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China's regional industrial energy efficiency and carbon emissions abatement costs

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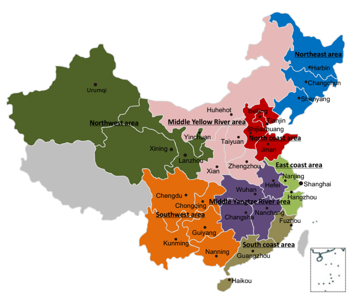
HIGHLIGHTS

- Industrial energy and emissions efficiency were evaluated for China's major cities.
- Shadow prices of CO_2 emissions were estimated for China's major cities.
- Efficiency increase potentials on energy utilization and CO_2 emissions are 19% and 17%.
- N-shaped EKC exists between levels of CO_2 emissions efficiency and income.
- Average industrial CO_2 emissions abatement cost for China's major cities is 45 US$.

GRAPHICAL ABSTRACT

Major cities in eight economy-geography regions of China.



MAJOR CITIES IN EIGHT ECONOMY-GEOGRAPHY REGIONS OF CHINA

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ABSTRACT

Evaluating the energy and emissions efficiency, measuring the energy saving and emissions reduction potential, and estimating the carbon price in China at the regional level are considered a crucial way to identify the regional efficiency levels and efficiency promotion potentials, as well as to explore the marginal abatement costs of carbon emissions in China. This study applies a newly developed Data Envelopment Analysis (DEA) based method to evaluate the regional energy and emissions efficiencies and the energy saving and emissions reduction potentials of the industrial sector of 30 Chinese major cities during 2006–2010. In addition, the CO_2 shadow prices, i.e., the marginal abatement costs of CO_2 emissions from industrial sector of these cities are estimated during the same period. The main findings are: (i) The coast area cities have the highest total factor industrial energy and emissions efficiency, but efficiency of the west area cities are lowest, and there is statistically significant efficiency difference between these cities. (ii) Economically well-developed cities evidence higher efficiency, and there is still obviously unbalanced and inequitable growth in the nationwide industrial development of China. (iii) Fortunately, the energy utilization and CO_2 emissions efficiency gaps among different Chinese cities were decreasing since 2006, and the problem of inequitable nationwide development has started to mitigate. (iv) The Chinese major cities could have, on average, an approximately 19% or 17% efficiency increase on energy utilization or CO_2 emissions during 2006–2010. (v) Promoting the industrial energy utilization efficiency is comparatively more crucial for Chinese cities at the current stage, and the efficiency promotion burdens on the west area cities are the heaviest among all Chinese cities. (vi) An N-shaped Environmental Kuznets Curve (EKC) exists between the level of industrial CO_2 emissions efficiency and income, and the inflection point the EKC is located between 12,052 and 12,341 US$ of GDP per capita, indicating that

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an accelerated CO_2 emissions efficiency increase will accrue when this income level is reached. (vii) In 2010, the industrial total energy saving and CO_2 emissions reduction potentials for Chinese major cities were 41 million tce and 143 million tCO_2, respectively. (viii) The average industrial CO_2 emissions abatement cost for Chinese major cities is 45 US$ during 2006–2010, and the existence of large gap on CO_2 shadow prices between different Chinese regions provide a necessity and possibility for establishing a regional carbon emissions trading system in China.

