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Regional Total Factor Energy Efficiency: An Empirical Analysis of Industrial Sector in China

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Abstract

The rapid growth of the Chinese economy has resulted in great pressure on energy consumption, especially the energy intensive sector – the industrial sector. To achieve sustainable development, China has to consider how to promote energy efficiency to meet the demand of Chinese rapid economic growth, as the the energy efficiency of China is relatively low. Meanwhile, the appeal of energy saving and emission reduction has been made by the Chinese central government. Therefore, it is important to evaluate the energy efficiency of industrial sector in China and to assess efficiency development probabilities. The framework of total factor energy efficiency index is adopted to determine the discrepancy of energy efficiency in Chinese industrial sector based on the provincial statistical data of industrial enterprises above designated size in 30 provinces from 2005 to 2009, with gross industrial output as the output value and energy consumption, average remaining balance of capital assets and average amount of working force as the input values. Besides, in considerate of the regional divide of China, namely eastern, central, and western, and economic development differences in each region, energy efficiency of each region is also analysed in this paper. The results show that there is room for China to improve its energy efficiency, especially western provinces which have large amount of energy input excess. Generally speaking, insufficient technological investment and fail of reaching best scale of manufacture are two factors preventing China from energy efficiency promotion. Based on our findings, some policy implications on the improvement of energy efficiency, particularly for economically underdeveloped regions in China, are also discussed.

Keywords

Total factor energy efficiency; Data Envelopment Analysis (DEA); Regional efficiency grads; Redundant energy input

1. Introduction

With the rapid pace of domestic industrialisation and urbanisation, the energy consumption of China has grown so fast that China has become the second largest energy consuming and CO2 emitting country in the world. According to the prediction of International Energy Agency (IEA) [1], until 2030, China and India will be the main drivers of non-OECD primary energy demand growth, and China will account for 39% of the global increase in primary energy use, whose share of total demand will jump from 16% in 2007 to 23% in 2030.

Specifically, they believe that the primary energy demand of China in 2015 will be approximately 2780 Mtoe, which will be equal to that of the total amount of the North America in the same year, and that amount will reach 3827 Mtoe in 2030 which will be largest in the word, with an annual increasing rate of 2.9%. Furthermore, there is no reason to feel optimistic about the energy intensity of China. According to the latest data from World Bank [2], GDP per unit of energy use of China in 2008 was only 3.6 $ per Kgoe, while that of the United States was 5.8 and the figure of Japan reached even as high as 8.1, which means that China consumes too much energy to support the economic growth, and the economic efficiency of energy use is rather low.

Energy use is a major source of GHG emission [3-6], causing environmental problems, which is a serious question given that extreme weather conditions are spreading rapidly across China. Continually rising energy consumption and highly-positioned energy intensity [7] have not only sounded the alarm for Chinese energy security, but also increased the pressure on whether or not China should bear more responsibility in cutting emissions in the post Kyoto-protocol era. Hence, cutting energy consumption has become a matter of urgency in China.

Evaluating whether energy is efficiently used can provide suggestions on how to reduce energy consumption. To achieve this goal, two indicators are usually adopted: energy intensity and energy efficiency. The former measures the amount of energy consumption per unit economic outcome, and the latter is defined as economic output divided by energy input. Several researches [8-10] have examined energy issues using them. Moreover, according to the number of input factor, energy efficiency can be classified as single factor energy efficiency and total factor energy efficiency. Single factor energy efficiency is equal to the ratio of efficient output by energy input, which can usually be represented by the inverse of energy intensity. However, both single factor energy efficiency and energy intensity have flaws: they only reflect the influence of energy on economic output, and ignore relations between energy and other factors. When other factors (e.g., labour and capital) are taken into consideration, it is not enough to evaluate energy use only using energy intensity or single factor energy efficiency. Moreover, the way energy intensity and single factor energy efficiency are calculated is flawed. If the weight of economic share is accounted when calculating energy intensity and single factor energy efficiency, the final result may have a statistical twist because of the economic gaps among units (e.g., provinces, or countries). We will also discuss this issue later in the paper. To overcome these problems, we decide to use total factor energy efficiency to conduct the evaluation.

Hu et al. (2006) realized the limitations and irrationalities caused by the method of single factor energy efficiency evaluation [11]. They argued that energy alone cannot produce any output; it must be put together with other inputs in order to produce outputs. Therefore, they introduced the concept of total factor energy efficiency, which emphasised the analysis of the relationships between economic output and multivariate inputs including energy, labour and capital reservation. They also measured and calculated the total factor energy efficiency of China from 1995 to 2002. Many other scholars examined this method and sought to improve it.

Wei et al. (2006) [12] and Xu et al. (2007) [13] used Hu et al.’s method to analyse the total factor energy efficiency of Chinese provinces. The former focused on a vertical comparison of ten-year provincial data, while the latter focused on horizontal comparison among regions. Honma and Hu (2008) [14] used the concept of TFEE to compute regional total factor energy efficiency in Japan. Shi et al. (2008) [15] and Wu et al. (2009) [16] improved the concept by introducing new factors to attain certain purpose of evaluation. Shi et al introduced knowledge reservation into production function, while Wu et al considered the influence of environmental impact as a negative factor which was produced simultaneously with economic output.

Although these prior literatures enhance our knowledge, they mainly focused on regional or sectional total energy efficiency, using gross domestic product as yield, with few research focusing on energy efficiency analysis of industrial sector in different regions. However, the industrial sector which consumes 70% of Chinese energy is the most crucial department thwarting Chinese energy efficiency development [17]. Besides, fewer researches were based on data of industrial enterprises above designated size despite that those enterprises are the main contributors to energy consumption of Chinese industrial sector. Due to the important role of industrial sector in Chinese economy and its rapid development in recent years, it is necessary to research energy efficiency based on data of industrial enterprises above designated size. Moreover, the divide of regions in China and decades of unbalanced policy leaning to the eastern region of China lead to development gaps among different regions. So, regional and even provincial differences should be emphasized. In this paper, provincial data will be chosen for the empirical analysis and regional differences will also be analysed.

