

## Study of CO<sub>2</sub> Emissions Embodied in China's Exports

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**Abstract**—This paper employs a revised input-output model to empirically investigate the CO<sub>2</sub> emissions embodied in export based on the input-output (I-O) table in China from 1999 to 2008. The key results indicate the carbon emission embodied in exports has risen from 0.38 Gt in 1999 to 1.19 Gt in 2008, in which 12–24% consumption demands come from other countries every year; mainly 5 industries originating the embodied carbon in China's exports are collectively responsible for nearly 80% carbon, which primarily going to the USA, EU and Japan, whilst a crucial implication is that responsibilities from the producers and consumers must be considered on estimating CO<sub>2</sub> emissions during the international negotiation. Meaningful energy policies and some other trade recommendations are presented finally.

**Keywords**—energy consumption; CO<sub>2</sub> emissions; international trade; input-output model

### I. INTRODUCTION

Global climate change and increasingly requirements to reducing greenhouse gas emissions are currently important international challenges. According to an International Energy Agency (IEA) report China replaced the USA and became the largest CO<sub>2</sub> emitting country in the world in 2007. China, as the world's top CO<sub>2</sub> emitter, is under great pressure from the domestic and international community to reduce carbon emissions. However, as the world factory, China's energy consumption is not all used for domestic consumption, the rapid growth of exports and the expanding trade surplus have greatly increased energy consumption and carbon emissions. Ahmad and Wyckoff (2003) <sup>[1]</sup> demonstrated that China is the largest exporter of embodied energy to OECD countries; and therefore OECD countries responsible for a substantial portion of China's carbon emissions. Demonstrating how the growth and structural change in China's exports affect the growth of China's CO<sub>2</sub> emissions may provide a reasonable estimate of China's responsibility for carbon emissions and a scientific basis for the Chinese government to participate in international climate negotiations and assist China appropriately adjusting its foreign trade policies and accelerating the process of energy savings and emissions reduction.

The purpose of this paper is to investigate embodied carbon in China's exports and try to figure out a reliable result. We applying a verified input-output method and customs statistical data from 1999–2008 to calculate embodied carbon in China's exports more accurately by

deducting embodied carbon in imports of intermediate goods and lengthening the study period.

The rest of this study is organized as follows. Section 2 gives a brief explanation of the data used in this paper, and then explains how we use the I-O model to estimate the CO<sub>2</sub> emissions embodied in China's exports. Section 3 presents the results of the model estimation. Section 4 shows some concluding remarks and extending policies implications.

### II. METHODOLOGY AND DATA

To calculate embodied carbon in China's exports from 1999 to 2008, we collected five categories of data: input-output data reflecting China's inter sectoral linkages in the economy, energy consumption data for various industries, annual statistical data for the output of different sectors, statistical data on trade with China's primary trading partners, and annual CO<sub>2</sub> emissions in China. Because the input-output tables in China are compiled every five years, we used the most recent tables—the 2002 China Input-Output Table and the 2007 China Input-Output Table. The data in the 2002 Input-Output Table was used to calculate embodied carbon for 1999–2003, while the data in the 2007 Input-Output Table was used to calculate embodied carbon for 2004–2008. Industrial energy consumption data for various sectors and annual output were excerpted from the China Statistical Yearbook 2000 to 2010. Export data for China to its main trading partners were derived from the Chinese Foreign Economic Statistical Yearbook 2000 to 2005 and the China Trade and External Economic Statistical Yearbook 2007 to 2009. CO<sub>2</sub> emissions data for China were obtained from the IEA Annual Statistical Report, Key World Energy Statistics from 2000 to 2010.

Because different sources of statistical data use different industry classification standards, industry classifications vary. To compare the data by industry, we sorted and merged the industries represented in the various sources of data, and divided the economy into 18 categories of products. Because we calculated only embodied carbon in trade goods, we ignored the services sector and non-export sector.

We employed an input-output method developed by Leontief to calculate embodied carbon in China's exports from 1999 to 2008. The input-output method is a quantitative analysis method used to analyze input-output relationships among different sectors within the entire economy. It provides a powerful tool for studying the

amount of emissions embodied in the production of products and services.

