Factors decomposition of carbon emissions embodied in China's agricultural export

Yuqin Dai*

College of Economics and Management,
Huazhong Agricultural University,
1 Shizishan Road, Wuhan 430070, China
and
School of Economics and Trade,
Hunan University of Commerce,
569 Yuelu Ave., Changsha 410205, China
Email: delladyq@163.com
*Corresponding author

Zhongchao Feng

College of Economics and Management,
Huazhong Agricultural University,
1 Shizishan Road, Wuhan 430070, China
Email: fengzhch@163.com

Xiaoxun Ouyang

School of Management,
Hunan University of Commerce,
569 Yuelu Ave., Changsha 410205, China
Email: daniel_ou@163.com

Abstract: An input–output model is established to calculate the volume of carbon emissions embodied in China's agricultural export and its distribution in China's agricultural sectors during the period of 2001–2013. The contributing factors in growth of carbon emissions embodied in China's agricultural export is then decomposed into scale effect, structure effect and technical effect, with which overall and sectional analysis are made through LMDI model. The empirical results show that scale effect is the main reason for the rise of carbon emissions embodied in China's agricultural export. Technical effect is the most important factor to inhibit the growth of embodied carbon emissions from agricultural export products. But it does not necessarily lead to a drop of embodied carbon emissions of agricultural products due to the increases of the rigid demand for energy and intensity of energy consumption in China's agricultural sectors. The influence of structure effect on changes of carbon emissions embodied in China's agricultural export remains less significant so far.

Keywords: embodied carbon emissions; environment; agricultural export; input–output model; LMDI model; factors decomposition.

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Biographical notes: Yuqin Dai is a PhD candidate at the College of Economics and Management, Huazhong Agricultural University, China. She is also an Assistant Professor at the School of Economic and Trade, Hunan University of Commerce. She obtained a master's degree in Hunan University in 2006. Her current research focuses on agricultural economics and management, and low carbon economics.

Zhongchao Feng is a Professor at the School of Economics and Management, Huazhong Agricultural University. He received his PhD and MS degree from the University of Huazhong Agricultural University of China. His research interests are agricultural economics and management.

Xiaoxun Ouyang is an Associate Professor at the School of Management, Hunan University of Commerce. He earned his PhD and MS degree from the University of Huazhong Sciences and Technology of China. His current research focuses on logistics economics and management.

1 Introduction

Accompanied by much more debate on carbon emission right allocation due to energy constraints and global climate change, the issue of embodied carbon emissions during international trade receives a lot of attention. According to IPCC of the UN's assessment reports, agricultural greenhouse gas emissions accounts for the proportion of 14.9% of global greenhouse gas emissions, and the China agricultural greenhouse gas emissions accounts for about 17% of the total emissions across the country. China agriculture has gradually become one of the main sources of carbon emissions. With the gradual increase in trade of agricultural products after China's accession to the WTO in 2001, more and more carbon emissions are embodied in the process of agricultural products trade, which is not conducive to the development of low carbon agriculture in China, also make export trade of agricultural products more likely to encounter various low carbon barriers from developed countries in the name of the environment protection. Current researches on low carbon trade are mostly concentrated in the field of manufacturing industry. However, agricultural trade has already significantly affected by the development trend of low carbon economy. Low carbonisation is getting a focus issue concerned in the field of world agricultural product export trades.

China is the world's largest trading nation. Domestic and foreign scholars have launched a number of studies on the carbon emissions embodied in China's foreign trade. Bin and Harriss (2006) studied the Sino-US trade's influence on American and the global embodied carbon emissions. They found that if imports from China shifted to domestic production of the USA, the embodied carbon emissions of the USA would increase 3–6%; around 7–14% of China's implicit carbon emissions was contributed by the products exported to the USA; Sino-US trade made global carbon emissions increased by as much as 720 million metric tons. Liu et al. (2010) found that products exported from China to Japan were much more carbon-intensive than that of Japanese to China and China was a net exporter of embodied CO_2 emissions to Japan in 1990–2000. The study of Li and Hewitt (2008) showed that the UK's CO_2 emissions had fallen by approximately 11% though the bilateral trade with China, whereas China–UK trade resulted in an additional 11.7 million tons of CO_2 to global CO_2 emissions in 2004, accounting for 0.4% of global emissions. Yunfeng and Laike (2010) adopt input–output analysis model to estimate the carbon emissions embodied in China import and export trade between 1997 and 2007, showing that the production of export products resulted in 10.03–26.54% of embodied carbon emissions every year in China. Jayanthakumaran and Liu (2016) measured the CO_2 emissions embodied in bilateral trade between Australia and China using a sectoral input–output model. They indicated that China performs lower than Australia in clean technology in the primary, manufacturing, energy sectors due to their overuse of coal and inefficient production processes.

