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Air emissions perspective on energy efficiency: An empirical analysis of China's coastal areas

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HIGHLIGHTS

- We investigate the static and dynamic energy efficiency in China's coastal areas.
- Both environmental pollutants and greenhouse gas are considered.
- Global benchmark technology is incorporated into the related DEA models.
- China's coastal areas have great potential of air emissions reduction.
- Technological progress is main driven factor to improve energy efficiency.

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ABSTRACT

Improving energy efficiency has been recognized as the most effective way to reduce the greenhouse effect and achieve sustainable development. From the perspective of air emissions, this paper adopts data envelopment analysis approach to evaluate the energy efficiency in China's coastal areas over the period of 2000–2012. Carbon dioxide, sulfur dioxide and nitrogen oxide are treated as undesirable outputs of energy consumptions. The proposed global Epsilon-based measure is used to estimate the static energy efficiency with an annual cross-section of data. The weights of the three undesirable outputs are determined according to their treatment costs. A global Malmquist-Luenberger productivity index based on directional distance function is employed to dynamically evaluate the energy efficiency. The results indicate the following in China's coastal areas: (1) the level of economic development is positively related to energy efficiency scores; (2) energy efficiency scores decrease when considering undesirable outputs except Beijing and Hainan; (3) the Circum-Bohai Sea Economic Region greatly improves energy efficiency and has great potential of air emission; (4) the annual growth rate of Malmquist-Luenberger productivity index change is overestimated; (5) energy efficiency improvement is mainly driven by technological improvement, and scale efficiency and management level are the main obstacles.

1. Introduction

The threats posed by global climate change, which are mainly caused by the emissions of greenhouse gases (GHG), are now widely recognized by the international community. Many countries have paid enormous attention to addressing these issues. Energy consumption is a major source of GHG emissions and air pollutants. In 2009, China became the largest global energy consumer [1]. According to the China Statistical Yearbook 2013, primary energy consumption in China accounted for 21.3% of the global level. Of the alternative ways for reducing energy consumption, improving energy efficiency has been regarded as one of the single most cost-effective ways [2]. It is widely acknowledged that monitoring energy efficiency performance can provide an analytical foundation for assessing the effectiveness of an energy policy.

Due to China's industrial structure and lifestyle, the coal share of China's total primary energy consumption is 66% in 2014. In China, industries using fossil fuels, such as the thermal power-generation [3,4], iron and steel industry [5,6], cement industries [7,8] and transport sectors [9–11], are found to be the major

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Nomenclature

DEA	data envelopment analysis
DMU	decision making unit
DDF	directional distance function
GBT	global benchmark technology
ML	Malmquist-Luenberger
GML	global Malmquist-Luenberger
SBM	slacks-based measure
EBM	epsilon-based measure
VRS	variable return to scale
CRS	constant return to scale
CO_2	carbon dioxide
SO_2	sulfur dioxide
NOx	nitrogen oxides
N	number of DMUs
L	number of inputs
M	number of desirable outputs
I	number of undesirable outputs
x	input vector
y	desirable output vector
b	undesirable output vector
g	director vector
$P(x)$	production set
w_m^y	weights of the desirable output variables
w_k^b	weights of the undesirable output variables

emitters of undesirable outputs, resulting in serious environmental problems, especially air pollutants. In order to explore the effect of these undesirable outputs on energy efficiency in China, this study considers three undesirable outputs in air emissions: carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_X). The motivation of choosing the three outputs are as follows: (1) global warming, acid rain, and ozone depletion are the three air pollution problems that cause the most concern both regionally and globally, and they are thought to be caused by large quantities of CO_2, SO_2, and NO_X emissions; (2) China has been the largest emitter of CO_2, SO_2, and NO_X around the world, and the Chinese government has included in its emissions reduction targets in the "Twelve Five Plan" specific reductions in CO_2 emissions per GDP of 17%, total reduction in SO_2 emissions by 8%, and total reduction in NO_X emissions by 10%.

