fluctuation range was the largest among the three regions.

The efficiency value of City E is in the middle of the three major regions, but there is a big gap with the efficiency value of City D. During this period, the overall trend showed a slow growth, from the initial 0.53 to gradually stabilized above 0.6.

The efficiency value of City F ranks last among the three cities, far lower than that of City D. Its efficiency value has always been around 0.45. It seems that City E still has a lot of room for improvement. During the period from 2014 to 2020, the EE value of City F has been maintained at the same level, but in 2019 there has been a downward trend, gradually approaching 0.4.

In general, according to the above analysis, find that there is a big gap in the EE of the three cities in Province A. Moreover, the EE value of city D is at a higher level, and the EE value of city F is at a lower level.

4.2. Path Selection of Total Factor Energy Efficiency

(1) Comprehensively improve the performance of pollution reduction in various regions and reduce environmental pollution

While improving energy efficiency, we should assist in reducing environmental pollution as an indicator. At the current stage, the consumption of coal is still the main use method of energy resources in province A. The development of industrialization and economic and social development will still require a high degree of development for a long time. Relying on the utilization of coal resources, coal consumption is currently the most important factor leading to pollution emissions [17]. In order to improve energy usage and realize energy conservation(EC) and emission reduction(ER), it is necessary to implement healthy and effective EC and ER policies, improve EC assessment and environmental protection review systems, reasonably select the investment of high-polluting energy in various regions, and continuously improve the use of new energy and clean energy in energy use. proportion, fundamentally solve the problem of energy and environmental pollution [18].

(2) Optimizing the energy consumption structure(ECS) and laying the foundation for improving EE

The ECS of Province A is still dominated by coal, which is also the main reason for the low EE in some areas. Therefore, the premise of improving EE in province A is the optimization of ECS. The optimization of ECS can be carried out from the following aspects: reducing coal consumption(CC) and reducing the proportion of CC. Eliminate outdated capacity in coal production, close down coal mines that seriously damage ecology and pollute the environment, and focus on the development of coalbed methane to comprehensively promote the transformation and upgrading of coal production; implement green mining, and thoroughly implement the "coal-to-gas" policy throughout the province. Eliminate the use of coal-fired boilers to reduce coal consumption in quantity; for areas with a large number of energy-intensive industries such as iron and steel, it is necessary to control the number of coal and improve coal utilization efficiency; gradually throughout the province Reduce the amount of coal-fired power generation and expand the total amount of hydropower and natural gas power generation [19-20].

5. Conclusion

This paper analyzes the energy consumption of province A and finds that coal consumption is the mainstay in this province. Although the industrial sulfur dioxide emissions have decreased in recent years, it is still an urgent problem to coordinate the relationship between 3E in this province. This paper uses the SE DEA method to calculate the TFEE of the province in recent years. It is found that the EE value of the prefecture-level cities in the province is around 0.7. There is still a certain gap to achieve efficient energy utilization. Improving energy efficiency can promote economic sustainability. For sustainable development, a TFEE improvement path is proposed for the situation in Province A.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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