Meanwhile, the research on carbon emissions in the field of China agricultural trade is being paid more attention. Xu et al. (2013) built a competitive input–output model to evaluate the embodied CO_2 in China agricultural products trade during 1995–2005. The conclusion is that 3.71–4.50% of China's agricultural CO_2 emissions are produced by agricultural exports; a large number of intermediate input in the process of agricultural production consumed a lot of energy that generated huge CO_2 emissions. Zhang (2010) studied the implied carbon transfer in China's agricultural foreign trade in 2002, and found that China was a net exporter of embodied carbon emissions that were mainly transferred to the areas in Asia. From carbon leakage and pollution industry transfer perspective, Sun and Chen (2014) proposed that developed countries have plenty of capital investment and R&D investment to continue to promote the development of low carbon agriculture and ecological agriculture, and agricultural production with intensive pollution and resource consumption were left in the countries with labour endowment advantage, such as China.

These studies have illustrated the extensive relationship between the continuous development of foreign trade and carbon emissions. Foreign trade leads to the implied energy consumption and carbon flows between countries, causing the problem of international pollution emissions transfer. Developed countries transfer CO_2 emissions to developing countries through offshore manufacturing and production of goods for domestic consumption (Schaeffer and de Sá, 1996).

China is now a net exporter of implied energy and carbon emissions, undertaking the carbon emissions that should be borne by the importer (Dai et al., 2016).

Scholars also follow the Grossman and Krueger's (1991) theoretical framework, adopting different factors decomposition method, to analyse the influence factors of carbon embodied in China's export trade. Li and Fu (2010) thought that the increase of carbon embodied in China's exports was contributed by four aspects, that are scale effect, export structure, carbon emissions intensity and production technology. Among them, production technology possessed positive effect, scale effect and structure effect present as negative. Some scholars insist that the influencing factors of carbon embodied in China's export trade should be decomposed into scale effect, structure effect and technology effect (Wang et al., 2011; Peng et al., 2012; He and Feng, 2015). They draw relatively similar conclusions, although they had selected different time period to research.

At present, there are few researches on calculation of embodied carbon emissions and its decomposition in the field of China's agricultural trade; at the same time, agricultural export products should be classified with the purpose of obtaining more comprehensive evaluation of structure distribution changes of carbon emissions embodied in agricultural exports, which might reveal the characteristics of embodied carbon emissions in agricultural sectors (Dai et al., 2016). Based on evaluating carbon emissions embodied in the exports of China agricultural goods between 2001 and 2013, we focus on Logarithmic Mean Divisia Index (LMDI) decomposition analysis on the factors resulting in the increase or decrease of embodied carbon emissions during the said period. Three questions are investigated in this paper. (1) What is the change trend of carbon emission embodied in China's agricultural export in 2001–2013? (2) What are the impacts of different factors playing in sizes and directions on the embodied carbon emissions of agricultural export? (3) What are the impacts of factors on carbon emissions embodied in different agricultural export sectors in China?

The rest of this paper is organised as follows. First of all, the carbon emissions embodied in China's agricultural exports is calculated based on the input–output method; LMDI method is then applied to decompose the factors that have been affecting carbon emissions embodied in China's agricultural export into three aspects of the scale effect, structure effect and technical effect, with an attempt to find the drivers and the reasons that may cause the change of carbon emissions embodied in China's agricultural exports; finally the corresponding conclusions with discussions are put forward.

2 Research model and sample data

2.1 Research model

2.1.1 Calculation model of carbon emission embodied in agricultural exports

Embodied carbon emissions not only refers to the CO_2 emissions that product contains itself, but includes the CO_2 generated in the process of intermediate input, transport, use and waste. Carbon emissions embodied in agricultural product export mainly refers to the carbon emissions generated by direct energy consumption in the process of agricultural production and export, such as the carbon emissions during the processes of farming, planting, drying, harvesting and transport, and the carbon emissions produced by middle substance production with indirect energy consumption, such as the carbon emissions generated by coal mining, transportation and the implied carbon emissions during the production, transportation, utilisation of fertilisers, pesticides, plastic sheeting, etc.

The basic calculation formula for the carbon emission embodied in export trade is:

$$EC = \sum_i R_i Y_i \tag{1}$$

in which EC stands for the embodied carbon emissions; R_i is the coefficient of embodied carbon emission; Y_i represents export volume; i is on behalf of industry or products. To calculate embodied carbon emissions, scholars like to utilise input–output analysis that is an analytical framework developed by Leontief (1936, 1941) to deal with the interdependence of industries. Since 1990s, input–output analysis has been widely applied to estimating embodied energy, CO_2 emissions, pollutants and land appropriation from international trade activities (Wyckoff and Roop, 1994; Machado et al., 2001; Munksgaard and Pedersen, 2001; Ferng, 2003; Hubacek and Giljum, 2003; Liu et al., 2015).