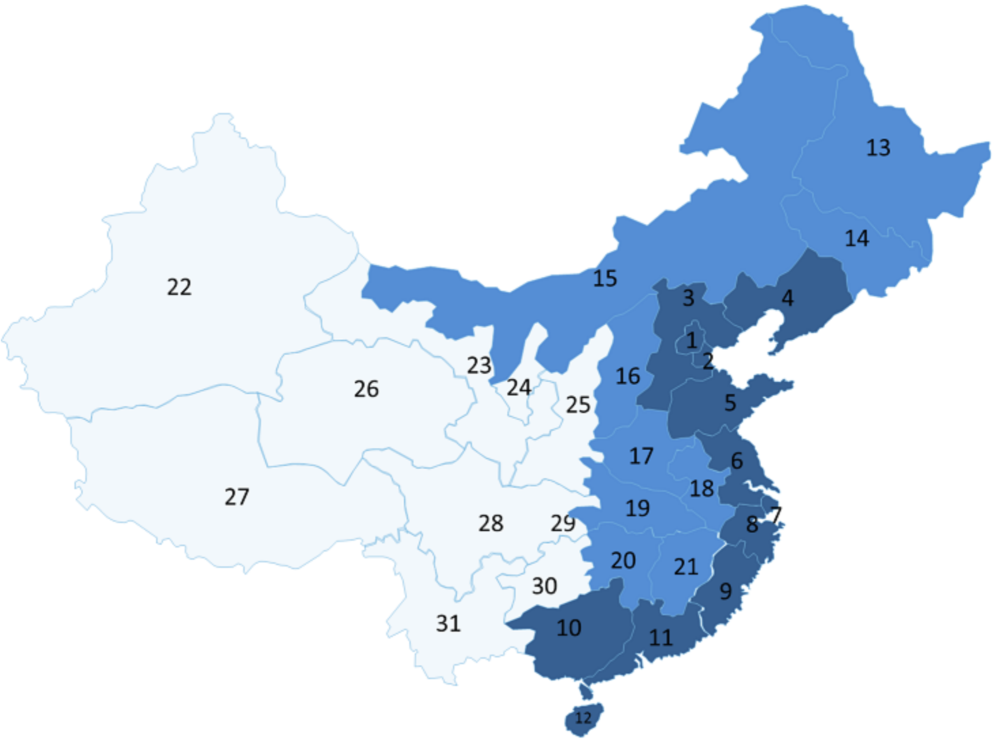
In this paper, we focused on analysing total energy efficacy of Chinese industrial sector using industrial data. Since China is eager to change its way of economic development, it is important to recommend relevant policies based on the results of the research.

The remainder of this paper is organized as follows. Section 2 describes the method of research and data sources. Section 3 presents the results of research and necessary discussion. Finally, in section 4, conclusions and recommendations are provided according to the results of the research.

2. Materials and Methods

2.1. Descriptive of regions in mainland China

For geographical and political reasons, mainland China is divided into three regions: eastern, central and western. For decades since Chinese economic reform in 1978, development priorities have been different among regions. As a result of the divide and policy preferring, the level of development differs much from each other, both economically and culturally. Because of the research purpose of this paper that regional analysis will be done, and the fact that readers may be lack of the knowledge of the regions, it is necessary to introduce the regional divide of China in the first place. To help understand the divide, mainland China map of figure 1 is drawn to identify the three regions and the consisting provinces.



1. Beijing 2. Tianjin 3. Hebei 4. Liaoning 5. Shandong 6. Jiangsu 7. Shanghai 8. Zhejiang
9. Fujian 10. Guangxi 11. Guangdong 12. Hainan
13. Heilongjiang 14. Jilin 15. Inner Mongolia 16. Shanxi 17. Henan 18. Anhui 19. Hubei
20. Hunan 21. Jiangxi
22. Xinjiang 23. Gansu 24. Ningxia 25. Shaanxi 26. Qinghai 27. Tibet 28. Sichuan
29. Chongqing 30. Guizhou 31. Yunnan

Figure 1: Regional Divide of Mainland China

Eastern region, which is coloured as deep blue in the map, consists of 12 provinces, which are marked from No.1 to No.12, that stretch from the province of Liaoning to Guangxi, including 9 coastal provinces and 3 municipalities: Shandong, Hebei, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, and Beijing, Tianjin, Shanghai. The region is famous for its GDP contribution and economic development level.

Central region, which is coloured as blue, is constituted by 9 inland provinces marked from No.13 to No.21 in figure 1: Heilongjiang, Jilin, Inner Mongolia, Henan, Shanxi, Anhui, Hubei, Hunan, and Jiangxi. This region is the base of agriculture, and has large population.

Western region, which is coloured as light blue in figure 1, covers almost half of China, but has lowest population density and is least developed due to geographical reasons. 10 provinces which are marked from No.22 to No.31 make up the region, and the members are Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Tibet, Yunnan, Xinjiang, Sichuan, and the municipality of Chongqing. However, for the reason of statistic data missing, Tibet will be excluded from the analysis.

2.2. Data Envelopment Analysis

Total factor energy efficiency provides us an effective frame to evaluate energy efficiency. Under this frame, new concepts can be introduced as either input or output factors according to the research purpose. Li et al. (2008) [18] evaluated energy efficiency in multiple scenarios based on the non-parameter method of production theory frame. Shi et al. (2010) [19]

evaluated regional industrial energy efficiency in China taking undesirable environmental impact and non-energy influencing factors into account, and concluded that the massive use of energy supporting economy gave rise to the drawback of the wastage of a large amount of energy. All those concepts including TFEE were developed based on data envelopment analysis, known as DEA.

Data Envelopment Analysis (DEA) was developed by an American operations researcher named Charnes in 1978 [20] and is a non-parametric statistical method based on linear programming technique to assess the efficiencies of decision-making units (DMU). In other words, if we consider a DMU producing outputs with various inputs, DEA can be used to assess the efficiency that inputs produce outputs. Therefore, it can be effectively used as a multiple input-output framework to compute the index of TFEE directly, which means that the DEA model is well-matched with the concept of TFEE. Hu et al. (2006) [11], who firstly introduced the concept of total factor energy efficiency, adopted DEA as the methodology in their paper.

Generally speaking, there are five kinds of DEA models which are used widely. The five basic models were named respectively as C^2R (A. Charnes, W. W. Cooper and E. Rhodes, 1978) [20], BC^2 (R. D. Banker, A. Charnes and W.W.Cooper, 1984) [21], C^2GS^2 (Charnes, Cooper, B. Golany, L. Seiford and J. Stutz, 1985) [22], C^2W (Charnes, Cooper and Q. L. Wei, 1986) and C^2WH (Charnes, Cooper, Q. L. Wei and Z. M. Huang, 1987) [23]. BC^2 and C^2GS^2 were used to verify technical efficiency, C^2W extended the basic C^2R model to the condition of infinite DMUs, and C^2WH introduced preferences of decision makers. In this paper, in considerate that we are going to comprehensively evaluate the overall efficiency, technical efficiency and scale efficiency in China, C^2R model is applied because of its ability of analysing these efficiencies.

