Analysis of regional total factor energy efficiency in China under environmental constraints: based on undesirable-minds and DEA window model

Shuying Zhang[1], Deshan Li[2], Shuangqiang Li[2], Hanyu Jiang[3] and Yuqing Shen[1]

[1]School of economics and management, Southwest Petroleum University, Chengdu, 610500, China
[2]School of economics, Sichuan University, Chengdu, 610064, China
[3]Chongqing College of Electronic Engineering, China

E-mail:1845734166@qq.com

Abstract. With China's entrance into the new economy, the improvement of energy efficiency has become an important indicator to measure the quality of ecological civilization construction and economic development. According to the panel data of Chinese regions in 1996-2014, the nearest distance to the efficient frontier of Undesirable-MinDS Xeon model and DEA window model have been used to calculate the total factor energy efficiency of China's regions. Study found that: Under environmental constraints, China's total factor energy efficiency has increased after the first drop in the overall 1996-2014, and then increases again. And the difference between the regions is very large, showing a characteristic of "the east is the highest, the west is lower, and lowest is in the central"; finally, this paper puts forward relevant policy suggestions.

1. Introduction

With the acceleration of industrialization and urbanization in China, the economic growth mode of "high energy consumption, high emission and low efficiency" has not been sustainable. In order to improve the quality of economic development, the report of The Eighteenth National Congress of the CPC clearly put forward the construction of ecological civilization as the main content of "five in one", the energy efficiency is the key measure to promote the construction of ecological civilization, and is an important basis for supporting the sustainable development of economy Chinese. For a long time in China, there is still a big gap compared with western developed countries of the energy efficiency. In 2014, Chinese total energy consumption is 42.6 tons of standard coal, the unit GDP energy intensity is about two times of the world average. At present, China's economy has entered a new normal, the transformation and upgrading of the economy is at an important inflection point in history, so is the efficiency of energy use in various regions rising or falling? Have the government's energy-saving emission reduction measures achieved the effect and how much of the effect? Therefore, it is particularly necessary to accurately measure the total factor energy efficiency of each region.

At present, due to the lack of uniform standards for energy efficiency, there are some differences in the results. At the present stage, the methods of calculating total factor energy efficiency include parametric method (SFA) and non-parametric method (DEA). Such as Miao Renyu, Li Deshan, Xu Jingqin, Yang Yongheng used the stochastic frontier production function method to measure the

energy efficiency and its influencing factors in various regions of China [1, 2, 3]. Compared with DEA method, the SFA method using the production function to construct the production frontier, considering the influence of random errors and potential errors, the result is more accurate than the DEA method, but in dealing with multi input and multi output, it's not as convenient as the DEA method; at the same time, the DEA method is not affected by the input and output dimension effect, and does not need to be given weight before, so it is used in various fields. Hu and Wang, Wei Chu, Shen Manhong used the data envelopment analysis method to calculate the total factor energy efficiency in various regions of China [4, 5]. Li Lanbing, using the method of the four stage DEA, argued that China's total factor energy efficiency is still at a low level in general, and the inefficiency of management and the inefficiency of environment are the two common factors that cause the low efficiency of energy [6]. Wang Feng, Feng Genfu used the window of energy and environment DEA model of double-orientation, non-radial, same-weighted, to evaluate energy and environmental efficiency of China's 2000-2010 regions that are comparable in cross section and time series[7]. Wu Chuanqing, Dong Xu used the super efficiency DEA model and ML index method, to analysis the total factor energy efficiency in 1999-2013, and they found that the total factor energy efficiency of the Yangtze River economic belt has been decreased by 2.9% year on year, and without considering the environmental, the factors of total factor energy efficiency declined at an average annual rate of only 0.4% [8]. Zhang Cheng et al. used DEA window model to analyze the trend of total factor energy efficiency in 23 developing countries, and found that there was a "U" relationship between energy efficiency and per capita income [9]. Chen Demin, Zhang Rui, and Tan Zhixiong used the DEA method and IV and SYS-GMM methods to prove that the energy efficiency can promote China's economic growth and convergence [10].