In this paper, the input–output model is used to calculate the actual domestic energy consumption of export goods that will directly be multiplied by the corresponding energy consumption coefficient to finally obtain the volume of carbon emissions embodied in export products. The calculation formula is as follows:

$$EC = V\theta\left(I - A\right)^{-1} Y \tag{2}$$

In formula (2), V is consumption coefficient matrix of different industry, commodity and energy, $V = \left\{\frac{E_{ik}}{X_i}\right\}$, E_{ik} is the k energy's consumption of the sector i and X_i is the output of the sector i. θ is carbon emissions direct coefficient matrix of energy; I is unit matrix; A is direct consumption coefficient matrix; $\left(I - A\right)^{-1}$ is Leontief inverse matrix, also known as the absolute necessary coefficient matrix; Y is exports volume matrix; So $V\theta\left(I - A\right)^{-1}$ is actually an equivalent of embodied carbon emission coefficient, namely R_i in formula (1).

Calculation formula for the carbon emissions coefficient of various energy is presented according to IPCC (2006):

$$\theta_k = NCV_k \times CEF_k \times COF_k \times \left(44/12\right) \qquad \left(k = 1, 2, \ldots, 8\right) \tag{3}$$

in which *NCV* is average low calorific value of primary energy according to China Energy Statistical Yearbooks; *CEF* is carbon emissions factors offered by IPCC; *COF* is oxidation rate for carbon factor, taking the default value of 1; 44 and 12 are respectively the molecular weight of carbon dioxide and carbon. Therefore, the carbon dioxide emissions coefficient θ of different energy can be acquired by employing formula (3). The results are listed in Table 1.

Table 1 Carbon dioxide emissions coefficient θ of different energy

Coal	*Coke*	*Crude oil*	*Gasoline*	*Kerosene*	*Diesel*	*Fuel oil*	*Natural gas*
2.03	2.66	3.07	3.19	3.08	3.16	3.22	21.84

Note: The unit of carbon emission coefficient of natural gas is 100,000 tons/billion cubic meters, the units of carbon emission coefficient of other energy sources is 10,000 tons/10,000 tons.

2.1.2 Decomposition model for influence factors

Grossman and Krueger (1991) proposed that the impact of international trade on the environment was mainly from three aspects: scale effect, structure effect and technical effect. Scale effect refers to the trade scale's impact on the environment; structure effect refers to the influence of trade structure change of different pollution intensity sectors on a country's environment; technical effect reflects the impact of technology adopted in the process of production and emission reduction on the environment. The multilayer effects of trade may cause positive or negative impacts on the environment (Anderson and

Strutt, 2000; Beghin et al., 2002). In this paper, we apply LMDI method (Ang, 2004; Zhang et al., 2016) with no-residual decomposition of all factors to decompose the influence factors of carbon emissions embodied in export trade into scale effect, structure effect and technical effect. The specific process is as follows:

$$EC_i = R_i Y_i = R_i \frac{Y_i}{Y} Y,$$

where EC_i is carbon emissions embodied in the export trade of the sector i, R_i is full emission coefficient of the sector i, Y_i is the export volume of the sector i, Y is the total export volume of all sectors. Assuming $S_i = \frac{Y_i}{Y}$, we have:

$$EC_i = R_i S_i Y \tag{4}$$

Assuming $t1$ is the base time, $t2$ is the reporting time, the change of embodied carbon emissions generated by export trade of the sector i from $t1$ to $t2$ can be then expressed as:

$$\Delta EC_i = EC_i^{t2} - EC_i^{t1} = R_i^{t2} S_i^{t2} Y^{t2} - R_i^{t1} S_i^{t1} Y^{t1}$$

LMDI decomposition model is employed to have the following formula:

$$\Delta EC_i = \Delta R_i + \Delta S_i + \Delta Y_i \tag{5}$$

$$\Delta R_i = L\left(EC_i^{t2}, EC_i^{t1}\right) \ln\left(\frac{R_i^{t2}}{R_i^{t1}}\right) \tag{6}$$

$$\Delta S_i = L\left(EC_i^{t2}, EC_i^{t1}\right) \ln\left(\frac{S_i^{t2}}{S_i^{t1}}\right) \tag{7}$$

$$\Delta Y_i = L\left(EC_i^{t2}, EC_i^{t1}\right) \ln\left(\frac{Y^{t2}}{Y^{t1}}\right) \tag{8}$$

Among them, $L\left(EC_i^{t2}, EC_i^{t1}\right) = \frac{EC_i^{t2} - EC_i^{t1}}{\ln EC_i^{t2} - \ln EC_i^{t1}}$, ΔR_i, ΔS_i, and ΔY_i represent respectively technical effect, structure effect and scale effect of embodied carbon emissions changes in export trade of the sector i. Therefore, the total change of carbon emissions embodied in export trade is shown as:

$$\Delta EC = \sum_{i=1}\left(EC_i^{t2} - EC_i^{t1}\right) = \Delta R + \Delta S + \Delta Y \tag{9}$$

