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Energy and emissions efficiency patterns of Chinese regions: A multi-directional efficiency analysis

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HIGHLIGHTS

- We evaluate China's regional energy and emissions efficiency using MEA approach.
- Not just the status but also the patterns of energy and emissions efficiency are investigated.
- China's MEA efficiency experienced an increasing process over the period 1997–2010.
- The efficiency patterns for energy and emissions variables vary considerably for different Chinese areas.

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ABSTRACT

Evaluation of the energy and emissions efficiency of Chinese regions has recently attracted increasing interest. A number of previous studies have contributed to the measurement of energy efficiency using various types of data envelopment analysis (DEA) techniques. However, most of these DEA-based energy efficiency analyses were restricted to the radial expansions of outputs or radial contractions of inputs. In this paper, we utilize the multi-directional efficiency analysis (MEA) approach instead of the traditional radial DEA to investigate Chinese regional energy and emissions efficiency. Since MEA selects benchmarks such that the input contractions or output expansions are proportional to the potential improvement identified by considering the improvement potential in each input or output variable separately, not just the efficiency status but also the efficiency patterns of different Chinese regions and areas can be detected. The empirical study results indicate that, in general, the MEA efficiency of China experienced an increasing process over the study period 1997–2010; the east area overall is more MEA efficient than the central area and the west area of China during the study period; the significant higher MEA efficiency of the east area to the central area and the west area are due to both the higher energy specific efficiency and the higher emissions specific efficiency of the east area compared to the other two areas; the provinces of Hebei, Shanxi, Inner Mongolia, Shandong, Henan, and Hubei etc. have both high energy saving potentials and high emissions reduction potentials, thus they will play the most important roles in China's effort on energy conservation and CO_2 emissions mitigation.

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1. Introduction

Evaluating and improving energy utilization efficiency and CO_2 emissions efficiency, which is considered a crucial approach to save energy and mitigate CO_2 emissions, has recently attracted increasing interest from both the academic researchers and the general public, as global warming has become one of the most serious environmental problems worldwide. Global warming is largely attributed to the effect of emissions of greenhouse gases (GHGs) such as CO_2 from the combustion of fossil fuels.

Between the 1980s and 2000, China significantly improved its energy efficiency and limited its energy demand growth to less than half of its GDP growth. Its energy intensity (energy consumption per unit of GDP) annually declined by approximate 5% during this period. However, during the period 2001–2005, its energy intensity decreasing trend was reversed and its energy consumption per unit of GDP on average increased by 1.6% per year. In order to slow down the overly rapid growths of China's energy demand

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and related CO_2 emissions, the Chinese government announced a mandatory goal of reducing energy intensity by 20% between 2006 and 2010, based on the level of 2005. This goal was officially incorporated into China's 11th Five-Year Plan, further decomposed at the regional level and assigned to each of the Chinese provinces. Furthermore, a series of policies, programs, laws and regulations were put forward to support the realization of this 20% energy intensity reduction goal [1]. It appears that the implementations of these energy efficiency policies and programs have been sufficient to meet the energy saving target, as the latest report issued by the Chinese central government in 2011 indicated that by the end of 2010, China's energy intensity had decreased by 19.1% based on 2005 level, and the energy demand growth reverted to less than the GDP growth during the period 2006–2010.

Despite the major energy efficiency improvements achieved during the last three decades, the rapid growth of China's economy since its reforms and its opening up to the outside world began in 1978 has substantially increased China's primary energy consumption and total CO_2 emissions. This is because China's economic growth has been attributable mainly to the growth of heavy industries and infrastructure constructions, which are all energy intensive and high energy consumption industries [2,3]. In 2010, China's primary energy consumption was 3.2 billion tonnes of coal equivalent (tce), and energy consumption related total CO_2 emissions of China rose to approximate 9.1 billion tonnes. Since 2007, China has already overtaken the US and become the world's largest energy consumer and the largest contributor of CO_2 emissions in the world. Therefore, in an effort to advance towards the construction of a resource-saving and environmental-friendly society, and the realization of sustainable development for China, it is worthwhile evaluating its regional energy and emissions efficiencies and estimating each area's potential for the energy saving and emissions reduction. This may provide useful information for energy and environmental policy making and management.