In summary, these literatures have been conducted in-depth analysis and discussion on the total factor energy efficiency, but there are also some shortcomings: First, most literature only added inputs in the traditional framework of total factor energy, the efficiency of measured value can be called the energy efficiency, also known as the efficiency of capital or the efficiency of labor [11]. Second, the majority of scholars basically adopts the radial model, the efficiency of the evaluation object can be overestimated when the input or output is non-zero relaxation under this model, and the use of non-radial model literature mainly adopts the SBM model to the forefront of the greatest distance, but from the evaluation point of view, expecting to get to the front through the shortest path, and SBM model is departed clearly. Thirdly, considering the undesirable output, most scholars considered the Malmqulist-Luenberger index, although it is widely used, but because this method doesn't properly reflect the characteristics of technological progress, it will get the efficiency index offset [12]. Therefore, according to the method by Hu and Huang, this paper introduces the recent strong efficient frontier containing non-expected output from the MinDS model and the DEA window model, and estimates the regional total factor energy efficiency in China under the environmental constraints. Meanwhile, under the "new normal" of Chinese economy, this paper gives suggestions of the way to promote the construction of ecological civilization and improve the energy efficiency, which enables China's economy to transfer to the path of sustainable development with high efficiency, high quality and low emission.

2. Model Building

2.1. *Minimum Distance Strong Model*
Data envelopment analysis (DEA) is a non-parametric production frontier model based on relative efficiency, which has been widely used in the field of production efficiency measurement and decision making. Because the traditional DEA model measuring the radial extent of the invalid rate only contains all input (output) ratio is reduced; for the invalid decision making unit (DMU), the gap between the current state and a strong and effective target value, in addition to the proportion of improved, also include improved partial relaxation. The current commonly used treatment method of non-radial distance is SBM model to the most distant Frontier [13], but the objective function of the model is to minimize the value of efficiency, considering the distance function, projection points

evaluated DMU is the frontier of distance is the farthest point evaluation DMU. From the Evaluators' point of view, expecting to reach the forefront of the shortest path, SBM model is obviously departed from this. Since the SBM model is unreasonable obviously, Aparicio et al. recently proposed efficient frontier distance Xeon MinDS model [14]. The method evaluate the DMU benchmark reference limit in the same super plane by adding a set of mixed integer linear constraints, after passing through the SBM model shortcomings of all valid DMU, whether how much the effective DMU is, it can solve the MinDS model by a programming model under the method proposed by Aparicio.

(1) suppose the number of DMU is J, each DMU has I inputs, Q outputs, the SBM model determines the effective DMU set for E.

(2) solving mixed integer linear programming to obtain MinDS efficiency value.

s.t

$$\begin{cases} \sum_{j \in E} x_{ij}\lambda_j + s_i^- = x_{ik}, i = 1, 2, \cdots, I \\ \sum_{j \in E} y_{qj}\lambda_j - s_q^+ = y_{qk}, q = 1, 2, \cdots, Q \\ s_i^-, s_q^+, \lambda_j \geq 0, j \in E \end{cases} \quad (1)$$

$$\begin{cases} -\sum_{i=1}^{m} \delta_i x_{ij} + \sum_{r=1}^{q} \gamma_q y_{qj} + \eta_0 + d_j = 0 \\ \delta_i, \gamma_q \geq 1 \end{cases} \quad (2)$$

$$\begin{cases} 0 \leq d_j \leq M b_j \\ \lambda_j \leq M(1 - b_j) \\ \sum_{j \in E} \lambda_j = 1 \\ b_j \in \{0,1\} \\ \eta_0 \text{ free} \end{cases} \quad (3)$$

Among them, M is a sufficiently large positive number, η_0 is a free variables. x_{ij} represent the i-th input of the j-th decision making unit; y_{qj} represent the q-th output of the j-th decision making unit; s_i^- and s_q^+ respectively represent the slack variable input and output; λ_j is the decision-making unit weight. The MinDS model is composed of three parts: the first part is the objective function and the constraint formula (1); the second part is the constraint formula (2); the third part is the constraint formula (3). The common purpose of the constraint formula (2) and constraint formula (3) is to make the reference pole in the same hyperplane.

