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Viewpoint

Decomposition analysis of CO_2 emissions from electricity generation in China

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ABSTRACT

Electricity generation in China mainly depends on coal and its products, which has led to the increase in CO_2 emissions. This paper intends to analyze the current status of CO_2 emissions from electricity generation in China during the period 1991–2009, and apply the logarithmic mean Divisia index (LMDI) technique to find the nature of the factors influencing the changes in CO_2 emissions. The main results as follows: (1) CO_2 emission from electricity generation has increased from 530.96 Mt in 1991 to 2393.02 Mt in 2009, following an annual growth rate of 8.72%. Coal products is the main fuel type for thermal power generation, which accounts for more than 90% CO_2 emissions from electricity generation. (2) This paper also presents CO_2 emissions factor of electricity consumption, which help calculate CO_2 emission from final electricity consumption. (3) In China, the economic activity effect is the most important contributor to increase CO_2 emissions from electricity generation, but the electricity generation efficiency effect plays the dominant role in decreasing CO_2 emissions.

1. Introduction

The global warming has become a serious issue in the world since the late 1980s. Among six kinds of GHG, the largest contribution to the greenhouse effect is carbon dioxide (CO_2), and its share of greenhouse effect is about 56% (IPCC, 1995). Next to the United States, China has become the second-largest CO_2 emitter in the world. So China is facing greater pressure to cut its CO_2 emissions down. In 2009, Chinese government announced it would cut its CO_2 emissions per unit of GDP by 40% to 45% in 2020 from 2005.

Since the start of economic reforms and opening-up in the late 1970s, China has experienced spectacular economic growth. Its electricity consumption rose from 77.63 Mtce in 1991 to 427.37 Mtce in 2009, representing an annual average growth rate of 9.93% (CESY, 2010). In 2009, thermal power accounted for 80.29% of the total electricity supply and 97.03% thermal power was generated by coal products, which has led to plenty of CO_2 emissions and huge pressure on reducing CO_2 emissions. A deeper understanding how CO_2 emissions from electricity generation evolves in China is very important in formulating future policies. Thus it is very necessary to investigate the driving forces governing CO_2 emissions from electricity generation and their evolution. In order to accomplish this purpose, the proper approach is to decompose the evolution of CO_2 emissions from electricity generation into the possible affecting factors.

In the literature, the index decomposition analysis (IDA) has been used, successfully so far, to quantify the impact of different factors on the change of energy consumption and CO_2 emissions. The complete decomposition method generalized by Sun (1998) is used to study energy consumption in China. Ang and Zhang (2000) presented a survey of IDA in energy and environmental studies. Paul and Bhattacharya (2004) utilized complete decomposition method to study energy-related CO_2 emissions in India. The results showed that economic growth had the largest positive effect in CO_2 emissions changes in all the major economic sectors and the energy intensity had a greater impact on energy-induced CO_2 emission. There are a variety of different indexing methods that can be used in IDA (Ma and Stern, 2008), they used the LMDI techniques to decompose changes in energy intensity in the period 1980–2003 and found that technological change is confirmed as the dominant contributor to the decline in energy intensity. Ang (2004) provided a useful summary of the various methods and their advantages and disadvantages and concluded that the LMDI method was the preferred method, due to its theoretical foundation, adaptability, ease of use and result interpretation, along with some other desirable properties in the context of decomposition analysis.

Nowadays, some researchers have devoted to investigate the decomposition analysis of the electricity consumption and CO_2 emissions from electricity generation. Based on completed decomposition technique, Steenhof (2006) studied electricity demand in China's industrial sector during the period 1998–2002 and found that

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both increased industrial activity and fuel shifts helped increase industrial sector electricity demand between 1998 and 2002. Al-Ghandoor et al. (2010) also used this method to analyze electricity use in the Jordanian industrial sector and found that increased industrial production caused electricity demand to increase between 1998 and 2005, significant improvements in energy efficiency and structural shift had contributed to reducing the rate of this increase. Wang et al. (2010) applied the LMDI method to analyze the potential factors influencing the growth of electricity consumption in China's industrial sector over the period 1998–2007 and concluded that structural change had contributed to the increase in electricity consumption; in contrast, the technological effect was responsible for a decrease in electricity consumption during this period. The LMDI method was also used by Malla (2009) to examine the role of the factors affecting the evolution of CO_2 emissions from electricity generation in seven countries.

To our knowledge so far only one study by Malla (2009) has used systematically the decomposition technique on the CO_2 emissions from electricity generation in China. That paper only considered three factors: electricity production, electricity generation structure and energy intensity of electricity generation. Thus this paper serves as a preliminary attempt to apply the LMDI method to analyze the contribution of six factors influencing China's CO_2 emissions from electricity generation during the period 1991–2009.

This paper is organized as follows. Section 2 presents the method used to estimated CO_2 emissions from electricity generation and the LMDI approach used to decompose the change of CO_2 emissions over time. Section 3 discusses data used. The analysis of CO_2 emissions from electricity generation is presented in Section 4. Finally, we conclude this study.

