Study on Estimates of Embodied Carbon of China: Based on Input-Output Analysis

Zhonglin Sheng, Yufei Xin, and Weida He

Abstract—**In this paper, we use input-output analysis and commodity exporting data of China during 1999-2012 to conduct an empirical study and calculate carbon embodiments in China's exporting goods. The results show that China has been exporting a large amount of carbon embodiments, and its increase of CO₂ emissions has a close relationship with its export and import, among the annual CO₂ emissions of China, about 12%-24% were caused by the demands of other countries.**

Index Terms—**Carbon emissions embodied, import, export, China.**

I. INTRODUCTION

Climate change is one of the most enormous challenges to international community. The extreme weather is rising and has attracted many organizations and researchers [1]. Countries have made efforts to reduce CO_2 emissions which are linked to climate change. The Kyoto Protocol set emission reduction goals for "Annex I" parties and most of them are developed countries. But these countries could reduce their national emissions in many ways, such as the relocation of production abroad, import substitution.

As the "world factory", China's current trade structure is relatively extensive and sustainability is also relatively weak. In the meantime, the product structures of exports and imports have great differences [2]. Imported products are mostly high value-added, high-tech, low energy density, low-emission, but export products are mostly high resource and energy inputs, high emission and low value-added. As a result, China has to sustain the growing trade surplus at the expense of domestic energy resources consumption and environmental pollution [3]. For developed countries, they prefer to transfer these production processes with high energy consumption, high pollution and CO_2 emissions to China in order to achieve their emission reduction targets [4].

In this paper, we conduct an empirical study and calculates carbon embodiments in China's exporting and imported goods by using input-output method. The results can reflect the impact of China's import and export on the growth of carbon emissions [5]. Based on the analysis, this paper points out the international society should consider both principle of producer responsibility and consumer responsibility in identifying emission responsibilities and emission reduction targets of each country, and Chinese government should make great efforts in improving production technology,

reducing the energy consumption intensity embodied in its production, and restricting the exporting of energy-intensive products.

II. LITERATURE REVIEW

Currently the national carbon emissions data released by IPCC is based on the Polluters Pays Principle (PPP), which is the principle on how to recognize the specific carbon emissions responsibility of one country. The PPP was firstly proposed by the Environment Committee of Organization for Economic Co-operation and Development (OECD) in 1972, and its core was to require all polluters to pay for their pollution. All along, the international community, especially the OECE countries, adopt the PPP as a fundamental basis for environmental policy [6]. In terms of carbon emissions, it requires producers to pay for all the carbon emission during product process. However, this method only considers the CO_2 emissions directly related to each sector within the national boundaries, that is to say, it only reflects its greenhouse gas emissions within the national boundaries, and does not take the embodied carbon transfer aroused by foreign trade into account [7].

As an environmental indicator, embodied carbon is used to describe all the direct and indirect pollution, from upstream to downstream production process. In recent years, many countries have paid more and more attention to embodied carbon. Many studies show that major developed countries in the world are essentially the net importing countries of carbon emissions [8]. In contrast, the net exporter of carbon are mostly developing countries and a few small developed nations which are mainly composed of resource products. Some research show that the total carbon emissions in recent years the total carbon emissions of China are increasing rapidly, part of which is the embodied carbon in international trade.

At present, there are few empirical studies on China's embodied carbon and they are mostly concentrated on the theoretical analysis so the research methods needs further improving [9]. In this study, we focus on empirical models and data, to work out carbon embodiments in China's exporting and imported goods.

III. METHODOLOGY

A. Input-Output Model

Input-output analysis is an effective tool to evaluate the resources and pollution embedded into the goods and services from the point of macro scale, and it has been widely

output can be showed as follows:

$$X = \left(I - A\right)^{-1} y \qquad (1)$$

X is a social gross output column vector. Y is the final product for society column vector. A is the coefficient matrix for production technology, and I is a unit matrix. $\left(I - A\right)^{-1}$ is the Leontief inverse matrix, which reflects the direct and indirect input of the final demand in a unit. In an open economy system, A is divided into two parts, A^d and A^m. One is for domestic inputs during usage, the other is for direct consumption coefficient matrix of imported inputs and $A = A^d + A^m$. They are both important when calculating the embodied carbon emissions in the international trade. The final social demand can also be decomposed into two parts, the domestic consumption demand y^d (including the final consumption and capital formation) and export demand (Z). Thus, in an open economic system, when considering the final purpose of demand, the total output of a country should be expressed as:

