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The key sectors for energy conservation and carbon emissions reduction in China: Evidence from the input-output method

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ABSTRACT

This research defines the key sectors driving China's energy consumption and CO_2 emissions from the input-output relationship and demand elasticity. This method allows us to analyze the correlation of energy consumption and CO_2 emissions with economic activities of various sectors, and reveal which sectors deserve more attention as Chinese Government shapes appropriate policies for energy conservation and carbon emissions reduction. The results indicate that the key sectors in China's economic system not only drive energy consumption and CO_2 emissions of other sectors, but also consume substantial fossil energy and emit tremendous CO_2 stimulated by the demand from other sectors. Therefore, they should be paid close attention by Chinese government, especially the sectors of Manufacture of Basic Chemicals, Construction of Buildings, Wholesale and Retail Trade, Transport via Road, and Real Estate. In addition, the case study shows that China's road transportation experiences extensive developing mode and effective measures should be taken to help achieve its low-carbon development due to its dominant role in the whole transportation sector.

1. Introduction

In response to global climate change, Chinese government has developed a number of environmental policies to control and reduce greenhouse gas emissions. In 2009, Chinese government officially announced that the CO_2 emissions per unit of GDP (*i.e.*, carbon intensity) will be reduced by 40%–45% by 2020 compared to the level in 2005. In June 2015, Chinese government submitted the "National Independent Contribution Document" to the United Nations to address climate change and proposed that China's CO_2 emissions will reach the peak by 2030 and the carbon intensity will be decreased by 60%–65% at that time compared with that in 2005 (Mi et al., 2017); however, environmental policy is often in conflict with socio-economic development. In particular, how to coordinate the relationship between carbon emissions and socio-economic development has long been a research topic in the energy-economy-environment literature (Zhang and Da, 2015; Zhao et al., 2017; Hao et al., 2016a, b). At the same time, greenhouse gas emissions, especially CO_2 emissions, mainly come from the consumption of fossil fuels. Therefore, exploring the relationship between economic activity and CO_2 emissions from the perspective of fossil fuel consumption is of great significance for developing relevant energy and environmental policies. In view of this, this paper focuses on the analysis of primary energy consumption by different sectors in the economy of China and further analyzes the contribution of different sectors to CO_2 emissions in the process of commodity production.

Many studies have suggested that CO_2 emissions are mainly caused by the use of primary energy in the industrial sector, particularly in the manufacturing sector (IPCC , 2007; Zhang et al., 2017c); however, while considering the deep-seated relationship between energy use and economic activity within the industrial sector, one can find that many sectors that consume less energy and have lower direct emissions, such as the transportation sector, may cause a lot of indirect energy consumption and CO_2 emissions (Alcántara and Padilla, 2009; Zhang et al., 2017b). However, current environmental policies generally control the sectors with large direct emissions but tend to ignore the restrictions on the sectors that lead to significant emissions of other sectors, i.e., indirect emissions, thus failing to reduce overall emissions (Alcántara and

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Padilla, 2009). Therefore, analyzing the relationship between energy use in the production of industrial sectors and economic activity, and finding the key sectors driving energy consumption and CO_2 emissions are important for China's policy-makers responsible for energy and environmental regulations. In particular, it is conducive to the design of better energy and environmental policies to curb the energy use of, and CO_2 emissions from, key sectors.

For a long time, the relationship between CO_2 emissions and economic activities has been the research focus in the literature. For example, Ehrlich and Holdren (1971) proposed the well-known IPAT model to explore the relationship between pollutant emissions and population, social status, wealth, and technology. Hao et al. (2016a, b) estimated both the direct and indirect effects of financial development on CO_2 emissions in China using a carefully designed two-stage regression and found that the influence of financial development on environment depends on the level of economic development. Some scholars studied the relationship between carbon emission and economic level (Kaika and Zervas, 2013a, 2013b; Al-mulali et al., 2015; Luo et al., 2017), using the environmental Kuznets curve (EKC) (Kuznets, 1955), which holds that there is an inverted U-shaped relationship between economic growth and environmental quality. That is, with the development of economy, the environmental quality deteriorates gradually at first and then reaches a peak before gradually recovering. This relationship can be characterised by a mathematical function (Beckerman, 1992; Cole, 2004). For example, Luo et al. (2017) employed the panel data fixed effect model to investigate whether the EKC for CO_2 emissions exist in G20 and indeed confirmed the existence of the EKC as a whole.

