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CO_2 emission changes of China's power generation system: Input-output subsystem analysis

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ABSTRACT

With the rapid development of economy, China's electric power consumption has increased sharply. Its carbon emissions derived from power generation now accounts for more than 45% of the national emissions. This study employs a structural decomposition analysis based on input-output subsystem model to explore sources for emissions increments in China's power sector from 2007 to 2015. Under this approach, the influential factors are classified into four categories. Quite a few scenarios are designed to further assess the impacts of power mix and the levy of carbon tax. The results show that the consumption is the main driving growth factor of CO_2 emissions, and most of the emissions are driven by continuing expansion of large-scale infrastructure, and this trend seems going to change in the future; carbon tax and price policies may be the alternative for reducing the emissions. In addition, both the generation efficiency and internal industrial structure are critical factors in emission reduction. Besides, cleaner energy sources effectively lead to carbon emission reduction but this change performs a relatively small effect. Finally, promoting the development of non-fossil energy power may lead to total CO_2 emissions perform decrease trend before 2030.

1. Introduction

The amount of greenhouse gases (GHG) in the atmosphere is increasing, which is leading to golobal climate change. The main anthropogenic driver of GHG emissions is fossil fuel combustion(Cansino et al., 2016). Among them, the electricity system accounted for more than 42% of fuel-led emissions worldwide in 2014 alone (IEA, 2016). In China, electricity is predominantly generated from thermal power plants; this high proportion is reflected in the fact that the power sector accounted for more than 48% of CO_2 emissions derived from fossil fuel combustion in 2014 (IEA, 2016). Thus, China has pledged not to allow its carbon emissions to go beyond their 2030 projection by reducing emissions intensity by 60–65% from 2005 to 2030. Accordingly, the power sector plays a critical role in achieving this goal, increasing the urgency to promote energy conservation and emission reduction in this sector. Analysis on the driving factors that may affect CO_2 emissions from the power sector may benefit policy formulation regarding energy conservation and emission reduction issues.

Considering the importance of the power sector, numerous studies have focused on the driving factors for CO_2 emissions. Due to the flexibility of modelling an aggregate indicator at the sectoral level, the index decomposition analysis (IDA) technique has been widely adopted. For example, from production perspective, Shrestha and Timilsina (1996) decomposed CO_2 intensity changes into generation mix effect and fuel intensity effect in studying the power generation sectors of some Asian countries, and they found an increasing trend of fuel intensity effect. In addition, the factors affecting changes in CO_2 emissions or CO_2 intensity of power sector were extended to the energy efficiency, fossil fuel mix, transmission and distribution (T&D), auxiliary (Steenhof, 2007), fuel quality (Shrestha et al., 2009), industrial scale and capital productivity (Zhao et al., 2016) effects. Besides, the influence of socioeconomic drivers related to CO_2 emissions of power sector—such as electricity intensity, level of activity (Hou and Shi, 2014; Zhang et al., 2013), electricity trade (Hou and Shi, 2014; Karmellos et al., 2016), population, economic growth (Sumabat et al., 2016; Yan et al., 2016), urbanization level, and industrial structure (Yan et al., 2017)—have also been discussed.

Despite contributions to mitigating CO_2 emissions, these aforementioned studies only analyzed the direct emission in power generation with a focus on production, while ignoring the indirect effects of consumption. Moreover, these studies, based on the IDA technique, did not identify the critical sectors that predominantly contribute to CO_2

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emission growth.

Electric power is the dominant secondary energy that provides support for almost all the industries. However, lack of attention to the indirect effects of the power sector may undermine emission reduction efforts (Yuan and Zhao, 2016). Against the backdrop of Chinese supply-side structural reform, this interaction is further strengthened; it is meaningful to take sectoral links into consideration when exploring critical factors for emission mitigation in the power sector.

Structural decomposition analysis (SDA) based on the I-O table allows researchers to analyze the internal production linkages within an economy. It has been widely applied in the analysis of factors that influence changes in energy consumption and CO_2 emissions (Brizga et al., 2014). Due to the application of the I-O model, SDA can distinguish direct and indirect production effects through the Leontief inverse matrix (Feng et al., 2017; Wang et al., 2017a). The impact of production technology and consumption patterns can thus be revealed from a supply chain perspective. Many scholars used SDA to analyze influencing factors in CO_2 emissions in different economies, such as China (Liang and Zhang, 2011; Wei et al., 2017), Korea (Lim et al., 2009), Spain (Cansino et al., 2016), and so on. In addition, influencing factors of CO_2 emissions embodied in China's exports and residential consumption were studied based on SDA (Xu et al., 2011; Zhu et al., 2012). Furthermore, SDA has also been applied in the analysis of emissions in economic sectors like manufacturing (Lim et al., 2009; Yuan and Zhao, 2016) and tertiary industries (Butnar and Llop, 2011; Yanmei et al., 2015). Generally, the factors in these studies can determine the effect of intermediate demand, consumption structure, final use scale in CO_2 emission changes (Cansino et al., 2016; Liang and Zhang, 2011; Yanmei et al., 2015), which cannot be determined by the IDA technique. Besides, critical, influential sectors can be identified by the coefficient gaps due to the advantage of I-O tables too. Considering the aforementioned advantages, the SDA technique is an appropriate tool to explore the driving sources for CO_2 emission changes in the power sector, whereby related literatures are still limited.

