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Investigating driving forces of aggregate carbon intensity of electricity generation in China

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ABSTRACT

In addition to total CO_2 emissions, an intensity indicator is also important to assess CO_2 emissions from electricity generation, allowing the spatial differences to be analyzed, which is crucial for regionally heterogeneous countries like China. This study analyzed the driving forces of aggregate carbon intensity (ACI), a measure of CO_2 emissions per unit of electricity generation, in China between 1995 and 2014, using the LMDI method incorporating geographical effects. Both the entire study period and individual 5-year periods were analyzed. The results show that the geographic distribution effect, utilization efficiency effect, and thermal power proportion effect were responsible for a decrease in ACI during this period, whereas the energy composition effect showed an inhibitory influence on reduction. The dominant factor was the utilization efficiency effect, and the thermal power proportion effect showed the largest growth. Geographic distribution is a non-negligible factor in the reduction of ACI, and the regional ACI can be reduced by redistributing electricity generation to areas with lower ACI through trans-regional policy guidance. For future policies on reduction of ACI from electricity generation, this study proposes focusing on the thermal power proportion and geographic distribution effects to the same extent as on the utilization efficiency effect.

1. Introduction

Increasing global average surface temperature has been observed for over half a century, and it is highly probable that anthropogenic factors, including greenhouse gas (GHG) emissions caused by human activities, are the main causes of this increase (IPCC, 2014). GHG emissions from electricity generation constitute a considerable proportion of global GHG emissions (IPCC, 2014). In 2011, China surpassed the United States and became the largest power generator in the world (EIA, 2016). China's estimated CO_2 emissions from electricity production increased by 277.42% from 1995 to 2014. However, the CO_2 emission intensity related to electricity production in China (CO_2 emissions per unit of electricity generation) decreased by −29.81% in the same period, which indicates some mitigation of the environmental impact caused by electricity generation.

Many studies have attempted to understand carbon emissions from electricity production by considering this issue from different angles, including calculation of carbon emissions, reduction potential forecasting, and analysis of influencing factors. The first approach concentrates on accurate calculation of carbon emissions from electricity, including emissions from fossil fuel combustion (Ari and Koksal, 2011), emissions from a life-cycle assessment perspective (Cao et al., 2016), marginal carbon emissions intensity (Harmsen and Graus, 2013), as well as emission coefficients for electricity production and consumption (Ji et al., 2016; Lindner et al., 2013). The second group of studies considers that there are various zero-carbon and renewable alternative electricity generation technologies available, therefore, there is significant potential for CO_2 reduction in the electricity sector. Many of these studies include quantitative analyzes of potential mitigation of CO_2 emissions from the electricity sector, by considering factors such as economic development, technological advances, and implementation of improved management measures (Saysel and Hekimoğlu, 2013; Telsnig et al., 2013; Li et al., 2013; Chen et al., 2011; Ari and Koksal, 2011; Cai et al., 2007; Mago and Luck, 2017). In addition, some studies conducted empirical analyses of influencing factors of carbon emissions from the electricity sector. Van den Bergh et al. (2013) studied the impact of renewable electricity sources on CO_2 reduction in the European electricity sector. Grant et al. (2016) conducted an empirical analysis of factors influencing CO_2 reduction from the perspective of power plants worldwide, and Cao et al. (2016) considered the influence of

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distributed generation.

Other than the above-mentioned studies, lots of studies adopted the LMDI (Logarithmic Mean Divisia Index) method to analyze the driving factors of carbon emissions from electricity generation due to its adaptability, ease of use and ease of understanding as well as result presentation (Ang, 2004). Studies using LMDI method show that, at present, a consensus has been reached regarding the driving forces of total CO_2 emissions from electricity generation in China. Several studies (Zhang et al., 2013a; Gu et al., 2015; Zhou et al., 2014; Yan et al., 2016; Yang and Lin, 2016) have analyzed CO_2 emissions and driving factors related to electricity generation in China over the period from 1985 to 2012. Three classes of factors were studied, including economic and social development factors, structural factors, and efficiency factors. GDP, electricity generation per GDP, electricity consumption, electricity generation, and population are all indicators of economic and social development. Structural factors include electricity-related energy source composition (share of coal power, hydropower, wind power, nuclear power etc.) and the composition of energy sources used in thermal electricity generation. Efficiency factors consist of the emission factor of fossil fuels, the energy efficiency of thermal electricity generation, and the line loss rate. The previous studies above indicate that, for electricity generation in China, the primary drivers of CO_2 emissions are economic development and the increasing demand for electricity, whereas energy efficiency, and the composition of electricity and thermal power related energy sources all show varying degrees of inhibiting effects on CO_2 emissions.

