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China's regional ecological energy efficiency and energy saving and pollution abatement potentials: An empirical analysis using epsilon-based measure model

Li Yang, Ke-Liang Wang*, Ji-Chao Geng

School of Economics and Management, Anhui University of Science and Technology, Huainan, Anhui 232001, China

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ABSTRACT

this paper applies an epsilon-based measure DEA approach to evaluate the regional ecological energy efficiency for 30 regions in China and its three major areas for the period 2007–2015. Based on this, the temporal and spatial disparities of China's regional ecological energy efficiency are investigated. To explore the sources of China's regional ecological energy inefficiency, the overall ecological energy inefficiency is decomposed into several input-specific inefficiencies. And then, the energy saving and pollution abatement potentials of each Chinese region is calculated using the differences between the target values and the actual values of energy consumption and pollution emissions. The empirical results show that China's ecological energy efficiency is relatively low and regional differences are significant for the period 2007–2015. It can be demonstrated that the inefficiency to abate pollution is the main contributor to China's regional ecological energy inefficiency. By calculating the potentials of energy saving and pollution abatement, it can be found that the east area has the lowest potential, followed by the central area, with the west area having the highest potential.

1. Introduction

In the past few decades, energy consumption and its adverse impact on the environment have increasingly attracted more and more attention in the international community due to the challenges including resource exhaustion, energy supply security, environmental protection and climate change.

Among the developing countries, China faces the greatest set of challenges related to energy production and consumption (Andrews-Speed, 2009). In 2010, China overtook Japan for the first time and became the world's second largest economy entity (Bi et al., 2015; Wu et al., 2015). However, a long-term extensive economic growth pattern has given rise to a series of problems such as resource exhaustion and environmental pollution. According to the prediction of the National Energy Administration, by 2030, China's total primary energy consumption will exceed 7 billion tons (Wang et al., 2013). Aside from the crisis in energy usage, another problem receiving a lot of attention in China is the increase in environmental pollutions resulting from massive fossil fuel consumption. In 2014, about 70% (NBSC, 2016) of China's total energy production was from burning coal, while only 8% of the energy was from non-fossil fuel. At present, China is also the largest Green House Gas emitter in the world, and one of the most polluted countries (Hu and Lee, 2008; Yeh et al., 2010; Choi et al., 2012). Furthermore, China is going through a period of rapid industrialization and urbanization, which is intensifying the pressure of environment pollution and energy consumption (Geng et al., 2018). To construct a resource-saving and environmentally friendly society, the Chinese government, for the first time in its 11th Five-year Plan, has developed an explicit target for energy conservation and emissions reduction. They have announced a goal for 16% reduction of energy consumption per ten thousand GDP in the 12th Five-year Plan (Wang et al., 2012). To achieve this goal of improving energy consumption and pursuing further economic development, China has started taking steps towards immediate reduction of emission of environmental pollutants and greenhouse gases and improving energy efficiency and environmental performance (Wei et al., 2011).

Improvement of energy efficiency is extremely important for sustainable development. A large number of scholars have studied the influence of energy efficiency on different economic entities. The traditional single-factor index used to estimate energy

* Corresponding author.
E-mail address: klwang@163.com (K.-L. Wang).

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efficiency is energy intensity, defined as the total energy consumption relative to the GDP (Ang, 1994; Patterson, 1996). Energy intensity embodies a large number of structural factors, such as industrial and energy consumption structures (Ang, 2006; Ramanathan, 2002). Besides, energy intensity considers energy consumption as a single input into the production process, neglecting the substitution between energy input and other non-energy input factors (e.g., capital stock, labor force). As a result, energy intensity may overstate energy efficiency. Therefore, Hu and Wang (2006) proposed the total-factor energy efficiency index (TFEE) based on data envelopment analysis (DEA) approach, which highlighted other inputs together with energy input should be considered in energy efficiency measurement. TFEE is calculated by the target energy input and actual energy input under production frontier, effectively correcting the defects of the traditional single-factor energy efficiency index, and has become a mainstream method for researching energy efficiency and environmental performance all over the world for the past few years. Hu and Lee (2008) employed DEA approach to measure energy utility efficiency in China during 2000–2003 and found that the east area owned the highest energy utility efficiency. Mukherjee (2008) applied DEA approach to examine the energy use efficiency of seven US manufacturing sectors during the period of 1970–2001. Honma and Hu (2009) evaluated the energy productivity changes of regions in Japan using total-fator frameworks based on data envelopment analysis. Shi et al. (2010) used DEA approach to evaluate China's industrial energy efficiency and measure the energy saving potential for each China's province. Zhang et al. (2011) investigated energy efficiency for 23 developing countries based on DEA approach and found only 7 countries with little change in energy efficiency for 1980–2005. Rao et al. (2012) analyzed energy efficiency of 30 regions in China mainland for the period of 2000–2009 based on the slacks-based measure approach of data envelopment analysis and investigated the energy consumption slacks and energy saving potential of each region in China at each year. Song et al. (2013a,b) proposed super-SBM model to measure energy efficiency of BRICS and investigate their present status and development trend. Wang et al. (2014) utilized the global data envelopment analysis to analyze China's regional energy efficiency from both static and dynamic perspectives based on China's provincial panel data for the period of 2001–2010. Guo et al. (2016) applied a modified slacks-based measure model measure the performance of energy saving and emission reduction for mainland China's provincial-level regions.

