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Study on calculation of carbon emission factors and embodied carbon emissions of iron-containing commodities in international trade of China

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ABSTRACT

Embodied carbon emissions (ECE) of iron-containing commodities (ICC) in international trade are an important basis for effectively allocating both carbon emissions responsibility and emission quotas among countries. China is a major consumer of iron resources worldwide and the world's largest trader in ICC. Accurately calculating the ECE of ICC in China's international trade is of great significance to objectively evaluate China's carbon emissions responsibilities and to rationally allocate carbon emission quotas among countries. In this study, we verified the carbon emission factor for China's import and export of ICC and analyzed the ECE of ICC between China and other countries worldwide from 2010 to 2015. The results are as follows. (1) The ECE of China's export of ICC is higher than those of imported ICC. (2) In 2010–2015, the amount of iron materials in the import and export of China increased to 192 and 138 million tons, respectively. Most of the iron material imported by China is iron ore (about 90%), and more than 98% of China's exported iron material is iron-containing end products (IEPs) and rolled steel. (3) The ECE of China's imports of ICC decreased from 98 million tons in 2010 to 77 million tons in 2015 and consisted primarily of rolled steel and IEPs. The ECE of China's exports of ICC increased from 249 million tons in 2010 to 482 million tons in 2015 and consisted primarily of IEPs and rolled steel. (4) The ECE of China's exports of ICC are much larger than that the exports of ICC. The ECE of net exports of ICC, primarily to the United States, Vietnam, South Korea, and Indonesia, increased from 151 million tons in 2010 to 405 million tons in 2015. (5) The ECE of exports of ICC were approximately 4.7% of China's domestic carbon emissions (calculated using the production-based principle) in 2015. The total amount of China's domestic carbon emissions in the production-based principle is huge, but a large part is embodied in ICC exported to other countries worldwide. The shared responsibility principle (SRP) can better reflect the fairness and also contribute to the global participation of climate policy, which has the highest effectiveness. Therefore, calculation of carbon emissions using the SRP is a more objective assessment of China's carbon emissions responsibility, thus making the allocation of carbon credits among countries more fair and reasonable.

1. Introduction

In recent years, the global climate has become an increasingly serious problem, and all countries must take countermeasures to ensure economic development and, at the same time, strive to control greenhouse gas emissions (Lee and Yoo, 2016). One focus of the discussions among countries regarding global climate

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negotiations is how to distribute the emission reduction responsibility among countries. In particular, the carbon emissions transferred through international trade must be considered when allocating emission quotas among countries (Liu et al., 2008; Ding et al., 2009; Zhang et al., 2009; Dong et al., 2011). China is a major consumer of iron resources worldwide and the world's largest trader in iron-containing commodities (ICC). Accurately calculating the embodied carbon emissions (ECE) of ICC in China's international trade is of great significance to objectively evaluate China's carbon emissions responsibilities and rationally allocate carbon emission quotas among countries.

Several studies have been carried out on the ECE in international trade using research methods mainly divided into two categories. The first category calculates the ECE of ICC in international trade mainly using the single region input–output (SRIO) model. Gale (1995) estimated the carbon dioxide (CO_2) emissions in Mexico's imports and exports by using the SRIO model. Lin and Sun (2010) analyzed the China's embodied CO_2 emissions in import and export in 2005 using the SRIO model. Yan and Yang (2010) estimated the amount of CO_2 emissions embodied in China's foreign trade during 1997–2007 by using the SRIO model. The SRIO model is based on the following assumptions: The carbon emission factor of imported products is equal to that of domestic products, through the interpretation that imported products are produced by using domestic production technologies and energy inputs. However, a country's imports come from many countries and worldwide, with different production techniques, energy consumption coefficients, and carbon emission factors. To obtain accurate research results as far as possible, many scholars used the SRIO model to calculate the ECE of unidirectional exports of many countries, such as Finland (Mäenpää and Siikavirta, 2007), Italy (Mongelli et al., 2006), Spain (Sánchez-Chóliz and Duarte, 2004), Brazil (Machado et al., 2001; Tolmasquim and Machado, 2003), and China (Lin and Sun, 2010; Yan and Yang, 2010; Ren et al., 2014; Zhang, 2015). Some scholars also improved the SRIO model to calculate the ECE of ICC in import by using the energy consumption coefficient and carbon emission factors of import countries. For example, Liu et al. (2010) examined CO_2 emissions embodied in the Japan–China trade during 1990–2010. Zhao et al. (2015) studied CO_2 emissions embodied in the China–Japan trade during 1995–2009 by using the bilateral trade input–output approach.