In order to analyze the power sector without separating it from the rest of economic system, we use the subsystem input-output framework, which allows us to study the importance of the power generation sector as a whole in the economic system, and to examine the role played by its different activity branches and their relationship with other productive sectors. This method has been previously applied in CO_2 emissions analysis of service industries in Spain (Alcántara and Padilla, 2009; Butnar and Llop, 2011) and energy-intensive industries in China (Yuan and Zhao, 2016). These studies calculated the changes of CO_2 emissions with a focus on production and consumption using SDA. Critical driving factors and influential sectors that impact CO_2 emissions on specific sectors were further examined.

The original I-O table uses an aggregated entry for the electricity sector. It assumes that each electricity generation technology is an average of that sector in China. However, the embedded CO_2 emissions in a unit of renewable power are significantly less than that of thermal power, and the upstream emissions of power plants vary significantly (Lindner et al., 2013). Besides, China pledged to increase its non-fossil energy proportion to 15% by the end of 2020 in its 13th Five Year Plan (FYP) for Energy Development; and the corresponding share will be further increased to 20% in 2030. Meanwhile, renewable power will accounts for 39% of nationally installed capacity with 27% of national power production by the end of 2020. Evidently, the increased share of renewable power calls for a different energy consumption and emission coefficient compared to the thermal power sector. Though renewable power was considered an effective measure to reduce emissions(Su and Ang, 2016; Zhou et al., 2015), studies on wind (Nagashima et al., 2017; Yang and Chen, 2016), solar (Kaufmann and Vaid, 2016), and biomass direct-fired (Wang et al., 2015) powers indicated that carbon emissions in different renewable power vary significantly from life cycle perspective.

According to Lenzen (2011), the disaggregation of economic I-O data leads to a smaller relative error than aggregating table even based on partial information. Therefore, it is appropriate to use Chinese I-O tables with a disaggregated electricity sector to explore the driving factors of CO_2 emissions in the electricity system. This study will disaggregate the electricity sector into six categories—a transmission and distribution (T&D) sector and five different power generation sectors for analysis.

To the best of our knowledge, this is the first attempt to introduce the subsystem input-output model with disaggregated power sectors to analyze the decomposition of embedded CO_2 emissions in China's power sector. Under this approach, the direct and indirect emissions from the power sectors are both taken into account; the results may provide novel and detailed information to the patterns that determine changes in CO_2 emissions of China's power sectors from 2007 to 2015. This study may also offer valuable suggestions for emission reduction policies.

The remaining paper is organized as follows. Section 2 develops the disaggregation process and decomposition model. Section 3 presents the results of the decomposition model. Section 4 discusses the critical factors behind the results, while Section 5 concludes our study.

2. Materials and methods

The electricity sector in national I-O table is split into six subsectors. To be consistent with the energy statistics, the initial 42×42 input-output tables are first aggregated into 39×39 tables, and then, the adjusted table's size is 45×45 after disaggregating. The sector information of the disaggregated I-O table and corresponding abbreviations can be seen in Table A1.

2.1. Disaggregating the electricity sector

Referring to Lindner et al. (2013), the Production and Supply of Electric Power and Heat Power sector in the I-O table is first disaggregated to generation sector and T&D sector. The former is further disaggregated into five subsectors according to type of generation—hydroelectric, thermal, nuclear, wind, and the other power generation sectors. According to existing studies, turnover (Wiedmann et al., 2011) and investment data (Lindner et al., 2013) are usually used to separate the aggregated electricity sector. Due to unavailability of turnover data for China's generation and grid companies, we estimate the approximate values of generation sector based on the amount of electricity generated the feed-in tariff, and sale price. Thus, we obtain the estimated gross output of generation and T&D sectors. Furthermore, we split their inputs by referring to the ratio of added values of China Southern Power Grid,[1] investment of power generation and T&D sectors. In addition, their outputs are disaggregated according to their corresponding proportions of gross output.

In order to disaggregate the electricity production sector, two sets of input and output weight factors should be estimated. In China, power mix varies significantly among regions; the proportion of inter-provincial power exchanges presents a recent sharp increase. In addition, the renewable energy endowment is not distributed uniformly across regions. These issues must be considered when disaggregating the electricity sector. This study assumes that the industry sectors of the power exporting regions consume electricity in proportion to their power generation mix, and the electricity consumption mixes of power importing regions are determined by the power generation mix of local and regional grid system jointly. Table 1 shows the regional grid systems and the provinces they cover.

Accordingly, we first disaggregate the electricity sector of 30 provincial I-O tables according to the power consumption mixes and their corresponding prices to get the output weights. Then, we extract five

[1] China Southern Power Grid Yearbook 2006–2010.