Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

New provincial CO_2 emission inventories in China based on apparent energy consumption data and updated emission factors

Yuli Shan [a], Jianghua Liu [b,*], Zhu Liu [c], Xinwanghao Xu [d], Shuai Shao [b], Peng Wang [e], Dabo Guan [a,b,f,*]

[a] Tyndall Centre for Climate Change Research, School of International Development, University of East Anglia, Norwich NR4 7TJ, UK
[b] Institute of Finance and Economics Research, School of Urban and Regional Science, Shanghai University of Finance and Economics, Shanghai 200433, China
[c] Resnick Sustainability Institute, California Institute of Technology, Pasadena, CA 91125, USA
[d] State Key Laboratory of Urban and Regional Ecology, Research Centre for Eco-Environmental Sciences, Chinese Academy of Sciences, 100085 Beijing, China
[e] Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China
[f] Ministry of Education Key Laboratory for Earth System Modelling, Centre for Earth System Science, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- We calculate the provincial CO_2 emissions in China from 2000 to 2012 based on the "apparent energy consumption".
- During 2000 to 2012, Shandong province contributed most to national emissions accumulatively.
- Provinces located in the northwest and north had higher per capita CO_2 emissions and emission intensities.

ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form 28 February 2016
Accepted 17 March 2016
Available online xxxx

Keywords:
CO_2 emissions accounting
Emissions socioeconomics
Energy flows
Chinese provinces

ABSTRACT

This study employs "apparent energy consumption" approach and updated emissions factors to re-calculate Chinese provincial CO_2 emissions during 2000–2012 to reduce the uncertainty in Chinese CO_2 emission estimates for the first time. The study presents the changing emission-socioeconomic features of each provinces as well. The results indicate that Chinese provincial aggregated CO_2 emissions calculated by the apparent energy consumption and updated emissions factors are coincident with the national emissions estimated by the same approach, which are 12.69% smaller than the one calculated by the traditional approach and IPCC default emission factors. The provincial aggregated CO_2 emissions increased from 3160 million tonnes in 2000 to 8583 million tonnes in 2012. During the period, Shandong province contributed most to national emissions accumulatively (with an average percentage of 10.35%), followed by Liaoning (6.69%), Hebei (6.69%) and Shanxi provinces (6.25%). Most of the CO_2 emissions were from raw coal, which is primarily burned in the thermal power sector. The analyses of per capita emissions and emission intensity in 2012 indicates that provinces located in the northwest and north had higher per capita CO_2 emissions and emission intensities than the central and southeast coastal regions. Understanding the emissions and emission-socioeconomic characteristics of different provinces is critical for developing mitigation strategies.

1. Introduction

China's economy has developed rapidly since joining the WTO in 2001. The nation's economy in 2014 was almost 4 times of the size of in 2000. According to the latest energy consumption revision by Chinese Statistics Bureau, China's total energy consumption also increased quickly, from 1470 million metric tonnes coal equivalent (tce) in 2000 to 4260 million metric tce in 2014. The huge amount of energy consumption has led to rapid increase CO_2 emissions recent years (shown in Fig. 1).

As the World's largest CO_2 emitter, China plays an important role in global climate change mitigation. The global emissions decreased slightly by 2015 for the first time, one of the important reasons behind it is Chinese coal consumption decreasing [1]. Contributing to the global climate change mitigation, China has recently pledged to peak its greenhouse gas emissions ahead of

* Corresponding authors at: Institute of Finance and Economics Research, School of Urban and Regional Science, Shanghai University of Finance and Economics, Shanghai 200433, China (J. Liu) and Tyndall centre for Climate Change Research, School of International Development, University of East Anglia, Norwich NR4 7TJ, UK (D. Guan).

E-mail addresses: liu.jianghua@shufe.edu.cn (J. Liu), dabo.guan@uea.ac.uk (D. Guan).

