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Factor Analysis Method of Energy Consumption Intensity Variation Based on Super-Efficiency DEA and its Application

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Abstract: Energy is an essential material basis for the development of industry and national economy. The problem of excessive energy consumption caused by the rapid growth of energy in my country has always been a concern of academic circles. Serious energy consumption, low utilization efficiency and the resulting environmental pollution problems make the contradiction between economic growth and energy shortage more and more prominent. So as to solve the increasingly severe environmental and economic development problems caused by excessive energy consumption(EC), it is imperative to reduce the intensity of EC. In this regard, this paper analyzes the factors that affect the change of EC intensity, and introduces the SE-CCR model and SE-BCC model of super-efficiency DEA. It is concluded that the EC intensity can be reduced from the perspectives of adjusting the energy structure(ES) and improving the level of energy research and development.

1. Introduction

Total EC rises can reflect a region's dependence on energy resources. Affected by many factors such as the speed of economic development, industrial structure adjustment, and improvement of people's living standards, EC rises presents an irregular trend of change. To maintain economic growth, it is necessary to reduce energy intensity(EI) and improve energy efficiency.

At present, researches on factor analysis of EC intensity change emerge in an endless stream. There are many studies on EC abroad. For example, a scholar used panel data analysis to study the relationship between EC intensity, energy price indicators, labor force, and GDP, and thus obtained the relationship between energy and economy. And found that there is no obvious relationship between GDP and short-term EC [1]. A certain scholar used an econometric model to study the impact of(TIO) technological progress on EI earlier, but since the selected data was before the oil price shock, it was concluded that price-induced innovation would increase EC instead. This conclusion is inconsistent with its assumptions [2]. A scholar's empirical research on EI shows that industrial structure adjustment plays a key role in the change of EI in my country, and it is of great value to study TIO industrial structure on EI [3]. A scholar believes that there are certain differences in energy consumption in different countries, and at the same time, the level of economic development(ED) in each region is different, and the corresponding energy consumption is also different. The same industry, due to the difference in technology level, energy consumption structure and degree of opening to the outside world, the The energy consumption of industries in the east and west is also different [4]. Compared with foreign studies, there are few domestic literatures on EC intensity, and the method for studying the variation of EC intensity needs to be improved.

This paper firstly proposes the super-efficiency DEA method on the basis of the DEA concept, then introduces several basic concepts about energy, and then takes the EC of a province as an example. From the aspects of coal and oil energy use, energy structure, EC changes, etc., analyze its influence on the change of EC intensity in the province. Finally, the super-efficiency DEA model is applied to the analysis of the variable factors of EC intensity, and the relationship between(TRB) different explanatory variables and EI is obtained.

2. Related Models and Concepts

2.1. DEA and Super-Efficiency DEA

The method of data envelopment analysis (DEA) is developed on the basis of relative effectiveness, and it is mainly a statistical method for evaluating decision-making(DM) units with multiple inputs and multiple outputs. Its essence is a kind of relative efficiency. By comparing and analyzing the evaluation subject and the best unit in the sample, the actual situation of the decision-making unit can be determined [5-6].

The super-efficient DEA method can be evaluated by excluding the already effective decision-making units from the linear combination, which makes up for the problem that the traditional DEA method cannot analyze the effective DM units and sort different evaluation subjects. It has been widely used in the business community [7-8].

There are two models of super-efficiency DEA, one is SE-CCR model and the other is SE-BCC model, and the basic assumptions of both are the same as those of traditional DEA [9]. The result calculated by the SE-CCR model is the comprehensive technical efficiency, while the calculated result of the SE-BCC model is the pure technical efficiency. The calculation result of pure technical efficiency is more in line with the actual situation of the enterprise, which is beneficial to adjust the efficiency of the enterprise [10].

2.2. Basic Concept Description

Energy utilization efficiency(EUE): refers to the ratio of the effective use of energy and energy to the actual consumption in a country or region.

Energy economic efficiency(EE): Energy EE is based on physical EE, but has a broader meaning than physical EE. It is closely related to the level of ED, industrial structure, ES and scientific and technological level of a country or region [12] .

