Applied Energy 132 (2014) 298–307

Contents lists available at ScienceDirect

Applied Energy

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

Changes of energy-related GHG emissions in China: An empirical analysis from sectoral perspective

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HIGHLIGHTS

- We analyzed the factors impacting China's emissions from a sectoral perspective.
- Sector-specific policies and measures for emissions mitigation were evaluated.
- Economic growth dominantly increased the emissions in the economic sectors.
- Energy intensity decrease primarily reduced the emissions in the economic sectors.
- Residential emissions growth was mainly driven by increase in per-capita energy use.

ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form 1 July 2014
Accepted 8 July 2014

Keywords:
China
Sector
GHG emissions
LMDI

ABSTRACT

In order to better understand sectoral greenhouse gas (GHG) emissions in China, this study utilized a logarithmic mean Divisia index (LMDI) decomposition analysis to study emission changes from a sectoral perspective. Based on the decomposition results, recently implemented policies and measures for emissions mitigation in China were evaluated. The results show that for the economic sectors, economic growth was the dominant factor in increasing emissions from 1996 to 2011, whereas the decline in energy intensity was primarily responsible for the emission decrease. As a result of the expansion of industrial development, economic structure change also contributed to growth in emissions. For the residential sector, increased emissions were primarily driven by an increase in per-capita energy use, which is partially confirmed by population migration. For all sectors, the shift in energy mix and variation in emission coefficient only contributed marginally to the emissions changes. The decomposition results imply that energy efficiency policy in China has been successful during the past decade, i.e., Top 1000 Priorities, Ten-Key Projects programs, the establishment of fuel consumption limits and vehicle emission standards, and encouragement of efficient appliances. Moreover, the results also indicate that readjusting economic structure and promoting clean and renewable energy is urgently required in order to further mitigate emissions in China.

1. Introduction

Since the Kyoto agreement in 1997, greenhouse gas (GHG) emissions have become an urgent priority of global environmental policy. As the world's largest primary energy consumer and GHG emitter, China was responsible for 25% of global energy resource consumption and 20% of global GHG emissions in 2009 [1]. The increase in China's emissions was also remarkable in recent years. According to a report from IEA [2], the growth in carbon dioxide (CO_2) emissions in China since 2000 was larger than the total level of emissions in 2012 from the other BRICS countries (Brazil, Russia, India, China, and South Africa) combined. Undoubtedly, China has a critical role in global emissions mitigation. In 2009, the Chinese government committed that by 2020, the CO_2 emission intensity of its gross domestic product (GDP) would be reduced by 40–45% compared with 2005 levels [3]. This commitment may be a difficult task, but is also an achievable goal.

To cope with the emission issue, the Chinese government has enacted a series of policy measures to mitigate emissions over the past decade. For example, in the agriculture sector, cleaner production technologies have been widely promoted, encouraging the improvement of farming practices, rational application of fertilizer, and the adoption of diversified crop systems [4]. In the industrial

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http://dx.doi.org/10.1016/j.apenergy.2014.07.025
0306-2619/

sector, uneconomic enterprises with high energy consumptions have been closed down [5]. A series of programs such as the "Top-1000 Enterprises Energy Saving Program" and the "10 Key Energy Saving Projects Program"[1] have been implemented [6]. In the transportation sector, vehicle emission standards and fuel consumption limits were established, and energy consumption taxes to penalize energy-inefficient vehicles were enacted [7]. In the commercial & service sector, national energy-efficient design standards for commercial buildings and electric equipment were implemented [7]. As for the residential sector, standards have also been established to improve the energy efficiency of buildings and appliances[2] [7]. However, the effects of these policies and measures on emissions mitigation are still unknown. Consequently, it is important to explore their impacts.

Decomposition analysis serves as a very effective tool to quantify factors impacting changes in emissions; it also allows investigation of the effects of policies and measures in terms of emissions reductions of the economy as a whole, and its separate sectors. In recent years, an increasing number of researchers have used decomposition analysis to study changes in emissions (i.e., CO_2 emissions and GHG emissions) in various countries, including Portugal [8], Soviet Union [9], Ireland [10], Italy [11], Turkey [12], Latin America [13], Brazil [14], European Union [15], Korea [16], United Kingdom [17], and Greece [18].