To date, a number of studies of Chinese regional energy and/or environmental efficiency using the frontier based approach have been published [4–14]. The conclusions of the extant studies are varied, particularly concerning the efficiency rankings of Chinese provinces, the efficiency difference of Chinese areas, and the estimated energy saving potentials for different Chinese regions. In this paper, we aim to investigate the issue of Chinese regional energy and emissions performance in greater depth through analyzing not just the level and variance trend of China's energy and emissions efficiency, but also the patterns and differences of the efficiencies in Chinese 30 provinces and three areas (east, central and west China). The realization of this research objective is made possible through applying the multi-directional efficiency analysis (MEA) approach [15], as MEA can identify both the status and the patterns of energy and emissions efficiencies for different regions and areas.

The remainder of this paper is organized as follows. An overview of Chinese regional development and Chinese energy efficiency policies and related management are proposed in Section 2. Section 3 reviews the related literatures. Section 4 outlines the methodology of MEA. The data and variables are described in Section 5. Section 6 presents the evaluation results and discussion, and the final section concludes this paper.

2. Chinese energy efficiency policies and Chinese regional development

The economic reform and opening up policy begun in the 1980s has allowed China to achieve significant progress in economic and social development over the past three decades. During this period, China's nominal GDP has increased more than 80-fold from 455 billion RMB to 40120 billion RMB. At the same time, China's total energy consumption has also risen tremendously from 603 million tce to 3250 million tce. The scale-oriented and energy intensive economic growth mode of China has given rise to a number of problems associated with high energy consumption and GHG emissions, as well as serious environmental pollution.

In order to realize sustainable development, and build a resource-saving and environment-friendly society, the Chinese government has proposed and implemented a number of energy efficiency policies and programs. According to [1], the main features of these energy efficiency policies, regulations, programs and laws include: (i) close oversight of industrial energy consumption; (ii) financial incentives for energy efficiency investments; (iii) consultation services on energy conservation; (iv) training, education, and policy advocacy on energy saving and efficiency promotion; and (v) research and development, and demonstrative projects of energy conservation and emissions reduction. During the period between the 1980s and 2000, the effect of these policies and programs was noticeable, in that the growth of energy demand was less than the growth of GDP, and energy intensity declined about 5% annually from 1980 to 2001. In addition, because of the Asian financial crisis which began in 1997 and the slowdown of economic growth in China during the period 1998–2001, energy intensity declined by more than 24% from 1997 to 2001. The emphasis on energy efficiency and the economic conditions of China during this period provided many benefits in terms of China's energy conservation and energy related CO_2 emissions reduction. In this paper, we consider this period (1997–2000) as the first study period for energy and emissions efficiency analysis.

The period 2001–2005 saw a noticeable reversal in China's energy intensity decline. The continuous decrease in energy intensity began to reverse in 2001, and the energy intensity increased by an average of 1.6% per year between 2001 and 2005. Energy demand also significantly increased by 57% during this period. In 2005, around 40% of global energy demand growth was the contribution of China, and since 2007, China has caught up with and surpassed the US as the world's largest CO_2 emitter. In this study, we consider this period (2001–2005, which was also the 10th Five-Year Plan period) as the second study period for energy and emissions efficiency evaluation.

In recognition of the overly rapid growth of energy demand and related CO_2 emissions, as well as the associated environmental problems, the Chinese government agreed in 2005 that the total energy consumption of China had to be brought under control. In November of 2005, a national energy intensity reduction goal was announced by the Communist Party that the energy intensity of China had to be reduced by 20% within the five years between 2006 and 2010 (i.e. period of the 11th Five-Year Plan), based on the 2005 level. This ambitious energy intensity reduction goal was further confirmed and ratified by the National People's Congress and stated in the 11th Five-Year Plan. Around 2005 and 2006, a series of policies, regulations and laws were proposed to support the realization of the 20% reduction goal. These policies and laws include the Medium- and Long-term Plan for Energy Conservation issued in 2005, the energy conservation law revised in 2006, the policy on reducing export tax rebates for low value-added but high energy-consuming products proposed in 2006, and the Top-1000 energy-consuming enterprise program started in 2006. Shortly after the announcement of the national goal of reducing energy intensity by 20%, in 2006, a scheme for disaggregating the national goal into the energy saving target for each Chinese province was issued, under which 19 provinces were assigned a 20% decrease target, seven provinces were given the targets of decreases between 12% and 17% decreases, and the decrease targets of four provinces were set above 20% (for an evaluation of and discussion on the disaggregation of energy intensity reduction, see [16]).

It appears that China has been on track to meet this energy intensity reduction goal since 2006, for its energy intensity

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