Energy and Buildings 96 (2015) 201–209

Contents lists available at ScienceDirect

Energy and Buildings

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

Residential energy-related carbon emissions in urban and rural China during 1996–2012: From the perspective of five end-use activities

Jing-Li Fan[a,b,c,*], Hao Yu[c,d,e], Yi-Ming Wei[c,d]

[a] School of Resources & Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100083, China
[b] State Key Laboratory of Coal Resources and Safe Mining (China University of Mining and Technology), Beijing 100083, China
[c] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China
[d] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[e] Visitor of Energy Policy Research Group, University of Cambridge, Cambridge CB2 1AG, UK

ARTICLE INFO

Article history:
Received 22 January 2015
Received in revised form 13 February 2015
Accepted 13 March 2015
Available online 20 March 2015

Keywords:
Residential carbon emissions
Urban and rural China
CO_2 emission
End-use activities

ABSTRACT

Residential sector is one of the greatest contributors to national CO_2 emissions in China, contributing towards 10.3% in 2012. With rapid urbanization and development in the future, it will inevitably keep increasing, thus it is of great importance to study the characteristics of residential carbon emissions. This paper investigates the carbon emission evolutions during 1996–2012 in urban and rural residential sector, from an end-use perspective. Especially, comprehensive emission factors of electricity and heat in terms of time-series are taken into consideration, and five end-use activities are analyzed. The key findings are: in urban areas, carbon emissions from private transportations grew the fastest and it still has great growth potential in the medium and short term; carbon emissions from space heating and cooling; and cooking and water heating accounted for the largest, with about 40% and 30%, respectively. The growth rates of these are also fast, therefore controls to maintain high standards for degree of comfort are needed. In rural areas, carbon emissions from private transportations also grew fast, even higher than that of urban residents, so it should develop rural public transportation; the rapid growth of carbon emissions from home appliances and lighting reflected the improvement of living conditions and modernization; carbon emissions from space heating and cooling accounted for the largest proportion and has great potential in the future.

1. Introduction

Anthropogenic greenhouse gases (GHG) emissions are the principal reason for climate change, which has become consensus of different countries around the world. It is estimated that fossil energy related GHG emissions account for about 70% of the total global GHG emissions [1]. Among all countries, China has become the biggest energy consumer and CO_2 emitter. National energy consumption in 2012 reached 3.62 billion tce (ton coal equivalent, where one tce equals to 29.31 billion of Joule) [2], accounting for 20% of global energy consumption [3]; Meanwhile, carbon emissions in 2012 was 7.99 billion tons of CO_2, accounting for 26% of global total amount [4]. In the face of huge pressure of addressing climate change and emission reduction, the Chinese government has set a series of quantitative targets. In 2009, China aspired to cut GHG (greenhouse gas) emissions per unit of GDP by 40% to 45% on the basis of the 2005 level. The Twelfth Five-year Plan also set binding targets on energy conservation and emission reduction: in 2015, energy intensity will decline by 16% and CO_2 intensity by 17% compared with 2010. Moreover, according to *the U.S.-China Joint Announcement on Climate Change* in November 2014, China intends to achieve the peak of CO_2 emissions around 2030 and to make best efforts to reach the peak earlier than 2030 [5]. In order to realize these low-carbon targets, it is necessary to introduce measures on energy conservation and emission reduction both in the national scale and the sectoral scale. Residential sector in China is one principle emitter which took up 10.3% of national carbon emissions in 2012, and also a major contributor to the increment with the average growth rate of 6.1% of residential carbon emission during 1996–2012. Therefore, it will be of great importance to study the history variations of residential carbon emissions in China due to its potential implications for China's task of emission reduction.

This work expands and provides further analyses on the basis of data in [6], especially focusing on the carbon emission evolution of

* Corresponding author at: School of Resources & Safety Engineering, China University of Mining & Technology (Beijing), Ding 11# Xueyuanlu Street, Haidian District, Beijing 100083, China. Tel.: +86 10 68918651; fax: +86 10 68918651.
E-mail addresses: fan@cumtb.edu.cn, fjlldq@163.com (J.-L. Fan).

http://dx.doi.org/10.1016/j.enbuild.2015.03.026

five end-use activities. In 2010 the National Bureau of Statistics in China adjusted energy statistics since 1996 dramatically, to avoid the distortions of statistical processing results due to the different statistics calibers. Based on the availability of latest energy data, the time interval of this study is 1996–2012. Specifically, from the perspective of end-uses (household behaviors), we investigated the historical variation in characteristics of residential carbon emissions in the residential sector, using the national statistics as well as other appropriate survey data from literature.

The approach of end-use analysis has great practical significance. First, the carbon emissions in the residential sector are achieved by several end-use activities directly (space heating, cooking, lighting, etc.), so it is necessary to investigate various end-use behaviors to study the carbon intensity in the residential sector. Secondly, each end-use energy-consumer behavior is affected by the technology and activity jointly, so comprehensive research is needed to clarify the impact degrees. Finally, to understand the effects of various energy policies, we need to identify what end-uses the policy will work on, for example, the energy efficiency labeling policy will influence the energy use of electrical appliances and the central heating policy will have an impact on space cooling and heating, and then to understand the roles of different policies in achieving energy savings in the residential sector [7]. In short, research the carbon emissions in the residential sector from the perspective of end-use behaviors is more pertinent and feasible to plan the energy conservation and emissions reduction of the residential sector.

