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Original Articles

Identification of key sectors and key provinces at the view of CO_2 reduction and economic growth in China: Linkage analyses based on the MRIO model

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ABSTRACT

In China, the largest carbon dioxide (CO_2) emitter in the world, reducing national CO_2 emissions while maintaining economic growth has become an important issue. Industrial linkage analyses can be applied to identify key sectors and provinces where policies need to be developed for this purpose. To identify the specific key sectors in these provinces, we designed a method based on inter-sector linkage analyses with a multi-regional input–output model, using 27 industries in 30 provinces as research objects. We analyzed backward and forward linkages, combined inter-sector production and CO_2 emissions linkages, and used both marginal and absolute measures. In the backward linkages, the key emissions reduction sectors included production and supply of electricity and heat in Shanxi and Inner Mongolia, and transportation and storage in Liaoning and other provinces. In the forward linkages, the key emissions reduction sectors included nonmetal mineral products in Hebei, and the smelting and pressing of ferrous metals in Inner Mongolia and other provinces. The key provinces from both the demand and supply sides were Hebei, Shanxi, Inner Mongolia, and Shandong. Policy implications for decision makers were derived from the demand and supply side perspectives, to guide sector-level and province-level CO_2 emissions mitigation strategies, respectively.

1. Introduction

Carbon dioxide (CO_2) emissions in China have grown at a rapid pace along with the country's rapid economic growth. China overtook the United States to become the world's leading emitter of CO_2 in 2007, with national CO_2 emissions increasing to 9.125 billion tons in 2015, accounting for 27.2% of the world's total emissions (EIA, 2016). Although the growth rate of China's CO_2 emissions has been declining due to environmental policies and the recent economic slowdown, they still pose a challenge to international CO_2 emissions mitigation targets because of the large size of the Chinese economy and its dependence on fossil fuels (Chang, 2015; Mi et al., 2016; Zhao et al., 2016).

Despite not being forced to reduce CO_2 emissions as a part of the Kyoto Protocol (Miller et al., 2011), China is obliged to curb emissions to meet its role as a major responsible country. It was early announced in China's 12th Five-Year Plenary Session that, faced with the tension between increasing energy requirements and environmental pressure, it is necessary to promote more environmentally friendly consumption practices, and make the transformation from high-carbon to low-carbon energy consumption. China has committed to lowering its carbon emissions per unit of GDP by 60–65% below the 2005 level by 2030, increasing the share of non-fossil energy carriers in the total primary energy supply to about 20% by that time, and increasing its forest stock volume by 4.5 billion cubic meters compared to the 2005 level. In addition, when submitting its intended nationally determined contributions[2] resulting from the Paris Agreement in December 2015 (Zhang, 2017), China made a commitment to reach a CO_2 emissions peak by 2030. The targets that China have set will have serious consequences, and if met, will significantly contribute to international mitigation efforts.

During the past 30 years, rapid economic growth has contributed to a serious CO_2 emissions problem in China. The economy has entered a new normal state, in which economic growth has slowed from rapid speed to medium to high speed, and the economic structure has become optimized to meet the factors driving growth (i.e., a transition from investment-driven to innovation-driven growth). To maintain economic development, a focus on improving product quality has become a strategic economic objective, and understanding how to reduce CO_2

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[2] Enhanced actions on climate change: China's intended nationally determined contributions(INDC), available at http://qhs.ndrc.gov.cn/gzdt/201507/t20150701_710232.html.

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emissions while improving economic growth has become an important issue. Industrial restructuring and optimization are important means for achieving the goals of economic transformation and reducing CO_2 emissions (Chang, 2015; Jones, 1976; Mi et al., 2015). There is also an optimization problem, in which the proportions of various types of industries have to be adjusted to satisfy one or more goals. This has received the attention of both academia and government (Chen et al., 2011; Mi et al., 2014). For example, the first measure to control greenhouse gas emissions announced by the "National plan for coping with climate change (2014–2020)" and issued by the State Council in November 2014 was to adjust the industrial structure, control high energy consumption, and limit expansion in the capacity of high-emissions sectors, while providing guidance regarding the adjustment of industrial structure.

Given that industries are closely linked among the different provinces in China, the measures implemented in a sector in a specific province could significantly affect other sectors in other provinces (Ewing et al., 2012). To achieve such a challenging low-carbon development target, each sector's carbon emission linkage and economic linkage should be considered together. Therefore, in this study, we estimated the inter-sector linkages (considering both production linkages and CO_2 emissions linkages) of 27 industrial sectors in 30 provinces in China; estimated the inter-province linkages (considering both production linkages and CO_2 emissions linkages) of 30 provinces; selected key sectors in specific provinces from the demand side (backward linkage analyses) and supply side (forward linkage analyses) perspectives, to separately represent the two ends of a supply chain generating CO_2 emissions; selected key provinces from the demand and supply side perspectives; and made suggestions for improving economic development and CO_2 emissions reductions based on the results. Regarding the intended outcomes of this study, our extensive assessment at the provincial level should fill gaps in knowledge by identifying key sectors of provinces as well as key provinces themselves. Unlike previous studies, we used a multi-regional input–output (MRIO) model based on modification of the classic multiplier method to identify key sectors of specific provinces and key provinces that deserve more attention with respect to CO_2 emissions reduction targets and economic development. In addition, by combining inter-sector production and CO_2 emissions linkages, our approach may be more complementary than previous approaches and it allowed us to quantify both direct and indirect inter-sector linkages at the provincial level. Moreover, our linkage analyses elucidate the relationship between economic structure and CO_2 emissions, to better understand the role each sector and province plays in CO_2 emissions and economic development and to identify key emissions reduction sectors and provinces, as well as key sectors and provinces where development would be encouraged. This could enable more-targeted sector- specific and province-specific policy interventions and ultimately achieve the goal of economic transformation and CO_2 emissions reduction in China.

