

Research on carbon emissions embodied in China-Russia trade under the background of the Belt and Road

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Abstract Based on the latest China-Russia input-output data sets over the period from 2007 to 2015, this study quantified the flow of embodied carbon emissions in China-Russia trade using the emission embodied in bilateral trade (EEBT) approach. In addition, the structural decomposition analysis (SDA) was employed to identify the potential driving factors that affect embodied carbon in imports and exports. The results showed as follow. 1) China was a net exporter of carbon emissions in bilateral trade between China and Russia during 2007–2015. Despite that the bilateral trade scale had expanded considerably, the net export volume of CO₂ from China to Russia decreased from 13.21 Mt in 2007 to 4.45 Mt in 2015. 2) From the perspective of different sectors, the metal manufacturing and the chemical sectors of China and Russia were the main sources of CO₂ emissions. 3) In terms of driving factors, it was found that the carbon emission coefficient was the main reason for contributing to embodied emission reduction. Moreover, the contribution rate of carbon emission coefficient to reduce the carbon emissions in imports reached to 95.26%, as well as 108.22% in exports. The bilateral trade scale was the main driver for the increase in embodied carbon emissions, and the contribution rate to embodied carbon emissions in imports and exports were 14.80% and 65.17%, respectively. 4) This study argued that China and Russia should further optimize the energy structure and improve the energy efficiency and intermediate technology in the future.

Keywords embodied carbon emissions, I-O model, China-Russia trade, SDA

1 Introduction

In 2013, the total volume of China's imports and exports

reached to 4.16 trillion USD, which surpassed the United States for the first time, indicating that China has become the world's largest trading country. Moreover, China's international trade is characterized by export-oriented and processing trade, which is in the downstream position in the global value chain. Nowadays, China's international trade structure is gradually changing, showing that the proportion of imports is increasing (Xing, 2012; Lien, 2015). In November 2018, the first China International Import Expo (CIIE) was held in Shanghai City of China, with a total transaction volume of 57.83 billion USD. Specifically, of all the countries participating in the CIIE, 58 participants, were mainly from the countries along the "Belt and Road" region.

The "Belt and Road" region, which is called the silk road economic belt and the 21st century maritime silk road, was first proposed by Chinese President Xi Jinping in 2013. Soon after, the national development and reform commission of China, the ministry of foreign affairs and the ministry of commerce jointly issued the vision and action for jointly building the silk road economic belt and the 21st century maritime silk road, aiming at promoting regional cooperation at a relatively higher level and jointly building an open, inclusive and balanced regional economic cooperation architecture. The promotion and implementation of the Belt and Road countries will promote trade liberalization, simultaneously promote economic growth, and contribute to expand the total volume of trade of countries along the "Belt and Road" region.

In recent years, some environmental problems brought by trade, such as greenhouse gas (GHG) emissions, have gradually attracted of many scholars' attention. In the study of the relationship between international trade and the environment sustainability, a large number of studies was initially carried out on the energy embodied in international trade to explore the energy flows in bilateral trade (Daly, 1968; Leontief, 1970). Subsequently, the concept of embodied carbon in trade was put forward.

The initial research on embodied carbon in trade was the exploration of embodied carbon emissions in OECD countries' trade by [Wyckoff and Roop \(1994\)](#). This paper showed that the imports of manufactured goods from Canada, France, Germany, Japan, Britain and the United States from 1984 to 1986 contained a large amount of carbon emissions, which accounted for approximately 13% of their total emissions. Afterwards, many scholars focused on researching embodied carbon emissions, and a wealth of research results have been achieved ([Ahmad and Wyckoff, 2003](#); [Weber and Matthews, 2007](#); [Lin and Sun, 2010](#)).

