Journal of Cleaner Production 149 (2017) 426–435

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Regional energy intensity reduction potential in China: A non-parametric analysis approach

Zhaohua Wang [a, b, c, *], Weijun He [a, b, c]

[a] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[b] Center for Energy & Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China
[c] Collaborative Innovation Centre of Electric Vehicles in Beijing, China

A R T I C L E I N F O

Article history:
Received 29 August 2016
Received in revised form
17 January 2017
Accepted 11 February 2017
Available online 20 February 2017

Keywords:
Energy intensity
Reduction potential
DEA
Global Luenberger index

A B S T R A C T

Recently, with increasingly concern on energy and environmental problems, China's new programs of energy intensity reduction were released in 11th&12th Five-Year-Plan, which results in an urgent need for regional energy intensity reduction potential evaluation. Based upon this recognition, this study mainly focuses on China's regional energy intensity reduction potential, by employing global data envelopment analysis approach. Moreover, investigating the sources of energy intensity reduction potential change with index decomposition analysis is also one of our targets. The results show that: (1) in the sample period, the energy intensity reduction potential of the western regions is significantly higher than that of central and eastern regions, and the eastern regions have the lowest energy intensity reduction potential. (2) The energy intensity of the eastern regions can be reduced approximately 10–20%, whereas that of the western region can be reduced 30–45%, and that of the whole country can be reduce 25–30% on current basis. (3) According to the sources of energy intensity reduction potential change, it can be found that the energy intensity reduction potential of eastern areas decreased over the sample period. Both the increasing technical efficiency and technical progress contribute to the decline of energy intensity reduction potential. But the western region's energy intensity reduction potential presents an upward trend during 2000–2011, and the technical regression is the main reason. Therefore, the western regions should pay more attention on optimizing the production technology.

1. Introduction

In the past decades, China has experienced a rapid economic development. Since 2010, her domestic gross production (GDP) has surpassed Japan's and become the second largest economy in the world, with more prominent growth rate than most countries'. According to the data reported by World Bank (2016), the growth rate of China's GDP in 2015 was 6.9%. Consequently, rapid growth of economy also led to the increasing of energy consumption. Based upon the data from BP-Statistical Review of Word Energy (2016), as the largest energy consumer, China's energy consumption increased at a rate of 1.5% in 2015, with 22.9% share of the world total.

Energy intensity, defining as the ratio of energy consumption to GDP, measures the energy efficiency of a region or country. Globally, China's energy intensity in 2015 was 0.29 ton per 1000 USD. Instead, that of the United States, Japan and European Union was 0.14, 0.09 and 0.01 ton per 1000 USD in 2015, respectively (World Bank, 2016; BP-Statistical Review of Word Energy, 2016). It is clear China's energy efficiency is lower than that of some developed economies, and the marginal output of China's energy consumption was much lower than that of the United States, European Union and Japan.

There can be no doubt that excessive energy consumption will lead to excessive carbon dioxide (CO_2) emissions and global greenhouse effect. In 2015, to control the global temperature at a stable level, most countries have submitted independent emissions reduction scheme in the Paris Climate Change Conference.[1] China

* Corresponding author. School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China.
E-mail address: wangzh1018@hotmail.com (Z. Wang).

[1] The Paris Climate Change Conference refers to the 21st United Nations Conference on Climate Change 2015, which was hold in Paris during Nov.30-Dec.11,2015.

http://dx.doi.org/10.1016/j.jclepro.2017.02.084
0959-6526/

has committed to limit its greenhouse gas emissions, with a commitment to peak emissions around 2030 and to make best efforts to peak early, and to increase its share of non-fossil energy consumption to around 20% by 2030. To meet achieve these goals, China is confronted with reducing her energy intensity. Fortunately, China government has released some important policies on energy intensity reduction, deceasing energy intensity by 20% on the basis of that of 2005, further deceasing it by 16% till the end of 2015 (11&12 Five Year Plan).[2] However, for most Chinese regions, their energy intensity reduction potentials maybe differ greatly due to their different economic development models and industrial structure. Therefore, Investigating the regional energy intensity potential is conducive to formulating specific energy saving and CO_2 emissions reduction policies, which is conducive to reaching peak CO_2 emissions as early as possible.

Based upon the above important recognition, with the fixed non-energy inputs and undesirable outputs, this study attempts to investigate China's relatively optimal regional energy intensity, i.e. energy intensity reduction potential, by employing non-parametric global data envelopment analysis approach. Then based upon index decomposition approach, we also investigate the sources of regional energy intensity reduction potential change from the perspective of technical efficiency change and technical change.

