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Regional differences and pattern classifications in the efficiency of coal consumption in China

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ABSTRACT

This research, which was based on the data envelopment analysis (DEA) model and the Malmquist index, studies the difference for the period 2000–2012 in the efficiency of coal consumption and pattern classification in China's 30 provinces as well as the major eastern, central, western, and northeastern areas. Firstly, the static analysis results showed that the technical efficiency (TE) of China's coal consumption was 0.710, the pure technical efficiency (PTE) was 0.803, and the scale efficiency (SE) was 0.889. The PTE, which needs to be further improved, was the main factor affecting the TE. The ranking for the TE of the four regions was the eastern region, northeast region, central region, and in last place the western region. The dynamic analysis results showed that the change index of China's total-factor of coal consumption efficiency was 0.899 and the average annual growth rate was −10.1%. Efficiency change (EC) and technical change (TC) of the average annual growth rate were −4.7% and −5.7%, respectively. The interaction of EC and TC resulted in a negative growth of the total-factor of coal consumption efficiency. The difference in the total-factor of the coal consumption efficiency among the four regions expanded each year. Secondly, by measuring the TE of China's coal consumption excluding environmental factors and then including environmental factors we were able to classify the coal consumption efficiency model of 30 provinces in China. Finally, we provided some policy suggestions aimed at improving the efficiency of China's coal consumption.

1. Introduction

Coal is the main energy source in China and the material base for its economic development. Effective coal energy use is linked to sustainability of social and economic development. Coal consumption accounts for approximately 70% of primary energy consumption in China. Therefore, China's coal consumption is growing rapidly with the acceleration of energy consumption. In 2012, China's coal consumption exceeded more than half (50.2%) of the total global coal consumption. The substantial consumption of coal energy causes smog that has plagued several regions in China. Moreover, it also the main cause of China ranking as first in producing essential air pollutants and greenhouse gas emissions. In September 2013, the State Council promulgated the *Air Pollution Prevention and Control Action Plan*, which proposed objectives to control coal consumption in the medium and long term and set out the objectives for its management. Their goal is for coal's proportion of total energy consumption to be reduced to below 65% by 2017, while regions such as Beijing–Tianjin–Hebei, Yangtze River Delta and Pearl River Delta have seen negative growth in coal consumption. To achieve this it is necessary to further improve the efficiency of coal consumption. Scholars are presently studying more about the factors affecting non-renewable energy consumption efficiency or overall energy consumption efficiency (Zou et al., 2013; Li and Shui, 2015; Lin and Long, 2015) but less about targeted research for countries like China, which has a special resource endowment and has coal as the main energy source. Therefore, this study seeks to improve the theories and methods of coal consumption efficiency and to present an organic integration with the relevant theories and methods of other scholars, thereby improving the theoretical system of coal consumption efficiency. Using an evaluation model to analyze coal consumption efficiency levels, we can discover the disparities in terms of coal consumption efficiency in different regions in China and facilitate methods to improve them. This approach can generate a strategy for China's energy development while improving national coal consumption

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efficiency. The promotion of regional coal consumption efficiency will eventually accelerate the overall coal consumption efficiency in China.

2. Literature review

In the 1970s, when the term energy conservation first appeared on the international scene, it was a synonym for efficiency and mainly referred to the scientific and rational measures to improve energy efficiency. In 1995 the World Energy Council, emphasized the need to reduce the energy input while providing the same output. This institution defined the concept of energy efficiency for the first time (Wang, 2003). Bosseboeuf et al. (1997) divided energy efficiency into the two aspects of technology and economy to elaborate on the concept. Energy efficiency at the technical level was related to reducing energy consumption because of the innovation of management and the use of innovative technical equipment while energy efficiency at the economic level referred to using the same energy inputs but achieving a higher level of output. Hu and Wang (2006) proposed the concept of total-factor energy efficiency (TFEE), which was defined as a ratio of the optimal-to-actual energy input under a multi-factor framework. The specific method of measurement was data envelopment analysis (DEA). The input indicators were energy inputs and other factors and the output indicators were gross domestic product (GDP). Then, Zhou and Ang (2008) studied on evaluating total-factor energy efficiency and started to consider undesirable (environmental) outputs. They researched on the undesirable outputs within a framework of environmental DEA technology (Zhou et al., 2008, 2010; Bian and Yang, 2010). Wang et al. (2014) selected waste gas, wastewater and solid waste as the undesirable outputs to analyze China's energy efficiency from both static and dynamic perspectives. Wang and Feng (2015) used a global DEA method to analyze the sources of production inefficiency and productivity growth in China, and they selected three environmental pollutants (SO_2, COD, and ammonia-nitrogen) as the undesirable outputs. This study selects energy efficiency evaluation indicators from the angle of TFEE and uses DEA to analyze the coal consumption efficiency of various regions in China.

