Applied Energy 165 (2016) 107–118

Contents lists available at ScienceDirect

Applied Energy

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

Estimating the carbon abatement potential of economic sectors in China

Shiwei Yu [a,b,c,*], Lawrence Agbemabiese [b], Junjie Zhang [a]

[a] School of Economics and Management, China University of Geosciences, Wuhan 430074, China
[b] Center for Energy and Environmental Policy, University of Delaware, Newark 19711, USA
[c] Center for Resources and Environmental Economic Research, China University of Geosciences, Wuhan 430074, China

HIGHLIGHTS

- A multivariable environmental learning curve panel model is proposed.
- The carbon abatement potential of 43 sectors in China is estimated by the model.
- Energy intensity has the stronger positive learning ability among the three variables for all sectors.
- Carbon potential for thirty-nine sectors in 2020 will be 33.0% and 39.0% based on two 2012 scenarios.

ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 17 December 2015
Accepted 17 December 2015
Available online 31 December 2015

Keywords:
Carbon emission
Abatement potential estimation
Sectors
Multivariable learning environmental curve

ABSTRACT

This study estimates the carbon abatement potential of 43 Chinese economic sectors by establishing and utilizing an environmental learning curve (ELC) model of carbon intensity. The model selects energy intensity, per capita value added and fuel consumption mix as the independent variables and obtains its learning coefficients using panel data regression. Based on this model, the carbon abatement potential of 43 economic sectors in 2020 is estimated for business-as-usual (BAU) and planned scenarios. The findings show that: (1) the established learning curves adequately simulate the carbon intensity of different sectors; (2) energy intensity has the strongest positive learning ability among the three variables for all sectors. A reduction in energy intensity will lead to reduced carbon intensities for 42 sectors (all except the agriculture sector). However, an increase in sectoral value added will make it possible to reduce carbon intensity in 34 sectors. Reducing the proportion of coal energy will result in decreased carbon intensities in only ten sectors; (3) the average carbon intensity reduction potential for 43 sectors in 2020 will be 33.0% and 39.0% based on 2012 in two different scenarios. Sectors related to the manufacture of food, medicine, beverages and chemical fiber have the largest carbon intensity potential among the 43 sectors.

1. Introduction

Global warming caused by GHG (greenhouse gas) has taken center stage in environmental topic. As the world's largest emitter of GHG, China accounted for 28% of global total CO_2 emissions in 2013 [1], owing to rapid economic growth, urbanization and population growth. To address climate change and mitigate the rapid growth of carbon emissions, China pledged to reduce its carbon intensity (defined as a reduction in CO_2 per unit of GDP) by 40–45% and in 2009 set a target to be below 2005 levels by 2020. In 2014, China committed for the first time that it would peak its carbon emissions by 2030 at the Beijing Asia-Pacific Economic Cooperation (APEC) summit. To minimize the negative impacts on economic development caused by emissions reduction, China should develop different reduction policies for different carbon emission sources. Production sectors that provide material goods or services are the primary sources of certain emissions [2]. For example, global energy-related carbon emissions accounted for 65% of the total GHG emission in 2010, of which 55% were from industry [1]. Therefore, determining how to reduce the carbon emissions of these sectors is the key to peaking China's carbon emissions. Different economic sectors have different carbon emissions and carbon intensity because they vary in terms of energy consumption, types of fuel mix and technological levels in their production processes. These conditions also result in different carbon emissions reduction capacities – namely, the carbon reduction potential for various sectors. Reasonable estimation of this potential is an important premise for easing the pressure of emissions reduction and issuing policy aimed at different sectors.

* Corresponding author at: School of Economics and Management, China University of Geosciences, Wuhan 430074, China. Tel.: +86 027 67883215; fax: +86 027 67883201.

E-mail addresses: swyu@udel.edu, ysw81993@sina.com (S. Yu).

http://dx.doi.org/10.1016/j.apenergy.2015.12.064
0306-2619/

Carbon abatement potential can be considered as an untapped emissions abatement capacity on the part of the emitter. This abatement potential is classified as the technical and economic emissions reduction potential by the Intergovernmental Panel on Climate Change (IPCC). Technical potential refers to the amount of GHG emissions avoided through implementation of reduction technology measures. Economic potential refers to the quantity of GHG emissions reduced at given costs compared to a Ref. [3]. This study focuses on the former. Several studies have evaluated the carbon abatement potential on national or regional scales by using bottom-up energy-economic models. For example, Höglund-Isaksson et al. employed the Greenhouse Gas and Air Pollution Interactions and Synergies/IIASA (GAINS /IIASA) model estimate of baseline emissions and mitigation cost curves for non-CO_2 GHGs in the European Union (EU-27) [4]. Yu et al. calculated China's provincial carbon intensity abatement potential generated by increasing per capita GDP and industrial restructuring [5]. Li et al. discussed the potential for renewable energy development and its CO_2 emissions reduction potentials in China rural areas [6]. Wang and Wei evaluated the emissions reduction potentials of the industrial sector of 30 Chinese major cities by using a Data Envelopment Analysis (DEA) model [7]. These estimations are a macro calculation. However, from the viewpoint of implementation, enterprises in various production sectors are likely to be the real bearers of emissions reduction. Therefore, estimating the reduction potential from the perspective of sectors may be more meaningful and instructive.