According to the literature ([Han et al., 2018](#); [Lu et al., 2020](#); [Yang et al., 2022](#)), most quantitative studies focus on the accounting of carbon emissions embodied in international trade, which is necessary for clarifying the responsibility of countries for CO₂ emissions. The principal model for studying embodied carbon emissions is the input-output analysis (IOA) model, which was proposed by [Leontief \(1936\)](#) to analyze the US economic structure. Subsequently, this model was extended to study the environmental issue ([Leontief, 1970](#)). The IOA model can be classified into a single-region input-output (SRIO) model and multi-region input-output (MRIO) model. The SRIO model assumes that the two countries studied in the model have the same level of production technology, that is, the two countries share the same carbon emission coefficient when calculating the embodied carbon emissions in bilateral trade ([Machado et al., 2001](#); [Shui and Harriss, 2006](#); [Li and Hewitt, 2008](#)). Although this model is simple and feasible, the assumption of technical homogeneity makes the calculation error of embodied carbon emissions too high. With respect to the MRIO model, technological heterogeneity is fully taken into account, and the carbon emission coefficient of each country is calculated. Therefore, the accuracy of the MRIO model in calculating embodied carbon emissions is higher than that of the SRIO model ([Su and Ang, 2014](#); [Liu and Wang, 2015](#); [Hasegawa et al., 2015](#)). However, due to the inconsistent division standards of industrial sectors in different countries, some additional calculation errors are possibly produced in the process of sector integration by MRIO ([Zhang et al., 2017](#)).

In addition, there are two different views on the attribution of carbon emissions by intermediate commodity consumption in the MRIO model. The first view holds that the carbon emissions embodied in international trade produced by the consumption of an intermediate commodity should be included in the bilateral trade. Hence, the single-region input-output model is used to calculate the embodied carbon emissions, namely, the emission embodied in bilateral trade (EEBT) approach. The second view is that the intermediate commodity is considered according to the global production and the multi-regional input-output model is utilized to calculate embodied carbon emissions

in trade. Based on the theory of consumer responsibility, [Peters \(2008\)](#) compared the two different views above and pointed out the application differences. The EEBT model considers total consumption and has higher transparency, which is important for policy making. It is more suitable for bilateral trades and political agreements between countries. However, the second view was more accurate in measuring the carbon emissions embodied in the final consumption of traded goods. It was widely used to analyze carbon transfer or flow in global countries or regions ([Zhong et al., 2015](#)).

Based on the methods mentioned above, existing studies focus mostly on the analysis of embodied carbon in single, bilateral and multilateral countries or regions. For example, [Machado et al. \(2001\)](#) used the SRIO model to explore the impact of international trade on energy and carbon emissions in Brazil in 1995, and the carbon emissions embodied in exports in 1995 was roughly 13.5 Mt by calculation, which was higher than the 9.9 Mt carbon emissions embodied in imports. [Weber and Matthews \(2007\)](#) found that the expansion of the import scale would lead to an increase in CO₂, SO₂, and NO_x embodied in the trade of the United States. For multilateral trade, [Liu et al. \(2017\)](#) calculated the carbon emissions in trade among China, the United States, the European Union, and Japan based on the modified non-competitive import input-output method. The results showed that China was a net carbon exporter and the total net export of CO₂ in 2007 was only 400 million tons, which was much lower than the previous forecast results. Considering the connections between countries or regions, [Chen and Chen \(2011\)](#) presented the study of the emission shift and carbon leakage at three supra-national coalitions, i.e., G7, BRICS, and the rest of the world. [Zhong et al. \(2015\)](#) confirmed emissions embodied in trade can be reduced if China's provinces form coalitions. Further, [Wu et al. \(2020\)](#) explored the carbon emission transfer embodied in the global supply chain, especially discussed the intermediate trade imbalance in terms of emissions.

For bilateral trade, the recent literature has shown that the increasing volume of China's exports has multiple impacts on different countries' embodied carbon in trade ([Liu et al., 2010b](#); [Du et al., 2011](#); [Zhao et al., 2014](#); [Liu et al., 2017](#)). Based on the scenario analysis method, [Liu et al. \(2010b\)](#) calculated the bilateral carbon emissions embodied in China-Japan trade from 1990 to 2000 and found that bilateral trade between China and Japan is conducive to global CO₂ emission reduction by comparison. [Dong et al. \(2010\)](#) drew the conclusion that the decrease in carbon emissions embodied in export trade from China to Japan was due to the decline in China's carbon emission by applying the exponential decomposition analysis method. Subsequently, [Du et al. \(2011\)](#) employed the bilateral trade data between China and the United States and reported that China's net

exports of CO₂ emissions increased gradually from 2002 to 2005, but decreased from 2005 to 2007, the result of which was mainly due to the decline in the carbon emission intensity. Furthermore, Zhao et al. (2016) researched on the factors of affecting carbon emissions embodied in China-US trade by structural decomposition analysis. They found that trade structure, the total volume of export, and energy intensity had a significant impact on embodied carbon emissions in China-US trade. Since 2018, the US government launched the trade war, which has triggered further research by numerous scholars on the energy or emissions embodied in China-US trade. Li et al. (2020) study the impacts of trade conflicts on global energy consumption by using MRIO model, showing that energy imbalance embodied in Sino-US trade was driven by the trade structure. With the same method, Liu et al. (2020) quantified the embodied carbon emissions as well as confirmed the existence of environmental trade deficit in China-US trade. In addition, some scholars also discussed the embodied carbon and driving factors of bilateral trades between China and Australia (Tan et al., 2013), China and South Korea (Yu and Chen, 2017).

