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Analysis on inter-provincial energy efficiency difference and energy saving potential in China under carbon emission constraint

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ABSTRACT

This paper analyzes inter-provincial energy efficiency and energy saving potential in China in 2010 based on DEA model. The research results indicate that the energy efficiency and energy saving potential in different areas are very different. The energy technology is low-efficiency in most areas in China due to massive investment redundancy, so the area differences should be fully considered when the energy saving and emission reduction targets are decomposed in provinces and the area targets should be reasonably set according to the phase of economy development level and current level of carbon emission. The research results can provide references for different economy policies set by area differences.

KEYWORDS

Energy efficiency; Carbon productivity; Energy saving potential; Carbon emission; DEA.

INTRODUCTION

To realize the target that the temperature increase is not over 2℃ in 2050, annual emission should be reduced to be less than 20 billion tons in 2050. The emission should fall much. The CO_2 emission in China is 1/4 of the overall emission in the world and the energy consumption in China is 1/5 of total energy consumption in the world. The coal output in China is 1/2 of total coal output in the world, but GDP output in China is only over 1/10 of the global GDP little, so the international trend is becoming urgent. Although some achievements are achieved in China, it is not optimistic. The energy efficiency is low and the economy development faces environmental restriction, so how to improve energy efficiency, reduce energy consumption strength and improve carbon productivity is meaningful for sustainable development of economy, resource and environment in China.

Although the traditional single-element energy efficiency indicators such as carbon emission strength and carbon productivity can be computed simply, it cannot measure efficiency of energy technology. Boyd and Pang (2000) thought that the energy cannot create any output and should be combined with other investment elements (laborer and assets) for output[1]. Improvement of energy efficiency depends on improvement of the full-element productivity, namely single-element indicator ignores replacement role among elements and changes of department structure and exaggerates energy efficiency. Hu, Wang (2006)[2] and Wei Chu (2007) assessed inter-provincial energy efficiency in China based on DEA method. Although the energy efficiency analysis based on data envelopment has non-replaceable advantage compared to the traditional single-element method, for output index, most research work only considers GDP output and "negative" output less involved. The carbon productivity variant used in this paper focuses on the energy efficiency. Higher GDP generated by per carbon emission indicates higher carbon productivity. If the "positive" output (GDP output) is effectively combined with "negative" output (carbon emission), it can offset the defect of no "negative" output at the output end. For the energy investment end, most research work only regards the total energy consumption as the input index and does not classify the energy. This paper classifies the energy investment into coal investment, oil product investment and natural gas investment in order to effectively evaluate utilization efficiency of three types of investment indicators. For energy saving potential, the research is only limited to single area or an industry. Research on different provinces in China is less, especially the energy saving conditions of different energy in different provinces are not analyzed in detail. This paper tries to discuss different conditions of different provinces and reduce carbon emission by improving efficiency.

MODEL CONSTRUCTION

Select variants and data sources

The fossil energy is the main factor which increases the carbon emission, so this paper mainly discusses the fossil energy efficiency in different provinces (cities and municipalities) in China. The investment indicators include coal investment, oil investment, natural gas investment, employee number in different areas (at the end of a year) and capital investment. Three energy investment indicators are from energy balance table of different areas in "2011 Energy Statistics Yearbook in China". The labor investment indicator is from "2011Statistics Yearbook in China". The capital investment indicator cannot be directly obtained from statistics yearbook. The computing method in this paper is the perpetual inventory method proposed by Zhang Jun (2004), which computes the capital stock in 2010 in different provinces by using invariable price in 2000[3]. The output indicator is the carbon productivity-the amount of GDP produced per unit of carbon equivalents emitted. Because this indicator cannot be directly obtained from the statistics yearbook, the CO_2 emission and the invariable GDP should be computed. With using the reference method recommended by IPCC and national energy supply data, this paper estimates CO_2 emission in different provinces of China. The invariable GDP in 2010 is computed by using deflator in different provinces of China.