1. Introduction

After 30 years of rapid economic growth, China's GDP has significantly increased by over 80-fold since the implementation of reform and opening-up policy. However, the rapid economic growth also leads to huge amount of energy consumption and related CO_2 emissions. Nowadays, China has overtaken the United States and became the largest energy consumer and CO_2 emitter in the world [1,2]. To realize sustainable development, improve energy efficiency, and control greenhouse gas emissions, the Chinese government has put forward a strategic target of constructing an environment-friendly and resource-saving society, and specifically, in the 11th (2006–2010) and 12th (2011–2015) Five Year Plan (FYP), China has put energy saving and environment protection as one of its highest priority policy, in which the energy intensity (energy consumption per unit of GDP) reduction targets were set to be 20% and 16%, and the total discharge of major pollutants (SO_2 etc.) reduction targets were set to be 10% and 8%, during 2006–2010 and 2011–2015, respectively [3]. In addition, China also proposed a mitigation action plan consists of reducing CO_2 emissions intensity (CO_2 emissions per unit of GDP) by 40–45% by the year of 2020 based on the 2005 level. In order to realize the above targets, a series policies, regulations and laws on energy utilization and environmental protection, as well as CO_2 emissions mitigation were proposed and implemented within the last ten years both at the national and provincial levels in China so as to support the Chinese government's efforts. According to official report issued in 2011, China's national energy intensity decreased by 19.1% during the 11th FYP period, indicating that the overall carbon emission reduction target was approximately achieved. However, during the first two years of the 12th FYP period (2011–2012), the national energy intensity just decreased by 2.02% and 3.62% respectively, both are lower than the annual reduction target (3.7%) for realizing the overall target of the 12th FYP. Thus the remainder national energy intensity reduction burden for Chinese government is still very heavy. Under such circumstance, it is worthwhile evaluating China's energy and emissions efficiency, measuring its energy saving and emissions reduction potential, and estimating its CO_2 emissions abatement costs, which may provide useful information for identifying the energy utilization and CO_2 emissions efficiency levels and efficiency promotion potentials of China, as well as provide policy making supports on emissions abatement cost estimating, carbon pricing in emissions trading system (which has been initially established in several pilot regions such as Beijing, Shanghai, Tianjin, and Chongqing), and other related energy and environmental issues in China.

In this study, we aim to evaluate the industrial energy and CO_2 emissions efficiency of China's major cities. Because the industrial sector of China is the largest energy consumer and produces more than 70% of the CO_2 emissions, the energy and emissions efficiency evaluation for industrial sector in China are considered more important than other sectors. In addition, since the natural resources endowments, energy consumption structures, industrial structures, and economic growth modes of different Chinese regions are various, and different Chinese administrative regions have different energy saving and environmental protection policies and strategies, the industrial energy and emissions efficiency of China may vary significantly across different Chinese cities. Thus, it may essential and valuable to evaluate the energy and emissions efficiency of industrial sector in China at its major city level.

Energy and emissions efficiency evaluation is often in the form of efficiency indices, and Data Envelopment Analysis (DEA) is considered a successful method to evaluate the efficiency of various decision making unit (DMU). In the energy and emissions efficiency evaluation, many researchers have utilized DEA models [4]. And especially for the efficiency evaluation and shadow price estimating of China, quite a few studies have contributed to the literatures. For instance, Wei et al. studied the energy efficiency levels and changes of China's iron and steel sectors through DEA Malmquist index technique [5]. Wang et al. combined two undesirable output treatments with DEA window analysis model and evaluated the total-factor energy and emissions efficiency of China's 30 provinces [6]. Li and Hu measured the ecological-energy efficiency of China's 30 provinces by applying the slacks-based measure (SBM) DEA model [7]. Li analyzed the carbon emissions efficiency changes of Chinese provinces based on a distance function DEA method [8]. Recently, Wang et al. empirically investigated the provincial energy efficiency and energy productivity of China during the 11 FYP period [39]. In their study, the efficiency were measured by employing a non-radial directional distance function approach and three different production scenarios representing different constraints on energy conservation, carbon emission reduction, and economic growth were assigned so as to provide a more specific efficiency evaluation result. Yi et al. utilized a super-efficiency DEA model to measure the eco-efficiency of Chinese provincial capital cities by including environmental pollution as an undesirable output, and their efficiency results were further utilized as an indicator for the measure of urban sustainable development [44]. Jin and Lin estimated the environmental technical efficiency of China's provinces by using economic and pollution data and through DEA approach, and then a further examination on the role of technical efficiency and industrial pollution control instruments on pollution intensity in China was conducted in their study [45]. Wu et al. developed several static and dynamic energy efficiency indexes based on environmental DEA models and applied these indexes to measure the industrial energy efficiency of Chinese provinces [46]. In addition, Kaneko et al. estimated the shadow price of sulfur dioxide in China based on a direction distance function DEA method [9]. Ke et al. applied the direction distance function DEA method to study the shadow prices of industrial wastes in China [10].

However, few studies have focused on the CO_2 emissions abatement costs estimation of China. For example, Choi et al. applied a SBM DEA method to evaluate the energy and emissions efficiency and marginal abatement cost of energy related CO_2 emissions in China at the provincial level [11]. Lee and Zhang estimated the shadow prices of CO_2 emissions for 30 Chinese manufacturing industries through a distance function approach [12]. Since few studies have estimated the abatement cost of CO_2 emissions in China and, to our best knowledge, no study has focused on the

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