The contributions of technical effect, structure effect and scale effect on export trade implicit carbon change are expressed as follows:

$$\Delta R = \sum_i \frac{\left(EC_i^{t2} - EC_i^{t1}\right)}{\ln EC_i^{t2} - \ln EC_i^{t1}} \cdot \ln\left(\frac{R_i^{t2}}{R_i^{t1}}\right) \tag{10}$$

$$\Delta S = \sum_i \frac{\left(EC_i^{t2} - EC_i^{t1}\right)}{\ln EC_i^{t2} - \ln EC_i^{t1}} \cdot \ln\left(\frac{S_i^{t2}}{S_i^{t1}}\right) \tag{11}$$

$$\Delta Y = \sum_i \frac{\left(EC_i^{t2} - EC_i^{t1}\right)}{\ln EC_i^{t2} - \ln EC_i^{t1}} \cdot \ln\left(\frac{Y^{t2}}{Y^{t1}}\right) \tag{12}$$

2.2 Sample data

Energy consumption data of 44 sectors is collected from *China statistical yearbook*, while export data comes from *China's trade statistics yearbook*. The secondary classification of HS code is selected as the basic export goods classification in this paper, a total of 98 chapters, 22 classes, including 24 chapters and four classes for agricultural products. Total input and direct consumption coefficient matrix are derived from *Chinese input–output table.* A compilation of China's input–output table is made on five years span due to little change of a country's production structure and production technology in a short term. Therefore, it is assumed that the direct consumption coefficient and consumption energy coefficients of different commodity on input–output table remain unchanged in a certain short term. Considering the detailed industry classification aids in accurate calculation, the 2002 China input–output table data with 122 sectors for period 2001–2006 and the 2007 China input–output table data with 135 sectors for period 2007–2013 are adopted to calculate carbon emissions embodied in China's agricultural trade.

The data source of this paper is involved in the *China statistical yearbook*, the *input–output table of China*, *China's trade statistics yearbook.* So the classification of different statistical calibre needs to be integrated and merged to establish a relatively comparable classification system. We firstly calculate industry energy intensity coefficient matrix based on the input–output table classification (122 and 135 sectors), then classify China's agricultural exports data into the corresponding agricultural sector shown on the input–output table, finally employ formula (2) to acquire carbon emissions embodied in China's agricultural trade. China input–output table lists a total of 18 kinds of agricultural sector which are classified into eight export sectors, that are crop farming, forestry, livestock, fisheries, food processing, food manufacturing, wine and beverage manufacturing and tobacco manufacturing. The corresponding carbon emissions embodied in the eight departments' export trade can be finally obtained.

3 Results and data analysis

3.1 Estimation results of carbon emissions embodied in China's agricultural export trade

As can be seen from Figure 1, the situation of carbon emissions embodied in China's agricultural export trade is roughly experienced three stages of change from 2001 to 2013: rapid growth stage (2001–2006), transition stage (2006–2009) and stable growth stage (2009–2013). Embodied CO_2 emissions in China agricultural export record a rapid growth for the first six years after accession to the WTO in 2001, reaching 91.71 million tons in 2006 increased by 193% than that of 2001, with an average annual growth rate of 24%. In 2007, the embodied carbon emissions decline sharply, plunged as low as 45.67 million tons, followed by 47.55 million tons in 2008 and 46.91 million tons in 2009. And after 2010, the trend shows stable upswing again. CO_2 emissions of agricultural exports reaches 87.84 million tons in 2013, back to a high level, with an average annual growth rate of 16% during the stable growth stage. Along with the increase of international trade of China's agricultural products, large quantities of embodied carbon has been also exported, which consumes a large number of domestic energy and resources, resulting in increased domestic carbon emissions. At present, China has become the world's largest CO_2 emitter, and agricultural product is considered as a very important source of greenhouse gas emissions in China.

Figure 1 The trend of China's agricultural export trade and carbon emissions embodied (2001–2013)

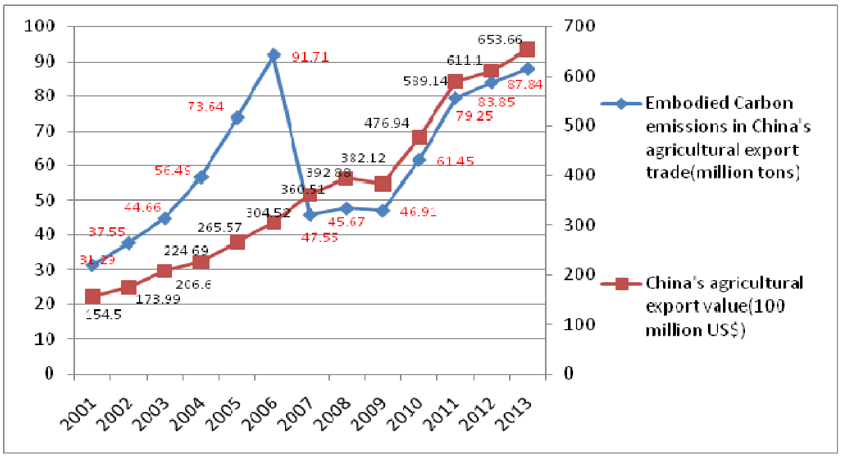


Figure 2 Carbon emissions embodied in China's agricultural sectors' export (2001–2013)

