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Ecological total-factor energy efficiency of China's energy intensive industries

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ABSTRACT

This paper uses a meta-frontier slack-based DEA model to measure the ecological total-factor energy efficiency as well as the energy conservation potential of China's four energy intensive subsectors. We incorporate both desirable and undesirable output together in the period, 2000–2013. The conclusions are: firstly, under the meta-frontier, the four subsectors of energy intensive industries have low average level of ecological total-factor energy efficiencies. They are 0.137, 0.212, 0.238, and 0.307 in the non-metallic mineral products manufacturing industry, raw chemical materials and chemical products manufacturing industry, smelting and pressing of ferrous metals industry, and smelting and pressing of non-ferrous metals industry, respectively. Secondly, the ecological energy efficiency in East China is the highest among three regions. Central China and West China are behind, but they are extremely close to each other. Thirdly, East China almost has no technology gap pertaining to energy efficiency, while Central China and West China almost have the same gap. Finally, Sichuan is considered to be the best province in West China under group frontier due to its perform in the three energy intensive subsectors. For Central and East China, no province has higher ecological energy efficiency in more than two energy intensive subsectors.

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1. Introduction

Energy is an indispensable factor in today's industrial production. However, the excessive exploitation of energy and other natural resources have apparently rendered energy shortage as a serious problem that needs to be looked at. How to utilize energy more efficiently has now been the focus of many researchers. In addressing this issue, the first thing is to improve energy efficiency, since supply of energy and its efficiency in the long run can determine a country's economy and sustainable development.

It is worth to state that China has witnessed rapid economic growth in recent years. GDP increased from 364.52 billion yuan in 1978 to 2180.65 billion yuan in 2013 (1978 constant price). Accompanying this high speed of development is a huge consumption of energy. In 1990, China consumed 0.98 billion tons of standard coal equivalent (SCE). This figure became 37.5 billion in 2013 which was thirty-eight times more than the former one. Amidst these developments, environmental problems have become serious and alarming. In particular, the haze weather since 2013 has caused a public outcry leading the central government to take several steps to curb the issue. In January 2014, the Ministry of Industry and Information Technology issued "*The Guidance on Energy Saving and Emission Reduction in China's Petrochemical and Chemical Industry*", stating that energy consumption per unit of industrial added value in petrochemical and chemical industries should decrease by 18% in 2017, compared with that of the year 2012. On May 15th 2014, the State Council set the goal to decrease energy consumption per unit of GDP by 3.9% at the end of 2015, compared with that of the year 2014. These policy documents show that Chinese central government has been aware of the seriousness of environmental pollution and energy shortage.

With the energy consumption in China surpassing that of America for the first time ever in 2010, China has since then become the world's largest energy consumer. Throughout Chinese history, more than two thirds[1] of the total energy consumption is consumed by the industrial sector. Within the industrial sector, *China Economic and Social Development Statistics Bulletin 2010* listed six largest energy-consuming industries. They are processing of

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[1] The figures are 70.1% in 2000, 71.9% in 2005, 72.5% in 2010 and 69.8% in 2013.

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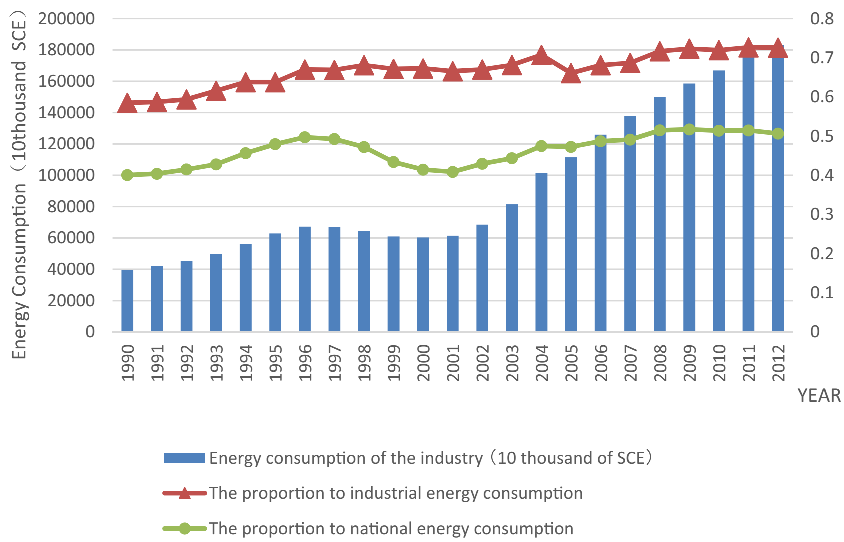

