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Driving forces of energy embodied in China-EU manufacturing trade from 1995 to 2011

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ABSTRACT

In this study, an empirically validated Environmental Input-Output Life Cycle Assessment (EIO-LCA) model was applied to calculate and decompose the amount of energy embodied in the manufacturing trade between China and the European Union (EU) in 1995–2011. The main findings are as follows: China's entry to the WTO (World Trade Organization) in 2001 has spurred the growth of energy embodied in exports from China to the EU, while environmental policies issued by Chinese government since 2006 have pulled it down. The export sectoral structure change and energy consumption intensity decrease are two key drivers of China's embodied energy export changes. China's embodied energy exports are mainly contributed by coal and other fossil fuels. Germany is the largest importer of China's embodied energy among the EU member states. This study can provide data support and reference basis for international trade and climate negotiations, and help Chinese government to improve its policies on industrial structure, primary energy structure and export state structure.

1. Introduction

In recent decades, excessive energy consumption in China has led to serious environmental deterioration (Xia and Chen, 2012). The assertion that China is an "energy threat" and "climate threat" is popular in the international community (Yang et al., 2014; Du et al., 2011; Zhao et al., 2016). This thinking is a significant part of global climate negotiations, such as the recent Paris Climate Accord, and is typically used as a way to target China for concessions or to be considered in the same category as developed economies, such as the United States (US). In contrast to energy consumption in the US, much of the energy used in manufacturing and other industrial processes in China do not have its final consumption within China itself (Chen et al., 2017). In this way, a huge amount of energy is embodied in manufacturing goods and is exported to other countries. However, such exports are often neglected in international climate negotiations (Yang et al., 2014; Gasim, 2015).

Since 2008, the European Union (EU) has replaced the US as China's largest export market, and has also been China's biggest source of imports since 1996. China has become the EU's second largest export market and its third largest source of imports since 2012. According to the statistics of the General Administration of Customs of China, bilateral goods trade between China and the EU in 2015 is 565.76 billion US dollars, accounting for about 3.54% of the global trade. Predictably, China-EU trade would have significant impact on the world's energy security and climate change. The EU, different from the US, is a specific trading partner, involving many bilateral agreements with developed and less developed economies that all exist to some extent under a unified regulatory framework. It is necessary, therefore, to assess what exactly is the amount of energy embodied in the bilateral trade between China and the EU. It is also of extreme significance to identify the sector, source, and specific state distributions of the embodied energy, as they are related to domestic policy goals and diplomatic agendas of the Chinese government.

Global energy shortage and environmental deterioration in recent years have greatly promoted the research on embodied energy in international trade (Tang et al., 2013; Chen et al., 2017). Wyckoff and Roop (1994) first studied the embodied energy and carbon emissions in imports of manufactured goods of the six largest OECD (Organization for Economic Co-operation and Development) countries. In previous literature, the amount of embodied energy was estimated for some major trading countries and economies, covering not only industrialized countries such as the United States (Yang et al., 2014), the

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European Union countries (Bordigoni et al., 2012), and the United Kingdom (Wiedmann, 2009; Tang et al., 2013), but also emerging economies, like Brazil (Machado et al., 2001) and China (Hong et al., 2007; Liu et al., 2010; Yang et al., 2014; Cui et al., 2015; Tang et al., 2015). It has been discovered that, industrialized countries, in most cases, are net importers of embodied energy and emissions, while developing countries are net exporters.

The previous literature attempted to identify the determinants driving embodied energy changes in international trade, for example, specialization (Gasim, 2015), trade balance (Liu et al., 2010; Bordigoni et al., 2012; Gasim, 2015), trade policy (Machado et al., 2001; Cui et al., 2015), energy intensity and efficiency (Yang et al., 2014; Gasim, 2015; Cortés-Borda et al., 2015; Xia et al., 2011; Jiang et al., 2017), consumption structure of energy sources (Liu et al., 2010; Yang et al., 2014), inputs structure and industrial sectoral structure (Wiedmann, 2009; Liu et al., 2010; Dente et al., 2017). Among these, international trade is considered to be one of the most important driving forces (Chen et al., 2018). However, the impacts of international trade on embodied energy structure changes are not clear. These structure changes cover sectoral structure, energy categories structure and the EU member states distribution.

In addition, the contribution of sectoral structure upgrading in developing nations to embodied energy changes needs more academic concern. In order to promote economic development, the developing economies like China often pursue strategies for industrial upgrading to transform from low value-added manufacturing to high value-added industries (Xia et al., 2011; Xia et al., 2014; Hu et al., 2015). However, industrial upgrading is a very tough and long process. Most of developing economies, therefore, still mainly depend on low value-added manufacturing that requires more energy inputs and more polluting outputs. At the same time, the energy required for these industries can be more or less harmful to the environment depending on how the energy was produced (Xia and Chen, 2012; Zhang et al., 2015; Tang et al., 2018). Developing nations have historically relied upon cheap and high-pollution fossil fuels to drive economic growth while already-developed nations, with a different energy consumption profile and environmental policy agenda, may have moved away from polluting energy sources (Zhang et al., 2011; Tang et al., 2013; Yang et al., 2014). For example, after joining the WTO, China saw a significant increase in its coal consumption and pollution emissions as a result of the rapid growth of its exports (Hong et al., 2007).

