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# A comprehensive analysis of China's regional energy saving and emission reduction efficiency: From production and treatment perspectives

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## HIGHLIGHTS

- We measured China's regional energy saving and emission reduction efficiency using two-stage DEA approach.
- The production and treatment processes are incorporated in evaluation.
- Eastern China performs best in terms of energy saving and emission reduction efficiency.
- Integrated efficiency of energy saving and emission reduction of China kept a stable trend during 2006–2010.

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## ABSTRACT

Energy and environmental issues have recently aroused increasing interest in China and many approaches are used to evaluate energy and environmental performance. In this paper, a two-stage network DEA framework is applied to evaluate the efficiency of energy saving and emission reduction in China during the period of the eleventh five-year plan, from 2006 to 2010. In this study, economic activities are divided into production and treatment processes. This is different from previous research which generally focused on either environmental efficiency or energy efficiency, omitting the integration of energy and environmental measures. Today, energy saving and emission reduction are both parts of the basic state policy of China and are equally important. The empirical results in this study show that: (i) eastern China has the best energy saving and emission reduction efficiency, performing is better than western and central China. (ii) The efficiency of the production process in central China is better than that in western China while the western area performs better than the central area in term of treatment efficiency. (iii) Integrated efficiency of energy saving and emission reduction of China was relatively stable in the five years and the pollution treatment efficiency maintained a rising trend.



## 1. Introduction

In the past few decades, environmental protection has been an issue of concern to governments and academics. On the one hand, energy conservation draws much attention among governments in the international community. Since the United Nations Climate Change Conference held in Copenhagen in 2009, energy conservation and emission reduction has become the focus of global concern. On the other hand, an increasing number of scholars focus on efficiency evaluation in terms of the environment and energy, which is considered a crucial approach to energy saving and emission reduction.

Since mainland China's economic reform and opening policy starting in 1978, China's economy has developed rapidly, and it became the world's second largest economy in 2010 (Bi et al., 2012). According to the Nation Bureau of Statistic of China (NBSC), China's real GDP has grown about 110 times in 2010 more than that in 1978. With such astonishing economic expansion, China's energy consumption is also growing rapidly. In 2010, China consumed 3.48 billion ts of standard coal, while in 1978 it was 571 million t. Since 2007, China has already overtaken the United States to become the world's largest energy consumer (Wang, 2010). However, the rapid economic development caused a series

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of problems like waste of resources and environmental pollution. The rapidly increasing energy consumption also hindered the sustainable development of China. Moreover, China is currently in the process of rapid industrialization, which will inevitably consume more energy, so that in the coming decades, the situation is even more serious. Meanwhile, with the international community's increasing emphasis on environmental issues, the Chinese government also faces enormous pressure from international organizations in the areas of energy conservation and emission reduction.

Seeking to balance environmental protection, rational utilization of resources, and sustainable development, the Chinese government set the target of reducing the energy consumption of per unit of GDP by 20% and the main pollutant total emissions by 10% in the eleventh five-year plan effective from 2006 to 2010. Such a goal is expected to set up a long-term mechanism for China's economic transition and also fully considers China's basic national conditions, as a developing country, development is the first priority. Hence, the proposal of energy saving and emissions reduction is not only a challenge in front of economic development, but it is a major opportunity for China's economic transformation to realize sustainable development. It is generally realized that improving energy efficiency and environmental efficiency is an important way for China to combat energy challenge and environmental pollution. Therefore, evaluation for China's energy and environmental efficiency is greatly important. In addition, since different regions in China are geographically different, they have different modes of economic growth and energy consumption structure, and policies on energy conservation and environmental protection for them are also not the same. This complexity motivates energy and environmental performance evaluation across different regions in China, which can serve as an empirical basis for government leaders and policy makers in preparing environment and energy policies.

Research on environmental issues has a long history. Zhou et al. (2008b) summarized more than 100 studies on the application of DEA to environmental and energy policy. In terms of energy efficiency, Hu and Wang (2006) proposed an index of total-factor energy efficiency to analyze energy efficiencies of 29 administrative regions in China for the period 1995–2002. However, in their research GDP was the single output while undesirable outputs were neglected. This may be unreasonable in real production processes, as the utilization of fossil fuels always produces pollutants. Zhou and Ang (2008) also presented several DEA-type models for measuring economy-wide energy efficiency performance and calculated the impacts on energy efficiency of changes in energy mix. They presented a simple formulation of weak disposability of undesirable outputs following Färe et al. (1989). Wu (2012) examined both static and dynamic industrial energy efficiency in China's 28 provinces for the period 1997–2008 by using several DEA models.