$$X^d = \left(I - A^d\right)^{-1}\left(y^d + Z\right) \qquad (2)$$

We set $E = \left\{F_j^d \big/ X_j^d\right\}$ as the direct carbon intensity matrix of domestic unit output, and F_j^d is the total amount of carbon emissions directly generated in the domestic sector j so the domestic embodied carbon emissions $\left(C^d\right)$ which could meet the final demands can be showed as:

$$
\begin{aligned}
c^d &= EX^d = E\left(I - A^d\right)^{-1}\left(y + Z\right) \\
&= E\left(I - A^d\right)^{-1} y^d + E\left(I - A^d\right)^{-1} Z \\
&= R^d y^d + R^d Z
\end{aligned} \qquad (3)
$$

$R^d = E\left(I - A^d\right)^{-1}$ is expressed as the direct and indirect carbon emissions that meet final demands for units; $R^d y^d$ represents domestic emissions $\left(C^{dd}\right)$ to meet domestic consumption, and $R^d Z$ is domestic exports emissions $\left(C^{dz}\right)$.

However, in order to achieve products and service of final demands, China still needs to import intermediate inputs $\left(A^m X^d\right)$. Besides, the final consumer products may be imported from abroad $\left(y^m\right)$. The China's total imports of goods and services from abroad $\left(M\right)$ is

$$
\begin{aligned}
M &= A^m X^d + y^m = \\
&\quad A^m \left(I - A^d\right)^{-1}\left(y^d + Z\right)
\end{aligned} \qquad (4)
$$

And the total carbon emissions from China's imported products or services in foreign countries is as follows:

$$
\begin{aligned}
C^{tm} &= R^m M = R^m A^m \left(I - A^d\right)^{-1}\left(y^d + Z\right) \\
&\quad + R^m y^m = R^m A^m \left(I - A^d\right)^{-1} y^d + \\
&\quad R^m A^m \left(I - A^d\right)^{-1} Z + R^m y^m
\end{aligned} \qquad (5)
$$

R^m shows the embodied carbon including direct and indirect carbon emissions from aboard, while $R^m A^m \left(I - A^d\right)^{-1} y^d$ is imported carbon emissions to obtain domestic consumption. $R^m A^m \left(I - A^d\right)^{-1} Z$ is imported carbon emissions for export demands, that is, import and re-export emissions $\left(C^{mz}\right)$. The emissions of imported consumer goods for final consumption is $R^m y^m$.

In order to meet the final demands of China, the total carbon emissions $\left(C^t\right)$, including domestic emissions $\left(C^d\right)$ and the total import emissions $\left(C^{tm}\right)$, can be showed as:

$$
\begin{aligned}
C^d &= C^d + C^{tm} = R^d y^d + R^d Z + \\
&\quad R^m A^m (I - A^d)^{-1} Z + R^m y^m = \\
&\quad \left[R^d + R^m A^m \left(I - A^d\right)^{-1}\right]\left(y^d + Z\right) \\
&\quad + R^m y^m
\end{aligned} \qquad (6)
$$

Considering the import and re-export emissions, the total embodied carbon of China's total export is:

$$C^{tz} = R^d Z + R^m A^m \left(I - A^d\right)^{-1} Z \qquad (7)$$

Moreover, taking off the import and re-export emission, the actual import embodied carbon in order to meet domestic consumers' demands is:

$$C^{md} = R^m A^m \left(I - A^d\right)^{-1} y^d + R^m y^m \qquad (8)$$

As a result, the net balance of embodied carbon emissions in Chinese import and export is as follows:

$$
\begin{aligned}
C^b &= C^{tz} - C^{tm} = C^{dz} - C^{md} \\
&= R^d Z - R^m A^m \left(I - A^d\right)^{-1} y^d
\end{aligned} \qquad (9)
$$

B. Data

We use the data of the import and export (including import and export of goods and services) are directly from the Chinese Input-output Table (Year of 1999, 2002, 2007, 2012).