DEA model

This paper constructs the energy efficiency model by using the data envelopment analysis (DEA) model. The governmental regulations and financial constraints may lead to non-optimal scale operation of the decision making unit, so Afriat (1972), Färe, Grosskopf, Logan (1983)[4], Banker, Charnes and Cooper (1984) proposed to adjust the constant returns to scale (CRS) of the DEA model in order to solve the variable returns to scale (VRS). This paper constructs the energy technology efficiency model by using C^2R model of Charnes and Cooper (1962) as well as the energy pure technology efficiency model by using BC^2 model of Banker, Charnes and Cooper (1984). Assume that n decision making units (DMU) are comparable. Each DMU has m types of "input" and s types of "output". The technology efficiency θ_{CRS} of i^{th} DMU is converted to solution of linear programming. The target function is $\min[\theta - \varepsilon(I_m S^- + I_s S^+)]$. The constraint conditions include $\sum_{j=1}^{n} X_j \lambda_j + S^- = \theta X_0$, $\sum_{j=1}^{n} Y_j \lambda_j - S^+ = Y_0$ and $\lambda_j, S^-, S^+ \geq 0$. If the constraint condition $\sum_{j=1}^{n} \lambda_j = 1$ is added to the above constraint condition, the pure technology efficiency θ_{VRS} can be obtained. The technology efficiency θ_{CRS} is decomposed to the pure technology efficiency θ_{VRS} and scale efficiency SE.

INTER-PROVINCIAL ENERGY EFFICIENCY COMPARISON AND ENERGY SAVING POTENTIAL ANALYSIS

Comparison and analysis of inter-provincial energy efficiency

2010 energy efficiency of 29 provinces in China (Tibet and Hainan are excluded due to no data) are analyzed by constructing DEA model of CRS and VRS. The analysis results are described as follows:

(1) Areas at optimal production scale points: they include Beijing, Tianjin, Shanghai, Jiangsu, Guangxi and Qinghai. $\theta_{CRS} = \theta_{VRS} = SE = 1$ and $S^- = S^+ = 0$ for these six areas, namely six areas are located at the optimal production scale points. The decision making unit (DMU) is the DEA effectively and reaches the optimal output level y_r based on the original input x_i.

(2) Areas which are located at the front production areas and do not reach the optimal scale: they include Fujian, Guizhou and Ningxia. $\theta_{VRS} = 1$ and $SE < 1$ for three areas. SE is respectively 0.911, 0.310 and 0.408. The results indicate that the energy has reached the maximum output under the existing investment in these three areas, but they can realize higher productivity via scale economy, especially the scale efficiency is very low in Guizhou and Ningxia and is far lower than the optimal production scale point. The scale efficiency is ranked as 29^{th} and 27^{th} position.

(3) Areas which are not in the front production area. They include Hebei, Shanxi, Neimenggu, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Shandong, Henan, Hubei, Hunan, Guangdong, Chongqing, Sichuan, Yunnan, Shanxi, Gansu and Sinkiang. $\theta_{VRS} < 1$ in 20 areas. The results indicate that the technology is inefficient due to inefficient pure technology and scale in 20 areas. In order to pursue the technology effectively, much energy saving potentials can be mined in these areas without output decrease and investment increase.

On the whole, the mean technology efficiency is 0.528, the mean pure technology efficiency is 0.65, and mean scale efficiency is 0.812 in China in 2010, so it indicates that inefficient technology is caused by inefficient pure technology and scale. The inefficient pure technology is the main cause. 20 areas with $\theta_{VRS} < 1$ can quickly improve energy efficiency by changing the pure technology efficiency.

Analysis on inter-provincial energy saving potential

The target investment and energy saving potential can be computed based on the original energy investment by using the measurement results of the energy efficiency. The energy saving potential includes the energy saving efficiency caused by inefficient scale and energy saving potential caused by inefficient pure technology.

(1) Low energy efficiency and huge energy saving potential: the energy efficiency is 0.528 in China in 2010. it indicates that the energy efficiency is very low in China, which is mainly caused by inefficient pure technology and scale, namely massive investment redundancy in production and non-optimal point of production scale. The energy efficiency can be improved by reducing investment redundancy and improving production scale, so it can reduce relative carbon emission and improve carbon productivity. Improvement of energy efficiency can save massive energy investment. From the whole conditions in China, the improved energy efficiency can reduce about 2.5 billion ton coal, about 250million ton oil and about 51.6 billion m^3 natural gas. Original investment of three kinds of energy can reduce by 74%, 62% and 56%.