In current literature, different methods are employed to estimate the amount of energy and emissions embodied in international trade (Chen et al., 2017). The environmental input-output model is often applied to quantify the energy consumption and environmental emissions of a final product or service that contains total intermediate inputs (Yang et al., 2014; Shao et al., 2013). Meanwhile, embodied energy in international trade covers both direct and indirect energy consumption throughout its entire life cycle of a product or service, which supports that the life cycle assessment should be introduced to quantify the embodied energy. Hendrickson et al. (1998) and Hendrickson et al. (2006) proposed the Environmental Input-Output Life Cycle Assessment (EIO-LCA) model which combines an environmental input-output table with life cycle assessment. EIO-LCA has become one of the methods used most widely to calculate the environmental impacts of a given product or service during the whole life cycle (Ji and Chen, 2016).

In this study, the EIO-LCA model is employed to calculate the amount of energy embodied in China-EU manufacturing trade over the period 1995–2011, and then the embodied energy is decomposed on sectoral structure, energy category and specific member state to identify the drivers of embodied energy change.

The remainder of the study is organized as follows. Section 2 introduces the structural decomposition analysis in an energy input-output model and details the data sources. Section 3 presents the results and discussions of energy embodied in China-EU trade. Finally, the conclusions and policy implications are presented in Section 4.

2. Methods and data description

2.1. EIO-LCA model

The EIO-LCA model using input-output tables has the advantage of tracing out the various economic transactions, resource requirements and environmental emissions during the entire life cycle of a particular product or service (Hendrickson et al., 1998; Hendrickson et al., 2006). An environmental input-output table treats both economies and the environment as systems, and quantifies the direct and indirect linkages between them.

The input-output model divides the entire economy into distinct sectors, and the matrix of quantitative relationship between the sectors can be expressed as follows:

$$AX + Y = X \tag{1}$$

where Y is the final demand for which the supply-chain output X is to be derived. A represents the economy's direct consumption matrix, where each element a_{ij} can be calculated using $a_{ij} = x_{ij}/x_j$. x_{ij} is the products of sector i consumed in sector j's production process; x_j denotes the total output of sector j; and y_i stands for the final use of products provided by sector i. With the linearity assumption of input-output analysis, the output X can be written as

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

where I is the identity matrix and $(I\text{-}A)^{-1}$ is Leontief's inverse matrix, which reflects the sum of direct and indirect consumption required to meet per unit final demand.

The input-output analysis using economic data can then be augmented with additional, energy consumption data. We define EI as the direct energy consumption to produce per unit total output, where each element ei_i, the direct energy consumption intensity of sector i, can be calculated as

$$ei_i = e_i/x_i \tag{3}$$

where e_i is the direct energy consumption of sector i. The total energy consumption of an economy can be expressed as

$$E = EI*X = EI*(I-A)^{-1}*Y = M*Y \tag{4}$$

where M is the total energy consumption intensity matrix, representing the sum of direct and indirect energy consumptions required to provide per unit final use.

Since national and regional systems are deeply embedded in global production networks caused by international trade and investment, distributed production activities have become key driving forces behind global energy consumption and climate change due to spatial linkages between local activities and remote impacts (Chen, 2016). Then, embodied energy in international trade can be estimated as

$$EE = M*EX = EI*(I-A)^{-1}*EX \tag{5}$$

where EE is the embodied energy matrix and EX is the international trade matrix. Through the EIO-LCA approach, all indirect and feedback energy relationships among the different processes and economic sectors can be included between trading countries.

In this paper, embodied energy in China-EU trade can be expressed as follows:

$$EE_{China\ to\ EU} = M_{China}*EX_{China\ to\ EU} = EI_{China}*(I-A_{China})^{-1}*EX_{China\ to\ EU} \tag{6}$$

$$EE_{EU\ to\ China} = M_{EU}*EX_{EU\ to\ China} = EI_{EU}*(I-A_{EU})^{-1}*EX_{EU\ to\ China} \tag{7}$$

where $EE_{China\ to\ EU}$ ($EE_{EU\ to\ China}$) is the embodied energy exported from China (the EU) to the EU (China). $EX_{China\ to\ EU}$ ($EX_{EU\ to\ China}$) is the export from China (the EU) to the EU (China). A_{China}, EI_{China} and M_{China} are calculated through Chinese input-output tables, while A_{EU}, EI_{EU} and M_{EU} are measured by the EU's input-output tables.

The net embodied energy exporting from China to the EU can be