Applied Energy 166 (2016) 282–291

Contents lists available at ScienceDirect

Applied Energy

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

CO_2 emissions and energy intensity reduction allocation over provincial industrial sectors in China

Jie Wu *, Qingyuan Zhu, Liang Liang

School of Management, University of Science and Technology of China, Hefei, Anhui Province 230026, PR China

HIGHLIGHTS

- DEA is used to evaluate the energy and environmental efficiency of 30 provincial industrial sector in China.
- A new DEA-based model is proposed to allocate the CO_2 emissions and energy intensity reduction targets.
- The context-dependent DEA is used to characterize the production plans.

ARTICLE INFO

Article history:
Received 29 June 2015
Received in revised form 12 December 2015
Accepted 6 January 2016
Available online 20 January 2016

Keywords:
Greenhouse gas emission
Industry
Energy intensity
CO_2 emission reduction allocation
Data envelopment analysis

ABSTRACT

High energy consumption by the industry of developing countries has led to the problems of increasing emission of greenhouse gases (GHG) (primarily CO_2) and worsening energy shortages. To address these problems, many mitigation measures have been utilized. One major measure is to mandate fixed reductions of GHG emission and energy consumption. Therefore, it is important for each developing country to disaggregate their national reduction targets into targets for various geographical parts of the country. In this paper, we propose a DEA-based approach to allocate China's national CO_2 emissions and energy intensity reduction targets over Chinese provincial industrial sectors. We firstly evaluate the energy and environmental efficiency of Chinese industry considering energy consumption and GHG emissions. Then, considering the necessity of mitigating GHG emission and energy consumption, we develop a context-dependent DEA technique which can better characterize the changeable production with reductions of CO_2 emission and energy intensity, to help allocate the national reduction targets over provincial industrial sectors. Our empirical study of 30 Chinese regions for the period 2005–2010 shows that the industry of China had poor energy and environmental efficiency. Considering three major geographical areas, eastern China's industrial sector had the highest efficiency scores while in this aspect central and western China were similar to each other at a lower level. Our study shows that the most effective allocation of the national reduction target requires most of the 30 regional industrial to reduce CO_2 emission and energy intensity, while a few can increase or maintain their 2010 levels.

1. Introduction

Due to the increasing emission of greenhouse gases (GHG), climate change and global warming has become a major policy issue in the world [1]. There is evidence that GHG emission is responsible for an increase in the average global temperature of air, sea, and land. In this context, the Kyoto Protocol of 1997 was established to advocate control over worldwide atmospheric GHG concentrations and it was followed by the Copenhagen Accord in 2009 which states, based on scientific evidence, the necessity for huge cuts in the global level of GHG emissions. As a major source of GHG emissions, the world's industrial sector alone reached 14.86 $GtCO_2e$ in 2010, representing 30% of total global GHG emissions [2].

The increasing GHG emissions from industry are mainly due to high energy consumption. According to the International Energy Agency [3], the global industrial sector accounts for approximately 40% of the world's total energy consumption. Due to increased environmental awareness and new technology to protect the environment, GHG emissions from industrial sectors in developed countries have experienced a declining trend while such emissions in developing countries are rapidly growing. As a large and fast-growing developing country, China emitted 6877 million tons of GHG emission from burning fossil fuels in 2009 that accounted 23.7% of global emission [4]. Therefore, China has overtaken the

* Corresponding author.
E-mail addresses: jacky012@mail.ustc.edu.cn (J. Wu), zqyustc@mail.ustc.edu.cn (Q. Zhu).

http://dx.doi.org/10.1016/j.apenergy.2016.01.008
0306-2619/

United States and became the largest energy consumer and GHG emitter in the world [5–8]. In addition, according to the National Bureau of Statistics of China (NBSC) in 2010, China's industrial energy consumption occupied approximately 71% of the country's total energy consumption and industrial GHG emission accounted for 85.3% of the total emissions. Therefore, it is particularly important to analyze the energy and environmental efficiency of China's industrial sector since doing so may provide much information to central or local governments seeking to improve the performance of industry. In addition, it is also necessary to pay close attention to the problem of reasonably reducing and controlling the GHG emissions and energy consumption of China's industrial sector.

To balance rational utilization of energy, GHG emissions, and sustainable development, many mitigation measures have been put forward by Chinese governments. China's 12th Five-Year plan seeks to establish a "green, low-carbon development concept". For example, in this plan during 2010–2015, China's government set the target of reducing unit GDP CO_2 emissions (also called CO_2 emission intensity which is the main component of GHG) by 18% by the end of 2015 with 2010 as the base year [9]. Furthermore, China has declared its goal to reduce its unit GDP CO_2 emissions by 40–45% by the year of 2020 based on the 2005 level. In addition, as part of China's national plan, continuing energy intensity reduction targets are part of China's 11th Five-Year Plan (20% reduction by 2010 compared to 2005) and 12th Five-Year Plan (16% reduction by 2015 compared to 2010).

