Atmospheric Pollution Research xxx (2015) 1–11

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Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Original article

A combined input–output and sensitivity analysis of CO_2 emissions in the high energy-consuming industries: A case study of China

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ARTICLE INFO

Article history:
Received 5 May 2015
Received in revised form
30 September 2015
Accepted 30 September 2015
Available online xxx

Keywords:
Input–output model
Sensitivity analysis
High energy-consuming industries
CO_2 emissions

ABSTRACT

This paper employed an input–output approach combined with a sensitivity analysis to explore the impact of technological changes on CO_2 emissions in the high energy-consuming industries. In contrast to most papers in the literature, which focused on the changes between two input–output tables in two different periods, this study analyzed the sensitivity of variations in the quantity of emissions caused by small changes in technical coefficients. An indicator, namely TCE (technical coefficient elasticity), was established to identify the transactions between economic sectors which lead to a large impact on CO_2 emissions in the high energy-consuming industries. Additionally, by analyzing factors affecting TCE, this paper divided TCE into structure-relevant TCE and technology-relevant TCE. Sectors have a higher structural TCE value because their products are much demanded by other sectors. Sectors have a higher technological TCE value because they have a large propensity to consume inputs which require many products of the high energy-consuming industries. Our results show that technical coefficients with a higher TCE value correspond to the direct requirements by the high energy-consuming industries themselves. However, the impacts of technological changes in the non-high energy-consuming industries on high energy-consuming industries cannot be overlooked, especially in Transportation industry, Construction industry and manufacturing industries. Several industries have a higher structural TCE value, thus, their influence on CO_2 emissions in the high energy-consuming industries is related to a high level of demand of their respective products. However, several industries have a higher technological TCE value, thus, technology innovation will be more effective to decrease CO_2 emissions. Therefore, different measures should be adopted for reducing CO_2 emissions in the high energy-consuming industries according to different conditions.

1. Introduction

Recently, China has become the global largest CO_2 emitter (Kang et al., 2014). Against this backdrop, China promulgated the policy target of reducing the carbon intensity (i.e. quantity of CO_2 emissions per unit of GDP) in 2020 by 40–45 percent based on the 2005 level (Geng et al., 2013). The goal has been reallocated to each sector by setting up more specific targets (Price et al., 2010).

According to '2010 National Economic and Social Development Statistics Bulletin of China' (National Bureau of Statistics of China (NBSC), 2011a,b), six industries were identified as high energy-consuming industries, including the Petroleum, Coking and Nuclear Fuel (h1); Chemical (h2); Non-metallic Mineral Products (h3); Ferrous Metals (h4); Non-ferrous Metals (h5); and Electricity (h6) industries. Among the various industries contributing to CO_2 emissions, the contribution of high energy-consuming industries is significant. In 2010, national total CO_2 emissions were estimated at 86.73 billion tons, and high energy-consuming industries accounted for 80.91% of that total. The high energy-consuming industries were dominated by Electricity industry (32.56%) and Petroleum, Coking and Nuclear Fuel industry (20.25%). More minor sectors included Non-ferrous Metals industry (10.90%), Ferrous Metals industry (6.23%), Non-metallic Mineral Products industry (5.87%) and Chemical industry (5.10%). To cope with growing emissions, the Chinese government began implementing comprehensive policies and strategies in 2005. For example, during the 11th Five-Year Plan

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2015.10.003

(2006–2010), energy-saving targets for China's 1000 highest energy consuming enterprises were arranged by the NDRC, aiming to save approximately 2.9 EJ of energy consumption (Xu et al., 2014). However, the total CO_2 emissions in these industries are still increasing. Fig. 1 illustrates the trend of CO_2 emissions in China's high energy-consuming industries from 2005 to 2010. CO_2 emissions in 2010 increased 37.74% compared with 2005, with an annual growth rate of 6.64%. Most CO_2 emissions in China's high energy-consuming industries clearly came from Electricity industry. Due to these trends showing that the fastest growth in CO_2 emissions is in the high energy-consuming industries, it is paramount to take the high energy-consuming industries serious in efforts.

Academically, several papers have applied different approaches to discuss CO_2 emissions from the high energy-consuming industries in China. Lin and Long (2014) adopted the factor decomposition and the EG co-integration methods to quantify the driving forces behind the Chinese Chemical industry's fossil energy consumption. Lin and Ouyang (2014) analyzed the trend in CO_2 emissions of the Chinese Non-metallic Mineral Products sector using the LMDI (Logarithmic Mean Divisia Index) method. Wen and Li (2014) utilized a LEAP model to evaluate energy conservation and CO_2 emissions abatement potentials for the Chinese Ferrous Metals industry. Zhou et al. (2014) employed the LMDI method to analyze energy efficiency and CO_2 emissions reduction of China's thermal electricity generation on a regional grid level. These studies essentially evaluate emission reduction potentials separately for each high energy-consuming sector. However, the emission reduction activities in different sectors affect each other. Therefore, emission reduction potentials across sectors must be explored by taking into account the interrelationships among them.