In this regard, numerous studies have undertaken estimate of carbon-cutting potential from a sector perspective. Of these, one of the most popular models is the long-range energy alternative planning system (LEAP). For instance, Limmeechokchai and Chawana estimated the emissions abatement potential of the adoption of improved cooking stoves and small biogas digester technologies in Thailand [8]. Cai et al. explored the carbon emissions cutting capacity of five of the major emissions sectors in China [9], and Özer et al. evaluated the reduction potential of Turkey's power sector [10].

Other energy-economic models have also been applied to estimate the carbon emissions cutting potential of various sectors in different countries. Among the various models, the Logarithmic Mean Divisia Index (LMDI) model may be the most popular. For example, Lin and Ouyang investigated the cutting potential of the Chinese non-metallic mineral sector [11], five OECD countries' transport sectors [12], China's textile industry [13], and China's cement industry [14]. In addition, there have been a Market Allocation (MARKAL) model for Taiwan's electricity, industry, construction, and transportation sectors [15]; GAC, a GHG costing model for the Macedonian transport sector [16]; the Asia-Pacific Integrated Assessment Model/Enduse (AIM/Enduse) for the Thai residential and building sectors [17]; other econometric approaches, namely, Panel-Corrected Standard Error (PCSE) for Portugal's industry and energy sectors [18], Fully Modified Ordinary Least Squares cointegration approach (FM-OLS) for OECD countries' transport sectors [19]; co-integration approach for Chinese textile industry [20]; and two-tier KLEM input–output structural decomposition analysis for energy-intensive sectors [21]. Moreover, Cheng et al. established a system dynamics model to explore the potential of mitigating CO_2 emissions in Taiwan [22]; Rogers et al. took an integrated analysis approach and an environmental life cycle assessment (LCA) to assess the options available for UK homeowners to reduce carbon emissions [23]. However, these have mainly focused on the estimation of potential abatement for an individual sector or a few sectors (five at most). Determining the potential of other sectors requires further analysis and study. Furthermore, no comparison of the potential has yet been conducted between sectors because only a few have been investigated in existing studies.

In addition to the aforementioned energy-economic models, the environmental learning curve (ELC) model has attracted much attention in estimating emissions cutting potential. The ELC model, borrowed from the conventional learning curve model, reflects the progressive improvements made environmentally by enterprises (or industries) through the accumulation of experience and advancement of technology [24]. This estimation model is easy to construct, and data are readily available. Several studies have successfully applied this model to estimate emissions cutting potential. However, the existing studies using the ELC model have mainly focused on the national [5] or regional levels [25,26] or an individual sector [27,28], similar to the other aforementioned models. Furthermore, the ELC models applied have tended to focus on a single factor, considering only the effects of economic development on carbon emissions and neglecting the reduction potential brought, for example, by improving energy efficiency and fuel mixtures.

Therefore, this study estimates the carbon abatement potential of China's 43 sectors by 2020 using carbon intensity learning curves. The proposed model selects per capita value added, energy intensity (energy consumption per unit of GDP), and the fuel mix of each sector as the independent variables of the curves and obtains their learning coefficients through panel data regression. Based on the ELCs established, the abatement potential values of the sectors are calculated by setting two scenarios (business-as-usual and planned policy). Furthermore, the sectoral comparisons are made concerning abatement potential values.

2. Carbon emissions of China's economic sectors

2.1. Target sectors

Based on *China's National Economic Sector Classification Standard (GB/T 4754-2002)*, this study selects its target sectors 43 from the second industry class, three from the third industry class and agriculture, as shown in Table A1. The period of each sector covered in this study is 1994–2012.

2.2. Total CO_2 emissions of sectors

Carbon dioxide emissions of each sector from fossil fuel consumption are calculated by the following formula [29]:

$$TC_{it} = \sum_j \left(A_{ijt} \times e_j \times c_j \times O_j \times \frac{44}{12} \right) \quad (1)$$

where TC_{it} represents the energy-related carbon emissions for the ith sector in tth year; A_{ijt} is the real final consumption of the jth fuel of sector i in the tth year, $j = 1, 2, \ldots, 18$[1]; e_j is the net calorific value of the jth fuel; c_j is the carbon content of the jth fuel; and O_j is the carbon oxidation rate of the jth fuel. The carbon emission coefficient of *electricity* is 8.0032 tonne CO_2/kW h according to the report of National Bureau of Statistics of China (NDRC) [30]. The coefficient of *heat* is 0.8514 tonne $CO_2/10^9$ kJ, which is converted from the net calorific value of raw coal because the heat supply is mainly based on raw coal in China. The other parameters of energy can be found in [31].

The carbon emissions for the 43 sectors are shown in Fig. 1. From Fig. 1, large differences can be seen among sectors in terms of their carbon emissions. Sectors S26, S21, S25, S41 and S43 are the largest five emitters. These five sectors accounted for 55.18% of the total emissions for all 43 sectors (1.3 billion tonnes) in

[1] The 18 fuels are Raw Coal, Cleaned Coal, Other Washed Coal, Coke, Coke Oven Gas, Other Gas, Other Coking Products, Crude Oil, Gasoline, Kerosene, Diesel Oil, Fuel Oil, LPG, Refinery Gas, Other Petroleum Products, Natural Gas, Heat, and Electricity.