In recent years, some scholars, with the concept of elasticity and the sensitivity analysis approach, have explored the relationship between economic activities in various sectors and the associated CO_2 emissions. For example, Hondo et al. (2002) used the method of resolving the limit of elasticity to analyze the effects of changes in economic activity and carbon intensity on CO_2 emissions. Meanwhile, Tarancón Morán and González (2007a) explored the impact of sectoral economic activities on CO_2 emissions from other sectors and total CO_2 emissions in the economic system to reflect the relationship among sectors. Besides, Tarancón Morán and González (2007b) introduced the sensitivity analysis approach combined with the linear programming to detect the relationship between inter-sectoral economic activity and CO_2 emissions, so as to reveal the most carbon-intensive sectors. These studies indeed provide important references for the current research.

In addition, the input-output (IO) method has been widely used to assess the environmental impact of socio-economic activities (Labandeira and Labeaga, 2002; Machado et al., 2001; Mongelli et al., 2006; Su and Thomson, 2016). In theory, the IO method reflects the input-output relationship among sectors in the whole economy and can help to check direct and indirect energy consumption in economic production activities. As a tool suitable for developing a linear model for economic accounting, the input-output method is able to track the production process of a product and helps people to find the source of all emissions and distinguish the direct and indirect emissions arising from product production (Zhang et al., 2017a). Meanwhile, the input-output analysis can quantify the effect of changes in the final demand of different sectors on total, or sectoral, emissions (Machado et al., 2001; Labandeira and Labeaga, 2002; Mongelli et al., 2006; Wiedmann et al., 2008; Guo et al., 2010).

The main contribution of this paper consists of three aspects: first, this paper explores the impact of various sectors on carbon emissions of the entire economic system at the sectoral level and that of the entire economic system on sectoral carbon emissions. This helps to reveal the complex inter-relationship among sectors. Second, this study uses the input-output method to divide all sectors into four categories based on their total effect and distributive effect. The total effect represents the effect of the 1% change in the demand of sector on the total CO_2 emissions in the entire economic system, while the distributive effect indicates the change of sectoral CO_2 emissions when there is a 1% increase of the final demand of all sectors. In this way, the key sectors that affect carbon emissions are identified, which is conducive to determining the focus of achieving the national target of carbon emissions reduction in China. Third, this paper takes the road transportation sector as a typical case to further analyze the influence of its economic activities on carbon emissions of other sectors, as well as the impact of economic activities of other sectors on carbon emissions of the road transportation sector.

The rest of the paper is structured as follows: Section 2 introduces the methods and data definitions, Section 3 analyzes the empirical results, and Section 4 concludes the paper.

2. Method and data

2.1. Method

To track the direct and indirect CO_2 emissions in industrial production processes, a total demand coefficient $(I-A)^{-1}$, which is also called the Leontief inverse matrix, is introduced (Leontief, 1936). It reflects the total resources consumed by the production of final-use commodities, including intermediate consumption and final consumption. Thus the total output X is calculated as shown in Eq. (1):

$$X = (I-A)^{-1}Y \tag{1}$$

where Y is the final demand; $A = \frac{x_{ij}}{x_j}$ is the technical matrix, also known as the direct consumption coefficient matrix, and describes the technical economic links between various sectors; and I is the unit matrix. The coefficient in matrix A describes the total consumption (including the direct and indirect consumption) for products of other sectors when the final-use products of one sector increase by one unit.

The definition of a key sector was first proposed by Rasmusen (1956). Despite some limitations, this idea has been acknowledged by many studies (Sonis et al., 1995; Legros et al., 2005; Cai and Leung, 2004; Dietzenbacher et al., 2005). Based on the concept proposed by Rasmusen, this paper explores the sectoral effects on carbon emissions in an economic system by using the method proposed by Alcántara and Padilla (2003) and the method of demand elasticity, which means an increase in CO_2 emissions caused by the increase in final demand. The variable definitions are shown in Table 1.

Then, we calculate the total CO_2 emissions during the production process of the whole economic system in a year according to the CO_2 emissions intensity and the total output. Through the Leontief inverse matrix, the process can be written as Eq. (2):

$$E = f'X = f'(I-A)^{-1}Y \tag{2}$$

where f' is the CO_2 emission coefficient of each sector.

And based on the derivation of Eq. (2), we obtain the changes in CO_2 emissions due to the change of per unit of total output, as given by Eq. (3):

$$\Delta E = f'\Delta X = f'(I-A)^{-1}Y\theta \tag{3}$$

where θ denotes the proportion of change in the final demand. In fact, Eq. (3) also reflects the elasticity of the final demand relative to CO_2 emissions.