More technically, DEA aims to construct a non-parametric envelope frontier composed of DMUs. The DMUs located on or above the frontier are efficient while those within the frontier are inefficient. C^2R model enables the overall efficiency (OE) to be divided into pure technical efficiency (PTE) and scale efficiency (SE), which offers more adequate information to analyse overall efficiency of inputs producing outputs [24]. The relationship among the three could be stated as formula (1):

$$Overall \quad Efficiency = Pure \quad Technical \quad Efficiency \times Scale \quad Efficiency \qquad (1)$$

To state the method of DEA clearly, a graph is used to help understand the decomposition of OE and the measure of multipliers. As shown in figure 2, the round in black, representing any random convex set, though a little rough, is data envelopment which holds all the samples and line ON is tangent to the round, which represents constant return to scale. For any point E in the data envelopment, under the calculation of C^2R, three formulas can be defined, which are respectively stated as formula (2) to (4):

$$Overall \quad Efficiency = \|\mathrm{BC}\| / \|\mathrm{BE}\| \qquad (2)$$

$$Pure \quad Technical \quad Efficiency = \|\mathrm{BD}\| / \|\mathrm{BE}\| \qquad (3)$$

$$Scale \quad Efficiency = \|\mathrm{BC}\| / \|\mathrm{BD}\| \qquad (4)$$

In the formula (2) to (4), the operator $\|\bullet\|$ means the module of the hyper line segment in the space. As can be conducted from the formula, it is obvious that the equation of formula (1) is valid.

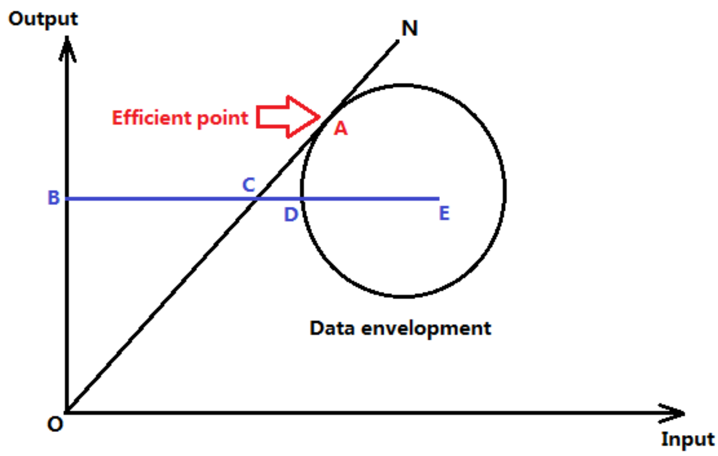


Figure 2: Illustration about the decomposition and measurement of overall efficiency

It can be concluded from figure 2 that for any point inside the data envelopment, its pure technical efficiency and scale efficiency are less than 1, and as a result of which, the overall efficiency is less than 1. However, for any point on the envelopment, D for example, according to the formula, the pure technical efficiency is 1, but the scale efficiency is less than 1, thus the overall efficiency is less than 1. For those points doting on the surface of data envelopment, i.e. points whose pure technical efficiency is 1, they are usually called DEA-effective; otherwise, they are usually called non-DEA-effective. Consider an extreme condition, point A, where C, D and E have been coincident, according to the formula of decomposition. OE, PTE and SE at point A are all equal to 1.

Figure 2 is just an example of two dimensional Cartesian coordinate, i.e. input is the only cause for output. If sample data are collected, they will form a multi-dimensional sphere in the space. Thus, we can imagine a flat or hyperplane forming the constant return to scale tangent plane as line ON in two dimensional condition and similarly efficiency can be evaluated.

2.3. Data Selection and Description

Referring to the research of Wu (2009) [16] and Li (2006) [25], this paper applies DEA to construct a set of energy-efficiency-accessing models: here taking the industrial sector of 30 provinces and municipalities (Tibet, Hong Kong, and Macao excluded) in China as DMUs to examine the relationship between energy input and industry output. Chang and Hu (2010) [26] have researched the regional data from 2000 to 2004, evaluating energy productivity change of provinces in China with total-factor framework. In China, the time span of an each economic developing plan of central government lasts five years. Until late 2010, China has experienced eleven economic developing plans. Since the 11th plan spans from 2006 to 2010, and the statistics of 2010 is yet to publish, we decided to set our sample data from 2005 to 2009 to research a five-year changing of energy efficiency in Chinese industrial sector to make sure that the research is latest. Similar but different with the former research, this model also includes economic index as output, however, the index is no longer gross domestic product but gross industrial product in order to set focus of research on industrial department of China. According to real industry production process, factors of energy, capital, and labour are deemed as inputs in the DEA model. That is, given the characteristics of the industrial sector and the differences in research purpose, the indicator selection differs [16, 18]. In this paper, the indicators and data sources are as follows:

Output:

Gross industry production (GIP) cannot fully reflect the purpose of our research. Since industry enterprises of large scale are the main consumer of energy and the main provider of provincial or municipal GIP, the gross product value of Industrial Enterprises above Designated Size is adopted as the measure of the output. The raw data are taken from the "Statistical Yearbook of China" [27] (2006 to 2010).

Input:

1) Capital input. Apply the annual average balance of fixed capital and working capital of industrial enterprises above designated size to measure the capital input.

2) Labour input. Apply the annual average number of employees of industrial enterprises above designated size to measure the labour input.

3) Energy input. Apply energy consumption of industrial enterprises above designated size to measure the energy input. Energy consumption calculated in this paper is the product of Industrial Added Value and Energy consumption per unit of Industrial Added Value.

The raw data of the inputs above are also from the "Statistical Yearbook of China" (2006 to 2010).