The second category calculates the ECE of ICC in international trade mainly using the multi-region input–output (MRIO) model (Chris K, 2015; Chen et al., 2017). Weber and Matthews (2007) used the MRIO model for the United States and its seven largest trading partners (Canada, China, Mexico, Japan, Germany, the United Kingdom, and Korea) to analyze the environmental effects of changes to the U.S. trade structure and volume from 1997 to 2004. Kulionis (2014) examined CO_2 emissions embodied in U.K. international trade from a consumption perspective by using the MRIO model during 1995–2009. Tian et al. (2017) accounted for the environmental and resources footprints embodied in the China–European Union trade for 2008 by employing the MRIO model, including both global and sectoral environmental and resources footprints caused by the trade between China and the EU-27 countries. The MRIO model considers the energy consumption coefficient and carbon emission factors of imported products in the importing countries. However, due to complexity of the model and high data-processing requirements, few studies estimated the ECE of import and export by using the MRIO model.

No matter whether one uses the SRIO model or the MRIO model to estimate the ECE of all commodities imported and exported by one country or department, it is impossible to estimate the ECE of all ICC (including iron-containing end products [IEPs] such as vehicles, machinery, and ships) in international trade. Carbon is implied because both models use the input–output table to calculate the implied carbon emissions for import and export, whereas the ICC cannot be separated into various sectors and industries in the input–output table. Moreover, although both models use input–output tables to calculate import-export ICC, it is impossible to separate IEPs into sectors and industries in the input–output table. Material flow analysis is one of the most important basic methods for resource management and environmental systems analysis (de Haes et al., 1997; van der Voet et al., 1995). It can accurately calculate the material flows of ICC in international trade. Nakajima et al. (2014) identified the global trade flow of iron embedded in every bilateral trade among 231 countries by multiplying the trade volume of the commodity in the database of the Base pour l'Analyze du Commerce International with the iron content of each commodity. Based on the carbon emission calculation Method 3 (product multiplied by product emission factor) provided by Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories 2006 (Lubetsky et al., 2006), the ECE of ICC in international trade can be calculated by multiplying iron material with the carbon emission factors of each ICC.

In this study, we accurately calculate the material flows of ICC in international trade and verify the carbon emission factor for China's import and export of ICC. Then, we analyze the ECE of ICC between China and other countries worldwide from 2010 to 2015.

2. Methodology and data sources

The IPCC National Greenhouse Gas Inventories 2006 provided three methods to calculate the carbon emission of products. Method 1 involves fuel multiplied by the carbon emission factors of each fuel. Method 2 uses the carbon balance method based on tracking the carbon emission of the whole production process. Method 3 multiplies the product with the product emission factor.

In this study, the calculation of carbon emissions from ICC was achieved by combining Methods 1 and 3. First, the carbon emission factor of the ICC was calculated by using Method 1. We determined the energy consumption of the ICC, and then adopted the corresponding energy emission factor to calculate the carbon emission of ICC, which was also their carbon emission factor. Second, the ECE of ICC in international trade was calculated by multiplying the iron material and carbon emission factors of each ICC.

The calculation formula for ECE of ICC in international trade is

$$C_\beta = W_\beta * E_\beta, \tag{1}$$

where β represents the different categories of ICC in import or export trade, W_β represents the mass of β-category ICC, and E_β represents the carbon emission factors of β-category ICC. The calculation formula (1) can be deformed to

$$C_\beta = \frac{W_\beta}{S_\beta} * \left(E_\beta * S_\beta\right), \tag{2}$$

where S_β represents the iron-content coefficient of β-category ICC. $E_\beta * S_\beta$ represents the pure iron mass of β-category iron-ICC.

Therefore, the calculation in this study is mainly divided into two parts: (1) the iron material (pure iron) flows of ICC in China's international trade and (2) the carbon emission factors of ICC.

2.1. System boundaries and data sources

We used mainland China as the spatial boundary and one year as the temporal limit to analyze the annual iron material flows between 2010 and 2015. We considered all types of iron-containing materials and commodities including iron ore, pig iron, crude