Many studies of energy efficiency evaluation in China widely concentrate on the whole country or one specific industry at national level [12–18]. Due to the uneven levels of regional economic development and energy consumption structures variations in different China's regions, whole-country studies of energy efficiency evaluation may lead to a biased measure in evaluating energy efficiency. In this paper, we focus on the coastal areas, which include nine coastal provinces (Hebei, Liaoning, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan) and three municipalities (Beijing,[1] Tianjin, and Shanghai)[2] [19,20]. In China's coastal areas, five provinces (Beijing, Tianjin, Hebei, Liaoning, Shandong) belong to Circum-Bohai Sea Economic Region. Yangtze River Delta Economic Zone includes Jiangsu, Shanghai, and Zhejiang. Four provinces (Fujian, Guangdong, Hainan, and Guangxi) are included in Pan-Pearl River Delta Economic Zone. Generally, the coastal areas in China with the advantages of location are the overall fastest developing economic regions as well those with the highest energy consumption and the greatest population concentration. According to data from the National Bureau of Statistics of China (NBSC), the energy consumption in coastal areas in 2012 accounted for more than 60% of that throughout the country.

Data envelopment analysis (DEA) approach is widely applied in the field of evaluating energy efficiency. Because DEA is a method used to measure the relative efficiency [21], it has a certain practical significance for detailed analysis in the coastal areas and can provide some cues and implications for other regions. Within a joint production framework of desirable and undesirable outputs, in this paper we construct both static and dynamic energy efficiency performance indices for measuring energy efficiency performance based on DEA models. The global benchmark technology (GBT) incorporates the Epsilon-based measure (EBM) [22] and Malmquist-Luenberger (ML) productivity index. We use the modified EBM to estimate the static energy efficiency with annual cross-section data from China's 12 coastal provinces. The static energy efficiency evaluation can offer relative energy efficiency scores and a general change trend, but it fails to give specific factors for the changes. The global Malmquist-Luenberger (GML) productivity index [23] based on DDF is used to measure the changes of productivity efficiency with panel data. Compared with the traditional ML productivity index, GML can evaluate dynamically the total-factor productivity efficiency and consider desirable and undesirable outputs. Moreover, it can overcome the shortcomings of traditional ML productivity index.

The features of this paper can be summarized as follows: (1) This paper presents the evolution of China's coastal areas' energy efficiency during the sample period, and identifies the influencing factors of energy efficiency. (2) From the air emissions perspective, both environmental pollutants (SO_2, NO_X) and greenhouse gas (CO_2) are treated as undesirable outputs in our DEA models. (3) China's most developed cities are concentrated in its coastal areas, which we choose due to their referential significance to China's inland areas. (4) A modified EBM is proposed to estimate the static energy efficiency. The weights of the three undesirable outputs in the EBM model are calculated in terms of their treatment costs. (5) The GML productivity index based on DDF is used to assess the energy efficiency performance of different regions in China's coastal areas over time.

The remainder of this paper is organized as follows. A literature review is given in Section 2. Section 3 introduces the EBM measure and GML productivity index based on the DDF approach. In Section 4, the paper illustrates the variables and data sources. Section 5 explores the empirical research of China's 12 coastal provinces and presents the results analysis. Section 6 draws the conclusions and provided policy implications.

2. Literature review

A number of previous studies have contributed to the evaluation of energy efficiency using different analytical techniques. DEA is a nonparametric analytical approach that uses mathematical programming to solve the relative efficiency problem of decision-making units (DMUs) with multi-inputs and multi-outputs [21]. The DEA approach does not have to assume the functional form between inputs and outputs and can avoid manmade subjectivity in parameter weighting for efficiency estimation

[1] In this paper, Beijing is included as a coastal city for the following reasons: (1) Beijing is the capital of China and an economically developed city; (2) Beijing is one of the two largest urban energy consumers in China, and its air pollution has received widespread attentions; (3) Beijing is near the sea, and some studies suggested that it is a coastal city [25,26].

[2] For simplicity, we call them China's 12 coastal provinces.