3. Empirical Results and Discussion

3.1 Simple Energy Intensity Statistical Review During 2005 and 2009

Before stating the empirical results of Total Factor Energy Efficiency, we present some simple statistical review of Energy Intensity in China during the year 2005 and 2009 here firstly, calculated using the same source of data, to help build an overlook of Chinese status in quo. Energy Intensity is calculated using equation (5), which is a universally accepted method.

$$EI = \frac{\sum_{i=1}^{n} E_i}{GIP} = \sum_{i=1}^{n} \frac{E_i}{GIP_i} \frac{GIP_i}{GIP} = \sum_{i=1}^{n} EI_i \cdot S_i \quad (5)$$

In equation (5), i and n represent provinces observed and the total amount of provinces, EI, E_i, GIP, GIP_i, EI_i, and S_i respectively represent Energy Intensity, energy use in the ith province, Gross Industrial Product, Gross Industrial Product in the ith province, Energy Intensity in the ith province, and economic output share of the ith province in the whole nation. The results are listed in Table 1.

Table 1: Energy Intensity in 30 provinces and industrial sectors (2005 to 2009)

Regions	2005	2006	2007	2008	2009
Beijing	0.360	0.298	0.266	0.203	0.188
Tianjin	0.398	0.381	0.358	0.298	0.261
Hebei	1.264	1.205	1.094	0.880	0.784

Shanxi	2.367	2.144	1.956	1.710	1.662
Inner Mongolia	2.344	2.306	2.127	1.654	1.463
Liaoning	0.900	0.854	0.783	0.647	0.618
Jilin	0.976	0.892	0.760	0.586	0.473
Heilongjiang	1.125	1.051	0.973	0.856	0.550
Shanghai	0.290	0.312	0.248	0.215	0.205
Jiangsu	0.414	0.391	0.341	0.275	0.254
Zhejiang	0.317	0.294	0.273	0.234	0.225
Anhui	1.056	0.912	0.849	0.731	0.629
Fujian	0.392	0.390	0.379	0.321	0.315
Jiangxi	0.858	0.825	0.677	0.531	0.447
Shandong	0.673	0.599	0.560	0.451	0.408
Henan	1.093	1.253	1.244	0.864	0.818
Hubei	1.116	1.069	1.026	0.765	0.716
Hunan	1.004	0.934	0.846	0.613	0.494
Guangdong	0.269	0.274	0.250	0.203	0.191
Guangxi	0.991	0.922	0.865	0.760	0.736
Hainan	1.151	0.936	0.757	0.704	0.685
Chongqing	0.720	0.766	0.765	0.745	0.799
Sichuan	1.227	0.990	0.953	0.829	0.745
Guizhou	1.939	1.884	1.728	1.461	1.475
Yunnan	1.498	1.274	1.150	0.998	1.004
Shaanxi	1.038	1.014	0.950	0.802	0.531
Gansu	1.275	1.308	1.225	1.254	1.064
Qinghai	1.331	1.475	1.445	0.822	1.196
Ningxia	2.933	2.671	2.826	2.531	2.330
Xinjiang	1.349	1.258	1.177	1.211	1.031
Eastern Area	0.355	0.340	0.306	0.252	0.233
Central Area	0.245	0.228	0.227	0.188	0.170
Western Area	0.123	0.104	0.100	0.091	0.084
Total	0.723	0.672	0.633	0.531	0.487

In Table 1, all the data of provinces are original Energy Intensity without weighing, but the data of Eastern, Central, Western and Total account are weighed according to their economic contribution. From the data, we can see the basic paradox of both Energy Intensity and single factor Energy Efficiency indicator: because of the gaps among Chinese provincial development, economic weighing will cause statistical twist. This conclusion can be obviously proved: according to table 1, although the individual energy intensity of each province in western area is relatively high, the overall energy intensity level of western area is finally the lowest after the economic weighing for the purpose of relative energy intensity comparison.

However, in table 1, we can be informed that the energy intensity in China was in a decreasing stage during the year 2005 and 2009, provincially, regionally and totally, only with different extents. But we lack detailed information of how energy use improves in Chinese industrial sector, whether there is room for further improvement, etc. Total factor energy efficiency evaluation based on DEA method helps to answer these questions.

3.2. Overall Efficiency Analysis

Table 2 lists the result of overall efficiencies, pure technical efficiencies and scale efficiencies of industrial sectors of 30 provinces and municipalities in China.

Based on the overall efficiency results, the industrial department energy efficiency of five provinces of Tianjin, Shanghai, Jiangsu, Shandong and Guangdong were DEA-effective from 2005 to 2009, which constitutes the frontier of energy efficiency in the inter-provincial industrial department. The overall energy efficiency of the Beijing industrial department increased to 1 and was in the frontier from 2006. So far, the provinces in which the overall efficiency was DEA-effective comprised 20% of all provinces and municipalities, which are all in eastern region. According to table 2, only the provinces of Liaoning, Zhejiang, Fujian and Guangxi, 4 out of 12, do not meet the overall efficiency above 0.9. In other words, the overall efficiency of 66.7% provinces in eastern region was above 0.9, while the overall efficiency of only 3 provinces out of 9 in central region and none of the provinces in western region reached 0.9. None of the western provinces can even reach the overall efficiency of 0.8. In all of 30 provinces, the overall efficiency of Shanxi was the lowest, with a score of only 0.503. From the above analysis, we can also see that the industrial departments with high energy efficiency were mainly located in the eastern regions, while the relatively low ones were located in the central and western regions.

By further analysing the non-DEA-effective provinces from the aspects of technology and scale of the comprehensive efficiency, according to table 2, it can be found that Hainan province industrial sector was technologically effective but not scale effective, which indicates that the role of pure technological progress in its output has been fully utilised, but the scale return has not been formed. This means, in accordance with current output calculation, that it is impossible to decrease its investment. In addition, the pure technical efficiency of Hebei, Zhejiang, Fujian, Jiangxi, Henan and Hunan provinces' industrial sectors reached above 0.9, and those of Liaoning and Jilin province were between 0.8 and 0.9. Therefore, the non-DEA-effective provinces whose pure technical efficiency reached more than 0.8 accounted for about 30%. Relatively speaking, scale efficiency was considerably higher, with none of the province's industrial departments being less than 0.8. Thus we can see that the industrial departments in China generally rely on a mass resource input of scale production, while technical aspects are relatively underdeveloped.

3.3 Efficiency Developing Trend Analysis

The 2005 to 2009 trends of provincial overall efficiency, pure technical efficiency and scale efficiency were drawn respectively as Fig. 3 to Fig. 5[1]. It is obvious to identify the trend of each kind of efficiency for each region.