2.2. DEA Window Model

For the traditional DEA method, it has some defects: First, the number of decision units must be two times of the number of variables of model selection, so for the model with large number of variables and less number decision making units, this method is not applicable or the results do not have the correct requirements; Second, decision making units must be homogeneous, for the model of different decision making unit, this method cannot be used; Moreover, this method cannot be directly used for the analysis of panel data, and the efficiency value obtained by the evaluation of DEA section cannot be compared inter-temporally. In order to solve the disadvantages of data envelopment analysis, Charnes et al. Proposed the DEA window model in 1985 [15], which inspects the utilization efficiency of decision-making units moving average method with time changes. The advantages of DEA analysis window is that a decision making unit can not only be compared with the same period of other decision-making units, but also regard the decision making units in different periods as different decision-making units, thereby it can increase the sample size to obtain more authentic efficiency evaluation. If the width of the window is D, the number of windows is w=T-d+1, the number of decision units within each window is d*J, equivalent to D times the number of DMU per period.

Charnes et al. [15] believe that the width of window of d=3 or d=4 can achieve a good balance between both reliability and validity.

The traditional DEA model, requires less input and more output, but in real life, for the result of output, may be consistent with the expected returns, and may also be negative returns that are offset with the expected returns, we called them the expected output and non-expected output. Suppose the number of DMU is J, each decision making unit has I non-energy input z_{ij}, K energy input e_{kj}, Q expected output y_{qj}, L non-expected output u_{lj}. Therefore, the DEA window model with non-expected outputs can be written as:

$$\theta^{mn} = \min \frac{1}{2}\left(\frac{1}{H}\sum_{h=1}^{H}\alpha_h^{mn} + \frac{1}{L}\sum_{l=1}^{L}\beta_l^{mn}\right), m = 1,2,\cdots,(T-d+1); n = 1,2,\cdots,d$$

$$s.t \sum_{j=1}^{d*J}\lambda_j^{mn} z_{ij}^{mn} + s_i^{z-,mn} = z_{i0}^{mn}, i = 1,2,\cdots,I, j = 1,2,\cdots,d*J$$

$$\sum_{j=1}^{d*J}\lambda_j^{mn} e_{hj}^{mn} + s_h^{e-,mn} = \alpha_h^{mn} e_{h0}^{mn}, h = 1,2,\cdots,H$$

$$\sum_{j=1}^{d*J}\lambda_j^{mn} y_{qj}^{mn} - s_q^{y+,mn} = y_{q0}^{mn}, q = 1,2,\cdots,Q \qquad (4)$$

$$\sum_{j=1}^{d*J}\lambda_j^{mn} u_{lj}^{mn} = \beta_l^{mn} u_{l0}^{mn}, l = 1,2,\cdots,L$$

$$\sum_{j=1}^{d*J}\lambda_j^{mn} = 1$$

$$\lambda_j^{mn}, s_i^{z-,mn}, s_h^{e-,mn}, s_q^{y+,mn} \geq 0$$

Among them, the superscript mn indicates that the variable is in the m window and at the n point. α_h^{mn} and β_l^{mn} represent the energy input effect and pollution effect respectively, λ_j^{mn} represent the weight of the J-th DMU, $s_i^{z-,mn}$, $s_h^{e-,mn}$, $s_q^{y+,mn}$ are slack variables. If $\theta^{mn}<1$, at least α_h^{mn} or β_l^{mn} is less than 1, or some slack variables are not equal to 0, then is the evaluation of the DMU_0 is non-DEA-effective, which means that its production frontier is in the production possibility set, and there is some efficiency loss compared with the optimal frontier of DMU.

3. Data Sources and Descriptions

This paper selects the panel date for the samples for 1996-2014 years of China's 29 provinces and autonomous regions, input indicators include capital stock, human capital stock, energy consumption; expected output index is the output of each region; non expected output index is sulfur dioxide emissions.

Physical capital stock K. The method of calculating the capital stock is the perpetual inventory method. $K_{it} = (1-\delta)K_{i,t-1} + I_{it}$. According to the result of calculation by Shan Haojie (2008), he calculated the capital stock of each region in 2007-2014, and converted into the comparable price with the base year of 1990. Data is from various regional in statistical yearbook.

