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Efficiency evaluation of regional energy saving and emission reduction in China: A modified slacks-based measure approach

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ABSTRACT

China's economic reform and opening policy has resulted in China's rapid growth, especially in terms of economy. Unfortunately, the growth has brought about huge consumption of energy and increasing emission of environmental pollution. Little research has been done which pays close attention to the efficiency evaluation of regional energy saving and emission reduction even though such evaluation is considered a crucial method in the fight to save resources and protect the environment. Aiming at evaluating the efficiency of regional energy saving and emission reduction of China, we firstly construct an evaluation index system for input and output selection. Then a modified slacks-based measure model is applied to measure the performance of energy saving and emission reduction. An empirical study is done on 30 of mainland China's provincial-level regions. The results show that the energy saving and emission reduction efficiencies of the regions in China are generally at a low level. More precisely, China's regional regions performed really badly in energy saving although their emissions results are passable, barely. To resolve this problem, several policy recommendations are proposed to improve the efficiency of regional energy saving and emission reduction of China.

1. Introduction

Through the past 30 years of China's reform and opening-up policies, the nation's economic construction has seen great achievements (Wu et al., 2015d). In 2010, China's annual GDP overtook Japan for the first time, and China became the world's second-largest economy (Bi et al., 2012; Wu et al., 2015b; Zhu et al., 2016). The Chinese living standard has had an unprecedented increase on the basis of great economic success, but at the expense of also increasing the cost to resources and the environment (Chen and Jia, 2016; Song et al., 2015a). The contradiction between economic development on the one hand, and resources and the environment on the other has become increasingly prominent. If the Chinese government cannot coordinate the relationship between the environment and economy, and cannot optimize economic growth structure in a timely way, then it may be difficult to achieve rapid and sound economic growth while using the existing amount of resources and maintaining the environment.

In Western countries, economic development started earlier, and after more than a century of development, they have accumulated much experience in addressing the ecological environment and natural resources issues. They have achieved the transformation of economic development mode from the extensive development of industrial economy to a circular economy. Take the United States, Germany, and the Netherlands for example. Their recycling rates for scrap steel were 67%, 78%, and 80% respectively in 2000 (Lee et al., 2004). Compared with the developed countries, China's industrial development started late, but has been developing rapidly since the reform and opening up by sacrificing the environment and using natural resources heavily. In the same period, the recycling rate for scrap steel in China was only 30%, far lower than that in Western countries. Developed countries have fought environmental pollution for more than a century, whereas China has faced up to increasingly serious energy and environmental problems only in the past 30 years. In December 1997, the Kyoto protocol was adopted in order to limit greenhouse gas emissions to curb global warming, and China officially signed the protocol in May 1998.

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Faced with the pressure from limited domestic resources and serious environmental concerns, as well as from the international community, China put forward the concept of "energy conservation and emissions reduction" for the first time in the eleventh five-year plan (2006–2010) as a move to save energy and reduce environment harmful emissions. In the plan the Chinese government solemnly pledged that during this five-year plan, unit GDP energy consumption should be reduced by about 20 percent, and major pollutants should be reduced by 10 percent (Wu et al., 2015a). Although the Chinese energy conservation work achieved some worthy results during the 11th Five-Year period, there were still many problems in the implementation process. There are huge differences between Chinese regions and autonomous regions in terms of economic and social development. The differences in proportion of heavy industry and other such industry structure differences are significant among these regions. Currently there is not a good solution to effectively share energy saving tasks, break down the overall target into goals for the various regions, and adjust the quotas flexibly according to the levels of completion of energy-saving and emission reduction targets.

Data envelopment analysis (DEA), a nonparametric method, was proposed by Charnes et al. (1978) to evaluate the relative efficiency of decision making units (DMUs) with multiple inputs and outputs. There is no need to determine the form of the production function with the DEA method, and also no need to determine the weight of inputs or outputs, which provides great convenience for efficiency evaluation (Cook and Seiford, 2009; Cooper et al., 2007; Wu et al., 2015c). For ineffective DMUs, DEA can provide corresponding improvement suggestions according to the projection theorem. Therefore, this method has been widely used in the area of efficiency evaluation and management science.