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[1] Due to the mass number of provinces, panel line chart of data from all 30 provinces will be a mess to understand. Taken the purpose of this paper into consideration, regional line chart based on average of provinces is given.

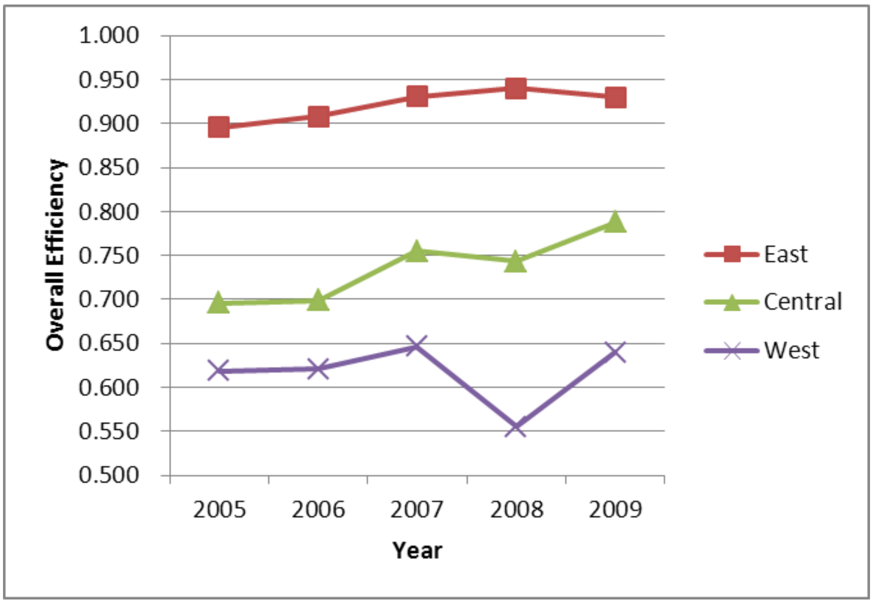

Figure 3: Comparison of overall efficiency among regions

Generally speaking, it can be referred from figure 3 that, the overall efficiency of eastern and central regions was rising while that of western region had been encountering the down side even since the beginning. It can be found from table 1 that Shanxi is the lowest overall efficiency province in central region, and even is the lowest in whole China at some time points. The reason is that Shanxi is abundant with energy resources, and thus the province did not concern too much about efficiency, and even the processing of other fuel like coke was inefficient. However, according to figure 3, no definite trends could be easily identified during western region development. The reason of the phenomena is that the overall investment environment of western region is not as ideal as central and eastern regions. Although west-construction plan of China has been called up by government for years, the scale of applicable investment and the conversion lag of investment to production are preventing the obvious promotion of overall efficiency.

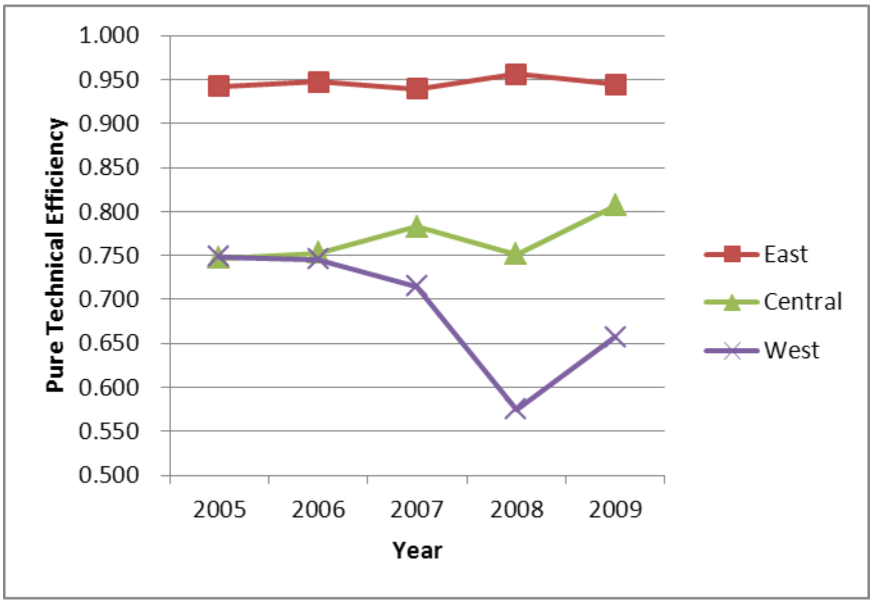

Figure 4: Comparison of pure technical efficiency among regions

From figure 4, pure technical efficiency in eastern region is relatively stable, and that of central region is gradually going up while with the similar trend of stableness. However, no optimistic signs can be found in western region shown in figure 4. The pure technical efficiency plummeted from 2007 to 2008 and bottomed out at 2008. Rebound was found in 2009, but the height did not exceed efficacy in 2007, and the overall trend is falling. It can be referred that at least until 2009, technological innovation had been ignored by the provinces. Considering the development environment of west region, it is not hard to understand the trend of the polyline. West region is still relying on the pattern of investment driven economic development, technical promotion is not a priority due to the time lag of converting technology to production.