http://dx.doi.org/10.1016/j.apenergy.2016.03.073
0306-2619/

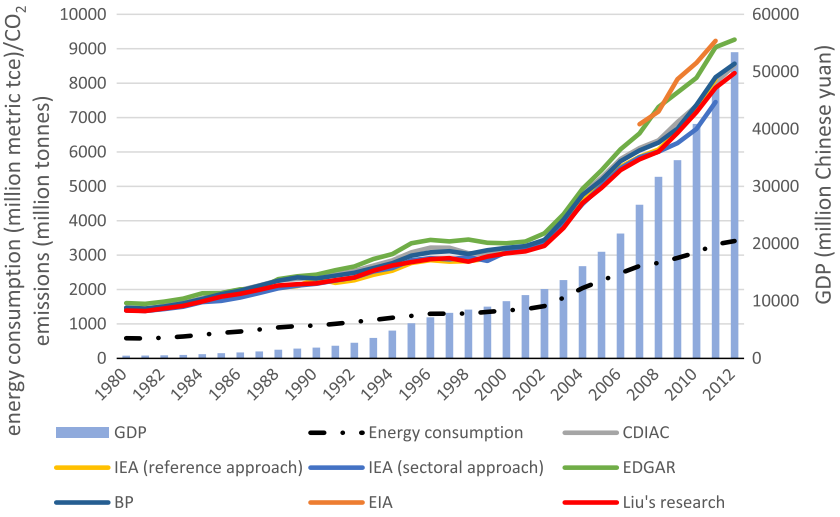

Fig. 1. Total energy consumption, GDP and fossil fuel-related CO_2 emissions growth in China, 1980–2012. *Data sources:* GDP [24], Energy consumption [25], emission estimates by Carbon Dioxide Information Analysis Centre (CDIAC) [26], emission estimates by International Energy Agency (IEA) [27], emission estimates by Emission Database for Global Atmospheric Research (EDGAR) [28], emission estimates by British Petroleum (BP) [29], emission estimates by EIA [30] and emission estimates by Liu's research [31].

2030 [2]. China's national mitigation targets are expected to be allocated to the sub-administrative region [3,4]. Therefore, it is of great importance to develop accurate and most up to date regional CO_2 emission inventories for China.

However, emissions estimated by previous researches [5–18] are generally estimated rather than measured directly. In many circumstances, emissions estimates are relatively uncertain [19,20]. This uncertainty may originate from the accounting scopes, basic energy statistics, the carbon content of fuel, and other potential sources [21,22]. These uncertainties have led to a wide range of CO_2 emission estimations by different world energy research institutions (see Fig. 1). In 2011, the lowest estimate was 7452 million tonnes of CO_2 by the IEA, and the highest estimate was 9229 million tonnes by the U.S. Energy Information Administration (EIA); the difference between these estimates, 1777 million tonnes (23.9%), is nearly equal to the total CO_2 emissions of India or Russia [23].

The uncertainty of China's CO_2 emission estimates mainly comes from two sources. The first is the uncertainty of energy statistics. Previous research on China's CO_2 emissions accounting collected energy consumption data from China's national statistics bureau [32–41]. However, there was a 20% gap between the aggregated energy consumption from 30 provinces and national consumption. Guan et al. [42] reported a gap of 1.4 gigatonnes between CO_2 emissions calculated on the basis of two publicly available official energy datasets for 2010. The gap may be caused by the application of different statistical standards [43] and misuse of units [25] for different provinces and the whole nation. The second source of uncertainty is the difference of estimated emission factors. We reviewed 2368 research articles about China's carbon emissions on the Web of Science published during 2004–2014, We found that most of the previous researches have collected emission factors from the IPCC or China's National Development and Reform Commission (NDRC), whereas fewer than ten studies (less than 1% of total studies) have adopted emission factors based on experiments and field measurements [44–49]. The study show that emission factors from different sources can differ by as much as 40% [31].

In this study we adopt the "apparent energy consumption" and updated emission factors [31] to re-calculate the China's provincial CO_2 emissions from 2000 to 2012 in this study. The new provincial CO_2 emission inventories will help reduce the uncertainty of China's provincial CO_2 emissions and present a clear emission-socioeconomic features of each province. Figuring out the emissions and emission-socioeconomic characteristics of Chinese provinces provide a foundation for both China and global carbon emissions control and industry transfer policy support.

The remaining sections of this paper are structured as follows: Section 2 describes the method and underlying database used in this study. Section 3 presents the results of provincial CO_2 estimation and analyses provincial emission-socioeconomic characteristics. Policy implications and conclusions are given in Section 4.

2. Method and data source

In this study, we calculate Chinese provincial CO_2 emissions based on "apparent energy consumption" and updated emission factors. The inventory includes all the fossil fuel related CO_2 emissions induced within the regional boundary.

2.1. CO_2 emissions calculation

In this study, we estimate fossil fuel-related CO_2 emissions by energy types based on the mass balance of carbon [50]. See Eq. (1),

$$CE_i = AD_i \times EF_i \quad (1)$$

where CE_i are CO_2 emissions from different energy types, AD_i (activity data) are the fossil fuels combusted within the province boundary measured in physical units (metric tonnes of fuel expressed as t fuel), and EF_i are the emission factors for the relevant fossil fuels.

By summarizing the emissions from different energy types together, we obtain the total CO_2 emissions for one province in Eq. (2).

$$CE = \sum CE_i \quad (2)$$

2.2. Data collection

2.2.1. Energy flows and apparent consumption calculations

In general, the energy consumption of one region can be directly calculated as the final consumption plus input usage of transformation, named "final and input/output consumption". Otherwise, it can also be estimated based on the mass balance of

Please cite this article in press as: Shan Y et al. New provincial CO_2 emission inventories in China based on apparent energy consumption data and updated emission factors. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.03.073