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Estimation of potential energy saving and carbon dioxide emission reduction in China based on an extended non-radial DEA approach

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HIGHLIGHTS

- A non-radial DEA model treating non-fossil energy as a fixed input is developed.
- A method of measuring potential reductions in energy and CO_2 emissions is proposed.
- Reducing coal consumption helps to identify much more inefficiency in China.
- Adjusting energy structure is a practical way of reducing CO_2 emissions in China.
- Technology innovation is an important way to improve the performance in China.

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ABSTRACT

In the process of setting operational targets to achieve sustainable development of economy, environment and natural resources, estimation of potential energy saving and potential CO_2 emission reduction becomes extremely important. This estimation can be conducted based on the energy efficiency evaluation for different decision-making units (DMUs) by data envelopment analysis (DEA). Non-fossil energy is an important component of energy consumption in China, and it has great impacts on energy efficiency and energy-related carbon dioxide (CO_2) emissions. This paper proposes a non-radial DEA model to evaluate regional energy efficiencies in China. In the proposed model, non-fossil energy is treated as a fixed input. Based on the model, a method of measuring potential energy saving and CO_2 emission reduction for efficiency improvement is also presented. The proposed approaches are illustrated by using a regional dataset in China. Based on the application results, some implications for improving energy efficiency and reducing CO_2 emissions in China are provided.

1. Introduction

In past three decades, rapid economic growth has caused great energy consumption and serious environmental and ecological problems in China (Li and Oberheitmann, 2009). China has become the second largest energy-consuming country and the largest emitter of carbon dioxide (CO_2) in the world. In 2009, the total energy consumption reached 3.07 billion tons of standard coal equivalent (SCE), which is about 5.37 times that of 1978 (Statistical Year Book of China in 2010). China's gross domestic product (GDP) accounts for no more than 6.2% of the world's total GDP, while its carbon emissions account for 20.85% of the world's total carbon emissions (World Bank, 2009). To achieve sustainable developments of economy, environment and natural resources, Chinese government has in recent years implemented various strategies and policies, e.g., closing down backward production facilities, promoting the use of energy-saving technologies and making fiscal and tax policies for energy saving (Jiang et al., 2010; Hou et al., 2011), to save energy consumption and to reduce carbon emissions. Particularly, on the 2009 Copenhagen conference, China announced to reduce the intensity of CO_2 emissions per unit of GDP by 40–45% by 2020 compared to the level in 2005. Note that, these strategies and policies should be carried out across all regions in China. It is well known that CO_2 emissions are largely attributed to burning fossil energy consumption. Therefore, improving energy efficiency has often been recognized as one of the most cost-effective ways to reduce CO_2 emissions and to increase the security of energy supply (Ang et al., 2010; Al-Mansour, 2011).

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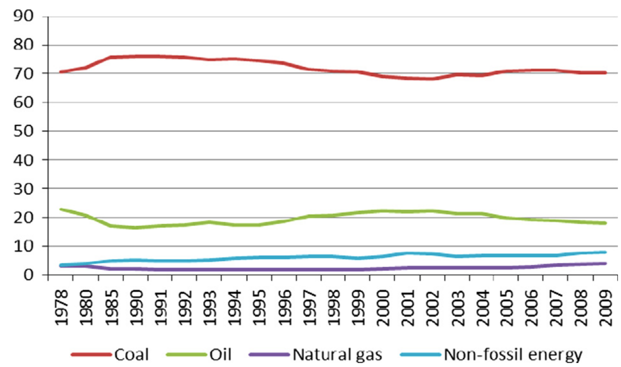

Fig. 1. Energy consumption in China during 1978–2009.

Energy consumption structure in China is composed of fossil energy and non-fossil energy, which has three evident features. First, energy consumption exhibits an overdependence on coal, and little utilization of natural gas and non-fossil energy in China, as shown in Fig. 1.

Fig. 1 describes energy consumption structure in China during 1978–2009 (the data is collected from Statistical Year Book of China in 2010). It can be observed in Fig. 1 that fossil energy (including coal, oil and natural gas) is the main source of energy consumption in China, while non-fossil energy (including hydropower, nuclear power, wind power, solar and others) accounts for a very low proportion of total energy consumption. In 2009, coal, oil and natural gas respectively account for approximately 70.4%, 17.9% and 3.9% of the total energy consumption.

Second, non-fossil energy has developed significantly in recent years. For example, since the renewable energy law was implemented in 2006, the increasing rate of wind power has been over 100% and China has taken the second position in the newly installed capacity in the world (Jiang et al., 2010). China has stated that by the year of 2020, 15% of primary energy consumption should come from non-fossil energy (Guo et al., 2011; Wang et al., 2011).