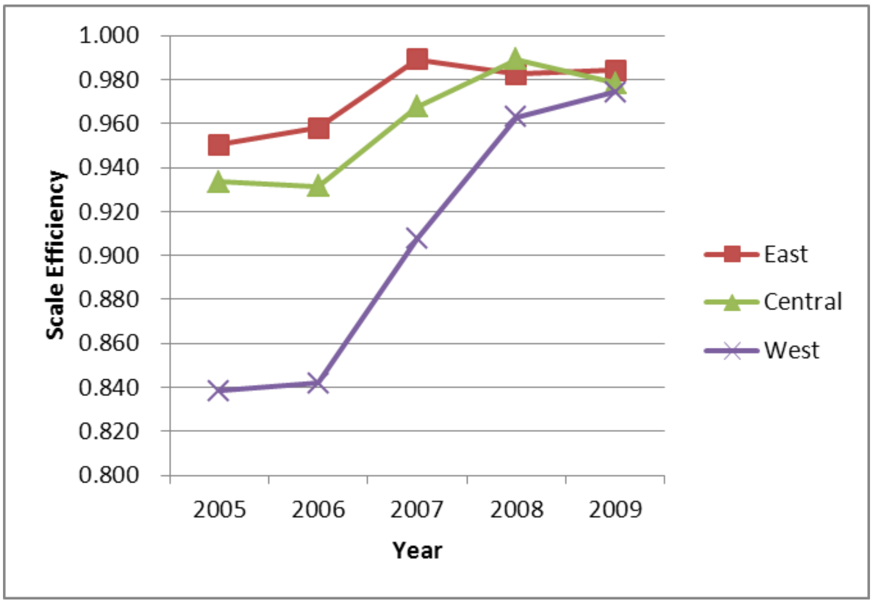

Figure 5: Comparison of Scale efficiency among regions

We can see from figure 5 that the scale efficiency of all three regions in China was going up during 2005-2009. Western region has rather high accelerating rate, especially the provinces of Ningxia and Qinghai which can be referred from table 1. From the figure, it is easy to conclude that the stableness of overall efficiency in western region was mainly contributed by massive investment, but not technological promotion, which gave support to our previous discussion when talking about figure 4. Due to the feature of extensiveness of western development map, scale efficiency will be much easier to take effect on overall efficiency than pure technical efficiency caused by technical promotion. It is dangerous if this kind of large-scale-investment-driven economic development continues, because it can cause giant energy waste.

Table 2: The total factor energy efficiency of 30 provinces and industrial sectors (2005 to 2009)

Regions	2005			2006			2007			2008			2009		
	OE	PTE	SE	OE	PTE	SE	OE	PTE	SE	OE	PTE	SE	OE	PTE	SE
Beijing	0.978	0.999	0.979	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Hebei	0.871	0.884	0.984	0.853	0.868	0.983	0.878	0.883	0.995	0.843	0.844	0.999	0.902	0.906	0.995
Shanxi	0.531	0.565	0.939	0.502	0.534	0.940	0.536	0.547	0.981	0.422	0.423	0.996	0.503	0.503	0.999
Inner Mongolia	0.666	0.708	0.941	0.643	0.685	0.938	0.747	0.749	0.998	0.848	0.850	0.997	1.000	1.000	1.000
Liaoning	0.775	0.776	0.999	0.765	0.775	0.987	0.792	0.800	0.990	0.855	0.865	0.985	0.869	0.893	0.973
Jilin	0.747	0.787	0.949	0.731	0.779	0.939	0.837	0.856	0.978	0.761	0.773	0.986	0.888	0.897	0.990
Heilongjiang	0.718	0.749	0.958	0.668	0.708	0.944	0.625	0.642	0.974	0.536	0.548	0.979	0.624	0.639	0.976
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	0.942	0.945	0.997	0.960	0.960	1.000	0.928	0.929	0.999	1.000	1.000	1.000	0.883	0.906	0.974
Anhui	0.695	0.755	0.921	0.708	0.772	0.917	0.719	0.750	0.959	0.697	0.706	0.987	0.735	0.740	0.993
Fujian	0.890	0.938	0.949	0.908	0.956	0.949	0.886	0.920	0.963	0.944	0.977	0.966	0.881	0.913	0.965
Jiangxi	0.708	0.837	0.846	0.791	0.921	0.859	0.863	0.948	0.910	1.000	1.000	1.000	0.904	0.975	0.927
Shandong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Henan	0.809	0.840	0.963	0.849	0.879	0.965	0.971	0.991	0.980	0.886	0.893	0.992	0.911	0.928	0.982
Hubei	0.631	0.642	0.982	0.618	0.632	0.977	0.648	0.653	0.992	0.640	0.651	0.984	0.664	0.674	0.985
Hunan	0.758	0.840	0.902	0.781	0.865	0.903	0.847	0.905	0.936	0.899	0.915	0.982	0.859	0.902	0.952
Guangdong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangxi	0.650	0.761	0.854	0.698	0.812	0.860	0.705	0.742	0.949	0.755	0.788	0.958	0.704	0.715	0.985
Hainan	0.644	1.000	0.644	0.716	1.000	0.716	0.975	1.000	0.975	0.880	1.000	0.880	0.918	1.000	0.918
Chongqing	0.657	0.779	0.844	0.673	0.800	0.841	0.680	0.765	0.889	0.638	0.670	0.953	0.680	0.742	0.916
Sichuan	0.630	0.653	0.965	0.639	0.665	0.960	0.679	0.689	0.986	0.663	0.665	0.996	0.720	0.722	0.998
Guizhou	0.534	0.636	0.839	0.541	0.676	0.802	0.549	0.616	0.891	0.456	0.471	0.970	0.539	0.552	0.978
Yunnan	0.679	0.728	0.932	0.647	0.701	0.923	0.658	0.681	0.965	0.615	0.619	0.993	0.643	0.646	0.996
Shaanxi	0.579	0.617	0.939	0.575	0.615	0.934	0.651	0.670	0.972	0.511	0.512	0.999	0.656	0.657	0.999
Gansu	0.631	0.731	0.863	0.609	0.712	0.855	0.668	0.709	0.943	0.525	0.542	0.968	0.615	0.628	0.979
Qinghai	0.571	0.878	0.651	0.597	0.834	0.716	0.634	0.792	0.800	0.519	0.584	0.889	0.631	0.666	0.948
Ningxia	0.546	0.887	0.616	0.542	0.886	0.612	0.562	0.772	0.728	0.464	0.511	0.907	0.557	0.578	0.964
Xinjiang	0.743	0.828	0.898	0.764	0.817	0.934	0.735	0.739	0.994	0.604	0.601	0.990	0.715	0.722	0.990

Note: (1) Arranged according to the data processing results of DEAP2.1 software, (2) overall efficiency = pure technical efficiency × scale efficiency

3.4. Scale Benefit Analysis

Table 3 contains the result of scale returns of all the provinces and municipalities in China. It can be seen from table 3 that the industrial sector of Beijing (2006 and 2009), Tianjin, Shanghai, Jiangsu, Shandong and Guangdong are at the stage of unchanged scale returns, and the comprehensive efficiency of those six provinces and municipalities achieves DEA-effectiveness. This result means that the input and output increased in the same proportion. In addition, the industrial sectors of Shanxi and Inner Mongolia province achieved unchanged scale returns in 2009. Only the industrial departments of Hebei, Liaoning, Zhejiang and Hubei showed decreasing returns to scale. Specifically, the scale return of Liaoning diminished during 2006-2009, and that of Hubei diminished during 2008-2009. The conditions of decreasing return of scale indicate that if we increase the input, the output growth rate could be less than the increase of the input ratio. In other words, the output efficiency is quite low. The rest of the industrial sectors in other provinces and municipalities are all at the stage of increasing return to scale, which means that if the industrial departments in these regions increased all the numbers of input in the same proportion, a larger proportion of return would be reached. Hence, the analysis also shows that the industrial sectors of most regions in China still fail to achieve economies of scale. Increased investment would bring about larger-scale output.