The remainder of this paper is organized as follows. Section 2 reviews previous studies related to linkage analyses. Section 3 proposes the relevant coefficients for inter-sector and inter-province production and CO_2 emissions linkages based on the MRIO model, and also provides details of the data sources and processing. Section 4 describes and discusses the selection of key sectors among 27 sectors in 30 provinces, and the key provinces for CO_2 emissions reduction in China according to 2010 statistics. Section 5 presents the conclusions of the study and policy implications based on the numerical analyses.

2. Literature review

There are four methods commonly used to assess industrial linkages: the classic multiplier method (Lenzen, 2003; Zhang, 2010), sensitivity analyses (Tarancón and Río, 2007), the hypothetical extraction method (Schultz, 1977), and the modified hypothetical extraction method (Wang et al., 2013). These methods can also be used to determine the contribution of each sector within an economic system to CO_2 emissions. Related methods include decomposition methods (Su and Ang, 2012; Kopidou et al., 2016), the input-output model (Tian et al., 2014), and econometrics models (Talukdar and Meisner, 2001; Zhou et al., 2013). Because it can incorporate direct and indirect industrial linkages simultaneously, the MRIO has been predominantly used (Leontief, 1941). The application of environmentally extended input-output techniques allows us to trace the direct and indirect CO_2 emissions associated with a particular product.

Under the MRIO framework, the classic multiplier method (Chenery and Watanabe, 1958; Rasmussen, 1956) and hypothetical extraction method (Strassert, 1968) are the two main methods used. The classic multiplier approach measures the relevance of a sector (i.e., to what degree the economy depends on this specific sector), and is used to examine structural interdependence in the production system. It was introduced by Rasmussen (1956) and has a long history within the field of input–output analyses. The concept of forward and backward inter-industry linkages used for the identification of key sectors was subsequently suggested by Hirschman (1958) to determine appropriate development strategies by identifying sectors that have an above-average impact on an economy (Hirschman, 1958). It was later improved and expanded to measure linkage coefficients, in situations where rapid growth in a relatively small number of industries amplifies initial small changes, which eventually affect the whole economy (Lenzen, 2003; Miller, 2001). The hypothetical extraction method extracts a hypothetic sector from an economic system, and then quantifies the degree to which the output of other sectors would decrease after the extraction (i.e., eliminating the sector's sales to and purchases from all other sectors) (Ali, 2015; Zhao et al., 2016). Therefore, the identification of key sectors is useful for economic planning and should generate above-average local increases in economic activity, thereby stimulating overall economic growth (Lenzen, 2003).

Given today's increasingly pressing CO_2 emissions problems, it is necessary to examine economic structure in terms of CO_2 emissions, and thus identify key sectors with greater impact on the environment (Sonis and Hewings, 1992; Guo et al., 2010; Zhang et al., 2017). For example, Lenzen (2003) identified key sectors and linkages that had large environmental impacts on the consumption of energy and water, land disturbance, and CO_2, NO_x, and SO_2 emissions in Australia. Wang et al. (2013) uncovered inter-industrial linkages of CO_2 emissions in China based on data for China in 2007 (Wang et al., 2013). Ali (2015) measured CO_2 emissions linkages among productive sectors in Italy using national-level data in 2011. Thus, environmentally extended key sector analyses in terms of CO_2 emissions are useful for identifying sectors in which mitigation policies are likely to be most effective (Ali, 2015).

For studies of CO_2 emissions linkages, backward and forward linkages are widely accepted concepts for describing the inter-sector relationship (Cai and Leung, 2004). Backward linkages refer to the consumption relationship formed during the use of intermediate goods bought by downstream industries from upstream industries (Zhao et al., 2015). The study of such linkages is important when determining CO_2 emissions generated in the upstream supply chain that are driven by the final demand of products (e.g., households, government, and capital formation) (Liang et al., 2015; Peters, 2008). Forward linkages refer to the supply relationship formed when upstream industry supplies intermediate goods to downstream industry (Zhao et al., 2015; Imansyah and Putranti, 2017). The study of such linkages is important when determining CO_2 emissions generated in the downstream supply chain that are sequentially induced by upstream industries through the supply chain. Identifying critical sectors that drive downstream CO_2 emissions using forward linkages can guide supply-side measures (Liang et al., 2015), while backward accounting can inform demand-side measures influencing the choice of the final users (López et al., 2015).

Numerous studies have conducted industrial linkage analyses. Although these studies have enriched our knowledge, several aspects of