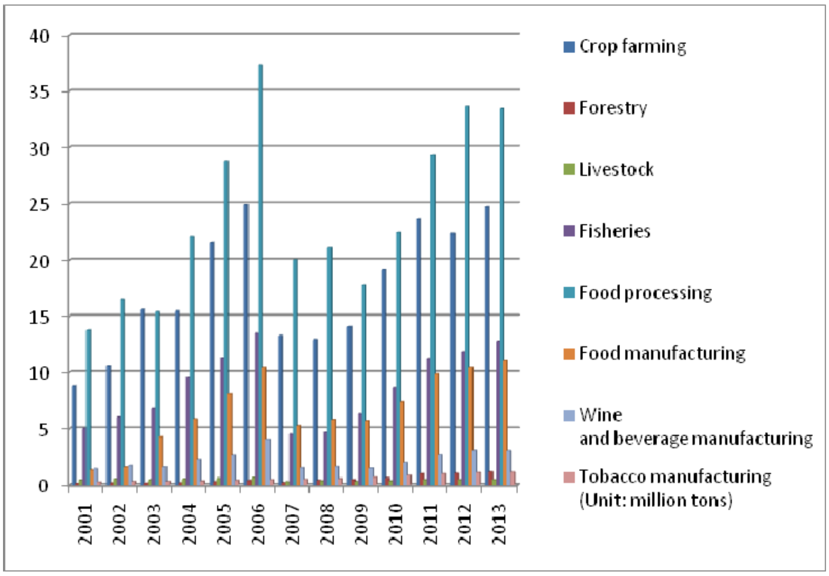
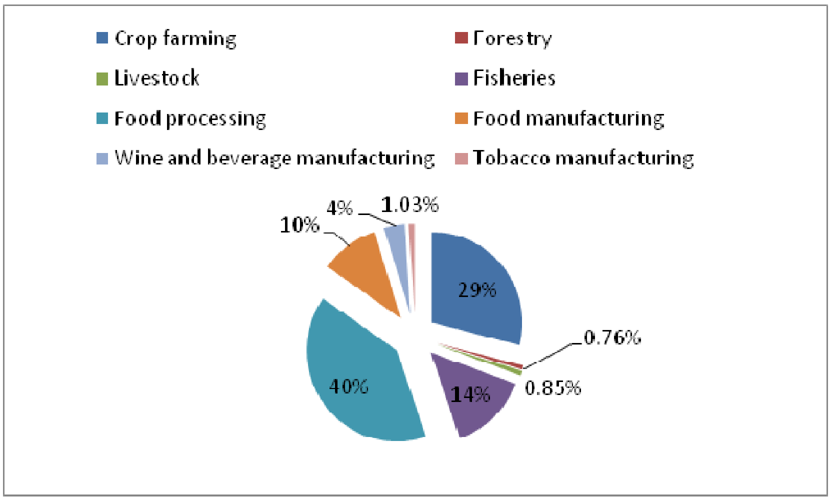


Figure 3 Average embodied carbon ratio of agricultural sectors' export trade (2001–2013)



From the point of view of the sectors composition of embodied carbon emissions, there are significant differences in the embodied carbon emissions of eight agricultural export sectors in 2001–2013 shown as Figures 2 and 3. Food processing industry exports embody carbon emissions of annual average 23.96 million tons, far more than other seven sectors, accounting for embodied carbon emissions in agricultural export trade by 40% on average; The crop farming sector is the second largest source of embodied carbon with average annual emissions 17.46 million tons, accounting for 29% of carbon emissions embodied in China agricultural export; the average emissions proportion of Fisheries and Food manufacturing departments stay in the middle, around 14% and 10%; wine and beverage manufacturing, tobacco manufacturing, forestry, livestock implies less carbon emissions, accounted for 4%, 1.03%, 0.85% and 0.76%, respectively.

3.2 *Decomposition of factors affecting carbon emissions embodied in China's agricultural export*

According to the estimate results above, we employ LMDI models (4)–(12) to decompose the influence factors of the changes in carbon emissions embodied in China's agricultural export trade. The time of 2001–2013 is divided into three stages as mentioned above. The decomposition for each stage and each agricultural sector are calculated, respectively. The results are shown in Table 2, Table 3 and Figure 4.