According to the basic principles of the input-output method, the process of production includes both direct consumption of raw materials from associated industries and indirect consumption of intermediate inputs. Here,  $i$  represents the intermediate inputs for the 18 industry categories ( $i = 1, 2, \dots, 18$ ) and  $j$  represents the 18 production industries ( $j = 1, 2, \dots, 18$ ).  $a_{ij}$  represents the quantity of product  $i$  directly consumed for production of a unit of product  $j$ , or the direct consumption coefficient;  $b_{ij}$  is the quantity of product  $i$  used to produce a unit of product  $j$ , including both direct and indirect consumption of product  $i$ , or the complete consumption coefficient.  $A$  is the matrix representing  $a_{ij}$  ( $i, j = 1, 2, \dots, 18$ ),  $B$  is represented by the matrix  $B$  ( $i, j = 1, 2, \dots, 18$ ), and  $I$  is the unit matrix. Based on the input-output model, we have:

$$B = (I - A)^{-1} - I \quad (1)$$

$$a_{ij} = \frac{q_{ij}}{Q_i} \quad (i, j = 1, 2, \dots, 18) \quad (2)$$

Note that the complete consumption coefficient matrix  $B$  in Equation 1 does not include deduction of the contribution of embodied carbon in imported intermediate goods. Many similar studies have not included this factor, resulting in an overestimate of embodied carbon. To obtain more accurate results, it is necessary to take into account imported inputs. Here,  $q_{ij}$  represents the quantity of product  $i$  required for production of a unit of  $j$ ,  $EX_i$  is the quantity of exports in sector  $i$ ,  $IM_i$  is the quantity of imports in sector  $i$ , and  $Q_i$  is the total output of sector  $i$ . We assumed that the coefficient matrix  $A_d$  represented the direct consumption coefficient excluding imports of intermediate goods, and matrix  $M$  represents the import coefficient used to measure the dependence on imports of sector  $i$ . Thus, we have:

$$A^d = (I - M) * A \quad (3)$$

where the formula for matrix  $M$  is as follows:

$$m_{ij} = \frac{IM_i}{(Q_i + IM_i - EX_i)} \quad (i = 1, 2, \dots, n), \text{ where } i \neq j, \quad m_{ij} = 0 \quad (4)$$

Once the direct consumption coefficient matrix  $A_d$  deducting the effect of imports of intermediate goods has been obtained, the complete consumption coefficient matrix deducting the effect of imports of intermediate goods can be obtained:

$$B = (I - A^d)^{-1} - I \quad (5)$$

Based on data for the 122 sectors in the input-output table of 2002 and the 135 sectors in the input-output table 2007 and the industry classifications after merging, we produced data for 18 sectors for 2002 and 2007. Using these data and Eq. (2), we obtained matrix  $A_d$ , including the influence of importing intermediate goods. Using Eqs. (3)–(5), we then calculated the complete consumption

coefficient matrix  $B$  for 18 sectors in 2002 and 2007, excluding the influence of importing intermediate goods. We assumed that the interdependence relationships among sectors did not change from 1999 to 2003 or from 2004 to 2008, and obtained two matrices  $B$ . Matrix  $B$  for 2002 was used to determine the interdependence relationships among sectors and calculate embodied carbon in exports from 1999 to 2003. Similarly, matrix  $B$  for 2007 was used to determine the interdependence relationships among sectors and calculate embodied carbon in exports from 2004 to 2008.

We then calculated the energy consumption intensity of the intermediate inputs  $i$  (i.e., energy consumption per unit output):

$$x_i = X_i / P_i \quad (6)$$

where  $x_i$  is the energy consumption intensity of  $i$  (the energy consumption per unit of output of  $i$ ),  $X_i$  is the total annual energy consumption of  $i$ , and  $P_i$  is the total production of  $i$  in the same year. Data for  $X_i$  and  $P_i$  were obtained from the China Statistic Yearbook. Because the study period was 10 years, there are 10 results for  $x_i$  for each individual sector.