Energy intensity: is the abbreviation of energy consumption intensity, which reflects the energy consumption level per unit of GDP. At present, the research on energy intensity mainly adopts the factor decomposition method. This method usually only considers the two aspects of structure and efficiency. However, the factors affecting energy intensity are multi-dimensional, so the analysis results obtained have large errors. It is necessary to examine the influencing factors of energy intensity from a multi-dimensional perspective [13-14]. Let E denote energy consumption and I denote energy intensity:

$$I = \frac{E}{GDP} \tag{1}$$

Energy consumption elasticity: If e represents energy consumption elasticity, G represents GDP, E represents energy consumption, subscript 1 represents the target period, and subscript 0 represents the base period, the calculation formula of energy consumption elasticity is:

$$e = \left[(E_1 - E_0)/E_0\right] / \left[(G_1 - G_0)/G_0\right] \tag{2}$$

3. Changes in the Intensity of Energy Consumption in a Province

3.1. Energy Factors of the Province's Energy Intensity Changes

Table 1. Main EC of industrial enterprises above designated size in the province

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coal	2338	2785	3163	3694	4572	5208	5637	6041	6239
Natural Gas	574	612	645	663	728	757	736	742	751
Oil	931	878	904	956	963	1024	982	1137	1120

Energy factor is also an important influencing factor of energy intensity. It is important to influence EI through EC structure and EUE. The energy tastes of different energy types are also different, and the EE is also very different. ES and EUE are mutually influencing factors, which directly affect the total EC. At present, the main energy sources in the province are coal, oil and natural gas(NG), and the main sources of electricity are coal power, hydropower, nuclear power and wind power. As shown in Table 1, coal has always been dominant in the province's EC structure. The rapid increase in the province's total EC in recent years is also mainly reflected in the growth of total coal consumption. It can be said that the energy resources required for the rapid ED of the province are mainly maintained by the rapid increase of coal resources. Although other energy resources such as oil and NG have increased to a certain extent, there is still a big gap between the proportion and absolute value of the increase compared with coal resources. As a result, economic growth is overly dependent on the growth of coal resources, and energy intensity cannot be effectively controlled and reduced.

3.2. The Impact of ES on Changes in EC Intensity

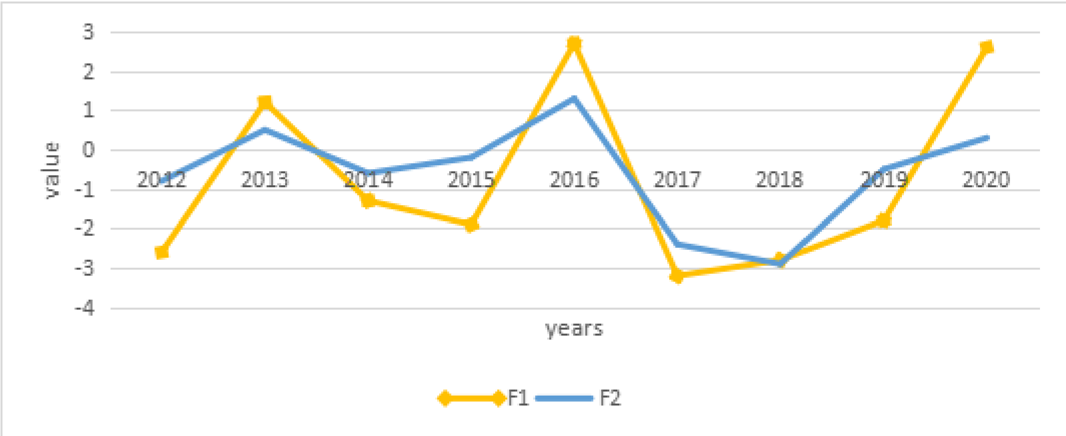

Figure 1. The impact of changes in ES on changes in EI

Figure 1 shows trb ES change and EC intensity, where F1 represents the change in EI caused by the change in energy structure, and F2 represents the actual value of the change in EI. It can be seen from the figure that in most years from 2012 to 2020, the change in EI caused by the change in energy structure is greater than the actual change in EI, which indicates that the change in ES has impact on EI. In addition, changes in ES have affected the direction and magnitude of changes in EI, of which about 2/3 of the years have negative effects, indicating that changes in ES in these years have reduced the EI of the province, and in the other 1/3 of the years A positive value indicates that EI was increased in 1/3 of the years, which reflects the slow pace of adjustment of the province's ES, which is mainly constrained by the province's energy situation of "rich coal and poor oil and gas". Coal-based” minor changes.