Table 3: The scale returns of 30 provinces and industrial sectors (2005 to 2009)

Region	2005	2006	2007	2008	2009
Beijing	irs	-	-	-	-
Tianjin	-	-	-	-	-
Hebei	irs	irs	irs	irs	drs
Shanxi	irs	irs	irs	irs	-
Inner Mongolia	irs	irs	irs	irs	-
Liaoning	irs	drs	drs	drs	drs
Jilin	irs	irs	irs	irs	irs
Heilongjiang	irs	irs	irs	irs	irs
Shanghai	-	-	-	-	-
Jiangsu	-	-	-	-	-
Zhejiang	irs	-	irs	-	drs
Anhui	irs	irs	irs	irs	irs
Fujian	irs	irs	irs	irs	irs
Jiangxi	irs	irs	irs	-	irs
Shandong	-	-	-	-	-
Henan	irs	irs	irs	drs	irs
Hubei	irs	irs	irs	drs	drs
Hunan	irs	irs	irs	irs	irs
Guangdong	-	-	-	-	-
Guangxi	irs	irs	irs	irs	irs
Hainan	irs	irs	irs	irs	irs
Chongqing	irs	irs	irs	irs	irs
Sichuan	irs	irs	irs	irs	irs
Guizhou	irs	irs	irs	irs	irs
Yunnan	irs	irs	irs	irs	irs
Shaanxi	irs	irs	irs	irs	irs
Gansu	irs	irs	irs	irs	irs
Qinghai	irs	irs	irs	irs	irs
Ningxia	irs	irs	irs	irs	irs
Xinjiang	irs	irs	irs	irs	irs

Note: (1) Arranged according to the data processing results of DEAP2.1 software;

(2) “irs” indicates increasing return to scale,, “-“ indicates that the scale returns have not changed, and “drs” represents diminishing return to scale.

3.5. Energy Redundancy Analysis

According to theory of operational research, the reason of DEA inefficiency is input redundancy and output insufficient. According to the framework of TFEE and the feature of DEA method, it is easy to calculate the redundancies of the input factors and redundancy rate as well. This paper only analyses the conditions of industry investment redundancy and insufficiency of provincial industrial sectors in 2009 because it is the latest statistical year we can get data from Statistical Yearbook of China. We arranged the data of provinces whose industrial departments are DEA technologically inefficient. The data shown in table 4 include both perspectives of input redundancy and output insufficiency. From table 4, actually, not only energy efficiencies but capital and labour efficiencies can be calculated by 1 minus the redundancy rate.

In this paper, the discussion of energy efficiency will be substituted with energy redundancy, in order to set alarm bells ringing. Besides, provinces and municipalities of Beijing, Tianjin, Inner Mongolia, Heilongjiang, Shanghai, Jiangsu, Shandong, Guangdong and Hainan, nine in total, are not included in table 4 because that there are no any signs of redundancies. In other words, among the nine provinces and municipalities, not only energy redundancy, but all input redundancies had reached minimum in 2009.

Moreover, it is not hard to see the advantages of Total Factor Energy Efficiency indicator compared with those of Single Factor Energy Efficiency and Energy Intensity. For example, in table 4, we can see that in the year 2009, Hebei has a higher rate of energy redundancy than that of Shanxi, which means Hebei is less energy efficient than Shanxi. However, according to table 1, Hebei is much less energy intense than Shanxi, which means Hebei is much more energy efficient than Shanxi. But when considering the realities of the two provinces, as well as their technical efficiency, the results under the framework of Total Factor Energy Efficiency is more convincing, which will be discussed later.

Table 4: The analysis of investment redundancy and output insufficient to 21 provinces industrial sectors in 2009

	Regional belonging (West, Central, East)	Energy investment redundancy (10,000 tco)	The rate of energy investment redundancy	Capital investment redundancy (billion YUAN)	The rate of capital investment redundancy	Labour force investment redundancy(ten thousand)	The rate of labour force investment redundancy	Output insufficient of gross value of industrial output (billion YUAN)
Hebei	East	8569.592	0.454	0.000	0.000	0.000	0.000	0.000
Shanxi	Central	4559.705	0.297	0.000	0.000	0.000	0.000	0.000
Liaoning	East	5922.364	0.340	0.000	0.000	0.000	0.000	0.000
Jilin	Central	302.806	0.064	0.000	0.000	0.000	0.000	0.000
Zhejiang	East	0.000	0.000	986.797	0.025	0.000	0.000	0.000
Anhui	Central	590.441	0.071	0.000	0.000	1.929	0.008	0.000
Fujian	East	0.000	0.000	0.000	0.000	48.668	0.128	0.000
Jiangxi	Central	19.358	0.004	0.000	0.000	45.194	0.258	0.000
Henan	Central	9591.969	0.423	0.000	0.000	58.344	0.130	0.000
Hubei	Central	2172.397	0.195	0.000	0.000	0.000	0.000	0.000
Hunan	Central	299.282	0.045	0.000	0.000	44.433	0.184	0.000
Guangxi	East	627.194	0.124	0.000	0.000	2.023	0.016	0.000

Chongqing	West	1113.973	0.206	0.000	0.000	18.787	0.137	0.000
Sichuan	West	2694.153	0.200	0.000	0.000	0.000	0.000	0.000
Guizhou	West	1210.473	0.239	0.000	0.000	0.000	0.000	0.000
Yunnan	West	450.798	0.086	0.000	0.000	0.000	0.000	0.000
Shaanxi	West	442.594	0.098	0.000	0.000	0.000	0.000	0.000
Gansu	West	963.602	0.240	0.000	0.000	0.000	0.000	0.000
Qinghai	West	128.359	0.099	419.790	0.166	0.000	0.000	0.000
Ningxia	West	1229.019	0.361	0.000	0.000	0.000	0.000	0.000
Xinjiang	West	0.000	0.000	454.265	0.071	0.000	0.000	0.000

Note: Input redundancy means the possible decreasing amount of input when keeping output as it were. Output insufficiency means the possible increasing amount of output when keeping inputs as they were.