We then calculated the embodied energy consumption intensity of the final products of sectors  $j$ . Let  $(XX)_j$  be the embodied energy consumption intensity of sector  $j$  [i.e., the sum of the energy consumption intensities for inputs to  $j$ , including direct and indirect consumption of intermediate inputs  $i$  ( $i = 1, 2, \dots, 18$ )]. From the energy consumption intensities  $x_i$  of the intermediate inputs  $i$  and the direct and indirect quantities of the products  $i$  used in production of product  $j$ , we calculated the embodied energy consumption intensities for each sector  $j$ :

$$(XX)_j = \sum_{i=1}^{18} b_{ij} * x_i \quad (j = 1, 2, \dots, 18) \quad (7)$$

This allows calculation of the embodied carbon in exports of sector  $j$ . If  $E_j$  is the quantity of exports in sector  $j$  and  $C$  is the CO<sub>2</sub> emissions intensity associated with energy consumption, the embodied CO<sub>2</sub> in the exports of sector  $j$  is:

$$(XC)_j = E_j * (XX)_j * C \quad (j = 1, 2, \dots, 18) \quad (8)$$

Because we divided the exported products into 18 categories, the total embodied carbon in China's exports each year is the sum of the embodied carbon in the 18 categories:

$$Y = \sum_{j=1}^{18} (XC)_j \quad (j = 1, 2, \dots, 18) \quad (9)$$

Finally, using  $x_i$ ,  $b_{ij}$ ,  $E_j$ , and  $C$  for each year, we calculated the embodied carbon in China's exports from 1999 to 2008.

TABLE I. EMBODIED CARBON IN CHINA'S EXPORTS IN 1999–2008 ( $10^8$  T  $\text{CO}_2$ ).

Year	Embodied Carbon in Exports	Annual Growth Rate (%)	Percentage of Total $\text{CO}_2$ Emissions (%)
1999	3.757	–	12.56
2000	4.158	10.69	13.87
2001	4.217	1.42	13.71
2002	5.182	22.87	15.84
2003	6.763	30.52	18.19
2004	9.411	39.15	19.89
2005	12.264	30.32	24.24
2006	13.419	9.42	23.93
2007	12.921	–3.71	21.43
2008	11.866	–8.17	18.23

### III. RESULTS ANALYSIS

The result indicates that, from 1999 to 2008, embodied carbon in China's exports increased from about 0.38 Gt in 1999 to 1.19 Gt in 2008, an overall increase of 215.85% (Table I). In 2005, 2006, and 2007, the embodied carbon in China's exports was 1.226 Gt, 1.342 Gt, and 1.292 Gt, respectively, equivalent to the total  $\text{CO}_2$  emissions of Japan in the same years (1.214 Gt, 1.213 Gt, and 1.236 Gt, respectively), and more than twice the  $\text{CO}_2$  emissions in the United Kingdom in the same years (0.53 Gt, 0.536 Gt, and 0.523 Gt, respectively). Since 2002, China's annual embodied carbon in exports has accounted for 15–25% of China's total  $\text{CO}_2$  emissions, and during 1999–2008, China's cumulative  $\text{CO}_2$  emissions from production of exported products reached 8.4 Gt.

Since 1999, embodied carbon in China's exports increased gradually, grew particularly rapidly after China's entry into the WTO in 2001, and the growth rate reached a maximum of 39% in 2004; in most years, growth was  $\sim 20\%$  (Figure 1). However, this growth slowed in 2006, and began to decline in 2007 and 2008, partly due to improvements in production technology and reductions in energy consumption intensity in China. However, although the amount of embodied carbon in China's export declined in those two years in absolute terms, the annual embodied carbon in China's exports was still 18% of the total  $\text{CO}_2$  emissions. Therefore, exports play an important role in China's  $\text{CO}_2$  emissions. The authors suggest that it is unreasonable for China to be held responsible for all carbon emissions from its production of goods, and consumers in importing countries should also take partial responsibility for China's carbon emissions.

Sector analysis of embodied carbon in China's exports We found that embodied carbon in China's exports was mainly concentrated in 5 sectors, including textile and clothing, chemicals and pharmaceuticals, ferrous and non-ferrous metal smelting and rolling, general and specific machinery and equipment, and electrical machinery and equipment. Embodied carbon in these 5 sectors of exports accounted for 80% of the total. Among them, the electrical machinery and equipment manufacturing and

general and specific machinery and equipment industries accounted for the highest percentages of total embodied carbon in exports, 30% and 20%, respectively. The electrical machinery and equipment industry, with the highest percentage, and the black and non-ferrous metal smelting and rolling industry, with the smallest percentage, both showed increasing trends.