Russia is the China's second largest trading partner along the "Belt and Road" region. Moreover, the trade volume between China and Russia in recent years presents a rapidly increasing trend (Fig. 1). Under China's Belt and Road initiative, the total trade volume between China-Russia has stepped up to a new level. In 2018, the total trade volume has exceeded 100 billion USD for the first time, which is an important milestone in the bilateral trade of China-Russia. Furthermore, the 23rd St. Petersburg international economy forum (2019) has proposed that the next trade target between China and Russia is 200 billion USD. Therefore, it is necessary for us to quantify the flow of embodied carbon emissions in China-Russia trade. Besides, the export structure of China and Russia is quite different, with a large proportion of

labor-intensive products in China exporting to Russia, while Russia export to China being resource-intensive ones. Both types of goods are highly pollutive and remarkably emitting, which is never considered from this viewpoint by the previous studies.

Based on the IO table of China and Russia from 2007 to 2015, this study uses the EEBT model to quantitatively calculate carbon emissions embodied in trade of different sectors. At the same time, structural decomposition analysis (SDA) was applied to explore the drivers of carbon emissions embodied in the China-Russia trade.

The rest of this study is arranged as follows. Section 2 elaborates on the methodology and data sources. Section 3 presents the results on calculation of carbon emissions embodied in China-Russia and describes the corresponding factor analysis by SDA. Finally, a discussion of the conclusions of this paper and the policy implications are given in Section 4.

2 Methodology and data

2.1 Input-output model

Many tools and methodologies have been developed to research embodied carbon emissions in trade, among which the input-output analysis (IOA) model, proposed by Leontief (1941), has been adopted by many researchers (Machado et al., 2001; Liu et al., 2010a; Zhao et al., 2016; Yu and Chen, 2017). This paper aimed at analyzing the direct trade between China and Russia, rather than considering the global production chains. Therefore, the EEBT approach will be suitable for calculating embodied carbon in bilateral trade between China and Russia (Peters et al., 2011; Wu et al., 2016). The basic model can be expressed as Eq. (1):

$$X = AX + Y, \quad (1)$$

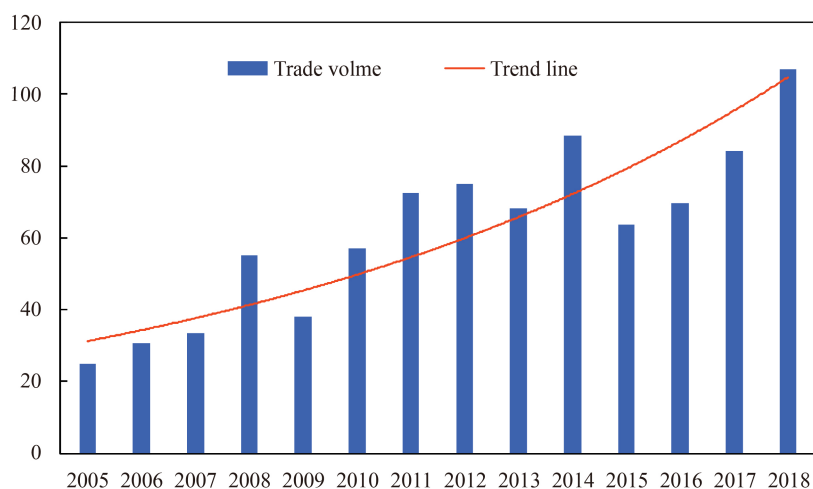


Fig. 1 Trade volume between China and Russia (unit: billion USD).

where A represents the direct input coefficient matrix demonstrating the relationship among all sectors, and the matrix coefficient $a_{ij} = X_{ij}/X_j$ denotes that per unit output from sector j needs to directly consume the amount of input from sector i . X denotes the total economic output vector, and Y represents the social final product demand vector. Eq. (1) can be further decomposed as

$$X = (I - A)^{-1}Y = CY, \tag{2}$$

where $C = (I - A)^{-1}$ is the Leontief inverse matrix, which is the complete consumption coefficient matrix, and can be calculated based on the I-O table.