An intensity indicator is important for analyzing CO_2 emissions from electricity generation because it disregards the underlying impacts of economic growth and the accompanying increase of electricity demand (Ang and Su, 2016) so that spatial differences in the environmental impact of electricity production can be analyzed. In addition, for a very large country such as China, an intensity indicator is appropriate for assessing regional carbon emissions and setting domestic reduction targets. Ang and Su (2016) and Ang and Goh (2016) studied the aggregate carbon intensity (ACI) and its driving factors on a global scale and within the ASEAN area. Mutual influencing factors analyzed in these two studies are the share of fossil fuels, the mix of fossil fuels, thermal efficiency, and emission factors. Results show that the main factor reducing the global ACI is thermal efficiency, but large differences exist in the performance of driving factors between countries, regardless of whether the scope is global or within the ASEAN community.

It is worth noting that more and more studies have started to focus on the geographic (or regional) effects on the CO_2 emissions. Some studies identified regional differences by comparing the decomposition results in different regions (Yan et al., 2016; Liu et al., 2012; Xu et al., 2014; Chen et al., 2016). Other studies regard the geographic effect as a structural influencing factor and incorporate it into the analysis model, under the hypothesis that, if the structure of electricity production shifts among sub-regions, the ACI and CO_2 emissions of the whole region can be influenced.[1] In their study of global ACI, Ang and Su (2016) found that there is an apparent anomaly between the fairly significant drop of ACI in many countries and the marginal decrease at the global level. For this reason, they included the geographic shift effect in the influencing factors. Their results showed that the global geographic shift in electricity generation, i.e., countries with relatively high ACI increasingly represent a larger share in electricity production during the study period, inhibited the global decrease in ACI. According to their study, the dominant factor that encourages a global ACI decrease is the thermal efficiency of fossil fuel generation; the reductive effect resulting from changes in the fossil fuel mix and in the share of electricity generated from fossil fuels are relatively very small. Zhou et al. (2014) analyzed the driving factors of CO_2 emissions from China's regional thermal electricity generation between 2004 and 2010, and considered the shift in regional distribution of electricity generation, but results of this study show that this regional factor is insignificant for changes in carbon emissions; this study failed to assess the driving mechanism of this regional factor on the ACI. However, the study period of this study was fairly short and the results could therefore not properly reflect the geographic shift in electricity production in China in recent years. In addition, several influencing factors, especially the mechanism behind the geographic shift effect, on China's ACI from electricity generation were not analyzed. From the perspective of power policy, as inter-regional electricity delivery has gradually been implemented in China (Zeng et al., 2016), the environmental impact of this power management measure has gained great attention, especially its CO_2 emissions reduction potential (Lindner et al., 2013; Chen et al., 2014).

Considering the primary energy utilization and the geographical distribution of electricity generation, this study builds the decomposition model to analyze the driving forces of carbon emission intensity from electricity generation by adopting the data in China between 1995 and 2014. Four main effects are included into the analysis: the geographic distribution effect, thermal power proportion effect, utilization efficiency effect, and energy composition effect. In addition, the domestic policies related to these effects are fully discussed and future policy focuses for regional ACI reduction are proposed based on China as a representative case. Section 2 of this paper presents the calculation method, decomposition method, and data sources used to estimate the ACI and the influence of each driving force; Section 3 analyzes the characteristics of electricity generation and relevant CO_2 emissions in China; calculation results using the LMDI method are presented and discussed in Section 4; and conclusions and policy implications are presented in Section 5.

2. Methodology and data

2.1. Calculation method

Guided by the Interim Measures for the Promotion and Management of Energy Saving and Low Carbon Technologies issued by the National Development and Reform Commission (NDRC, 2014), in each year, total CO_2 emission at the domestic level from electricity generation can be calculated by the following formula:

$$C = \sum C_{ij} = \sum E_{ij} \times EF_i \quad (1)$$

where C is the total CO_2 emission from electricity generation in China; C_{ij} and E_{ij} represent the CO_2 emission and fossil fuel consumption for electricity generation of fossil fuel i in province j, respectively; EF_i denotes the CO_2 emission factor of fossil fuel i. There are 12 types of fossil fuels and 29 provinces included in the calculations in this study, specified in Section 2.3.

In this study, an important indicator is adopted, the ACI (aggregate carbon intensity), to show the CO_2 emission level from electricity generation in China, which was introduced by Ang and Su (2016). The ACI of China in each year is calculated as follows:

$$V = \frac{C}{G} \quad (2)$$

where V represents the ACI in a given year in China, and C and G denote the CO_2 emission and total electricity production in China, respectively, in the same year.

In addition, this study also analyzes the differences in ACI between all provinces in a later section. The ACI at the provincial level in a

[1] To give an intuitive example, suppose that region A comprises only sub-regions B and C. In 2010, the ACI values for B and C are 0.6 and 0.8 $kgCO_2/kW·h$, and the electricity production for each is 100 and 300 kW h (proportions of 25% and 75%), respectively. In 2011, if the electricity productions for B and C change to 80 and 320 kW h (proportions of 20% and 80%), even if the ACI values for the two sub-regions remain the same, the ACI for region A would increase from 0.75 to 0.76 $kgCO_2/kW·h$, and the total CO_2 emission of region A would increase from 300 kg to 304 kg.