In the case of China, decomposition analysis of emissions has also been extensively applied. Wang et al. [19] analyzed the changes in aggregate CO_2 emissions in China from 1957 to 2000 based on an LMDI method. This study indicated that China has considerably decreased its CO_2 emissions, mainly through improvements in energy intensity. Wu et al. [20] investigated the driving forces behind CO_2 emissions in China from 1985 to 1999 using the three-level decomposition method. This study indicated that a decrease in energy intensity along with a slowdown in the growth of average labor productivity of industrial enterprises may have been the dominant contributors to the decrease in China's CO_2 emissions. Fan et al. [21] quantified the driving force behind China's primary energy-related carbon intensity, demonstrating that the overwhelming contributor to the decline of energy-related carbon intensity was the reduction in real energy intensity. Zhang et al. [22] utilized an LMDI method to analyze the nature of the following four factors: CO_2 intensity, energy intensity, structural changes, and economic activity. The results showed that economic activity has the largest positive effect on CO_2 emission changes in all of the major economic sectors and that China has achieved a considerable decrease in CO_2 emissions mainly due to improvements in energy intensity. More recently, Tan et al. [23] examined the driving forces behind the reduced CO_2 emission intensity in China between 1998 and 2008, paying special attention to activities related to the electric power industry. Several other decomposition studies, however, focused on the emissions in one specific sector of China. For example, Liu et al. [24] explored the factors influencing carbon emissions of the industrial sector. Wang et al. [25] and Loo et al. [26] decomposed the emissions in the transport sector. Zha et al. [27] and Fan et al. [28] studied the driving forces of emissions in the residential sector.

Even though decomposition analysis has been widely applied in China, previous studies have only focused on aggregate emissions or specific sectors (e.g., industry, transport, and residential sector), little attention has been paid to sectoral disparities in the driving forces of emissions. More importantly, the underlying policies and measures behind the decomposition results for each specific sector were not fully discussed and evaluated in the previous studies. Because a large series of sector-specific policies, notices, and measures have been put in place to mitigate emissions in China over the past decade, a comparative evaluation of them is urgently required.

This study applies an LMDI decomposition method to analyze the changes in energy-related GHG emissions in China, placing a focus on the sectoral disparities in the driving forces of emissions. Five sectors are considered, including four economic sectors (agricultural, industrial, transportation, and commercial & service) and a residential sector. Moreover, based on the results of the decomposition analysis, the underlying policies and measures implemented for each specific sector of China in recent years are evaluated. The period examined in the study spans from 1996 to 2011. The results of the study aid in identifying suitable policy measures needed to address the key driving forces of emissions at the sectoral level. They also provide some insights into the future direction of emission mitigation strategies in China.

The rest of this paper is organized as follows. Section 2 discusses methodology, including the estimation of energy-related GHG emissions, the decomposition method, and the assumptions and boundaries used in the current study. Section 3 provides the data sources, while Section 4 introduces the specific case of China. The results of the decomposition analysis are reported in Section 5. Section 6 concludes the study and Section 7 offers some policy recommendations.

2. Methodology

2.1. Estimation of energy-related GHG emissions

In this study, carbon emissions are expressed in carbon dioxide equivalents (CO_2e). GHG emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), were all converted into carbon dioxide equivalents by multiplying by the global warming potential (GWP) parameters, which are 1, 21 and 310 for CO_2, CH_4 and N_2O, respectively [29]. Following the Intergovernmental Panel on Climate Change (IPCC) 2007 guideline, the total energy-related CO_2 emissions in China can be calculated based on energy consumption, emission factors, and the fraction of oxidized carbon by fuel as follows:

$$CO^t_{2_i} = \sum_j CO^t_{2_{ij}} = \sum_j E^t_{ij} \times EF_j \times O_j \quad (1)$$

where $CO^t_{2_{ij}}$ refers to direct CO_2 emissions based on fuel type j in sector i in year t (Mt); $CO^t_{2_i}$ refers to the total energy-related CO_2 emissions in sector i in year t (Mt); E^t_{ij} refers to the consumption of fuel j in sector i in year t (TJ); EF_j refers to the carbon emission factor of the fuel j (ton CO_2/TJ); and O_j refers to the fraction of the carbon oxidized by fuel type j.

The carbon emission factors (EFs), oxidation rate, and net calorific value of the 16 considered fossil fuels are listed in Table 1. The CH_4 and N_2O emissions can also be estimated based on equations similar to Eq. (1) using their respective emission factors, as observed in Table 1. All emissions types were ultimately converted into CO_2e emissions by multiplying by their GWP parameters. They were added together to obtain the total energy-related GHG emissions (t CO_2e).

GHG emissions from heat and electricity were calculated from fuel combustion in power generators and then redistributed to the five sectors proportional to their consumption of heat and electricity as given in the energy balances. It should be noted that only considering the electricity generated from fossil fuels fails to show

[1] Refer to [7] for a detailed explanation of these two programs.

[2] China currently has three major programs of appliance standards and labeling, including Mandatory minimum efficiency standards, Voluntary energy-efficiency labeling, and Mandatory energy information labeling. Refer to [7] for further explanations of these programs.