Human capital stock H. Considering the heterogeneity of human capital, this paper divides human capital into high skilled human capital (HL) and low skilled human capital (HH). We regard the employees with junior high school as low skilled labor, and regard the employees with high and mid-level employment as high skilled workers. We use the method that average life expectancy of employees can approximately represent the human capital stock put by Barro and Lee (1993). Data is from the Chinese Labor Statistics Yearbook.

Energy consumption E. It uses the standard that tons of standard coal as a unit of energy consumption over the years to the region, the data is from the annual energy statistics yearbook.

Expected output Y. It is represented by the actual GDP in each region. The GDP deflator is calculated by GDP index and nominal GDP, converted into the constant prices with the base year of 1990. Data is from the Chinese statistical yearbook.

Undesirable output S. It refers to the emission of environmental pollutants, because there is no uniform standard at home and abroad, we use the sulfur dioxide emissions to represent it. Data is from various regions of the annual environmental statistics yearbook.

## 4. Analysis of Regional Total Factor Energy Efficiency in China

This paper firstly uses the Undesirable-MinDS model and DEA window model to calculate the slack variables of energy input of the evaluated provinces, then calculates the total factor energy efficiency according to the method by Hu and Wang [4], and then calculates the average value of the total factor energy efficiency in each point and each window in each province. Total factor energy efficiency (TFEE) = (real energy consumption - adjusted energy consumption) / actual energy consumption.

Table 1. Average value of the total factor energy efficiency of 1996-2014 in China

	1996	2000	2005	2010	2014	Average
Liaoning	0.8253	0.9311	1.0000	1.0000	1.0000	0.9817
Beijing	0.8759	0.8509	0.9938	1.0000	1.0000	0.9424
Tianjin	0.9153	0.9491	1.0000	1.0000	0.9685	0.9889
Hebei	0.6151	0.6736	0.8467	0.7263	0.8284	0.8139
Shandong	0.8822	0.9319	1.0000	0.7510	0.8068	0.8637
Shanghai	0.9942	1.0000	1.0000	1.0000	1.0000	0.9969
Jiangsu	0.9804	0.9841	0.8380	1.0000	1.0000	0.9499
Zhejiang	1.0000	0.9714	1.0000	0.9785	0.8806	0.9630
Fujian	1.0000	1.0000	0.9975	1.0000	0.8672	0.9825
Guangdong	0.6433	1.0000	0.9719	0.9586	0.8473	0.8895
Average of the east	0.8732	0.9292	0.9648	0.9414	0.9199	0.9373
Jilin	0.5441	0.9078	0.9457	0.9675	1.0000	0.8284
Heilongjiang	0.5055	0.6365	0.8414	0.8235	1.0000	0.7278
Shanxi	0.3342	0.3804	0.6137	0.5158	0.5768	0.5045
Neimenggu	1.0000	0.5682	0.6657	0.7931	0.7392	0.8040
Henan	0.8928	0.8968	1.0000	1.0000	1.0000	0.9557
Anhui	0.4645	0.6725	0.9893	0.9774	0.7369	0.8095
Hubei	0.5092	0.8710	0.9985	0.7971	0.9419	0.8116
Hunan	0.5444	1.0000	0.9106	0.9366	1.0000	0.8736
Jiangxi	1.0000	1.0000	0.8937	0.8915	1.0000	0.9685
Average of the Central	0.6779	0.7698	0.8674	0.8445	0.8564	0.8182
Shanxi	1.0000	1.0000	1.0000	1.0000	1.0000	0.9866
Guangxi	1.0000	1.0000	1.0000	1.0000	0.9781	0.9934
Gansu	1.0000	0.8614	1.0000	1.0000	1.0000	0.9613
Qinghai	1.0000	0.9657	1.0000	0.9579	1.0000	0.9696
Ningxia	1.0000	0.9338	1.0000	0.8567	0.9211	0.9409
Xinjiang	0.8881	0.5325	0.8404	0.6875	0.5147	0.7270
Guizhou	0.4585	0.4498	0.8070	0.7384	0.8416	0.7086
Sichuan	0.8191	1.0000	0.9885	0.5950	0.7176	0.8927
Yunnan	1.0000	1.0000	0.9509	1.0000	1.0000	0.9934
Chongqing	1.0000	0.9025	1.0000	0.9580	1.0000	0.9598
Average of the West	0.9166	0.8646	0.9587	0.8794	0.8973	0.9133
Average of the Nation	0.8170	0.8576	0.9342	0.8935	0.9023	0.8893