It is well-known that economic output (e.g. GDP) is desirable output in the course of energy consumption. However, energy consumption also produces undesirable outputs, such as sulfur dioxide (SO_2) and nitrogen oxide (NO_X) emissions, etc., which leads to environmental deterioration. As such, some scholars have regarded environmental pollution as an undesirable output in estimating energy efficiency (Zhou and Ang, 2008; Zhou et al., 2008; Mandal, 2010; Wang et al., 2012; Wu et al., 2015). Yeh et al. (2010) compared the energy efficiency difference with SO_2 and CO_2 emissions as undesirable outputs between China's mainland's 30 regions and Taiwan from 2002 to 2007. Wang et al. (2012) used several models based on data envelopment analysis to evaluate energy and emission efficiency of China's 30 regions incorporating desirable and undesirable outputs. Yang and Wang (2013) estimated environmental efficiency of energy utilization and measured the environmental regulation cost for China's 30 regions considering CO_2 as undesirable output. Zhang and Choi (2013) used non-oriented slacks-based measure model to evaluate energy efficiency by incorporating three undesirable outputs-carbon dioxide, sulfur dioxide, and Chemical Oxygen Demand in China's regional economies during 2001–2010. Song et al. (2013a,b) used the bootstrap-DEA model to explore the quantitative relationship between the carbon emissions and energy efficiency and investigated the relationship among energy efficiency, energy consumption structure and environmental quality. Hang et al. (2015) treated SO_2 as undesirable output and investigated sources of energy inefficiency simultaneously considering the heterogeneity of production technology for China's 209 cities. Zhang et al. (2015) proposed a meta-frontier slack-based efficiency measure approach to measure ecological total-factor energy efficiency considering the group heterogeneities of regions and the undesirable outputs related to energy consumption simultaneously for China's provinces during the period 2001–2010. Wang and Feng (2015) used a developed slacks-based measure to evaluate the performance of energy, environmental, and economic ('E3') efficiency and the sources of E3 productivity growth for China's each regions from 2002 to 2011. Li and Lin (2015) applied a meta-frontier approach and developed directional distance function with carbon dioxide emissions as undesirable output to measure the energy efficiency performance in China's 30 provinces during the period of 1997–2011.

To sum up, different studies have evaluated efficiency at micro or macro levels based on radial or non-radial data envelopment analysis models, such as the CCR, the BCC and the SBM models. However, both radial and non-radial analysis models have inherent shortcomings. The main shortcoming of the radial model is that it neglects the non-radial slacks. This can lead to a biased measure while evaluating the efficiency of the DMUs. Furthermore, radial models require input or output variables to change proportionally, which cannot cope with such cases properly (Tone and Tsutsui, 2010). In contrast, non-radial models to directly capture the non-radial slacks that not considered in the radial models may loss the original proportionality that is inappropriate for efficiency analysis. Hence, it is necessary to compile the radial model and non-radial model into a composite model to measure efficiency in a more reasonable way. To address this, Tone and Tsutsui (2010) proposed the "epsilon-based measure (EBM)" model by combing both the radial and non-radial features into a unified framework. The EBM model effectively addressed the shortcomings of the radial and non-radial models has been successfully used for energy efficiency measurement in recent years. For example, Qin et al. (2017) integrated the EBM model with the global Malmquist-Luenberger productivity index to estimate the static and dynamic energy efficiency for 12 coastal provinces of China for the period 2000–2012. Cui and Li (2017) used the dynamic EBM models to evaluate the dynamic efficiencies of 19 airlines from 2009 to 2014. Xu and Cui (2017) introduced an integrated approach with network epsilon-based and network slacks-based measures to evaluate the airline energy efficiency. Therefore, considering the advantages of the EBM model in measuring the efficiency, this paper makes the first attempt at introducing the EBM model to calculate the ecological energy efficiency, which is conducive to obtaining a more accurate result of efficiency evaluation. It may provide a new research strategy for the study of this kind of problem. Specifically, this paper uses the input-oriented EBM model with a joint production framework of economic output, energy consumption and environmental pollution to evaluate the total factor ecological energy efficiency for 30 provinces in China between 2006 and 2015. This paper also investigates the changing trends and regional differences of these 30 provinces. The overall energy inefficiency is decomposed into several input-specific factors to identify the sources of China's ecological energy inefficiency. Finally, the energy saving and pollution abatement potentials of each Chinese region are estimated by calculating the difference between the actual and the targeted values of energy consumption and pollution emissions. The proposed policy suggestions are helpful for policy-makers in different regions to address the emphasis or priority of