Table 2 2001–2013 decomposition of influence factors based on time division (million tons)

	2001–2006	*2006–2009*	*2009–2013*	*Change status*	*Cumulative contribution*
ΔEC	60.42 (193.1%)	–44.81 (–48.86%)	40.93 (87.27%)	+ – +	56.55 (231.51%)
ΔY	35.77 (114.34%)	4.84 (5.28%)	28.62 (61.02%)	+ + +	69.24 (180.64%)

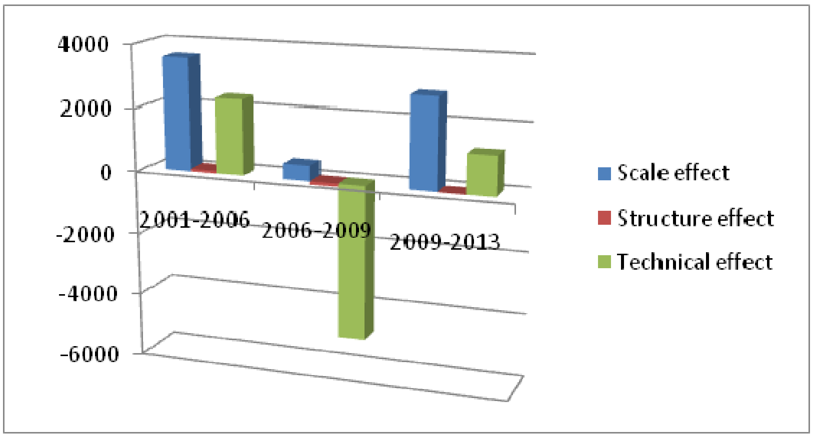
Table 2 2001–2013 decomposition of influence factors based on time division (million tons) (continued)

	2001–2006	*2006–2009*	*2009–2013*	*Change status*	*Cumulative contribution*
ΔS	0.78 (2.5%)	–0.98 (–1.06%)	–0.07 (–0.14%)	+ – –	–0.26 (1.3%)
ΔR	23.86 (76.27%)	–48.67 (–53.07%)	12.38 (26.39%)	+ – +	–12.43 (49.59%)

Table 3 2001–2013 decomposition of influence factors based on sector division

Time stage	*Sector*	*Scale effect ΔY_i*	*Structure effect ΔS_i*	*Technical effect ΔR_i*	*Total effect ΔEC_i*	*Contribution*
2001–2006	Food processing	48.34%	6.77%	20.05%	75.16%	38.92%
	Crop farming	31.74%	–4.19%	23.89%	51.44%	26.64%
	Food manufacturing	9.07%	3.05%	16.95%	29.07%	15.05%
	Fishery	17.55%	–1.75%	11.13%	26.93%	13.95%
	Wine and beverage manufacturing	5.21%	0.25%	2.93%	8.39%	4.34%
	Tobacco manufacturing	0.75%	–0.34%	0.22%	0.63%	0.33%
	Forestry	0.53%	–0.03%	0.35%	0.85%	0.44%
	Livestock	1.13%	–1.25%	0.75%	0.63%	0.33%
2006–2009	Food processing	2.08%	–2.30%	–21.06%	–21.28%	43.55%
	Crop farming	1.50%	1.10%	–14.42%	–11.82%	24.19%
	Food manufacturing	0.62%	–0.38%	–5.38%	–5.14%	10.52%
	Fishery	0.75%	1.28%	–9.83%	–7.80%	15.96%
	Wine and beverage manufacturing	0.20%	–1.31%	–1.69%	–2.80%	5.73%
	Tobacco manufacturing	0.05%	0.13%	0.07%	0.25%	–0.51%
	Forestry	0.04%	0.39%	–0.35%	0.08%	–0.16%
	Livestock	0.04%	0.03%	–0.42%	–0.35%	0.72%
2009–2013	Food processing	23.18%	0.51%	9.69%	33.38%	38.25%
	Crop farming	17.67%	–2.76%	7.76%	22.67%	25.98%
	Food manufacturing	7.59%	0.56%	3.33%	11.48%	13.15%
	Fishery	8.57%	1.42%	3.79%	13.78%	15.79%
	Wine and beverage manufacturing	2.04%	0.23%	0.97%	3.24%	3.71%
	Tobacco manufacturing	0.84%	–0.25%	0.36%	0.95%	1.09%
	Forestry	0.72%	0.38%	0.32%	1.42%	1.63%
	Livestock	0.37%	–0.23%	0.16%	0.30%	0.34%

Figure 4 Comparison of factors affecting changes of carbon emissions embodied in China's agricultural export



3.2.1 Influence factors analysis for the three stages

The carbon emissions embodied in China's agricultural export, from 2001 to 2006, increase 60.42 million tons with a growth of 193.1%. The scale effect, technical effect and structure effect are all positive to promote the steady growth of the embodied carbon emissions of agricultural export in this stage. The contribution of scale effect (35.77 million tons) reaches as high as 114.34%; structure effect (0.78 million tons) contributes 2.5%; technical effect (23.86 million tons) offers 76.27%. The results indicate that the rapid expansion of agricultural export is the main reason for the increase of embodied carbon emissions during this stage. From the point of technical effect, the accession to the WTO brings China huge energy consumption of coal, crude oil, diesel and coke in agricultural production, resulting in a sharp rise of carbon emissions embodied in agricultural export. The products with high energy consumption account for a large proportion in China's agricultural export structure, which is not conducive to carbon emissions reduction of China's agricultural export. Structure effect in the stage is weak.