TABLE I: 2012 CHINESE AUTHORITIES EMBODIED CARBON EMISSIONS (MTC)

Departments	Aggregate demand emissions	Direct emissions	Domestic emissions	Import emissions	Actual export emissions	Aggregate export emissions	Domestic export	Net export
Agriculture	56.54	38.13	53.65	2.89	2.52	3.53	3.16	1.64
Coal mining and dressing	4.38	89.78	3.58	0.80	0.53	4.16	3.89	3.36
Petroleum & gas	12.64	19.25	0.90	11.74	7.56	5.60	11.41	-6.15
Metal mining	13.15	2.52	2.19	10.96	6.38	5.46	0.88	-5.50
Nonmetal minerals mining	1.78	3.78	1.13	0.65	0.50	1.46	1.31	0.81
Food and tobacco processing	85.14	17.41	83.53	1.60	1.40	7.96	7.75	6.35
Textile industry	51.31	13.77	50.03	1.28	0.57	52.12	51.41	50.84
Clothing, feather and leather	58.45	2.30	57.71	0.74	0.59	27.67	27.52	26.93
Timber processing and furniture	23.37	2.37	22.96	0.41	0.31	14.64	14.54	14.23
Paper printing	20.19	19.32	18.64	1.55	1.08	17.43	16.95	15.87
Petroleum, coking and nuclear fuel processing	25.80	395.42	16.48	9.31	6.34	22.70	19.72	13.38
Chemical industry	130.90	131.93	104.78	26.11	16.54	92.60	83.03	66.49
Non-mental mineral products	18.97	102.52	17.64	1.34	1.16	21.18	21.00	19.84
Metal smelting and rolling processing	77.98	329.78	60.66	17.32	11.11	88.86	82.65	71.54
Metal products	48.10	2.96	46.55	1.55	1.07	38.33	37.74	36.67
General and special equipment manufacturing	163.53	10.79	149.41	14.12	11.34	48.79	46.01	34.66
Transportation equipment manufacturing	112.42	6.31	107.43	4.99	4.24	22.58	21.82	17.58
Electrical machinery and communication electronics manufacturing	263.55	3.57	232.72	30.83	19.06	188.00	176.23	157.17
Instrumentation and cultural office machinery manufacturing	23.46	0.26	18.41	5.04	3.72	17.95	16.62	12.90
Other manufacturing	18.83	2.68	16.98	1.85	1.29	6.66	6.10	4.81
Electric and heat power supply	49.06	716.25	48.88	0.19	0.13	2.74	2.68	2.56
Gas production and supply	5.40	8.78	5.40	0.00	0.00	0.00	0.00	0.00
Water production and supply	3.10	0.22	3.10	0.00	0.00	0.00	0.00	0.00
Construction	548.07	8.79	547.47	0.50	0.50	3.69	3.69	3.19
Transportation	88.01	108.62	85.16	2.85	2.21	42.25	41.61	39.40
Retail and catering	72.20	14.55	71.75	0.45	0.37	16.49	16.41	16.03
Other services	243.60	21.22	240.05	3.54	3.14	15.55	15.15	12.01
Total	2217.92	2066.30	2053.60	151.61	102.65	767.26	718.31	615.65

1) Results and analysis

a) Structure of the total embodied carbon emissions
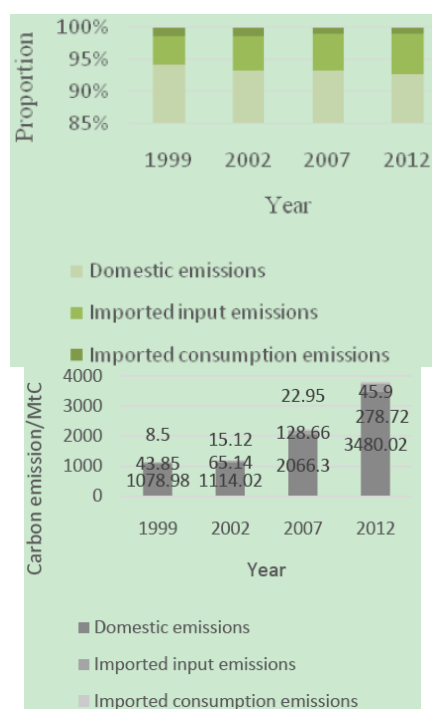

Fig. 1. Structure of the total embodied carbon emissions.

Fig. 1 shows the structure of the total embodied carbon. On the total, China's emissions (including domestic and foreign emissions) in 1999, 2002, 2007 and 2012 showed sustained growth, and its growth in 2001 has a significant change after China joined the WTO.

b) Import and export embodied carbon emissions in each sector

In 2012, the construction industry, other services, the electrical machinery and communication electronic equipment manufacturing industry, and the chemical industry are the most emissions in the total demand, totally accounting for 53.47% of the national total emissions. In contrast, non-metallic mining industry (0.08%), water production and supply industry (0.14%), coal mining and washing industry (0.20%), gas production and supply industry (0.24%) these four sectors are the smallest emissions. We can refer to more specific numerical results from the Table I.

c) The composition and change of the total imports of departments

In four years, the number of departments whose imported inputs emissions proportion of total imports is higher than the national average is respectively 14, 13 and 13, that is to say, these sectors have a higher proportion of imported emissions from the intermediate inputs. We can see the results from the following Table II.