In addition, it is necessary to introduce direct carbon emission coefficients of all sectors, and the coefficient vector is expressed as $C^d = (c_1^d, c_2^d, \dots, c_j^d)$, in which the direct carbon emission coefficient c_j^d of sector j is defined as

$$c_j^d = \sum_{k=1}^m f_k \frac{s_{jk}}{g_j}, \tag{3}$$

where m represents the type of energy, f_k is the carbon emission coefficient of energy k ($k = 1, 2, \dots, m$), g_j is the total output of sector j , and s_{jk} is the consumption of energy k of sector j . Then, the formula of the carbon emissions embodied in products exported to Russia by China's sector j can be expressed as follows:

$$C_j^{\text{ex}} = c_j^d(I - A)^{-1}a, \tag{4}$$

where a is the total amount of products exported from China to Russia by sector j . Besides, the carbon emissions embodied in China's import trade can be calculated by

$$C_j^{\text{im}} = c_j^{d'}(I - A')^{-1}b, \tag{5}$$

where $c_j^{d'}$ is the carbon emission coefficient of sector j in Russia, $(I - A')^{-1}$ is the complete consumption coefficient matrix calculated based on the I-O table of Russia, and b is the total amount of products imported from sector j of Russia to China.

2.2 Structural decomposition analysis

Under the input-output framework, SDA was widely used to identify the intrinsic factors affecting trade embodied carbon changes (Lee and Lin, 2001; Yabe, 2004; Tan et al., 2013; Lenzen, 2016). In this study, SDA was employed to explore the driving factors, which were responsible for fluctuations in carbon emissions embodied in China-Russia trade. First, the equation for calculating the embodied carbon emissions in the trade is written as below:

$$Q = C(I - A)^{-1}Y. \tag{6}$$

As for the variable Y , it can be decomposed into the

product of the total import or export (F) and the import or export structure matrix (S). In regard to S , it can be expressed as $S_i = Y_i/F$, in which Y_i is the total import or export products of sector i . At the same time, let L equal to $(I - A)^{-1}$. In the end, Eq. (6) is

$$Q = C \times L \times F \times S, \tag{7}$$

where C , L , F , and S denote the carbon emission coefficient, intermediate technology, trade scale, and trade structure, respectively. We assume that the base period is 0, and the reporting period is 1. Hence, the change in embodied carbon over the two periods can be calculated as follows:

$$\Delta Q = Q_1 - Q_0 = C_1 \times L_1 \times F_1 \times S_1 - C_0 \times L_0 \times F_0 \times S_0. \tag{8}$$

Based on the above formula, this paper uses the two polar decomposition method to carry out structural decomposition (Dietzenbacher and Los, 1998). First, the decomposition result of the base period is expressed as follows:

$$\Delta Q_0 = \Delta C L_0 F_0 S_0 + C_1 \Delta L F_0 S_0 + C_1 L_1 \Delta F S_0 + C_1 L_1 F_1 \Delta S. \tag{9}$$

Secondly, the decomposition result of the reporting period can be described as

$$\Delta Q_1 = \Delta C L_1 F_1 S_1 + C_0 \Delta L F_1 S_1 + C_0 L_0 \Delta F S_1 + C_0 L_0 F_0 \Delta S. \tag{10}$$

Combined with the above analysis, the final decomposition result is the mean of Eq. (9) and Eq. (10), which is as follows:

$$\begin{aligned} \Delta Q = & \frac{1}{2} (\Delta C L_0 F_0 S_0 + \Delta C L_1 F_1 S_1) \\ & + \frac{1}{2} (C_1 \Delta L F_0 S_0 + C_0 \Delta L F_1 S_1) \\ & + \frac{1}{2} (C_1 L_1 \Delta F S_0 + C_0 L_0 \Delta F S_1) \\ & + \frac{1}{2} (C_1 L_1 F_1 \Delta S + C_0 L_0 F_0 \Delta S). \end{aligned} \tag{11}$$