To investigate China's regional energy intensity reduction potential, we should first examine the relatively minimal regional energy intensity. In this paper, we will use data envelopment analysis (DEA) proposed by Charnes et al. (1978), which provides an appropriate method to deal with multiple inputs and outputs in examining relative efficiency, to investigate the regional minimal energy intensity in China. Actually, in the previous studies, many scholars have investigated China's relatively minimal energy consumption, and defined the ratio of the minimal energy consumption to actual energy consumption as energy efficiency or energy performance (See Wang et al., 2012a,b; Hu and Wang, 2006; Wei et al., 2009; Zha et al., 2016; Li and Hu, 2012; Shi et al., 2010; Wang et al., 2013a,b. etc.). However, some of them ignored undesirable outputs, i.e. the by-product of economic outputs due to the use of fossil energy, (e.g. CO_2, SO_2, and NO_x, etc.). Obviously, neglecting undesirable outputs cannot reflect practical production and lead to a biased estimation of energy efficiency. Therefore, many scholars argued that undesirable outputs should be incorporated into energy efficiency analysis framework.

Among these literatures incorporated the undesirable outputs into the efficiency estimation models, their approaches of dealing with undesirable outputs, were mainly divided into two groups: one was to treat undesirable output as inputs through data translation (Seiford and Zhu, 2002; Kopp, 1998; Dyckhoff and Allen, 2001). In this case, inputs and outputs still satisfied strong disposability requirements.[3] However, this approach is also criticized by many scholars due to the following reasons Firstly, regarding the undesirable output as inputs is inconsistent with the practical production. Secondly, it violates the law of mass conservation (Wang et al., 2014). Alternative one is to employ the environmental reference technology with original data, proposed by Färe and Grosskopf (2004). In the environmental reference technology, the undesirable outputs do not satisfy strong disposability any more, but weak disposability, which indicates that the reduction in undesirable outputs would lead to the same proportion reduction in desirable outputs. Due to its reasonability and convenience in dealing with undesirable outputs, the environmental reference technology has been more widely applied to evaluating the efficiency issues in energy and environmental fields (Guo et al., 2011; Wang et al., 2012a,b, 2013a,b; Yang and Wang, 2013; Li and Hu, 2012; Song et al., 2015; Zhang and Choi, 2013 etc.). Within the framework of environmental reference technology, Wang et al. (2013a,b) evaluated the provincial energy and environmental efficiency in China, with non-radial DEA model and analysed the efficiency change with window analysis approach. Zha et al. (2016) investigated the energy and carbon emissions efficiency by a chance constrained DEA approach. Song et al. (2015) evaluated the energy efficiency of coal-fired power in China. Similar studies on energy efficiency were also conducted by Shi et al. (2010), Li and Hu (2012), Zhang and Choi (2013), Zhou et al. (2012), Wang et al. (2014), Wei et al. (2007), Wang et al. (2013a,b), and Pacudan and de Guzman (2002).

However, although these studies have examined China's regional energy efficiency and energy performance, the potential innovation of this paper can mainly be summarized as follows: firstly, differing from Shi et al. (2010), Zhang and Choi (2013), Zhou et al. (2012), Wang et al. (2014, 2014), which focused on the reduction in total energy consumption, we focus on the energy intensity reduction potential in this paper, since energy intensity is an important indicator in energy economics. In China's "Eleventh Five-Year Plan" and "Twelfth Five-Year Plan", Chinese government has declared that China will be devoted to reducing regional energy intensity. Therefore, this study can provide some suggestions on the potential of the reduction in Chinese regional energy intensity. Secondly, in this paper, the global environmental reference technology constructed by the data of the whole sample periods is employed. The previous studies Chung et al. (1997), Zhou et al. (2008a,b), Meng et al. (2013), Bai and Hao (2012), Wang and Wei (2014) and Färe et al. (1994) mainly employed single-phase reference technology constructed by the data of one period to evaluate the energy performance, with the flaws that the evaluated performance is not stable, and the trend of inter-temporal efficiency cannot be examined directly due to the technology varies with the time. (Chambers et al., 1996; Oh, 2010; Pastor and Lovell, 2005). Thirdly, these studies focused on China's regional energy performance, only incorporated CO_2 into evaluation model but ignored Sulfur dioxide (SO_2), which is also one of the important by-products of economic outputs due to the use of fossil energy. Incorporating SO_2 into the framework of performance evaluation model is conducive to improving the accuracy of the results.

According to the discussion above, in this study, we will propose a global fractional DEA model on the basis of Zhou et al. (2008a,b), to investigate the China's regional energy intensity reduction potential. In addition, examining the energy intensity reduction potential change and the sources of its change from the perspective of technical efficiency change and technical change is also the targets of this study.

The remainder of the paper is organised as follows: in Section 2, the relevant theory, methodology and the models used in this study will be introduced. Section 3 presents relevant variables and data. Next, the main empirical results analysis and discussion are presented in Section 4, and Section 5 concludes the study.

2. Methodology

2.1. Non-parametric global environmental reference technology

Non-parametric DEA approach is mainly applied to evaluating the relative efficiency of decision-making units (DMU) with

[2] The period of the 11th and 12th Five Year Plan is 2006–2010 and 2011–2015.

[3] Strong disposability of the inputs and desirable outputs implies that when desirable outputs are fixed, we can arbitrarily enlarge the inputs on the basis of their initial value, and we can arbitrarily contract desirable outputs on the basis of their initial value, when inputs are fixed.