(2) Big differences of energy saving potential for different kinds of energy in different areas: for the coal investment, the maximum coal saving potential is 319.19 million ton in Shandong, followed by 267.81 million ton in Shanxi, 240.7 million ton in Hebei and 233.76 million ton in Neimenggu. The coal saving potential is over 90% of current investment in these areas. The sum of the coal saving potential in four areas is over 40% of total saved coals in China. Besides 6 areas at the optimal production scale points, the areas with less energy saving potential includes Chongqing, Fujian and Gansu where the energy saving potential is under 50% of the current investment. The sum of energy saving potential in three areas is only 3% of the total energy saving potential in China. For oil investment, the oil saving potential is maximum and reaches 42.7 million ton in Guangdong, followed by 35.85 million ton in Shandong and 22.93 ton in Liaoning. The oil saving potential in three areas is over 80% of the current investment and the sum of energy saving potential in three areas is over 40% of the total saved oil in China. Besides six areas with $\theta_{CRS}=1$, for Chongqing, Gansu, Anhui and Fujian with less oil saving potential, except Gansu, the oil saving potentials are under 45% of current investment in other areas. The sum of the oil saving potential in four areas is only about 4% of the total oil saving potential in China. For natural gas investment, the natural gas energy saving potential is maximum and reaches 9.62 billion m^3 in Sichuan, followed by 7.53 billion m^3 in Guangdong, 5.2 billion m^3 in Sinkiang and 4.4 billion m^3 in Jiangsu. The natural gas energy saving potential is over 80% of current investment in four areas. The sum of the natural gas potential in four areas is over 50% of the total natural gas energy saving in China. Besides six areas with $\theta_{CRS}=1$, for Guizhou, Gansu, Hunan, Anhui and Jilin with less natural gas energy saving potential, except Guizhou and Hunan, the natural gas energy saving potentials are under 50% of current investment in other areas. The sum of the natural gas saving potential in five areas is only about 4% of the total natural gas saving potential in China.

(3) 20 areas with $\theta_{VRS}<1$ induce energy saving potential due to inefficient technology. From the view of whole country, 20 areas do not operate at the front of the production. Inefficient pure technology can lead to low energy use efficiency, namely most energy will be wasted in production, which leads to massive redundant investment. For 20 areas with $\theta_{VRS}<1$ which are not located at the front of the production, when the output does not increase in these areas, the energy saving potential caused by inefficient pure technology can reduce about 2 billion coal investment, 230 million oil investment and 50 billion m^3 natural gas investment. The input index can be adjusted to quickly reach the front of the production quickly. For three areas which do not reach the optimal production scale points and twenty areas which are not located at the front of the production, the energy saving potential caused by inefficient scale can reduce 470 million ton coal investment, 20 million ton oil investment and 1.7 billion m^3 natural gas investment. It indicates that the important reason inducing energy saving potential in China is inefficient pure technology. The energy saving potential caused by inefficient pure technology is 81% for coals, 92% for oil, and 97% for natural gas in total energy saving potential.

(4) Three areas with $\theta_{VRS}=1$ & $SE<1$ indicate energy saving potential due to inefficient scale, which include Fujian, Guizhou and Ningxia. Although three areas are located at the front of production,

the scale is inefficient. It indicates to improve energy efficiency by adjusting the scale. The scale efficiency in relatively developed Fujian is higher and is 0.911, so it indicates that the scale can be adjusted little to approach to the optimal scale point in Fujian. After scale adjustment, the coal investment can reduce 20%, the oil investment can reduce 33%, and the natural gas investment can reduce 8%. For the relatively underdeveloped Guizhou and Ningxia, the scale efficiency is 0.31 and 0.408. Our research indicates that the coal investment can reduce about 90%, the oil investment can reduce over 65%, and the natural gas investment can reduce over 60% via scale adjustment. Although Fujian, Guizhou and Ningxia are located at the front of production, their scale efficiencies are very different. The government is recommended to mainly consider the production scale in Guizhou and Ningxia in policy making, their production scale should be adjusted for a long period to approach the production scale point and realize their maximum energy saving potential.

(5) The production scale should be expanded in the areas where the inefficient scale induces negative energy. Except six areas at the front of production, the energy saving potential of most other areas caused by inefficient pure technology and scale are positive. It indicates redundant investment and too large production scale, but the energy saving potentials caused by inefficient scale are negative in a small number of areas, so it indicates that the investment should be added and the scale should be expanded to reach optimal scale in these areas. To realize efficient pure technology, investment should reduce. The energy saving potentials caused by inefficient technology is positive. So the reduced investment caused by inefficient pure technology should be over the increased investment caused by the inefficient scale. On the whole, the energy can be further saved in this area. For different kinds of energy investment, the conditions are different. The coal saving potentials is negative in Jiangsu, Zhejiang and Guangdong due to inefficient scale. The oil saving potentials is negative in Liaoning, Shandong, Hubei and Sinkiang due to inefficient scale. The natural gas saving potentials is negative in Chongqing and Sichuan due to inefficient scale. After the above areas reach their production front, they can approach to the optimal production scale point by expanding the scale.