It can be seen from table 4 that there are different degrees of input redundancy in the DEA technologically efficient provinces of industrial sectors. It means that there is a waste of resources, particularly energy input redundancy. The highest is Hebei, where the energy input redundancy rate reaches as high as 0.454, which means that the energy input of the industrial sector can also be reduced by 45.4% on the current basis. It is not hard to understand the result with the help of knowing the background. Hebei is famous for its steel industry, and as is well known that, steel industry is highly energy-demanding. Due to the inefficient technology investment, a large amount of energy redundancy can easily occur. Provinces of Henan, Ningxia, and Liaoning are in the second place, and their energy input redundancy rates are respectively 0.423, 0.361 and 0.340. In addition, Shanxi reached more than 0.25. Guizhou and Gansu were only a little bit less than 0.25. Central provinces as Sichuan and Chongqing were also as high as approximately 0.20.

Comparatively speaking, the status of labour input redundancy and capital investment redundancy are better. In respect of labour inputs, redundancy rate of Jiangxi province reached the highest of 0.258, which means, its industrial department labour inputs can reduce by 25.8%. The redundancy rates of Hunan, Fujian, Chongqing, Henan are respectively 0.184, 0.128, 0.137 and 0.130. Anhui and Guangxi are better, with the score of 0.008 and 0.016. The condition of capital investment redundant is better, as redundancy is only found in Qinghai, Xingjian, and Zhejiang, appearing redundancy, with rates of 0.166, 0.071 and 0.025 respectively. This also explains from another perspective that there is a serious waste of resources in industrial sectors in China. Labour input also needs to be optimised but capital investment is broadly appropriate.

In addition, the rightmost column of table 4 also shows that the output of the industrial departments of all the provinces and municipalities can achieve the basic goals with the current inputs. It means, if current inputs remain, the output cannot be better.

4. Conclusions and recommendations

In this paper, we use DEA method and the framework of total factor energy efficiency to establish an energy efficiency evaluation model, in which output is based on gross industrial output value of industrial enterprises above designated size, and inputs are measured by energy consumption, average annual balance of fixed capital and working capital, as well as the average annual number of employees. Based on these, we conducted an empirical analysis for Total Factor Energy Efficiency of industrial sectors of 30 provinces and municipalities in China.

Overall, the results of this paper show that the energy efficiency of China is experiencing developing gaps among regions. However, generally speaking, the development of eastern region and most provinces in central region is rather optimistic. Similar conclusion was also drawn by some scholars. For example, Zhang et al. (2010) [28] pointed out that, during 1980-2005, China had experienced the most rapid rise in total factor energy efficiency among 23 selected developing countries. However, the lack of energy efficiency for the rest of the provinces in central region and almost the whole western region has been dragging China from being called an energy-efficient country, which should be emphasized.

During the years of 2005-2009, areas where energy efficiency of industrial sectors has attained DEA-efficiency are mainly distributed in the coastal provinces and municipalities of the east, such as Tianjin, Shanghai, Jiangsu, Shandong, Guangdong, etc. On the other hand, the energy efficiency of industrial sectors in central and western regions is relatively low. Especially, scale efficiency of provinces in the western region is superior to pure technical efficiency, which shows that the industrial sectors of these areas are mostly at the stage of relying on the large input scale of extensive resources. Technology needs to be improved.

The industrial sectors of the east which have attained DEA-efficiency have entered the stage of constant returns to scale, which means that output increases in the same proportion as the input, and its development is saturated. However, the industrial sectors of the central and western areas which have not attained DEA-efficiency are still at the stage of increasing returns to scale, which means that increased inputs will lead to larger-scale production of output. This also reveals that, compared with the east region, industrial development in the central and western regions has more potentiality, on the premise that their energy efficiency will catch up with that of the eastern region.

Generally speaking, DEA-inefficient industrial sectors in central and western areas have the problem of redundant inputs, particularly energy inputs. Therefore, other than saying that capital, energy and labour can substitute each other [29], we find that wastage in provinces is quite serious. However, it also reflects that there is huge energy-saving potentiality in these areas. Moreover, in view of the important position of industry in China’s economy, if the central and western regions can effectively reduce redundant investment of energy in industrial sectors, the overall energy consumption of China can be reduced considerably and remarkably.

Based on the conclusions above, we proposed the following suggestions:

1) For those provinces such as Shanxi, Heilongjiang, Anhui, and Hubei in the central region, and Shaanxi, Guizhou, Sichuan, etc. in the western region, in which the pure technical efficiency of industrial sectors is lower than average, it will be necessary to focus on the role that technological improvement plays in energy efficiency. They should encourage technological innovation, as well as accelerating the development of high-tech industries and reform traditional industries with advanced technology. At the same time, the application of energy-saving technologies in industrial production needs to be promoted.

2) For the industrial sectors in Hebei, Liaoning, Zhejiang and Hubei, which have entered the stage of decreasing returns to scale, especially Liaoning, which have entered this stage since 2006, it is necessary to focus on controlling the scale of investment of resources.

Conversely, the industrial sectors in other provinces of Jilin, Heilongjiang, Anhui, Fujian, Jiangxi, Henan, Hunan, Guangxi, Hainan, and all other provinces and municipalities of western region which are still at the stage of increasing returns to scale should continue to invest, on the premise of scientific and rational arrangements of the allocation ratio of various resources. Further extensive expansion should no longer be permitted.

3) For those provinces such as Hebei, Henan, Ningxia, and Liaoning, etc., whose industrial sectors have a higher redundancy rate of the energy input, it is necessary to eliminate the backward industries which are high energy consumers or have low output. It is also important to control the use of high energy-consuming equipment strictly, and encourage the use of energy-efficient terminal products to reduce the unnecessary waste of energy.

The target of energy saving and emission reduction has been emphasized in further development by the Chinese central government. It can be seen that eliminating backward production will continue in the future to build resource-saving and environment-friendly society. To realize the plan, it is important to promote efficiency, especially energy efficiency in China. Based on the analysis of this paper, DEA inefficient industrial sectors in central and western regions should speed up innovation in changing their mode from extensiveness to intensiveness, in order to comply with the call of energy-saving and emission-reduction by government, as well as to reduce energy consumption and contribute to the overall improvement of China’s energy efficiency.

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