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Study and Estimation of Embodied Carbon Based on Input-output Analysis

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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 Chinaôs exporting goods. The results show that China has been exporting a large amount of carbon embodiments, and its increase of CO_2 emissions has a close relationship with its export and import, among the annual CO_2 emissions of China, about 12%-24% were caused by the demands of other countries.

Keywords: Carbon Emission, Input-output, Import, Export, Demands

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. Countries have made efforts to reduce CO_2 emissions which are linked to climate change[1]. The Kyoto Protocol has set emission reduction goals for ñAnnex Iò 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 ñworld factoryò, Chinaôs 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. 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[2]. In this paper, we conduct an empirical study and calculate carbon embodiments in Chinaôs exporting and imported goods by using input-output method. The results can reflect the impact of Chinaôs import and export on the growth of carbon emissions. 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.

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Experimental Section

Methodology

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 emission responsibility of one country[3]. 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[4]. All along, for the international community, especially the OECE countries, adopt the PPP as a fundamental basis for environmental policy[5]. In terms of carbon emissions, it requires producers to pay for all the carbon emission during product process[6]. 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]. If a country is importing products manufactured in their national borders to replace domestic production, it is possible to avoid large amounts of greenhouse gas

emissions[8]. For other countries producing goods, they have to pay for the export of CO_2 emissions, which is obviously unfair[9]. As an environmental indicator, embodied carbon is used to describe all the direct and indirect pollution, from upstream to downstream production process[10]. 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[11]. At present, there are few empirical studies on Chinaôs embodied carbon and they are mostly concentrated on the theoretical analysis so the research methods which needs further improving. In this study, we focus on empirical models and data, to work out carbon embodiments in Chinaôs exporting and imported goods.

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 used in environmental issues since 1960s. From the perspective of final demands, a countryôs total output X can be $(I-A)^{-1}y$. Y is the final product for society column vector. A is the coefficient matrix for production technology, and I is a unit matrix. $(I-A)^{-1}$ is the Leontief inverse matrix. 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 $(I-A^d)^{-1}(y^d+Z)$. We set $E=\{F_j{}^d / X_j^d\}$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 (C^d) which could meet the final demands is EX^d, that is the total of R^dy^d and R^dZ. $R^d=E(I-A^d)^{-1}$ is expressed as the direct and indirect carbon emissions that meet final demands for units; R^dy^d represents domestic emissions (C^{dd}) to meet domestic consumption, and R^dZ is domestic exports emissions (C^{dz}). The Chinaôs total import of goods and services from abroad (M) is the total of A^mX^d and y^m. And the total carbon emission from Chinaôs imported products or services in foreign countries is:

$$\begin{aligned} Ctm &= RmM = RmAm(I - Ad) - 1(yd + Z) + Rmym \\ &= P\mu A\mu(I - A\delta) - 1\psi\delta + P\mu A\mu(I - A\delta) - 1Z + P\mu\psi\mu \end{aligned} \quad \text{é} \quad (1)$$

R^m shows the embodied carbon including direct and indirect carbon emissions from aboard, while $R^mA^m(I-A^d)^{-1}y^d$ is imported carbon emissions to obtain domestic consumption. $R^mA^m(I-A^d)^{-1}Z$ is imported carbon emissions for export demands, that is, import and re-export emissions (C^{mz}). In order to meet the final demands of China, the total carbon emissions (C^t), including domestic emissions (C^d) and the total import emissions (C^{tm}), can be showed as:

$$\begin{aligned} Ct &= Cd + Ctm = Rdyd + RdZ + RmAm(I - Ad) - 1yd + RmAm(I - Ad) \\ &- 1Z + Rmym = [P\delta + P\mu A\mu(I - A\delta) - 1](\psi\delta + Z) + P\mu\psi\mu \end{aligned} \quad \text{é} \quad (2)$$

Considering the import and re-export emissions, the total embodied carbon of Chinaôs total export C^{tz} is the total of R^dZ and $R^mA^m(I-A^d)^{-1}Z$. Moreover, taking off the import and re-export emission, the actual import embodied carbon (C^{md}) in order to meet domestic consumersô demands is $R^mA^m(I-A^d)^{-1}y^d$ and R^my^m. As a result, the net balance of embodied carbon emissions in Chinese import and export is as follows:

$$\begin{aligned} Cb &= Ctz - Ctm = Cdz - Cmd \\ &= RdZ - RmAm(I - Ad) - 1yd - Rmym \end{aligned} \quad \text{é} \quad (3)$$

Data preparation

This paper uses the data of the import and export (including import and export of goods and services) are directly from the Chinese Input-output Table 1 (Year of 1999, 2002, 2007, 2012).

Results and analysis

Structure of the total embodied carbon emissions

Fig.1 shows the structure of the total embodied carbon. On the total, Chinaôs 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. In total emissions , more than 93% of the emissions come from domestic production process , in which 1997, 2002,2007 and 2012 domestic emissions were 1020.98 MtC, 1114.02 MtC , 2066.30 MtC and 3240.50 MtC, respectively accounted for 95.31%,

Table 1ð 2012 Chinese authorities embodied carbon emissions (MtC)

Departments	Aggregate demand emissions	Direct emissions	Domestic emissions	Import emissions	Actual import 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	1.41	-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 and education articles	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	38.22	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	547.57	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	2066.30	151.61	102.65	767.26	718.31	615.65

93.23%, 93.16% and 91.25% of total emissions corresponding year. China 's total imports emissions less than 7 %, with 1997, 2002, 2007 and 2012 total imports emissions were 50.29 MtC, 80.86 MtC, 151.61 MtC and 126.72MtC, respectively accounted for 4.69%, 6.77%, 6.84% and 6.91% of total emissions of the corresponding year and the total imports share of the emissions rise slightly. Emissions in total imports, respectively, 84.68% (42.58 MtC), 81.30% (65.74 MtC), 84.86% (128.66 MtC) and 85.13% (134.76 MtC) for use imported intermediate inputs used in the production of foreign emissions (including direct and indirect emissions). Direct imports for final consumption emissions using the corresponding year were only 15.32 percent of total imports emissions (7.70 MtC), 18.70% (15.20 MtC), 15.14% (22.95 MtC) and 17.38% (28.59 MtC).

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

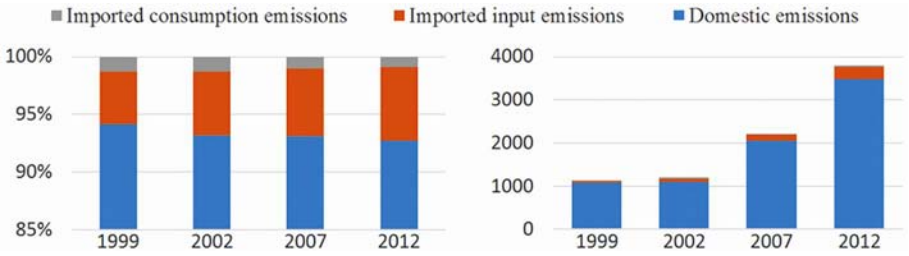

Fig.1ð Structure of the total embodied carbon emissions

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 1. Domestically, electricity and heat production and supply industry, petroleum processing, coking and nuclear fuel processing industry, metal smelting and rolling processing industry, chemical industry and transport are the main productive sectors Chinese domestic direct emissions of that year, accounting for 2012 were domestic direct total emissions (2066.30MtC) of 34.66% (716.25 MtC), 19.14 (395.42 MtC), 15.96% (329.78 MtC), 6.38% (131.93 MtC) and 5.26% (108.62 MtC), the total amount exceeds 80%. However, when 26.50 percent of the total national emissions (547.57 MtC) is to meet the final demand in the construction industry, 11.62% (240.05 MtC) for other services, 11.26% (232.72 MtC) for electrical machinery and electronic communication equipment manufacturing, 7.23% (149.41 MtC) for general equipment manufacturing industry, which used to meet domestic emissions of the four sectors of final demand total domestic emissions account for nearly 60% of the domestic final demand sectors most emission sector. In contrast, domestic demand-emissions sector is mainly for the oil and gas exploration industry (0.04%), non-metallic mining industry (0.05%), mining industry (0.11%), coal mining and washing industry (0.17%) and other extractive industries sector and water production and supply industry (0.15%), gas production and supply industry (0.26%).

Composition and change of the total imports of departments

The total imports by source sector emissions constituted can be divided into imported inputs emissions and emissions of imported consumer goods these two parts. According to end-use demand, it can be divided into imports for domestic consumption and emissions of actual imports for re-export export demand emissions. During the year 1999-2012, the ratio of imports emissions in total imports is higher than the national average for the year (respectively 84.68%, 81.30%, 84.86% and 83.97%), respectively 14, 13 and 13, and the total emissions from these sectors have a higher proportion of imports from the intermediate sector for production inputs. Among them, the mining industry, petroleum processing, coking and nuclear fuel processing industry, metal smelting and rolling processing industry, the proportion of imports for intermediate inputs emissions overall during production process is the highest. In contrast, other sectors, such as construction, other services, clothing, leather and feather products industry, food and tobacco processing industry, the relative proportion of their imports and total imports emissions are the lowest, indicating that these sectors imported emissions are mainly from direct consumer demands so that the imported emissions for intermediate inputs are relative low.

Conclusions

With the increasingly active foreign trade (especially after China joined the WTO), Chinaôs carbon emissions have increased year by year. Since Chinaôs 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 Chinaôs 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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