Due to space limitations, here we only list some of the year's data
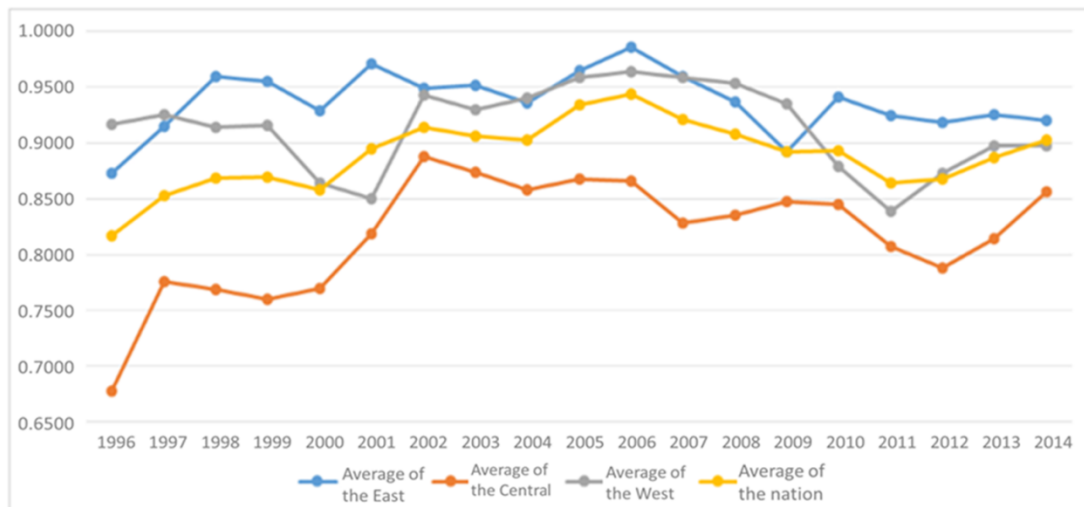
Figure 1. Average Value of the Total Factor Energy Efficiency of 1996-2014 in China

Based on these data, we may conclude that:

(1)   For the whole country, the total factor energy efficiency presents the "N" trending in 1996-2014 of rising first, then decreasing, and rising again. The main reason for the decline of energy efficiency in 2006-2011 is that with the rapid development of China's industrialization, large-scale investment has promoted the rapid development of heavy industry. The main cause of the energy efficiency increasing in 2012-2014 is that with Chinese economy gradually coming into the new normal, the country made a strategic decision to vigorously promote the construction of ecological civilization, giving priority to conservation, protection, and the natural recovery policy , which make the energy efficiency rise steadily.

(2)   As can be seen from the table, the province's energy efficiency changes showed a significant polarization trend. The three provinces with the highest energy efficiency are Shanghai, Guangxi and Tianjin, which are basically at the optimal frontier. According to the DEA model, although these provinces in the optimal frontier, saving energy is zero, but this does not mean that these provinces have no energy efficiency loss, it can only tell that compared with other provinces, further saving energy cannot be achieved in these provinces under the current technical conditions. And the three provinces with the lowest energy efficiency are Shanxi, Xinjiang and Guizhou, which means the energy efficiency of the three provinces have a large loss, or from another perspective, these provinces are of maximum energy saving potential compared to other provinces.