TABLE II: THE COMPOSITION OF THE DEPARTMENTS' TOTAL IMPORTS (%)

Departments	Imported inputs emissions and total import emissions				Import re-export emissions and total import emissions			
	1999	2002	2007	2012	1999	2002	2007	2012
Agriculture	54.47	56.76	71.72	75.63	9.18	10.26	19.5	22.87
Coal mining and dressing	98.75	83.25	98.16	97.32	20.73	18.96	33.32	40.13
Petroleum & gas	105.34	95.15	99.49	98.43	25.3	25.02	35.63	37.81
Metal mining	98.36	99.02	98.67	98.31	28.18	26.82	41.73	47.82
Nonmetal minerals mining	97.47	95.52	99.88	103.41	14.52	14.15	23.9	24.5
Food and tobacco processing	37.98	43.35	55.58	58.67	5.85	8.12	12.8	13.7
Textile industry	86.50	86.44	96.84	94.17	34.64	40.34	55.72	68.92
Clothing, feather and leather	32.95	38.18	52.93	61.67	10.41	14.69	19.82	20.53
Timber processing and furniture	72.87	87.68	80.78	80.69	12.16	15.74	24.67	31.28
Paper printing	90.00	89.45	96.30	92.45	19.75	22.35	30.41	38.07
Petroleum, coking and nuclear fuel processing	100.70	98.05	96.95	94.36	18.42	22.24	31.93	37.84
Chemical industry	91.97	91.82	95.59	97.88	23.69	27.04	36.66	42.43
Non-mental mineral products	89.85	93.96	98.50	99.08	7.35	12.03	13.06	15.47
Metal smelting and rolling processing	105.90	97.72	98.87	103.25	24.73	23.30	35.84	39.08
Metal products	84.99	91.15	90.21	90.47	15.23	20.02	31.21	35.66
General and special equipment manufacturing	60.50	57.49	60.72	63.67	11.17	12.18	19.69	22.35
Transportation equipment manufacturing	56.78	60.93	59.42	57.88	9.97	12.35	15.05	17.84
Electrical machinery and communication electronics manufacturing	72.19	71.23	77.89	80.61	19.05	26.54	38.18	44.79
Instrumentation and cultural office machinery manufacturing	86.53	80.64	76.52	77.49	17.79	17.64	26.30	27.38
Other manufacturing	75.74	70.14	78.13	84.36	19.91	17.63	30.21	39.02
Electric and heat power supply	93.81	85.47	92.80	97.69	20.66	20.94	31.60	35.86
Gas production and supply	0.00	66.59	0.00	0.00	0.00	14.77	0.00	0.00
Water production and supply	6.11	6.55	3.24	2.81	0.83	1.02	0.46	0.38
Construction	84.89	81.21	85.32	86.10	15.20	15.36	17.16	18.95
Transportation	70.44	66.01	60.00	52.33	15.02	15.36	17.16	16.87
Retail and catering	37.09	38.40	40.76	41.55	6.46	7.81	11.26	13.45
Average	85.68	81.30	84.86	83.29	19.45	22.10	32.29	39.07

IV. CONCLUSION

With the increasingly active foreign trade (especially after China joined the WTO), China's carbon emissions have increased year by year. Since China's imports come from different countries and regions, we analyze the imported embodied carbon of China and find that the average of total imports emissions which accounts for about 30% is for re-export demand, while the actual emissions for the import of domestic consumer demands account for about 75% of the total each year. Whether total import or actual import (excluding import and export emissions), electrical machinery and electronic communication equipment manufacturing industry, chemical industry, metal smelting and rolling processing industry, general special equipment manufacturing industry these four departments are most import emissions. From the point of the net balance of embodied carbon, China has always been a net country of embodied carbon emissions in international trade. Due to the efficiency of China's energy use and technological backwardness, the exports of carbon emissions of China is much higher than other countries, especially the year from 2005-2007. In all departments, metal smelting and rolling processing industry, fabricated metal products and transportation industry these three sectors are the fastest growing emissions of all.

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