In terms of environmental efficiency, Zhou et al. (2008a) measured the carbon emission performance of eight world regions exhibited DEA technologies with non-increasing variant returns to scale, and divided outputs into desirable and undesirable outputs without considering non-energy inputs. Song and Wang (2014) calculated China's regional environmental efficiency scores for 1992, 1997, 2002 and 2007 by applying DEA decomposition method from perspectives of technological progress and government regulation. Xie et al. (2014) proposed a dynamic environmental efficiency evaluation of electric power industries in BRIC countries (China, India, Russia and Brazil) by using the environmental Malmquist index. Based on environmental super-efficiency data envelopment analysis (SEDEA) model, Yang et al. (2015) evaluated the environmental efficiency of 30 provinces in China during the period of 2000–2010.

However, in the aforementioned studies, the authors generally focused on a single issue, environmental efficiency or energy efficiency, omitting the integration of energy and environmental measures. Fortunately, in recent literature, there are some improved DEA models to adopt integrated efficiency. For instance, Bian and Yang (2010) proposed some DEA models for estimating the energy efficiencies and environment efficiencies simultaneously. Shi et al. (2010) evaluated the energy overall efficiency, pure technical efficiency, and scale efficiency of the 28 administrative regions in China. Yeh et al. (2010) presented a comparative energy utilization efficiency between Taiwan and mainland China, and the undesirable outputs were handled following Seiford and Zhu (2002). Wang et al. (2012b) proposed a group of efficiency models based on environmental production technology to study China energy and emission performance. Wang et al. (2013a, 2013b) measured China's energy and environment efficiency with a range-adjusted measured model and a dynamic window DEA analysis.

Benefited from the contribution of previous studies, we can summarize many insightful conclusions. Although different methods have been involved, there are some universally applicable findings: (i) energy efficiency and environmental efficiency of China are still at a very low stage. (ii) There is an obvious performance disparity between different provinces in China. (iii) The majority of Chinese provinces are environmental inefficient or energy inefficient. However, although the above-mentioned research provides a comprehensive evaluation of energy and environment efficiency in the economic production process, they still ignore the process of pollution treatment and have weak discriminating power. To the best of our knowledge, very few of them have considered pollution treatment in the framework of efficiency evaluation. Specifically, pollution treatment is an indispensable part of the industrial production and the quantitative impact of industrial pollution treatment on the efficiency of China's energy saving and emission reduction is still not explored.

According to the IEA (2009), the industry accounts for approximately 40% of the word's total energy consumption. Since China's economic reform and opening up in 1978, the country has entered the phase of rapid industrialization, and the industry has been a main driver of China's economy. According to NBSC statistics, in 2010, industrial energy consumption occupied approximately 71% of the total final energy consumption and industrial SO2 emissions accounted for 85.3% of the total emissions. Since industry has become the largest energy consumer and major sources of pollution, the importance of industrial pollution treatment is self-evident. Therefore, if ignore the pollution treatment process, only concern about either environmental efficiency or energy efficiency, the whole study cannot provide an overall and comprehensive appraisal.

The current study first applies the two-stage network DEA model to a set of 30 regions in China, in order to optimize the energy saving and emission reduction efficiency by considering undesirable outputs (pollutant emissions) as critical intermediate outputs. By using the network DEA model, the economic activities are divided into two stages, namely production process and treatment process. We evaluate the overall efficiency of these two stages through a cooperative game approach and provide a more convincing and reliable efficiency measure. Therefore, the evaluation framework in this paper differs from the previous ones and not only are the regional production and treatment efficiency scores in China measured, but the integrated efficiency of energy saving and emission reduction are explored. The evaluation results leads to a more practical and empirical basis for policy-making combining energy conservation and environmental issues.

The rest of the paper unfolds as follows. In Section 2, we present the methodology of our two-stage model and introduce