However, reviewing previous research we find that there are some shortcomings, which can be shown as follows including how we solve these issues. (i) Few previous studies have considered the efficiency evaluation of the processes of energy saving and emission reduction. Published studies are mostly based on the evaluation of efficiency of energy or environment usage, rather that the efficiency of steps taken to improve usage. (ii) About the inputs and outputs selection, previous studies did not show how to choose them and even did not demonstrate the rationality. In this paper, we firstly give some major principles in choosing the index. Then, expert consultation method is used to select the evaluation index. In other words, the evaluation index including inputs and outputs is determined through comprehensive analysis. (iii) Considering the lack of studies on Chinese regional energy saving and emission reduction, it is important to build a scientific and feasible abatement efficiency evaluation system to guide the regions' energy saving and environmental protection behavior, evaluate the efficiency of energy saving and emission reduction, understand the problems, and make appropriate adjustments. To objectively evaluate the efficiency of energy saving and emission reduction in China, this paper systematically establishes an energy saving evaluation system based on the input-output perspective, and does a comprehensive efficiency evaluation of energy saving and emission reduction efficiency by using the DEA method. In addition, we also show some theoretical implications and managerial implications according to our empirical results.

The structure of this paper is as follows. Section 2 reviews the relevant literature. In Section 3, we show our indicator system for selection of inputs and outputs. Section 4 presents the methodology of our study. In Section 5, an application is analyzed, and finally conclusions are shown in Section 6.

2. Literature review

Considering the problems accompanying the rapid economic development in China, widespread attention has focused on energy saving and emissions reduction. It is significant to have a comprehensive understanding of the current research status and learn from successful experience to carry out such saving and reduction work in China. Research on policies for energy conservation and emission reduction can be classified into two categories.

One category of policies uses the tax perspective, which says the effect of energy conservation and emission reduction can be adjusted by price tools like tax laws. Among these research works, Moore (1988) described the concept of environmental price and procedural law so as to promote the transformation from external aptitude to internalization. Considering tax mechanisms affecting wastewater emissions, Bergstrom et al. (2002) thought that the tax effect can protect groundwater, especially in the financing process.

The other category of policies looks at the issue from the regulatory perspective, which says the government can use laws and regulations to guide energy saving and emissions reduction. In this category, Worrell and Price (2001) pointed out that the government can conduct the work of energy saving and emission reduction by regulations and policies in developed countries. Brown (2001) proposed policy indicators on energy conservation and emission reduction, and they thought products should not be allowed to enter the market if their indicators are less than certain policy indicators.

Many studies on energy conservation and emission reduction have been discussed and published in terms of energy systems and environmental systems. Kraft and Kraft (1978) firstly used the Granger causality test on the relationship between energy consumption and GNP, and hypothesized a unidirectional causal relationship between them. Fukasaku (1995) studied comprehensive government incentive policies on renewable energy usage in developing countries from 1995 to 2004. Liu et al. (2002) did a qualitative and quantitative analysis of the energy saving effect during China's eleventh five-year plan (2006–2010) and found that the energy efficiency is an important factor in energy saving. Neves and Leal (2010) proposed a new framework of local energy sustainability indicators, which is used both as an assessment and as an action-planning tool. Dubey et al. (2015) developed mixed methods to study the green supply chain management. Dubey and Gunasekaran (2015) designed a structure questionnaire for sustainable transportation based on synthesis of exhaustive review of extant literature. Shibin et al. (2016) developed flexible operation management practices in India to analyze energy sustainability.

In addition, there are some studies concerned with direct efficiency evaluation of energy or the environment. For example, in terms of energy efficiency, Hu and Wang (2006) utilized the traditional Charnes-Cooper-Rhodes (CCR) model to analyze the energy efficiencies of 29 administrative regions in China during the period 1995–2002. Zhang et al. (2011) used a total-factor framework to investigate energy efficiency in 23 developing countries during the period 1980–2005. Shi et al. (2010) proposed DEA models to measure Chinese industrial energy efficiency and investigated the maximum energy-saving potential in 28 administrative regions in China. Based on both static and dynamic data, Wu (2012) evaluated China's industrial energy efficiency. In terms of environmental efficiency, Dyckhoff and Allen (2001) used a DEA model to evaluate and analyze ecological environmental performance. Zhang et al. (2008) proposed a DEA model to measure the Chinese industrial environmental efficiency. Zhou et al. (2008) also utilized a DEA approach to evaluate the carbon emission performance of eight world regions. Song and Wang (2014) analyzed China's regional environmental efficiency by applying a DEA