The input–output (I–O) model (Leontief, 1936, 1970) is a classical and rational method for analyzing energy-related CO_2 emissions because it allows one to trace the direct and indirect energy-related CO_2 emissions associated with a product (Machado et al., 2001; Hubacek et al., 2009; Zhu et al., 2012). An increasing number of researchers have employed the input–output model to analyze changes in energy consumption and energy-related CO_2 emissions in China (Minx et al., 2011; Liang and Zhang, 2011; Xu et al., 2011; Liu et al., 2012; Wang et al., 2013; Weitze and Ma, 2014; Xie, 2014). However, most previous empirical studies within an input–output framework are based on structural decomposition analysis (SDA). The changes in CO_2 emissions between two different periods are explained by the changes in final demand and structural coefficients. This methodology does not focus on small variations in the technical coefficients taking place within the mathematical model. Thus, it is unable to identify the influence of technological changes on CO_2 emissions in different economic sectors in depth (Mattila et al., 2013).

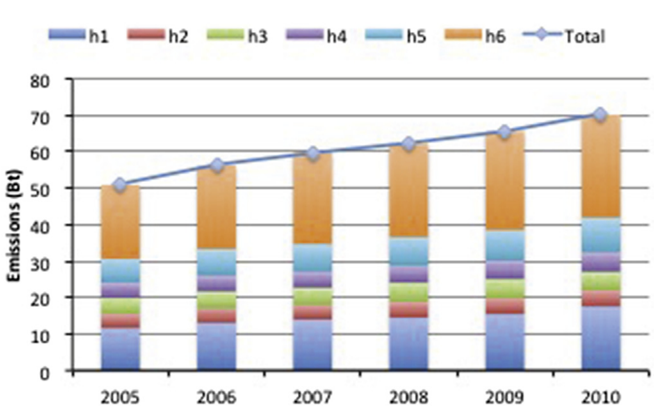

Fig. 1. CO_2 emissions evolution trend in the high energy-consuming industries (2005–2010).

The sensitivity analysis within an input–output framework has provided a new approach to identify the impact of changes in the technical coefficients on CO_2 emissions from different economic sectors (Tarancon and Río, 2012). The dependence and proportional relationship among various sectors can be modeled in depth, and in this way, the chain reaction between the national economic activities can be revealed. It has served as a very effective tool in quantifying technological changes to emissions within a production chain perspective. Tarancon et al. (2011) assessed the sensitivity of electricity generation with respect to changes in the technology of the manufacturing sector. Wilting (2012) examined the impact of changes in the technical coefficients on energy consumption by sensitivity analysis. Mattila (2012) also identified the relationship between coefficients and environmental pressure using sensitivity analysis. However, the sensitivity analysis on CO_2 emissions in China is still limited. Among the limited studies, Meng et al. (2014) investigated the impact of technology innovation and price policy on electricity-saving potential for 20 industrial sectors across 30 provinces in China. However, to the best of our knowledge, no studies have been conducted on CO_2 emissions changes in Chinese high energy consuming industries despite their important role in China's energy demand and related CO_2 emissions.

Hence, this paper filled such a gap by estimating the effects of technology changes on CO_2 emissions in Chinese high energy-consuming industries. In this study, we applied the sensitivity analysis within our input–output model to determine the degree of (direct and indirect) influence of different economic sectors on CO_2 emissions in Chinese high energy-consuming industries. An indicator, namely TCE (technical coefficient elasticity), was developed to assess which transactions between economic sectors can be expected to bear a greater impact on CO_2 emissions in the high energy-consuming industries. Sectors with a high TCE value will greatly contribute to CO_2 emissions in high energy-consuming industries, since any small variations in the technological coefficients of these sectors leads to large changes in CO_2 emissions in the high energy-consuming industries. This paper also analyzed the factors affecting TCE and divided TCE into structure-relevant TCE and technology-relevant TCE. Structure-relevant TCE is used to estimate the effects of technological changes on CO_2 emissions affected by the structure of the vector of final demand. Sectors with a higher structural TCE value are those whose products are much demanded by other sectors and this leads to large amounts of CO_2 emissions. Technology-relevant TCE is used to identify key technical coefficients with high emissions-mitigation potentials, which is independent of the specific composition of the final demand vector. Sectors with a high technological TCE value are those whose technologies use inputs which either directly or indirectly require many products of high energy-consuming industries.

The remainder of this paper is organized as follows. Section 2 describes the methodology and data. The main results are reported in Section 3. Section 4 discusses policy implications. Finally, Section 5 presents the conclusions.

2. Methodology and data

2.1. Estimation of CO_2 emissions

We adopted the reference measurement model and parameters in The 2006 IPCC Guidelines for National Greenhouse Gas Inventories together with China's relevant released parameters. The CO_2 emissions of the high energy-consuming sector h from fossil energy consumption data can be estimated as follows: