Analysis on CO_2 Emission Embodied in Sino-US Trade Based on the GTAP8.0 Database

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Abstract: By constructing global multi-regional input-output (MRIO) table based on GTAP8.0 database, production-based and consumption-based CO_2 emissions of China and the United States were calculated in this paper, as well as CO_2 emissions embodied in exports of China and the U.S and the industry distribution. The results showed that the consumption-based CO_2 emissions of China in 2004 and 2007 were 428 Mt and 522 Mt lower than production-based CO_2 emissions. To the United States, the consumption-based CO_2 emissions in 2004 and 2007 were 272 Mt and 221 Mt higher than production-based CO_2 emissions. China is a net exporter of CO_2 emission while the U.S. is a net importer of CO_2 emission embodied in international trade. Compared to the United States, the CO_2 emissions embodied in China's exports accounted for higher proportion than that of the U.S. in total domestic CO_2 emissions, while the emissions in imports accounted for lower proportion than that of the U.S. in total domestic CO_2 emissions.

Key Words: Sino-US Trade; embodied CO_2 emission; MRIO; GTAP

1. Introduction

Climate change has become one of the serious challenges that faced by human being. The United Nations Convention on Climate Change (UNFCCC) determined the national responsibility for emissions reductions based on each country's total greenhouse gas (GHG) emissions. The total GHG emissions refer to the emissions and absorptions within the jurisdiction scope of national sovereignty. However, in the process of global economic integration, this accounting method ignored the impact of international trade on national carbon emissions. With the deepening of the international division of labor and the development of international trade, the products that a country produced and consumed occurred to be geographically separated. When a country consuming the imported goods from foreign countries and exporting its own commodities, there remained direct and indirect energy consumption and CO_2 emissions embodied in the production process of trade goods, namely the CO_2 emissions embodied in international trade. According to the production-based accounting principles, domestic emissions include CO_2 emissions from both in domestic consumer goods and export commodities which are domestically made. However, it doesn't include CO_2 emissions from imported consumer goods for its absence in domestic production in the country. This carbon emissions accounting method leads to the increasing of the total CO_2 emissions of a country when its exports keeps increasing, and other highly import-dependent countries decreased its own total CO_2 emissions by avoiding the domestic production. Consequently, it is necessary to take production-based and consumption-based CO_2 emissions into consideration at the same time.

Since China's accession to the WTO, foreign trade has developed rapidly, and the exports to developed countries increased significantly. Meanwhile, China has become the world's largest carbon emitters, while the studied on the CO_2 emissions embodied in China's imports and exports gained widespread concern. Chen et al. (2008) used input-output method finding that in 2006, the CO_2 emissions embodied in China's export trade reached 3.14 billion tons, and net CO_2 emissions

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embodied in exports was 1.25 billion tons. Lin and Sun (2010) applied input-output analysis (IOA) to estimate CO_2 emissions embodied in China's exports, indicating that about 3.357 billion tons CO_2 emissions were embodied in exports and the emissions avoided by imports were 2.333 billion tons in 2005. Li and Hewitt (2008) used input-output method to study the carbon embodied in trade between the UK and China, the results showed that in order to meet the consumer demand of the United Kingdom, China exported 186 million tons (Mt) CO_2 in 2004 through Sino-British trade, which accounted for 4% of the total carbon emissions of China in that year and thus reduced 11% of CO_2 emissions for UK, increasing the world's CO_2 emissions by 117 Mt. Liu et al. (2010) analyzed the carbon emissions embodied in Japan-Sino trade using input-output analysis based on Japan's industrial emissions data and studied the impacts that the Japan-Sino trade had on two countries' carbon emissions. The empirical results showed that the bilateral trade was conducive to reducing carbon emissions of two countries, but at the same time there also existed the phenomenon that Japan transferred part of carbon emissions to China through trade which made China a net exporter country of carbon emissions embodied in trade because of the exports to Japan. Hyun-SIK Chung and Hae-Chun Rhee (2007) estimated total CO_2 emissions of Japan and South Korea for 1990 using an input-output model. Their analysis shows that even though the absolute level of emission is much lower in South Korea than in Japan, total emission intensities are generally higher in the former. Korean exports to Japan are more emission intensive than the reverse, while exports of both countries to the rest of the world are more emission intensive than their bilateral trade. Frank Ackermana, et.al (2007) analyzed the greenhouse gas emissions embodied in trade between Japan and the US by extending the Japanese government's linked Japan–US input–output model to include carbon emission coefficients for each sector. They indicated that the most important policy implication of the research may be that US industry could cut its carbon emissions by more than half if it matched the environmental performance of industry in Japan.

In addition, China and the United States occupy important places in response to global climate change process as two trading power and main carbon emission countries. So the estimation of the carbon emissions embodied in the trade between these two countries has also become the research focus of concern. Shui and Harriss（2006）examined the influence of US–China trade on national and global emissions of carbon dioxide. Their initial findings reveal that US CO_2 emissions would have increased from 3% to 6% if the goods imported from China had been produced in the US, and about 7%–14% of China's current CO_2 emissions were a result of producing exports for US consumers during 1997-2003.They suggested that an improved international accounting methodologies for assigning responsibility for CO_2 emissions must be designed to account for the dynamic nature of international trade. Yu and Wang (2009) calculated the carbon emissions embodied in Sino-US trade in 1997 and 2002, which showed that in those 2 years, 6.77% and 9.32% of the total carbon emissions in the United States were transferred to China respectively. In order to measure the carbon embodied in Sino-US merchandise trade, Yin and Cheng (2010) calculated the carbon emission factor of trade goods of China and the U.S. based on the input -output tables of 2 countries, which avoided the situation that using the data of only one country to estimate the carbon embodied in bilateral trade and a big measuring deviation appearing. The results showed that with Sino-US trade, China increased domestic CO_2 emission, while the U.S. avoided 55 -200 million tones of CO_2 emission each year, accounting for 1% -3.6% of its annual CO_2 emissions. Xu et al. (2009) found that in 2002 and 2007, the CO_2 emissions in

China's exports to the United States accounted for 12%-17% and 8%-12% of domestic CO_2 emissions. Guo et.al (2010) quantified the impact of Sino-US international trade on national and global CO_2 emissions based on an input–output model. The results shows that Sino-US international trade increased global CO_2 emissions by 385.32 Mt as a whole in 2005, and suggested that China should adjust the trade structure and US should accelerate the export of advanced technologies to China in order to reduce the negative impact of Sino-US trade on national and global CO_2 emissions. Shi and Zhang (2011) used input-output tables of China to calculate the carbon emissions embodied in exports of China to the U.S. from 2003 to 2007.

In recent years, some foreign scholars began to explore the carbon accounting embodied in trade based on the multi-regional input-output model (Ahmad and Wyckoff, 2003; Wiedmann T., 2008). Multi-regional input-output model can break out of the scope of a country's economy, and internalize the relationship of import and export for the national production sectors based on the input-output tables of each country, then get the input-output relationship of the various industries of each countries and regions worldwide, as well as the direct and indirect investment relationship between the final consumption of a country and other countries' production. The domestic emissions obtained in this way is often higher than that based on single regional input-output model because when the domestic consumption increases, it also increases the demand of domestic middle input indirectly through the international production chain (Miller R.E., Blair PD., 2009). Ahmad and Wyckoff (2003) were the very scholars who first used multi-regional input-output model to complete the calculation of carbon embodied in production, production and trade between multinational sides. They studied the emissions of 24 OECD countries and China, India and Russia that covering 80% of the global carbon emissions in 1995 based on each country's input-output tables in the OECD database. The results showed that contained a lot of carbon emissions embodied in the international trade. In 1995, the consumption-based emissions of OECD countries were 5% higher than domestic production-based CO_2 emissions, which accounted for 2.5% of the total global emissions in that year. This implied that a considerable scale of emissions were embodied in the imports of goods from China, India, Russia and other developing countries, while China and Russia are the countries that produced highest carbon embodied in the exports to OECD nations. The domestic study that used multi-regional input-output model came out these two years. Zhou (2010) calculated the carbon emissions embodied in the trade between 10 countries or regions in the Asia-Pacific region in 2000, finding that the United States was the largest net importer of carbon emissions embodied in trade, followed by Japan, while China is the largest net exporter of carbon emissions embodied in trade. However, the data used in this study was earlier and the scope of the study was limited to the Asia-Pacific region, it wasn't a truly global carbon accounting embodied in the international trade.

This paper builds global multi-regional input-output tables based on GTAP 8.0, and calculates the production-based and consumption-based CO_2 emissions of China and the United States respectively and the CO_2 emissions embodied and the industry distributions in exports of two countries.

2. Methodology and data sources

The data used in this paper came from GTAP8.0 database. GTAP8.0 was published in 2012 which contained the data of 57 industries in 129 countries and regions in 2 norm years (2004 and 2007). GTAP8.0 database doesn't only provide the input-output tables of each country and region, but also distinguish the intermediate inputs and final consumption from domestic supply and foreign exports of each country. What's more, it provides the data of bilateral trade and CO_2 emissions by industry and energy (coal, petroleum, natural gas, electricity, oil products and coal gas).

2.1 Aggregation by region and industry

First of all, this paper integrated the 129 countries and regions provided by GTAP8.0 into 5 countries (or regions) which were China, the United States, European Union, Japan and rest of world (ROW). Table 1 provided further details on the specific integration.

Table 1

Aggregation by region in GTAP8.0.

No.	Region	Countries (or regions) contained in this region [a]
1	China	CHN、HKG、XEA、TWN
2	The United States	USA
3	European Union	AUT、BEL、CYP、CZE、DNK、EST、FIN、FRA、DEU、GRC、HUN、IRL、ITA、LVA、POL、LTU、LUX、MLT、NLD、PRT、SVK、ESP、SVN、SWE、GBR、BGR、ROU
4	Japan	JPN
5	The rest of world	AUS、NZL、XOC； KOR、KHM、IDN、LAO、MYS、PHL、SGP、THA、VNM、BGD、XSE、IND、PAK、LKA、XSA、KAZ、KGZ、XSU、IRN、ARM、AZE、GEO、TUR、XWS； CAN、MEX、XNA、BOL、BRA、CHL、ARG、URY、COL、ECU、PRY、PER、VEN、XSM、CRI、GTM、NIC、PAN、XCA、XCB； CHE、NOR、ALB、BLR、HRV、RUS、UKR、XEE、XEF、XER； EGY、MAR、TUN、XNF、NGA、SEN、XWF、XCF、XAC、ETH、MDG、MWI、MUS、MOZ、UGA、ZMB、ZWE、XEC、BWA、ZAF、XSC

[a] *See the Appendix A for the explanations for each abbreviation.*

Then, this paper integrated the 57 industries provided by GTAP8.0 into 10 industries which were agriculture, food processing, transportation, services, mining and resources, construction, manufacturing, paper products and publishing, mineral products and petrochemical. Table 2 provided further details on the specific integration.

Table 2

Aggregation by industry in GTAP8.0.

No.	Aggregate Industry	Industries contained in this aggregate industry [b]
1	Agriculture	pdr、wht、gro、v_f、osd、c_b、pfd、ocr、ctl、oap、rmk、wol
2	Food processing	cmt、omt、vol、mil、pcr、sgr、ofd、b_t
3	Mining and resources	coa、oil、gas、frs、fsh、omn
4	Paper products and publishing	ppp
5	Petrochemical	p_c、crp
6	Mineral products	i_s、nfm、fmp、nmm
7	Manufacturing	tex、wap、lea、lum、mvh、ele、otn、ome、omf
8	Construction	cns
9	Transportation	atp、wtp、otp
10	Services	ely、gdt、wtr、trd、cmn、ofi、isr、obs、ros、osg、dwe

[b] *See the Appendix B for the explanations for each abbreviation.*

2.2 Building the global multi-regional input-output table

By convention, i, j used in this paper represent each industry. r, s represent each country (or region). In GTAP8.0, the input-output relation of domestic product of country r can be represented as

$$x_i^r = \sum_j vdfm_{ij}^r + vdpm_i^r + vdgm_i^r + \sum_s vxmd_i^{rs} \qquad (1)$$

x_i^r is the total output of industry i of country r. $vdfm_{ij}^r$ is the intermediate input demand of industry j of country r towards industry i. (In GTAP 8.0, this variable values contain the demand to investment of r country towards the product of industry i.) $vdpm_i^r$ is the personal consumption demand of country r towards the product of industry i. $vdgm_i^r$ is the government consumption demand of country r towards the product of industry i. $vxmd_i^{rs}$ is the output demand of country s towards the product of industry i of country r.

What’s more, GTAP 8.0 provides the data of the intermediate inputs and final consumption in each country’s total imports, but doesn’t divide the total imports by different importing country. Therefore, if we use GTAP8.0 to build global multi-regional input-output tables, we need to do the further subdivisions of each country’s intermediate inputs and final consumption of total imports by importing country. In order to achieve this goal, this paper assumed that when country r imported product i from the whole world (including country s) and used product i as the intermediate inputs or final consumption, the percentage of product i that became the intermediate inputs of country r from country s compared to the total global imports of product i of country r, equals to the percentage of product i as the final consumption of country r imported from country s compared to the total global imports of product i of country r. Both of them were equal to the percentage of country r’s imports from country s compared to country r’s total global imports. Therefore,

$$z_{ij}^{sr} = z_{ij}^{*r} \times \frac{e_i^{sr}}{m_i^r} \qquad (2)$$

$$y_i^{sr} = y_i^{*r} \times \frac{e_i^{sr}}{m_i^r} \qquad (3)$$

z^{sr}_{ij} is the imports from industry i of country s as the intermediate inputs of industry j in country r. z^{*r}_{ij} is the total imports from industry i of the whole world as the intermediate inputs of industry j in country r. e^{sr}_i is the imports from country s to industry i of country r. m^r_i is the imports from around the world to industry i of country r. y^{sr}_i is the imports from industry i of country s as the final consumption of industry j in country r. y^{*r}_i is the total imports from industry i of the whole world as the final consumption of industry j in country r.

After applying the above treatment, we got the global MRIO tables contained 5 countries (or regions) and 10 industries. The basic structure is given in Table 3 as follows.

Table 3

The basic structure of the global multi-region input-output（MRIO）tables.

		Intermediate inputs				Final consumption				Total Output	CO_2
		A	B	…	E	A	B	…	E		
Intermediate inputs	A	Z^{AA}	Z^{AB}	…	Z^{AE}	Y^{AA}	Y^{AB}	…	Y^{AE}	X^A	C^A
	B	Z^{BA}	Z^{BB}	…	Z^{BE}	Y^{BA}	Y^{BB}	…	Y^{BE}	X^B	C^B
	…	…	…	…	…	…	…	…	…	…	…
	E	Z^{EA}	Z^{EB}		Z^{EE}	Y^{EA}	Y^{EB}		Y^{EE}	X^E	C^E
Added values		…	…	…	…						
Total investment		X^A	X^B	…	X^E						

A, B…E all represent the countries. The intermediate inputs Z^{AA}, Z^{AB} are 10×10 matrixes reflecting the input-output relations of 10 industries among or within countries (or regions).Y^{AA}, Y^{AB}…Y^{EE}, X^A, X^B…X^E, C^A,C^B…C^E are 10×1 matrixes. Y^{AA}, Y^{AB}…Y^{EE} are the final consumption of each country (or sector) for domestic use and foreign output. X^A, X^B…X^E are the total output. C^A, C^B…C^E are the CO_2 emissions.

2.3 Production-based and consumption-based CO_2 emissions amounting

On the bases of the above MRIO tables, the input-output relations of all the counties can be represented as

$$\begin{pmatrix} X^A \\ X^B \\ \vdots \\ X^E \end{pmatrix} = \begin{pmatrix} A^{AA} & A^{AB} & \cdots & A^{AE} \\ A^{BA} & A^{BB} & \cdots & A^{BE} \\ \vdots & \vdots & \ddots & \vdots \\ A^{EA} & A^{EB} & \cdots & A^{EE} \end{pmatrix} \begin{pmatrix} X^A \\ X^B \\ \vdots \\ X^E \end{pmatrix} + \begin{pmatrix} \sum_{k=A}^{E} Y^{Ak} \\ \sum_{k=A}^{E} Y^{Bk} \\ \vdots \\ \sum_{k=A}^{E} Y^{Ek} \end{pmatrix} \qquad (4)$$

The column vector on left-hand side of the equation is the total outputs of each industry in each country (or region). The first part on the right side of the equation is a 50×50 matrix representing the direct consumption coefficient composed by the element $a_{ij}^{sr} = z_{ij}^{sr} / x_i^r$, showing that the input-output relations of the industries between different countries (or regions). A^{rr} on the diagonal of the matrix is the input-output relations of domestic industry, while A^{rs} on the off-diagonal of the matrix is the input-output relations of industries between country r and country s. The last column of the matrix on the right side of the equation is the final demand matrix, representing the final consumptions produced by each country that provided to its own country (Y^{rr}) and exported to foreign countries (Y^{rs}).

In equation (4), we got the final consumption column vector of country r, $\mathrm{d}^r = \left(\mathrm{Y}^{Ar} \quad Y^{Br} \quad \cdots \quad Y^{Er}\right)^T$, including the final consumption of the imports (Y^{sr}) and the domestic final consumption (Y^{rr}). We also got the production row vector of country r, $\mathrm{p}^r = \left(\mathrm{Y}^{rA} \quad Y^{rB} \quad \cdots \quad Y^{rE}\right)$, including the final consumption of the domestic production of goods (Y^{rr}) and the final consumption of domestic production of goods exported to country s (Y^{rs}). The consumption-based CO_2 emissions C_d^r and the production-based CO_2 emissions C_p^r of a country can be represented as

$$C_d^r = E\left(I - A\right)^{-1} \hat{d}^r \tag{5}$$

$$C_p^r = E\left(I - A\right)^{-1} \hat{p}^r \tag{6}$$

Here, $\hat{d}^r$, $\hat{p}^r$ are diagonal matrix. E is a 50×1 CO_2 direct consumption coefficient matrix composed by element $\mathrm{e}_i^r = c_i^r / x_i^r$.

3 Results and analysis

3.1 Production-based and consumption-based CO_2 emissions

Fig. 1 depicts the production-based and consumption-based CO_2 emissions of China and the United States in 2004 and 2007. In 2004, the production-based CO_2 emissions of the U.S. reached 5.900 billion tons; while it was only 4.072 billion tons for China. When it came to 2007, the production-based CO_2 emissions of China reached 5.123 billion tons and got close to the United States' emissions (5.942 billion tons). If we take a look at the consumption-based CO_2 emissions, the outputs for China and the U.S. in 2004 were 3.645 and 6.172 billion tons respectively; while in 2007, the CO_2 emissions of China reached 4.600 billion tons and it was 6.162 billion tons for the U.S. The above results showed that the production-based and consumption-based CO_2 emissions of China and the United States differed remarkably. For China, the consumption-based CO_2 emissions were 428 Mt and 522 Mt less than production-based CO_2 emissions in 2004 and 2007 respectively. For the U.S., it remained 272 Mt and 220 Mt increasing. This implied that a fraction of China's CO_2 emissions came from the production the exports consumed by foreigners; however, the United States avoided a fraction of CO_2 emissions by using exports product from other countries.

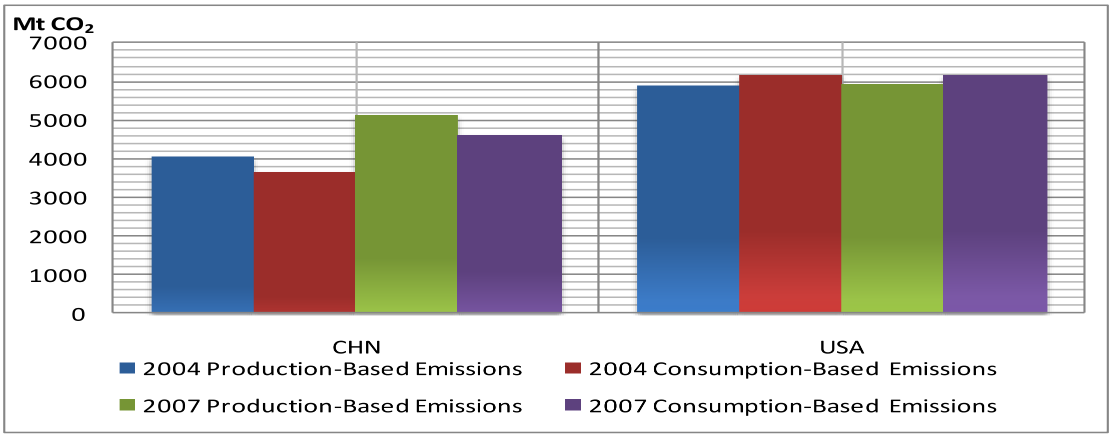

Fig. 1. The production-based and consumption-based CO_2 emissions of China and the United States in 2004 and 2007 (Mt: million ton).

3.2 CO_2 emissions embodied in the foreign trade

3.2.1 CO_2 emissions embodied in imports and exports

Fig. 2 shows the result of the CO_2 emissions in embodied imports and exports of China and the United States in 2004 and 2007. The CO_2 emissions embodied in exports of China in 2004 and 2007 reached 516 Mt and 616 Mt, which accounted for 12.67% and 12.02% of the total emissions of domestic production in those 2 years. The CO_2 emissions embodied in imports were 88.29 Mt and 93.57 Mt in 2004 and 2007, accounting for 2.42% and 2.03% of the total emissions of domestic consumption. For the United States, the CO_2 emissions embodied in exports in 2004 and 2007 reached 243 Mt and 249 Mt, which made up 4.12% and 4.19% of the total emissions of domestic production in those 2 years. The CO_2 emissions embodied in imports were 515 Mt and 469 Mt in 2004 and 2007, accounting for 8.34% and 7.61% of the total emissions of domestic consumption.

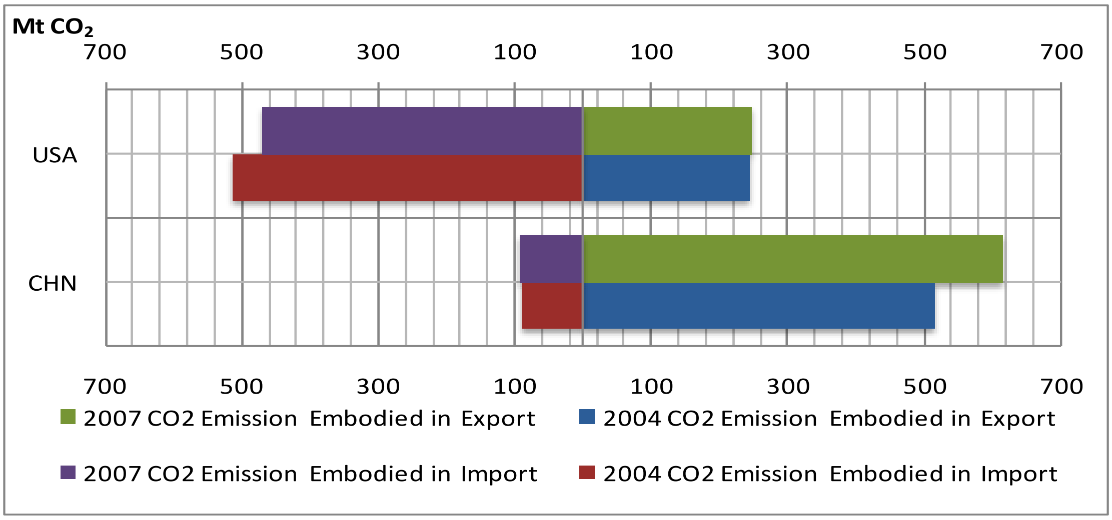

Fig. 2. The CO_2 emissions embodied in imports and exports of China and the United States in 2004 and 2007 (Mt: million ton).

3.2.2 Net exports/imports of CO_2 emissions embodied in international trade

Subtracting the CO_2 emissions embodied in imports of a country from that in exports, the country turns out to be a net exporter of CO_2 emission embodied in trade if the result is positive, whereas the country is a net importer. Fig. 3 shows the result of China and the United States.

According to Fig. 3, China is a net exporter of CO_2 emission embodied in the international trade. Its net exports of CO_2 emissions embodied in trade reached 428 Mt and 522 Mt in 2004 and 2007, accounting for 10.51% and 10.19% of domestic production-based CO_2 emissions of those two years. The U.S. is a net importer of CO_2 emission embodied in trade. Its net imports of CO_2 emissions embodied in the international trade reached 272 Mt and 221 Mt in 2004 and 2007, making up 4.40% and 3.58% of domestic consumption-based CO_2 emissions of those two years.

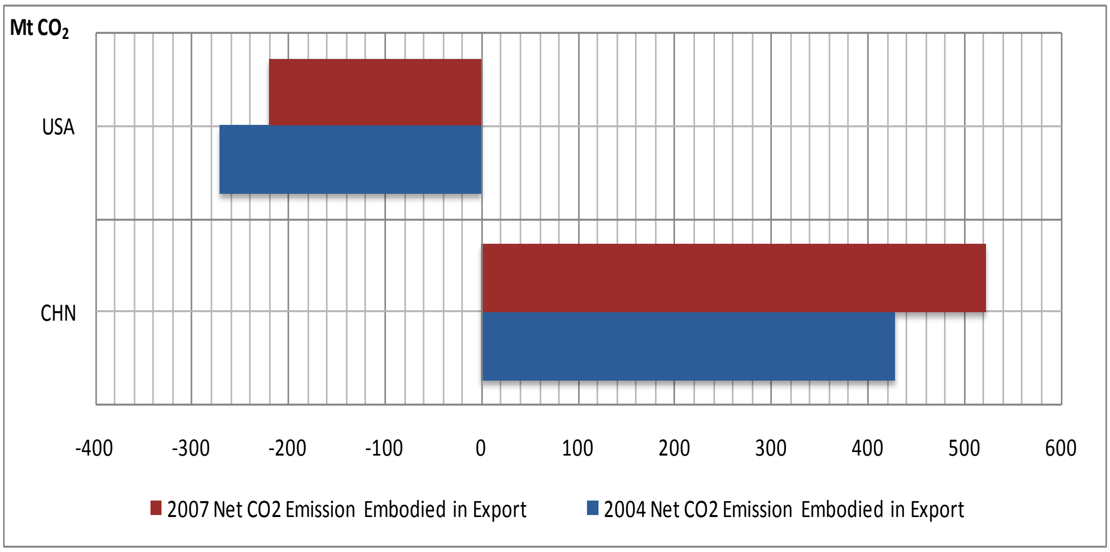

Fig. 3. The net exports of CO_2 emission of China and the United States embodied in trade in 2004 and 2007 (Mt: million ton).

As a whole, the United States avoided massive domestic CO_2 emissions through imports, while China produced great CO_2 to satisfy the global consumption demand as a net exporter of CO_2 emissions embodied in trade. The accounting methods of production-based CO_2 emissions ignore the carbon offsetting in export commodities. However, the accounting method of consumption-based CO_2 emissions measures the CO_2 emission level of a country more precisely.

3.3 Industry analysis

3.3.1 Industry distribution of CO_2 emissions embodied in exports

Fig. 4 depicts the industry distribution of the CO_2 emissions embodied in exports of China and the United States in 2004 and 2007. Manufacturing was the main industry of CO_2 emissions embodied in China's exports, whose CO_2 emissions embodied in exports reached 354 Mt and 441 Mt in 2004 and 2007, accounting for 68.56% and 71.60% of all CO_2 emissions in China's exports in those two years. Similarly, manufacturing was also the main industry producing massive CO_2 embodied in exports of the U.S. The CO_2 emissions embodied in exports reached 112 Mt and 111 Mt in 2004 and 2007, accounting for 46.2% and 44.7% of all CO_2 emissions in exports of the United States in those two years.

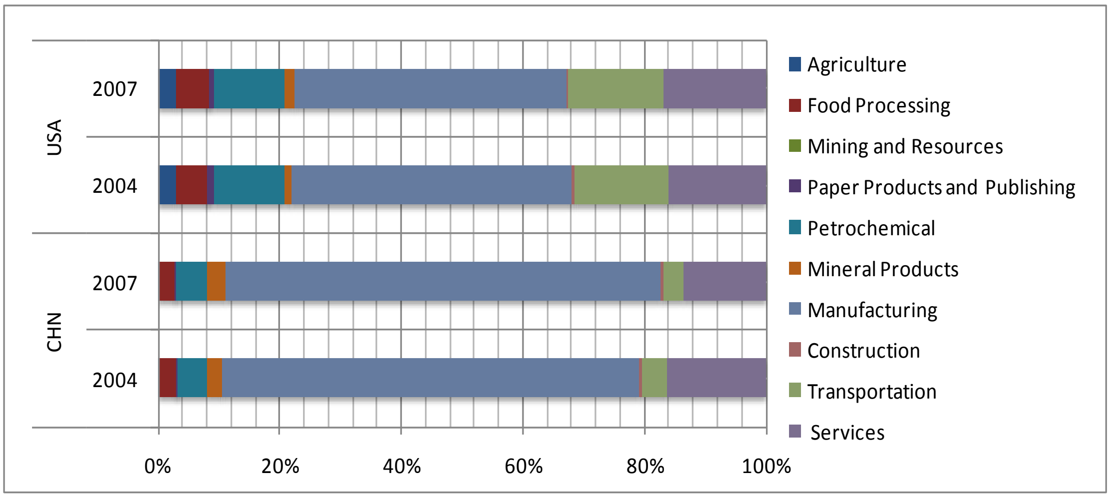

Fig. 4. The industry distribution of the CO_2 emissions embodied in exports of China and the United States in 2004 and 2007.

Fig. 4 shows that the proportions of the CO_2 emissions embodied in the exports of agriculture, transportation and petrochemical of the U.S. were significantly higher than those of China. When we look at the absolute number of the CO_2 emissions of these 3 industries embodied in exports, it can be summarized that in both 2004 and 2007, the CO_2 emissions of agriculture and transportation embodied in America's exports were higher than those in China. The CO_2 emission embodied in the exports of petrochemical of the U.S. was higher than that of China in 2004 and lower than that of China in 2007. Although the CO_2 emissions embodied in services sector of 2 countries' exports occupied the similar proportion, the absolute numbers turned out to be 84.42 Mt and 83.08 Mt in 2004 and 2007 for China, and 38.82 Mt and 41.62 Mt for the United States.

3.3.2 Industry distribution of the CO_2 *emissions embodied in net imports/exports*

Fig. 5 depicts the Industry distribution of the CO_2 emissions embodied in net exports and imports of China and the United States in 2004 and 2007. In 2004 and 2007, except for mining and resources, all of the other 9 industries of China were net exporters of CO_2 emissions embodied in the international trade. For the United States, except for agriculture, construction, transportation and services, other industries belonged to net importers of CO_2 emissions embodied in trade. Manufacturing was the main net importer of CO_2 emissions embodied in U.S.'s trade but the main net exporter of CO_2 emissions embodied in China's trade at the same time.

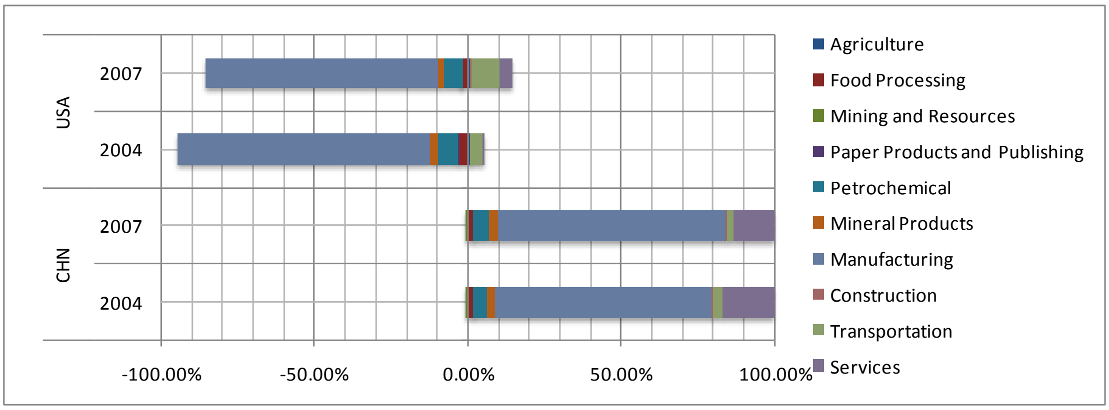

Fig. 5. The Industry distribution of the CO_2 emissions embodied in net exports/imports of China and the United States in 2004 and 2007.

4. Conclusions and discussions

Using GTAP8.0 to build global multi-regional input-output tables to measure each country's CO_2 emissions can fully reflect a country's production and emissions on the production chain of imported products caused by domestic consumption. What's more, it also reflected the real changes of domestic production and emissions caused by the increase of domestic consumption under the influence of international production chain through the feedback effect of the chain. The results were more accurate when compared to using single-regional input-output tables.

The calculating results of each country's production-based and consumption-based CO_2 emissions varied significantly, especially for large foreign trade countries such as China and the United States. The present results show that the consumption-based CO_2 emissions of China in 2004 and 2007 were 428 Mt and 522 Mt lower than production-based CO_2 emissions. To the United States, the consumption-based CO_2 emissions in 2004 and 2007 were 272 Mt and 220 Mt higher than production-based CO_2 emissions. In the context of globalization, the developed countries like the United States avoided the CO_2 emissions by reducing its production of import commodities as a major importer, while China and other exporting countries bore a large number of CO_2 emissions because of the massive production of the exports.

Compared to the United States, the CO_2 emissions embodied in China's exports accounted for higher proportion than that of the U.S. in total domestic CO_2 emissions, while the emissions in imports accounted for lower proportion than that of the U.S. in total domestic CO_2 emissions. China was a net exporter of CO_2 emissions embodied in international trade, whose net exports of CO_2 emissions reached 428 Mt and 522 Mt respectively in 2004 and 2007. However, the United States is a net importer of CO_2 emissions embodied in trade, whose net imports of CO_2 emissions reached 272 Mt and 221 Mt in 2004 and 2007, respectively.

In 2004 and 2007, except for mining and resources, all of the other 9 industries of China were net exporters of CO_2 emissions. For the United States, except for agriculture, construction, transportation and services, other 6 industries belonged to net importers of CO_2 emissions. Manufacturing was the main net importer of CO_2 emissions embodied in the U.S.'s trade but the main net exporter of CO_2 emissions embodied in China's at the same time.

In conclusion, in order to ease China's pressure on the reductions in GHG (greenhouse gas) emissions, it remains the orientation of development that needs to be consistently adhered to in the future to adjust economical structure, speed up technical innovation and improve energy utilization efficiency. On the one hand, policy guidance and funding investment should be used to develop and exploit new renewable energy like solar, geothermal, wind and biomass energy at suitable regions. This can increase the proportion of clean energy in China. There is a need for China to control the development of energy-intensive manufacturing industry properly. The eliminating of the backward production capacity and the encouraging of the technology innovation to promote transformation of high-grade manufacturing should also be paid attention to at the same time. For other export-dependent industries, they can seek business opportunities from the global wave of "low-carbon" by designing and producing low-carbon product to realize the restructuring of exports. China might also make its effort to implement carbon tax on domestic enterprises at the appropriate time, and use the tax revenues to supplement the energy and greenhouse gas reductions of companies, to promote the transformation of China's enterprises to low carbonization and put them on a low carbon path. On the other hand, just because the recent economic growth of China relied heavily on the external market, the carbon emissions started moving to domestic environment and China's export-oriented economy will be punctured when the U.S. and Europe start to impose carbon tariffs towards China in the future. Therefore, it can be the future development orientation for China to encourage the shifts of capital, technology, talents and markets to domestic-consumption-dependent industries.

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Appendix A

Abbr.	Country	Abbr.	Country
alb	Albania	mng	Mongolia
arg	Argentina	mar	Morocco
arm	Armenia	moz	Mozambique
aus	Australia	nam	Namibia

aut	Austria	npl	Nepal
aze	Azerbaijan	nld	Netherlands
bhr	Bahrain	nzl	New Zealand
bgd	Bangladesh	nic	Nicaragua
blr	Belarus	nga	Nigeria
bel	Belgium	nor	Norway
bol	Bolivia	omn	Oman
bwa	Botswana	pak	Pakistan
bra	Brazil	pan	Panama
bgr	Bulgaria	pry	Paraguay
khm	Cambodia	per	Peru
cmr	Cameroon	phl	Philippines
can	Canada	pol	Poland
xcb	Caribbean	prt	Portugal
xcf	Central Africa	qat	Qatar
chl	Chile	xca	Rest of Central America
chn	China	xea	Rest of East Asia
col	Colombia	xec	Rest of Eastern Africa
cri	Costa Rica	xee	Rest of Eastern Europe
civ	Cote d'lvoire	xef	Rest of EFTA
hrv	Croatia	xer	Rest of Europe
cyp	Cyprus	xsu	Rest of Former Soviet Union
cze	Czech Republic	xnf	Rest of North Africa
dnk	Denmark	xna	Rest of North America
ecu	Ecuador	xoc	Rest of Oceania
egy	Egypt	xsc	Rest of South African Customs
slv	El Salvador	xsm	Rest of South America
est	Estonia	xsa	Rest of South Asia
eth	Ethiopia	xse	Rest of Southeast Asia
fin	Finland	xwf	Rest of Western Africa
fra	France	xws	Rest of Western Asia
geo	Georgia	xtw	Rest of World
deu	Germany	rou	Romania
gha	Ghana	rus	Russian Federation
grc	Greece	sau	Saudi Arabia
gtm	Guatemala	sen	Senegal
hnd	Honduras	sgp	Singapore
hkg	Hong Kong	svk	Slovakia
hun	Hungary	svn	Slovenia
ind	India	zaf	South Africa
idn	Indonesia	xac	South Central Africa
irl	Ireland	esp	Spain
irn	Islamic Republic of Iran	lka	Sri Lanka
isl	Israel	swe	Sweden
ita	Italy	che	Switzerland
jpn	Japan	twn	Taiwan
kaz	Kazakhstan	tza	Tanzania
ken	Kenya	tha	Thailand
kor	Korea	tun	Tunisia

kwt	Kuwait	tur	Turkey
kaz	Kyrgyzstan	uga	Uganda
lao	Lao People’s Democratic Republic	ukr	Ukraine
lve	Latvia	are	United Arab Emirates
ltu	Lithuania	gbr	United Kingdom
lux	Luxembourg	usa	United States of America
mdg	Madagascar	ury	Uruguay
mwi	Malawi	ven	Venezuela
mys	Malaysia	vnm	Viet Nam
mlt	Malta	zmb	Zambia
mus	Mauritius	zwe	Zimbabwe
mex	Mexico		

Appendix B

Abbr.	**Industry**	**Abbr.**	**Industry**
ATP	Air transport	OFD	Food products nec
B_T	Beverages and tobacco products	OFI	Financial services nec
C_B	Sugar cane, sugar beet	OIL	Oil
CMN	Communication	OME	Machinery and equipment nec
CMT	Bovine meat products	OMF	Manufactures nec
CNS	Construction	OMN	Minerals nec
COA	Coal	OMT	Meat products nec
CRP	Chemical, rubber, plastic products	OSD	Oil seeds
CTL	Bovine cattle, sheep and goats, horses	OSG	Public Administration, Defense, Education, Health
DWE	Dwellings		
ELE	Electronic equipment	OTN	Transport equipment nec
ELY	Electricity	OTP	Transport nec
FMP	Metal products	P_C	Petroleum, coal products
FRS	Forestry	PCR	Processed rice
FSH	Fishing	PDR	Paddy rice
GAS	Gas	PFB	Plant-based fibers
GDT	Gas manufacture, distribution	PPP	Paper products, publishing
GRO	Cereal grains nec	RMK	Raw milk
I_S	Ferrous metals	ROS	Recreational and other services
ISR	Insurance	SGR	Sugar
LEA	Leather products	TEX	Textiles
LUM	Wood products	TRD	Trade
MIL	Dairy products	V_F	Vegetables, fruit, nuts
MVH	Motor vehicles and parts	VOL	Vegetable oils and fats
NFM	Metals nec	WAP	Wearing apparel
NMM	Mineral products nec	WHT	Wheat
OAP	Animal products nec	WOL	Wool, silk-worm cocoons
OBS	Business services nec	WTP	Water transport
OCR	Crops nec	WTR	Water