It is more complex for the residential sector than other sectors to study the variation characteristics of carbon emissions from the perspective of end-use behaviors. The industrial sector can be divided into the primary industry, the secondary industry and the tertiary industry. And the industrial sector consists of several industrial sub-sectors and the transportation sector includes passenger and freight. The above are all consistent with the conventional classification method of National Bureau of Statistics, while the residential sector is divided into space heating and cooling, lighting, cooking and water heating, private transportation, etc., according to the needs of different end-uses, which is different from the classification of the statistical data [7].

From previous literature, upon analyzing the characteristics of overall energy consumption or carbon emission in the residential sector, it was found that these studies evaluated the energy-saving technologies from only one or few end-use behavior [8,9], or it carried out the questionnaire survey analysis, taking certain rural or urban area as a unit [10–12]. A handful of documents researched the characteristics of urban and rural carbon emissions in the whole residential sector, integrating each end-use activity. To the best of the authors' knowledge, only a few literature study carbon intensity of the residential sector and its influencing factors from the end-use activities in OECD countries [7,13], but there are no research that focus on end-uses in developing countries except [6], especially China's residential sector. This mainly results from the certain limitations of data mining, so it is difficult to study the carbon emissions of China's residential sector comprehensively from the perspective of end-use activities. However, Fan et al. [6] focused on the bottom-up decomposition results of four drivers of residential carbon emissions in China and very little content directly concerned the features of emissions from the five end-use activities.

In addition, because of the basic characteristics of China's dual economic society, the disparity between urban and rural residents' living standards is directly reflected in the differences of energy-use patterns and energy requirements, for example, urban residents mainly live on natural gas and electricity, while a large number of traditional biomass is used as living fuel in rural areas. Specifically, gas stoves, electric cookers, etc. have been popularized in urban areas, while rural residents still rely on inefficient straw, firewood, briquettes and some liquefied gas stove to boil water or cook. This huge difference requires us to study the emissions characteristics of urban and rural residents separately.

To this end, integrating national statistics and literature survey data, this work calculates and investigates the historical variation characteristics of carbon emissions related with various residential activities in China's urban and rural residential sector during 1996–2012, to provide more direct basis for relevant operational decisions for the emissions reduction of the residential sector and the whole country. The rest of this paper is organized as follows: Section 2 describes the methodology and data, results of the main calculation and discussions are shown in Section 3, and Section 4 concludes and proposes some policy implications.

2. Methodology and data

2.1. Calculation of comprehensive emission factor

IPCC compiled and updated the inventory of carbon emission coefficients of fossil energy, respectively, which have been widely applied in calculation of energy related CO_2 emissions in various countries [14,15]. But the non-fossil secondary energy, heat and electricity have not been given the same importance regarding carbon coefficient inventory. This is due to the following reasons, first, electricity and heat themselves do not emit CO_2 directly; second, to avoid double counting problem, only primary energy related emission is needed when computing regional or one country's emissions; third, it is difficult to figure out one commonly used emission inventory for electricity and heat because they usually vary greatly with yearly period as well as different countries due to different technology, efficiency, input structure and renewable power development. For example, electricity generation from coal, oil, gas and non-fossil energy in China account for 79.00%, 0.20%, 1.80% and 16.60%, respectively, in 2011, while the corresponding share in Japan are 26.96%, 14.71%, 35.86% and 17.74%, and in US are 43.35%, 0.91%, 24.16% and 26.42% [2].

In contrast, however, when computing the energy related emission caused by final consumption of each sector, it would cause problems if we regard emission coefficients of electricity and heat as zero. On the one hand, from global perspective, the sectoral carbon emission would be underestimated due to ignorance of emissions from production process which contains considerable emissions for both kinds of energy. On the other hand, emission calculation results would cause a series of biased judgments such as responsibility allocation of emission reduction for different agents. Therefore, we first figure out the comprehensive carbon factors of electricity and heat in time-series term in China to take into consideration the emissions from the whole system. For this purpose, we calculated the integrated carbon content factor of electricity and heat in China, that is, the implied carbon content per unit of electricity and heat in year t, denoted as $CC_{ele,t}$ and $CC_{heat,t}$, respectively. They can be obtained by the following equations:

$$CC_{ele,t} \equiv \frac{\sum_j \left[E_{j,t}^{ele} \times \left(CC_{j,t}\right)\right]}{\sum_k P_{k,t}^{ele}}, \qquad j \neq \text{ele, heat} \tag{1}$$

$$CC_{heat,t} \equiv \frac{\sum_j \left[E_{j,t}^{heat} \times \left(CC_{j,t}\right)\right]}{Q_t^{heat}}, \qquad j \neq \text{ele, heat} \tag{2}$$

where $E_{j,t}^{elt}$ and $E_{j,t}^{heat}$ mean the amount of the j energy consumption during the electricity generation and heat generation in year t, excluding electricity and heat themselves; $CC_{j,t}$ means the carbon content rate of the j fossil energy in year t, here we assume it remains unchanged during the studied years, that is, technology