2. Methodology

2.1. Estimation of CO_2 emissions

Following the IPCC (1995) method, the total CO_2 emissions from electricity generation in a year is estimated by

$$C = \sum_i E_i \times F_i \times O_i \times M \tag{1}$$

where the subscript i represents fuel type; E_i denotes energy consumption based on fuel type i; F_i is the carbon emission factor of the ith fuel ($t\text{-}C/TJ$); O_i is the fraction of the carbon oxidized based on fuel type i; and M is the molecular weight ratio of carbon dioxide to carbon (44/12). In this paper, CO_2 emissions is measured by Million tons (Mt).

The carbon emission factors (F) and the fraction of carbon oxidized (O) are given in Table 1. Because the 1991–2009 period analyzed in this paper is a relatively short term, we assume that the carbon emission factors of coal, gasoline, kerosene, diesel oil, fuel oil and natural gas are constant. In fact, these coefficients have changed over time because of a change in grade of fuels; these changes are so small that they are negligible when we analyze the macro changes in CO_2 emissions.

2.2. Decomposition of CO_2 emissions

The CO_2 emissions from electricity generation (C) can be expressed as Eq. (2)

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i} \times \frac{E_i}{ELF_i} \times \frac{ELF_i}{ELF} \times \frac{ELF}{EL} \times \frac{EL}{GDP} \times GDP = \sum_i CF_i \times EI_i \times ES_i \times EFS \times ELI \times GDP \tag{2}$$

Table 1
Carbon emission factors and fractions of carbon oxidized.
Source: IPCC[1].

Fuel	EF(t-C/TJ)	O
Coal	25.8	0.9
Coke Oven Gas	12.1	0.9
Other Gas	12.1	0.9
Crude Oil	20	0.98
Gasoline	19.1	0.98
Kerosene	19.6	0.98
Diesel Oil	20.2	0.98
Fuel Oil	21.1	0.98
LPG	17.2	0.98
Refinery Gas	15.7	0.98
Other Petroleum	20	0.98
Natural Gas	15.3	0.99
Other Energy	25	0.98

where C_i denotes CO_2 emissions based on fuel type i; ELF_i denotes thermal power generation based on fuel type i; ELF denotes thermal power generation; EL denotes total electricity generation;GDP as the gross domestic production; $CF_i{=}C_i/E_i$ is the CO_2 emissions coefficient of i fuel type; $EI_i{=}E_i/ELF_i$ is the electricity generation efficiency based on fuel type i; $ES_i{=}ELF_i/ELF$ is the share of electricity generation based on fuel type i in total thermal power generation; $EFS{=}ELF/EL$ is the share of thermal power generation in total electricity generation. $ELI{=}EL/GDP$ is the electricity intensity.

According to the LMDI method given by Ang (2004), differentiating Eq. (2) with respect to time yields:

$$\begin{aligned}\dot{C} = &\sum_i \dot{CF_i} \times EI_i \times ES_i \times EFS \times ELI \times GDP \\ &+\sum_i CF_i \times \dot{EI_i} \times ES_i \times EFS \times ELI \times GDP \\ &+\sum_i CF_i \times EI_i \times \dot{ES_i} \times EFS \times ELI \times GDP \\ &+\sum_i CF_i \times EI_i \times ES_i \times \dot{EFS} \times ELI \times GDP \\ &+\sum_i CF_i \times EI_i \times ES_i \times EFS \times \dot{ELI} \times GDP \\ &+\sum_i CF_i \times EI_i \times ES_i \times EFS \times ELI \times \dot{GDP}.\end{aligned} \tag{3}$$

The right-hand side of Eq. (3) can be written in terms of growth rates:

$$\begin{aligned}\dot{C} = &\sum_i g_{cf} \times C_i + \sum_i g_{ei} \times C_i + \sum_i g_{es} \times C_i + \sum_i g_{efs} \times C_i \\ &+ \sum_i g_{eli} \times C_i + \sum_i g_{gdp} \times C_i.\end{aligned} \tag{4}$$

where g_{cf}, g_{ei}, g_{es}, g_{efs}, g_{eli} and g_{gdp} are growth rates of the CO_2 emissions coefficient, electricity generation efficiency, share of electricity generation, share of thermal power generation, electricity intensity and GDP at different levels of desegregations. The next step is to integrate both sides of Eq. (4) with respect to time interval [0 t]:

$$\begin{aligned}\Delta C = &\int_0^t \sum_i g_{cf} \times C_i dt + \int_0^t \sum_i g_{ei} \times C_i dt + \int_0^t \sum_i g_{es} \times C_i dt \\ &+ \int_0^t \sum_i g_{efs} \times C_i dt + \int_0^t \sum_i g_{eli} \times C_i dt + \int_0^t \sum_i g_{gdp} \times C_i dt.\end{aligned} \tag{5}$$

To solve the integrals, the logarithmic mean weight function based on its desirable properties is used and can be expressed