Table 2. Contribution rate trend of influencing factors of EC intensity in this province

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy consumption structure	-21.6	18.7	6.9	-31.2	-43.8	26.3	22.5	-7.4	-2.1
Energy consumption technology	85.2	62.7	71.8	43.5	38.3	-63.4	48.3	71.2	115.4
Output structure	14.9	21.5	10.7	24.8	12.6	158.9	37.4	16.9	-21.8

In Table 2, it can be seen that in 2017, the impact of output structure and EC technology factors on energy intensity has undergone great changes. The energy consumption technology factors have changed from the largest positive contribution rate to the largest negative contribution rate, while the production The output structure factor is the opposite and becomes a positive maximum contribution rate. The main reason for such large fluctuations is that the province's industries with high energy consumption and high cost are forced to undergo structural adjustment or go bankrupt, thus causing a huge adjustment in the output structure, making the output structure a dominant factor in the influencing factors of EI. However, in the period of vigorous structural adjustment of EC technology, some newly adjusted enterprises need a period of time to adjust the optimization of the output structure, and the EC technology cannot be displayed immediately. However, from the adjusted years, the contribution rate of EC technology to energy intensity began to increase rapidly, confirming the adjustment of ES. In the long run, EC technology has been the dominant factor in reducing EI, and it is also the main direction for reducing EI in the province in the future.

3.3. The Impact of the Rate of Change in EC on Changes in EI

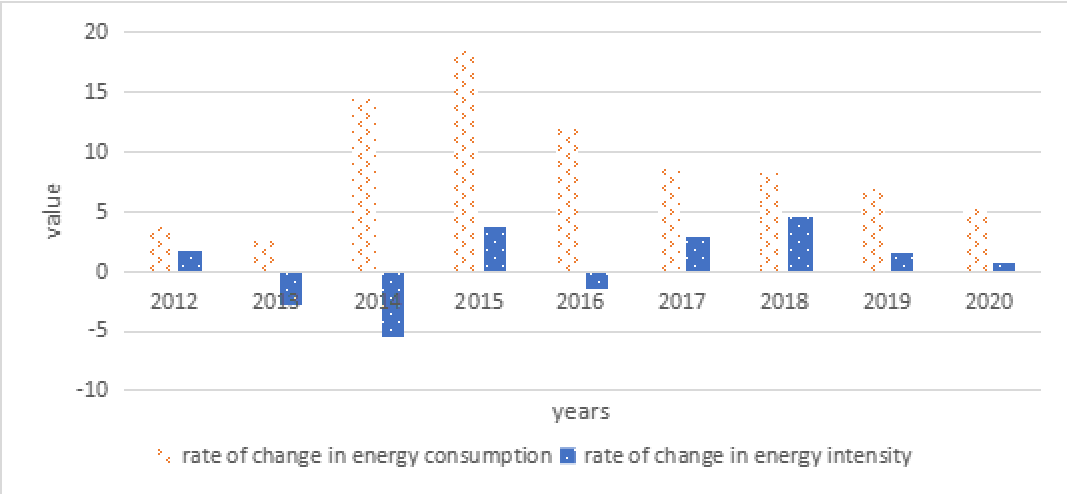

Figure 2. Rate of change in EC versus rate of change in EI

In Figure 2, by comparing TRB the rate of(TRO) change of EC and TRO EI in this province, it can be clearly found that the fluctuation range of total EC in this province has a strong consistency with the fluctuation range of EI. TRO change of EC intensity basically decreased from 2012 to 2014, and increased from 2016 to 2018, with the fastest decline in 2014 and the slowest decline in 2016. The change rate of EC in the province showed an overall upward trend from 2012 to 2015, and a downward trend from 2016 to 2019. The change rate of EC increased the least in 2013 and increased the most in 2014 and 2015. For the entire 2012-2020 period, the year with the largest increase was 2015.

4. Application of Super-efficient DEA Model

4.1. Selection of Explanatory Variable Indicators

Transport infrastructure (ROAD): Good transport infrastructure is essential for energy used by businesses to flow across regions at lower prices. And it has a great influence on enterprises to optimize the combination of input factors and improve productivity, and it is also meaningful to study the regional differences in energy consumption intensity [15].