The carbon emissions embodied in China's agricultural exports appear a significant decline in the overall during 2006–2009, reduced by 48.86%. In this stage, the positive influence of scale effect becomes very small, while the negative influence is getting larger, which jointly makes sharp decline of carbon emission. Specifically, the scale effect is still positive drivers with a contribution of 5.28% as the technical effect and structure effect reverse to be negative to drive decrease of embodied carbon emission by –53.07% and –1.06%, respectively. In this stage, the world trade volume has shrunk dramatically due to the financial crisis in 2008. The size of China's agricultural exports has also been affected, that is why the scale effect is greatly reduced. Meanwhile, the technology effect becomes significant to drive the reduction of carbon emissions. It is believed that the main reasons for great fall in carbon emissions of agricultural export during 2006–2009 are technology progress and improvement of energy utilisation efficiency in China's agricultural sectors. Considering the policy implemented at that time, we can further find that technology progress achieved and energy efficiency improvement in agricultural sectors have close relationship with the following background: both the central and local governments greatly strengthened the environmental protection since China began its '11th Five-Year Plan for National Economic and Social Development' in 2006. The central government put forward the requirement that the environmental protection and economic growth should be of the same importance and be developed synchronously and comprehensively which is called as the 'historic change of environmental protection' in China. The Five-Year Plan determined to reduce energy intensity by 20% and also explicitly pointed out that the development of resource saving agriculture would improve the efficiency of agricultural production. With the Chinese government's efforts on energy saving and emission reduction and energy structure adjustment in agriculture, the carbon emissions embodied in agricultural exported products are obviously reduced.

In the stage of 2009–2013, the carbon emissions embodied in China's agricultural export return to growth, with total increment of 40.93 million tons increased by 87.27%. The contribution of the scale effect is 61.02%. Technical effect and structure effect contribute 26.39% and –0.14%, respectively. The scale effect once again becomes the main driving factor affecting the increase of carbon emissions embodied in agricultural export in this stage. Technical effect, however, does not continue to reduce carbon emissions embodied in exports as did in previous stage. The main reason may lie in the slowdown speed of energy efficiency technology progress and high price of alternative cleaner energy. Structure effect still remains negative to the growth of carbon emission, which suggests that the export structure of agricultural products in China might keep optimised.

3.2.2 Influence factors analysis based on sector division

For food processing industry, the total factors effect are 75.16%, –21.28% and 33.38%, respectively, in the three stages, offering a contribution of more than 1/3 (38.92%, 43.55%, 38.25%) to changes of carbon emissions embodied in export of the corresponding period, which indicates that this industry is the main source of carbon emissions embodied in China's agricultural export trade.

Crop farming, with total effect 51.44%, –11.82% and 22.67%, respectively, in the three stages, is the second industry leading carbon emissions changes in China's agricultural product export. The proportions to the total effect of crop farming in the three stages are 26.64%, 24.19%, 25.98%. Specifically, the scale effect of each stage is positive, which suggests that the export scale is an important factor leading to the growth of carbon emissions embodied in export trade of this industry.

Food manufacturing contributes to changes of carbon emissions embodied in export of the three stages by 15.05%, 10.52% and 13.15%, respectively. In 2006–2009, technical effect and structure effect, –5.38% and –0.38%, respectively, are negative that makes the carbon emissions embodied in agricultural export trade during this period reduced by –5.14%.

The effect construction of fishery industry is similar with food manufacturing, with proportion of 13.95%, 15.96%, 15.79%, respectively, in the three stages to the total changes of embodied carbon emissions. The export of tobacco manufacturing industry, forestry and livestock contribute small proportion to changes of embodied carbon emissions, almost all less than 1%. The three industries are of low carbon emissions source.

3.2.3 Classification analysis of influence factors

Overall, the order of the three factors' influence on the carbon emissions embodied in China's agricultural exports is Scale effect > Technical effect > Structural effect as seen in Figure 4.