Graph 1. Energy consumption and its proportion to the total industiral and national energy consumption of China's six energy intensive industries.

petroleum, coking and processing of nuclear fuel industry, raw chemical materials and chemical products manufacturing industry, non-metallic mineral products manufacturing industry (building materials industry), smelting and pressing of ferrous metals industry (iron and steel industry), smelting and pressing of non-ferrous metals industry, production and supply of electric and heat power industry. These six industries together consume about half of total energy consumption in China (See Graph 1). Since these industries supply energy and materials, economy cannot develop without them. The clean development for China presently lies in three parts: economic development, resource saving, and environment protection. It is however imperative to know that for China, the most important thing is economic development; this is because China is still the largest developing country in the world, with a large number of poor people. In the next few years, China will enter the late stage of industrialization and urbanization, and these two key processes still need sufficient energy supply (electricity, kerosene, gasoline, diesel, etc.) and material supply (cement, glasses, iron and steel, cooper, aluminum, fertilizers, etc.), which are the products of energy intensive industries.

In consideration of the indispensable role in economic development and huge energy consumption of energy intensive industries, as well as energy shortage and environment pollution, the best way is to improve the energy efficiency. However, existing researches on energy efficiency mainly focus on energy itself. Carbon dioxide will inevitably be emitted when energy is consumed. That is, we have to consider energy consumption and carbon dioxide emissions simultaneously to measure energy efficiency; this is called ecological energy efficiency. In other words, the calculation of energy efficiency previously only allows for the desirable output of the economic system, such as GDP and so on. This energy efficiency is called "traditional energy efficiency". But for ecological energy efficiency, both the desirable outputs and the undesirable outputs such as carbon dioxide are considered (Li and Hu, 2012). Ecological energy efficiency is of more significance since it implies the concept of sustainability. In the calculation of ecological energy efficiency for energy intensive industries in this paper, five variables are used. They are three inputs: energy, labor and capital; two outputs: total industrial value and carbon dioxide emissions. The ratio of target energy input, obtained from the SBM model considering both desirable output and undesirable output, to the actual energy input is defined as ecological energy efficiency (Li and Hu, 2012; Zhang et al., 2015). This will be explained in detail in Section 3.1.1. Finally, we calculate the energy conservation potential taking regional discrepancy into account based on the ecological energy efficiency. As we know, there are few existing researches on the ecological energy efficiency of China's energy intensive industries until now (Graph 1).

The rest of this paper is organized as follows: the second part depicts a review of literature on energy efficiency and the mainly adopted methods used in calculating energy efficiency. In the third part, we state our data, data processing, data resources and the method adopted in this paper. In the fourth part, we show our results and related discussion. Finally, we conclude this paper and put forward some policy recommendations.

2. Literature review

There is numerous literature on energy efficiency of which they can be divided into two categories: the first is single-factor energy efficiency and the second is total-factor energy efficiency (Yang and Shi, 2008; Fei and Lin, 2016). The former usually takes the ratio of energy to GDP to measure energy efficiency; however, other factors, such as capital and labor are not considered. Hence, more researches like Shi (2006), Lin and Du (2013) begin to measure total factor energy efficiency. The data envelopment analysis (DEA) is the most widely used one in energy efficiency calculation. Hu and Wang (2006) first used DEA to calculate China's total-factor energy efficiency. But they did not consider the unexpected outputs. The following researches made up this defect: Zhou and Ang (2008) and Yeh et al. (2010) took into account desirable outputs together with undesirable outputs in their models; Fukuyama and Weber (2009) pointed out that these papers neglected the slack variables so they may overestimate energy efficiency; Tone (2001) combined a slack-based efficiency measure (SBM) in DEA to solve this problem. Using the same method, much literature, for example, Choi et al. (2012), Li and Hu (2012), Song et al. (2013), Bi et al. (2014), Zhang and Choi (2013) arose.

China is a country with a large regional difference, and industries in different regions must have different technology levels which should be taken into consideration in the research. The meta-frontier approach provides us with such a method to do this. In this paper, we adopt the method put forward by Zhang et al. (2015) to calculate ecological energy efficiency in China's energy intensive sectors. The new method considers the regional heterogeneities,

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