Environmental Regulation Intensity (IER): Industries with high energy consumption intensity are also highly polluting enterprises to a large extent. The government's environmental regulation has an effective role in industrial technology upgrading and the recycling of energy.

Industrial Agglomeration (SIY): Industrial agglomeration will increase competition within the industry to a large extent, forcing enterprises to upgrade technology, improve energy efficiency, and at the same time, technology will have stronger spillovers.

Industrial structure (N3P): A scholar believes that my country's high-speed economic growth is achieved with a relatively low energy elasticity coefficient, and the main reason is that changes in industrial structure are conducive to the reduction of EC intensity [16].

Energy structure (EC): Energy structure refers to the energy consumption structure, which is expressed by the proportion of coal resource consumption and total energy consumption.

Research and Development Intensity (RD): The level of scientific research has a profound impact on the utilization rate of energy. Therefore, research and development capabilities can reduce the intensity of EC. Academia generally believes that technological progress can promote the reduction of EC intensity [17].

Energy Affluence (EP): The degree of energy abundance in each region largely determines the energy output of different provinces. Driven by the growth of GDP, the governments of resource-rich regions have focused on supporting the development of high-energy-consuming industries, resulting in talent and capital supply. High energy-consuming industries are inclined [18-19].

4.2. Analysis of Influencing Factors of EC Intensity Change Based on Super Efficiency DEA

In order to express TRB variables more clearly, DEA analysis and super-efficiency DEA (SE-CCR, SE-BCC) analysis were carried out on the driving factors(DF) of EC intensity in this province, and the DF analysis of EC intensity was obtained by sorting out The results are shown in Table 3. (Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels)

Table 3. Analysis results of influencing factors of changes in EC intensity

	Traditional DEA	SE-CCR	SE-BCC
ROAD	-0.524 (-1.273)	-2.614 (-2.875)	-4.638 (-4.562)
IER	-63.284 (-0.721)	-107.312 (-0.631)	-45.864 (-2.845)
SIY	156.766 (-2.504)	-67.827 (-1.043)	-36.582 (-0.673)
N3P	113.852** (-2.328)	46.821 (-6.936)	40.875 (-7.457)
EC	67.591*** (0.133)	12.810 (0.084)	3.792*** (-4.712)
RD	37.294 (-0.345)	13.967 (-1.648)	-28.573 (-0.167)
EP	8.637 (1.265)	18.426*** (5.718)	6.835 (-2.048)
R^2	0.148	0.236	0.257

In the analysis results of the traditional DAE model, traffic facilities and environmental regulations have negative effects on unit EC, but they are not significant. There is a significant and positive correlation between(CB) ES and EC intensity, which highlights the urgency of adjusting the ES.

In the SE-CCR model analysis, environmental regulation, transportation facilities and industrial agglomeration have negative but insignificant effects on unit EC, and the CB energy abundance and

EC intensity is relatively significant and positively correlated. The greater the energy abundance, the higher the EC intensity.

In the SE-BCC model analysis, many indicators showing negative coefficients are not significant, that is to say, if you want to better reduce the unit energy consumption, you can start with such indicators. The relationship between transportation infrastructure and energy consumption intensity is negative, but not significant.

Both the energy structure and energy abundance are positively correlated with EC intensity to a large extent, which also shows that the deterioration of the ES and the increase in the proportion of coal consumption will bring a large amount of unit EC and improve the traditional energy use methods. It is imperative to increase the proportion of alternative energy and clean energy, improve EE and develop clean and sustainable energy.

R&D intensity is the proportion of R&D expenditure in industrial added value, and this result still has a significant negative correlation with unit energy consumption. The effect of reducing energy consumption intensity. The higher the degree(HD) of industrial agglomeration(IA), the lower the energy consumption intensity. It may be because the HD of IA, the unified management and governance of the local area, which is conducive to the reduction of EC intensity.

5. Conclusion

This paper studies the variation factors of EC intensity in a province through the super-efficiency DEA method, and finds that the relationship between transportation infrastructure, environmental regulation, industrial agglomeration and changes in EI is not significant, while changes in energy structure, technology research and development level, energy affluence and EI are not significant. Therefore, the EC intensity can be reduced by adjusting the proportion of energy use, developing clean energy, and improving the technical level to improve energy utilization.

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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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