Multi input-expected output and multi input-multi output (including the desirable and undesirable outputs) are two methods of energy efficiency evaluation that are based on the structure of total-factor productivity. By studying provincial and industrial panel data in China, some scholars have analyzed the related energy efficiency using the multi input-expected output energy efficiency evaluation method (Wang and Zhou, 2008; Wang and Ning, 2011; Wang et al., 2012; Zhao et al., 2014). Others have used the undesirable output model for energy efficiency evaluation when considering the two aspects of economic output and environmental pollution (Lin et al., 2011; Wang et al., 2013; Zhang et al., 2015).

The above research on energy efficiency was mostly directed at overall energy efficiency rather than being specifically directed at coal and other energy sources. This study continues to use DEA to study regional coal consumption efficiency, which is more applicable and accurate in the evaluation of energy efficiency. Honma and Hu (2008) used traditional DEA methods including 14 input indices such as production, labor employment, capital stocks, energy resources and GDP as a single output variable to conduct empirical research for total factor energy efficiency of 47 counties from 1993 to 2003 in Japan. Sueyoshi and Goto (2011) adopted non-radical DEA to measure the efficiency of fossil fuel power generation and compared the proposed approach with other previous DEA approaches used for the performance evaluation of energy firms. Herrala et al. (2012) used traditional DEA methods to analyze whether governance model had any impact on the waterworks in Finland. Blomberg et al. (2012) used DEA methods to evaluate the potential improvement in electricity efficiency of the Swedish pulp industry. Mousavi-Avval et al. (2012) used an input oriented traditional DEA model to compare technical efficiency and scale efficiency on Iran's farms at different scales. Nouri et al. (2013) applied multistage DEA methods to analyze plant oil industry related efficiency in Iran. Avadí et al. (2014) adopted methods with combination of life-cycle assessment and multistage DEA to analyze the eco-efficiency differentiation of Peru's national fishing fleet. And a modified 5-step LCA + DEA method was used to obtain the desired operational benchmarks and to estimate the target environmental gains. The modified 5-step Life Cycle Assessments and DEA methodology (LCA + DEA method) was linked to average inventories per fleet segment rather than individual vessels referring to the selection of the decision-making unit (DMU), and ReCipe is proposed in order to deepen LCA + DEA benchmarking in the light of the environmental dimensions covered (Goedkoop et al., 2009). Wu et al. (2014a,b) used a DEA–Malmquist index calculation to measure industrial utilization efficiency of 30 provinces, autonomous regions and municipalities in China. Huang et al. (2014) proposed an extended DEA model, named GB-US-SBM model, which combined global benchmark technology, undesirable output, super efficiency and slacks-based measure, to evaluate the dynamic of regional eco-efficiency in China. Wu et al. (2014a,b) proposed a new DEA approach, which considered both the fixed and variant sum desirable outputs in the performance improvement of a DMU, to investigate the environmental efficiency of industry in China. Bian et al. (2015) presented a two-stage DEA model based on slacks-based measure to investigate the efficiency of regional industrial systems in China.

This research used the BCC (Banker–Charnes–Cooper) model and the Malmquist index to study regional coal consumption efficiency from two aspects and to classify the mode of the coal consumption efficiency of 30 provinces in China. This research can help to formulate the objectives for the control of coal consumption in China and to improve the efficiency of coal consumption. This is an effective way to hasten China's energy structure adjustment and achieve energy savings and emission reduction.

The paper is structured as follows. Section 3 introduces the model and variables. Section 4 presents a static analysis on the regional coal consumption efficiency, and Section 5 presents a dynamic analysis on the regional coal consumption efficiency in China from 2000 to 2012. Pattern classifications in the efficiency of coal consumption in China' 30 provinces are presented in Section 6. The conclusions and policy recommendations are presented in Section 7.

3. Model and data

3.1. DEA model

The DEA method proposed by Charnes et al. (1978) is mainly used to evaluate the relative effectiveness of a department or unit that has a plurality of inputs and outputs. The department or unit is referred to as a DMU. Its basic idea is to construct an efficient production frontier for the evaluation of the results of a DMU through the DEA model and then to use the efficient production frontier and the geometric distance of each DMU to determine whether the DMU is DEA effective. There are two kinds of basic DEA models: CCR (Charnes–Cooper–Rhodes) model and BCC model. The CCR model can be used to compare the relative efficiency value of a DMU under the condition of constant returns to scale (CRS), but the DMU may be increasing returns to scale or decreasing returns to scale in the actual production. So the scale inefficiency is likely to affect the overall efficiency. The BCC model can compensate for the

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