(3)   Eastern, central and western regions have large differences in the total energy efficiency. We divide the mainland China into three parts which are the west, the central, and the east, excluding Tibet and Hainan. It is shown that the difference of total factor energy efficiency in three regions is relatively large, the total factor energy efficiency in the eastern region is the highest, the average was 0.9373; the highest is in the province of Shanghai (0.9969), the lowest is in the province of Hebei (0.8139). As for the western region, with an average of 0.9133; the highest is in Guangxi province (0.9934), the lowest is in Guizhou province (0.7086). The central region has the lowest energy efficiency, with an average of 0.8182, the highest is in Jiangxi (0.9685), and the lowest is in Shanxi (0.5045). This is due to the fact that the energy efficiency of Shanxi and Heilongjiang in the central region is very low, resulting in a low average value in the central region, which is consistent with the conclusions of Hu & Wang (2006). Due to the transfer of high energy consumption and high emission industries from the eastern part to the central region, so the energy efficiency in the central is low. Therefore, the industrial transfer among the three regions is an important cause of energy efficiency differences among regions. In addition, due to the differences in resource

endowments and development level of each province, there are significant shifts in the internal energy intensive industries in the three regions. For example, in the central regions, energy intensive industries gather in Shanxi, Henan and other provinces. In the western regions, energy intensive industries gather in Sichuan, Xinjiang and other provinces.

(4)   During the period of 2010-2014, the energy efficiency decreased in the eastern region, while the central and western regions increased. It is shown in the figure, because the energy efficiency of Zhejiang, Fujian and Guangzhou declined from 2010, the energy efficiency of the east declined in 2010-2014; while Henan and Hubei's energy efficiency rise, resulting in the central region of the energy efficiency increased over the same period; at the same time, the energy efficiency rose in Qinghai, Yunnan, and the west regional energy efficiency showed a rising trend.

(5)   Although there are differences of development trend in each region, the difference among the eastern, central and western regions is getting smaller and smaller.

5. Suggestions on Improving Energy Efficiency in China

This paper introduces the recent strong efficient frontier containing non-expected output from the MinDS model and the DEA window model, and calculates the environmental constraints of China's 1996-2014 total factor energy efficiency in each region. Based on the analysis above, the following policy recommendations are put:

First, vigorously promote the construction of ecological civilization, improve energy efficiency in various regions. In the decomposition of energy efficiency goals, to avoid the one size fits all phenomenon, each region should seize the constraints of the construction of ecological civilization. The financial and technical advantages should be the used in eastern region, continue to increase development of advanced energy technologies and investment, and actively implement the new management mechanism of energy saving, the good experience of energy saving and emission reduction and management system should be promoted; For the central region undertaking industrial transfer, must pay attention to the technical content of the project, improve the ability to digest high technology introduced, actively introduce high-tech industry with high technology, high value-added, and green environmental protection; the western region should pay attention to the introduction of high-tech talent, enhance the independent innovation capability of local enterprises, through the introduction and study of the eastern region of the advanced production technology and management experience, to improve energy efficiency through technological upgrading.

Second, continue to optimize the industrial structure adjustment, and implement of industrial policy. The policy and institutional environment in especially central and western regions need to improve the development of the third industry; accelerate the elimination of backward production capacity and exit mechanism of the second industry, and guide the second industry to the development of resource saving and environmental friendly industries. The relationship between industrial transfer and industrial upgrading should be well managed. Local conditions should suit one's measures, and continuous innovation is needed, and cannot simply rely on fiscal subsidies to reduce environmental standards to attract foreign investment. To prevent backward production capacity to transfer to the region, and actively introduce and develop high-tech industries and services, reduce the proportion of energy intensive industries, by optimizing the industrial structure to improve energy efficiency.

Third, deepen the reform of the energy industry, rationalize the energy price formation mechanism. To break the monopoly of state-owned energy enterprises and a variety of price controls, and break the monopoly of upstream and downstream integration, and guide more, in line with certain qualifications of private enterprises to participate in market competition. Improving energy production capacity and increase imports of energy at the same time, we should strengthen the energy demand side and the supply side management, and create basic conditions for the formation of a reasonable price of energy, and give full play to the market mechanism in the allocation of energy.

Fourth, strengthen legal supervision, and establish the environmental economic compensation mechanism. Due to the low standard of sewage charges, some enterprises are willing to pay the sewage charges in order to pursue the interests, and they also do not improve the technology to reduce

emissions of pollutants. Therefore, we should increase the standard of sewage charges of the emission of industrial wastewater, industrial waste gas and industrial emissions, establish a new pollutant-exceeding standard and the ecological tax system, strengthen regional joint prevention and control of environmental pollution, and lead the economic and social development to the road of sustainable development.

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