In a world, from the view of the energy type, the energy saving potential of three kinds of energy is very huge. The energy saving potential reaches over 50% of the original investment in 2010 and improved energy efficiency can reduce about 50% of carbon emission. The energy saving potential is very different in different areas and different energy types. E.g. the coal and oil saving potentials is higher in Shandong. When the government makes the energy saving and emission reduction policies, it should first control the coal and oil investment to improve the energy efficiency. Although total energy saving potentials of three kinds of energy cannot reach 1% of total energy saving in China in the areas with smaller energy saving potentials such as Gansu, the energy can be further saved for three kinds of energy. The energy saving potentials of the coal and oil are 47% and 57% of the original investment. When the government makes the energy saving policy, it should not ignore own problems due to smaller energy saving potentials. The energy efficiency is still low in the areas with less energy saving potentials, so massive carbon emissions can be reduced by improving energy efficiency. The inefficient pure technology and inefficiency scale lead to low energy efficiency in China. Inefficient pure technology is the main factor. It indicates that the utilization rate is not high and the investment is very redundant in present phase.

RECOMMENDATIONS

First, the key for energy saving is to reduce resource waste in most areas in present phase. Redundant investment is the main cause to lead to low utilization efficiency of different kinds of energy in China. The energy utilization rate is not high in 20 areas which are not at the front of production ($\theta_{VRS} < 1$), including Hebei, Shanxi, Neimenggu, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Shandong, Henan, Hubei, Hunan, Guangdong, Chongqing, Sichuan, Yunnan, Shanxi, Gansu and Sinkiang. Improving pure technology efficiency and reducing redundant investment can reduce 60% of the coal investment, 57% of oil investment and 54% of natural gas investment in above 20 areas.

Secondly, different areas have different energy saving targets. The development levels are different in different areas, so the carbon emissions are very different and the energy investment structures are also different. The uniform energy saving target is not necessary in different areas. Their energy saving targets can be set by two phases by referring to the research results in this paper. The energy saving potential caused by pure technology in different areas should be set according to the computing results in this paper to reduce the redundant investment and approach to production front on the phase I. The energy saving potentials caused by inefficient scale should be set to approach to optimal production scale point via adjustment of production scale on the phase II. After the phase target is set in different areas, the first task is to urge different areas to approach to production front, reduce massive redundant investment, reduce waste to most extent, and improve carbon productivity under constant output in the present phase.

Thirdly, the areas with huge energy saving potential should be monitored as the key. The energy saving potentials is very different in different energy types and areas. The central government should monitor the areas with higher energy saving potential in real time. E.g. for the coal, the key is to improve use efficiency in Shandong, Shanxi, Hebei and Neimenggu. For the oil, the key is to improve the utilization efficiency in Guangdong, Shandong and Liaoning. For the natural gas, the key is to improve energy saving potentials in Sichuan, Guangdong, Sinkiang and Jiangsu. If the above areas can be effectively improved, the total energy saving potentials can reach over 50% of the total energy saving potentials in China.

Fourthly, the energy efficiency change should be monitored dynamically. The data envelopment analysis DEA measures relative rank of the decision making units. If the input and output indicator of an area changes, it may affect the rank of all areas. It is recommended to dynamically monitor energy efficiency change in different areas to adjust two-phase energy saving target in different areas.

In a word, the energy efficiency is very low on current phase in China. The energy should be saved by improving energy efficiency. Now the main cause for low energy efficiency in China is inefficient pure technology, namely massive redundant investment. The first task is to eliminate redundancy and reduce waste. The provincial governments can make reasonable emission reduction plans according to own targets by setting two-phase target. Only when the provincial governments effectively complete energy saving and emission reduction task, it can ensure smooth energy saving and emission reduction in China. The governments should collaborate in deployment to guide improvement of energy efficiency. The carbon emission can be quickly reduced by improving energy efficiency in a short period in China. To realize responsible carbon emission promise as a large country, we should not wait and should take due actions.

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