Third, there exist great disparities in energy structure among different regions in China. For instance, coal consumption in Shanghai accounts for about 50% of its total energy consumption; while in Anhui province, this proportion reaches 90% in 2008. In Fujian province, the percentages of fossil energy and hydropower in its total energy consumption are 84% and 15.8%, respectively (Wang et al., 2011).

Fossil energy consumption rather than non-fossil energy consumption is a primary driver of CO_2 emissions. Different energy structures (i.e., the percentages of energy sources in total energy consumption) result in different carbon emission structures (i.e., the percentages of CO_2 emissions related to coal, oil and natural gas). Therefore, energy structure has significant impacts on regional energy efficiencies and CO_2 emissions. This raises three important issues: (1) How to discriminate the effects of fossil energy and non-fossil energy on regional efficiencies and CO_2 emissions? (2) How to measure the efficiency of each type of fossil energy? (3) How to measure potential energy saving and CO_2 emission reduction? These issues need to be effectively addressed before making appropriate policies for energy saving and CO_2 emission reduction in China.

In the literature, various approaches have been explored to evaluate energy efficiency or environmental efficiency at macro economy level in recent years. These existing approaches can be generally classified as parametric and non-parametric methods (Sadjadi and Omrani, 2008). Parametric approaches such as stochastic frontier analysis (SFA) measure performance through estimation of a restrictive production or cost function. Therefore, deviations in function forms affect results of such methods. The non-parametric approaches, e.g., data envelopment analysis (DEA), evaluate performance based on a linear programming, which relies on construction of a piecewise linear combination of all observed inputs and outputs. A major advantage of the DEA approach is that it does not impose any functional form on the underlying technology (Zhang et al., 2011; Choi et al., 2012). Thus, comparing to parametric approaches, DEA can effectively avoid model misspecification (Wei et al., 2007; Chung, 2011). In addition, DEA can provide sufficient information for improving the efficiency of an inefficient decision making unit by slack and radial adjustments (Shi et al., 2010). With these methodological advantages, DEA has been widely applied to evaluate energy efficiencies or environmental efficiencies in recent years (Zhou et al., 2008).

The existing studies on evaluating energy efficiency with CO_2 emissions based on DEA approach can be mainly classified into three categories. The first one focuses on investigating the relationships among energy consumption, CO_2 emissions and GDP growth for regions or counties, e.g., Ramanathan (2006), Lozano and Gutiérrez (2008) and Li et al. (2011). The second applies DEA approaches to compare efficiencies of energy or energy with carbon emissions for different regions (or countries), or to monitor the efficiency trends for regions or countries, e.g., Zhou et al. (2006), (2010), Chang and Hu (2010), Li (2010), Liou and Wu (2011), Zhang et al. (2011) and Wang et al. (2012). The third not only measures efficiencies for regions or countries, but also explores the potential targets of energy saving or carbon emission reduction by using DEA-based target setting approach, e.g., Hu and Wang (2006), Hu and Kao (2007), Zhou and Ang (2008), Shi et al. (2010), Guo et al. (2011), Lee et al. (2011) and Wei et al. (2012).

The above studies have three outstanding features. The first is that, most of them treat energy consumption as an overall input variable in DEA models except Zhou and Ang (2008) who use non-radial measures for all energy inputs. The second is that in efficiency evaluation, the impact of non-fossil energy as an individual input on regional efficiencies is not taken into consideration. The third is that the targets setting for energy and CO_2 emissions are obtained completely resting on DEA-based target setting approach, ignoring the effects of changes in energy structure on energy saving and CO_2 emission reduction. One special case is Guo et al. (2011), who take energy structure adjustment into account in measuring CO_2 emission reduction in China. However, it is not the same case as our problem. Thus it can be concluded that up till now there is no effective approach to simultaneously deal with the efficiency evaluation and estimation of potential energy saving and CO_2 emission reduction issue in China.

To reasonably evaluate regional energy efficiencies with CO_2 emissions in China, the current paper proposes a non-radial DEA model based on environmental DEA technology (Färe and Primont, 1995; Färe and Grosskopf, 2004). Since CO_2 emissions are mainly generated from fossil energy consumption rather than non-fossil energy consumption, to improve the energy efficiency, it is better to decrease fossil energy consumption as much as possible but not to reduce the non-fossil energy consumption in real production. As a result, we in the proposed model take non-fossil energy as a fixed input. The rest of the paper is organized as follows. Section 2 introduces a methodology for estimating CO_2 emissions in China, constructs a non-radial DEA model for evaluating energy efficiencies of regions, and presents a method based on the proposed model for measuring potential energy saving and CO_2 emission reduction. In Section 3, we illustrate the proposed approaches by using regional dataset in China. Conclusions are described in Section 4.

2. Methodology

This section firstly presents a method for estimating CO_2 emissions of regions in China, and secondly introduces a non-radial DEA