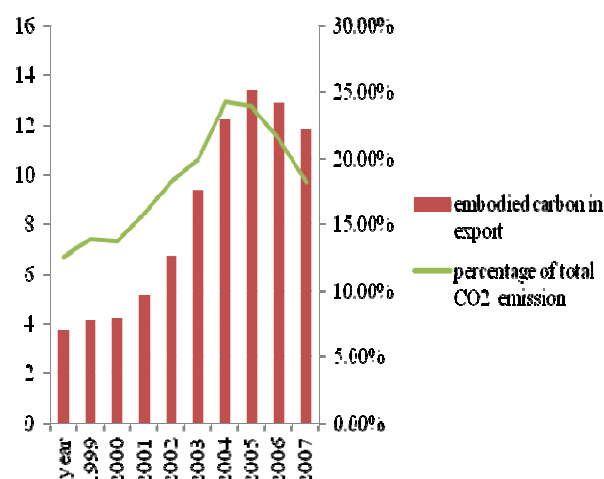


Figure 1. Embodied carbon in China's exports and its percentage of total emissions in 1999–2008 ( $10^8$  t and %).

The USA, Japan, the EU, and Hong Kong are the main trading partners of the Chinese mainland. In 2006, China's exports to these 4 trading partners accounted for more than 65% of the total exports of China. Many goods are exported to Hong Kong and then re-exported to the USA, the EU, and other countries. Because of a lack of relevant re-export statistics, we use statistical data for exports from China's Foreign Economics Statistical Yearbook and Foreign Trade and Economics Statistical Yearbook to calculate the embodied carbon in China's exports to the USA, the EU, and Japan.

For China, the USA is a major trading partner and also a major importer of China's embodied carbon. Since 1999, along with the increase in China's exports to the USA, in absolute terms, the amount of embodied carbon exported to the USA increased rapidly. In 1999, China exported 0.08 Gt embodied carbon to the USA, while in 2007, it increased to 0.275 Gt (243.75%), accounting for 3.5–4.5% of the total  $\text{CO}_2$  emissions of China.

In recent years, China's exports to the EU have also increased rapidly, as has embodied carbon. In 1999, China exported 0.064 Gt embodied carbon to the EU, and in 2007 it increased to 0.289 Gt, accounting for 4.4% of the total  $\text{CO}_2$  emissions of China. From 1999 to 2008, embodied carbon exported to the EU accounted for 3.4% of the total  $\text{CO}_2$  emissions of China on average.

From 1999 to 2008, China's exports to Japan increased over time. However, embodied carbon in China's exports to Japan peaked in 2005 (0.121 Gt) and

then began to decline, decreasing to 0.103 Gt and 0.092 Gt in 2007 and 2008, respectively.

#### IV. CONCLUSION

The CO<sub>2</sub> emissions embodied in the China's export using the verified input-output model are investigated. This paper employs the input-output method, based on the data of 18 merged industry sectors, deducting embodied carbon in imports of intermediate goods in order to calculating the embodied carbon in China's exports from 1999 to 2008.

We find that China is a large exporter of embodied carbon; growth of exports, particularly after China's accession to the WTO, contributing greatly to China's overall CO<sub>2</sub> emissions. With the growth of exports, embodied carbon in China's exports increased from 0.38 Gt in 1999 to 1.19 Gt in 2008, a 215.85% increase. This amount is equivalent to the total CO<sub>2</sub> emissions in Japan in the same year, and is more than twice that of the United Kingdom. During 1999–2008, 12–24% of China's CO<sub>2</sub> emissions were associated with production to meet the demands of the international market and foreign consumption. Actually, Embodied carbon in China's exports was mainly concentrated in 5 sectors, including textile and clothing, chemicals and pharmaceuticals, ferrous and non-ferrous metal smelting and rolling, general and specific machinery and equipment, and electrical machinery and equipment. Embodied carbon in the exports of these 5 sectors accounted for 80% of total embodied carbon emissions. Among them, the electrical

machinery and equipment industry and the general and specific machinery and equipment industry had the highest percentages, 30% and 20% respectively.

The result implies China's embodied carbon was exported mainly to the USA, EU, and Japan. Embodied carbon in China's exports to the USA, the EU, and Japan made important contribution to reductions in carbon emissions in these three regions. Therefore, these three regions should be considered partially responsible for China's CO<sub>2</sub> emissions. Based on the findings we suggest that the international community should use both the principles of producer responsibility and consumer responsibility to identify responsibility for carbon emissions and targets for emission reductions for each country. While China should improve its production technology, lower the energy consumption intensity of production, and appropriately limit export of energy-intensive products in order to make good on the commitment of reducing carbon emissions.

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#### REFERENCE

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