While the regional authorities have been required to adjust their economic growth mode and restructure their policies, this may not guarantee that local efforts on energy saving and emission reduction are in line with the national target. In addition, lack of accountability for reduction efforts of emission and energy at the provincial level may lead to poor implementation of the national policy. Therefore, it is particularly important for the Chinese central government to carefully allocate parts of its total GHG emissions and energy intensity reduction into targets for each provincial industrial sector.

Industrial production is always accompanied by energy consumption and GHG emissions. Like energy resources, GHG emissions also can be seen as a source of wealth; that is, each industrial sector can produce more products with more GHG emissions [10,11]. Therefore, GHG emission reduction allocation in provincial industrial sectors can be seen as the allocation of fixed resources. The former usually determines the reduction amounts of GHG emissions while the latter determines the increased amounts of resources, but both of them have the same objective to determine each province's final GHG emission or resource use through the allocation of GHG emissions reduction or input resources.

As a non-parametric method, data envelopment analysis (DEA) has been widely used in solving the problem of resource allocation. Developed by Charnes et al. [12], DEA is a programming-based technique for evaluating the relative efficiency of a group of homogenous decision making units (DMUs) [1,13–15]. DEA does not use any prior functional form and also does not require the many assumptions that arise from the use of statistical methods for function estimation, yet it gives good results when used to allocate resources [16]. For example, for the problem of allocating central grants to Greek local authorities, Athanassopoulos [17] integrated resource allocation and target setting in multilevel planning problems based on goal programming and data envelopment analysis. Beasley [18] established a nonlinear alternative DEA-based approach which can be used to simultaneously allocate input resources and set output targets for the DMUs. Korhonen and Syrjänen [16] developed an interactive formal approach based on DEA and multiple-objective linear programming (MOLP) to find the most preferred allocation plan that maximizes the amount of multiple output variables simultaneously. Their approach is based on assuming that the units are able to modify their production in the current production possibility set subject to certain other assumptions. Further assumptions are that the units can modify their production plan on the basis of returns to scale or unchanged efficiency. Amirteimoori and Tabar [19] presented a DEA-based model for allocating resources or costs when output targets can be set beforehand. Bi et al. [20] proposed DEA-based methodology for resource allocation and target setting by assuming that the resources can be transferred between internal parts of a DMU which has two parallel production systems. Wu et al. [21] presented a DEA-based approach for the problem of resource allocation considering both economic and environmental factors. Du et al. [22] allocated resources by using the concept of cross-efficiency in DEA. In addition, there has also been some research based on centralized resource allocation [23]. More detailed reviews of centralized resource allocation studies can be seen in Asmild et al. [24], Mar-Molinero et al. [25], and Fang [26].

Recently, there has also been some DEA-based research directly addressing the problem of emission reduction allocation. By introducing zero sum game concepts into the DEA approach, Gomes and Lins [27] employed a zero sum gains DEA (ZSG-DEA) method to allocate the total CO_2 emissions among the signatory countries of the Kyoto Protocol. Lozano et al. [28] proposed two three-phrase DEA-based approaches for centralized reallocation of emission permits. The three objectives are maximizing aggregate desirable production, minimizing undesirable total emissions, and minimizing the consumption of input resources. Wang et al. [11] proposed an improved ZSG-DEA optimization model to allocate China's CO_2 emission allowance over provinces. Chui et al. [29] also applied the ZSG-DEA model to allocate and reallocate the emission allowances among the 24 European Union members. Wu et al. [30] proposed an approach for fair reduction and reallocation of emission permits by incorporating a bargaining game into DEA models. Sun et al. [10] proposed DEA-based emissions reduction allocation methods, giving two variations. One is individual allocation of energy permits (AEP) where a dominating enterprise enjoys the right of AEP and all the other enterprises do not have this right. The other is central AEP where a governing body is established to coordinate the AEP among member enterprises in the group. Feng et al. [31] proposed a two-step carbon emission reduction allocation and compensation method. In the first step, the optimal carbon emission level of each DMU is identified, then two compensation schemes are used as further supplements for the allocation results in the second step. By using several centralized DEA models, Zhou et al. [32] studied the optimal allocation of CO2 emissions under spatial, temporal and spatial–temporal allocation strategies, respectively.

Surveying the prior studies, we find that little research has paid close attention to the allocation of both GHG emission and energy intensity reduction. In addition, we find that existing DEA approaches to resource allocation or emission reduction allocation generally impose three strong assumptions regarding a DMU's new production. The main limitations can be concluded that:

(1) The first assumption on the new production is that the efficiency for each DMU is changeable after resource or emission reduction allocation. Most of the researches based on the assumption of changeable efficiency indicated that each DMU's new production can lie on the efficient frontier formed by efficient DMUs. Models based on this assumption therefore do not consider the DMU's actual production ability, and they generate an output target that may not be easily achieved by some DMUs, especially for some DMUs with low efficiency.