Scale effect is the main influence factors that cause changes of carbon emissions embodied in China's agricultural export trade. It contributes cumulative changes of carbon emissions embodied in agricultural export as much as 69.24 million tons during 2001–2013. The contribution rate reaches as high as 180.64%. It is already proved that the rule of Environment Kuznets Curve (EKC) has strong explanatory ability for the relationship between China's agricultural development and environment resources. China, at present, is still in the left side of the EKC turning point, which means the rapid development of agricultural economy has been leading to the deterioration of environmental quality. Therefore, in the foreseeable future, the continued expansion of the scale of agricultural exports will remain to be the main factor in the increase of carbon emissions embodied in China's agricultural exports. From the view of sector distribution, the most affected industry by scale effect in carbon emissions is food processing, followed by crop farming, fisheries, food manufacturing, wine and beverage manufacturing. Livestock, tobacco manufacturing, and forestry are less influenced by export scale.

Technical effect is the most important factor to inhibit the growth of embodied carbon emissions from agricultural export. It has experienced situation changes of positive, negative, positive to the growth of carbon emission embodied in China's agricultural export from 2001 to 2013, with a cumulative contribution of –12.43 million tons. The impact of technical effects on the changes of carbon emissions embodied in China's agricultural export depends on technology progress and energy intensity of the various sectors. If sectors' efficiency of energy utilisation had been enhanced, the technical effect would be negative to the growth of carbon emissions; but if fail to improve the energy efficiency or even reverse, the technical effect would become positive. Lowering the energy intensity of agricultural production sector is the key means to realise the reduction of carbon emissions embodied in agricultural export. Crop farming, fisheries, food processing and food manufacturing industry are greatly influenced by technical effect, whether it is a positive drive or negative drive, larger changes of carbon emissions embodied in all these sectors' export would be caused.

Currently, structure effect has weak impact on changes of carbon emissions embodied in China's agricultural export trade. It has experienced situation of positive, negative, negative to the growth of carbon emissions during 2001–2013. The cumulative contribution of structural effect to carbon emissions embodied in China's agricultural export is only –0.261 million tons with a contribution rate of 1.3%. Some agricultural sector exports rise and others fall meanwhile. The offset between the situation of positive and negative makes the impact of structure effect in total on changes of carbon emissions embodied in China's agricultural export less significant. It is stated, according to China's empirical evidence, that the changes of export structure of agricultural products slightly reduced carbon emissions embodied in the trades so far.

4 Conclusions and discussion

Our evaluation of carbon emissions embodied in China's agricultural export trade and its factorising changes through decomposition has revealed that the environmental consequences of China's agricultural export trade are highly relevant to agricultural products' export scale, export structure and technology efficiency. The three factors can well explain the change of CO_2 emissions embodied in China's agricultural export trade in 2001–2013 which can be divided into three characteristic stages. The agricultural export sectors have experienced the similar change trend in the observed years, but their factorising changes through deposition were quite different. Food processing, crop farming, food manufacturing and fisheries are the four main sectors that have caused most of the changes of carbon emission embodied in China's agricultural export trade, while the other sectors show little influence both on volume and change of the CO_2 emission. It is necessary to implement different management strategies for different agricultural products to ensure the effectiveness of the carbon emissions reduction policy in China.

The scale effect is the main factor leading rapid increasing carbon emissions embodied in China's agricultural export trade especially during the first six years after China's accession into WTO in 2001. The cumulative contribution of scale effect in 2001–2013 is 69.23 million tons, which account for 180.64% increases since 2001. The scale effect played positive role on the CO_2 emission embodied in agricultural export trade and always promoted the rise of the CO_2 emission in the observed years. The carbon emissions in China increase partly as a result of the production of agricultural products exported to the world. Our research proves that China's agricultural export expansion and growth, to some extent, are at the expense of the environment.

Though the technical effect is the leading reason to reduce the carbon emission embodied in China's agricultural export trade, it did not exert continuous negative influence on energy saving and emission reduction in the observed years. Owing to the dependence on industrial products such as chemical fertilisers, pesticides, machinery use, the China's agricultural products exported involve large consumption of energy which make the high level of carbon emission intensity. It is believed that the positive influence of technical effect in exported agricultural products of China would exist for some time as result of the consistent demand for energy and high carbon emission intensity. Government policy's guidance and support to use energy saving technology in agriculture, adjust the agricultural energy structure, increase efforts to develop low carbon energy such as nuclear, solar and wind are inevitable. And government policy is also considered as an important reason to explain the sharp reduction of carbon emission embodied in China's agricultural export trade in 2006–2009 and it would play greater role to control the CO_2 emission embodied in China's agricultural export at current stage.

Exerting the negative influence of structure effect is another possible effective way to reduce the carbon emission embodied in exported agricultural products, although the influence of structure effect remains less significant so far. While we recognise to limit China's export of high carbon-intensive agricultural products will undoubtedly bring down the CO_2 emission embodied in China's agricultural export, the increasing cost in international agricultural market may exceed the increasing benefit in environment from embodied carbon emissions reduction, for the costs and benefits of export trade have both economic and environmental dimensions. It is still believed that developing low carbon agriculture and upgrading agricultural export structure would be the persistent goal in the long term.

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