Moreover, this paper will calculate the contribution rate of the four factors mentioned above to embodied carbon emissions. First, the contribution value of each factor to embodied carbon emissions can be obtained as follows:

$$f(\Delta C) = \frac{1}{2} (\Delta C L_0 F_0 S_0 + \Delta C L_1 F_1 S_1), \tag{12}$$

$$f(\Delta L) = \frac{1}{2} (C_1 \Delta L F_0 S_0 + C_0 \Delta L F_1 S_1), \tag{13}$$

$$f(\Delta F) = \frac{1}{2}(C_1 L_1 \Delta F S_0 + C_0 L_0 \Delta F S_1), \quad (14)$$

$$f(\Delta S) = \frac{1}{2}(C_1 L_1 F_1 \Delta S + C_0 L_0 F_0 \Delta S). \quad (15)$$

Thus, the contribution rate (R) of the carbon emission coefficient, intermediate technology, trade scale, and trade structure to embodied carbon emissions can be expressed respectively as follows:

$$R_C = \frac{f(\Delta C)}{\Delta Q} \times 100\%, \quad (16)$$

$$R_L = \frac{f(\Delta L)}{\Delta Q} \times 100\%, \quad (17)$$

$$R_F = \frac{f(\Delta F)}{\Delta Q} \times 100\%, \quad (18)$$

$$R_S = \frac{f(\Delta S)}{\Delta Q} \times 100\%. \quad (19)$$

2.3 Data description

It is known that China's input-output table is released every five years, and an input-output extension table is issued during this period. Therefore, the published China's I-O Table (2007, 2010, 2012, 2015) and Russia's I-O Table (2007, 2010, 2012, 2015) are employed in this paper. The China's I-O Tables for 2007, 2010, 2012 and 2015 are derived from the National Bureau of Statistics of China (NBSC, 2009, 2012, 2014, 2017). The Russia's I-O Tables for 2007, 2010 and 2012 are from the World Input-Output Database (WIOD, 2013). The Russia's Tables for 2015 are obtained from the Organization for Economic Co-operation and Development (OECD, 2018). The annual trade data of involved sectors between China-Russia trade are all from the United Nations Comtrade Database (UNCD, 2018). The energy consumption data of China and Russia are from the China Energy Statistical Yearbook (NBSC, 2018) and the World Energy Statistical Yearbook published by BP (WESY, 2017), respectively. The carbon emission coefficients of dif-

ferent kinds of energy are based on the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Considering that the decomposition analysis requires the constant price, data involved with price variables were calculated at constant prices of 2007. Importantly, it is worth noting that there are many differences in the sector divisions of energy consumption and input-output data. Su et al. (2010) suggested that sector aggregation has effect on the research results and pointed out the hybrid data treatment was reasonable. We carried out sector aggregation based on the China-Russia trade sectors. The largest volume of China-Russian trade is in the industrial sector, and less frequently in the service sector. Therefore, we have grouped the service sector after other sectors and highlighted manufacturing and energy sectors. Finally, sectors involved this paper are divided into 12 categories for intuitive analysis (Table 1).

3 Results and discussion

By using the EEBT and SDA approaches mentioned above, the embodied carbon emissions in China-Russia trade are calculated, and the influential factors of embodied carbon due to the China-Russia trade are discussed in detail.

3.1 Embodied CO₂ emissions in the bilateral trade

Embodied carbon emissions in imports and exports of China in China-Russia trade are presented in Table 2, as well as net exported embodied CO₂ emissions from China to Russia and total volume of China-Russia trade.

Table 2 shows that the total bilateral trade volume between China and Russia is gradually increasing, but the scale of embodied carbon emissions in exports and imports is becoming smaller and smaller. This means that trade between China and Russia would be beneficial for decarbonization. In 2007, the embodied carbon emissions in imports and exports were 21.31 Mt and 34.52 Mt, respectively, which were the highest during 2007–2015. In 2010, China-Russia bilateral trade volume was increased by 70% with respect to 2007, while the trade embodied carbon emissions were declined by 25%.

Table 1 Classification of the sectors

Code	Sector	Code	Sector
1	Agriculture, hunting, forestry, and fishing	7	Paper, printing, and publishing
2	Mining and washing of coal	8	Chemical manufacturing
3	Extraction of petroleum and natural gas	9	Non-metallic mineral manufacturing industries
4	Beverages and tobacco	10	Metal manufacturing industries
5	Textiles, leather, and clothing	11	Other manufacturers
6	Wood and wood products	12	Other sectors

Table 2 Total embodied carbon emissions and trade volume

Year	Embodied CO ₂ emissions (Mt CO ₂)			Total traded volume (billion USD)
	CO ₂ emissions imports	CO ₂ emissions exports	Net exports of CO ₂ emissions	
2007	21.31	34.52	13.21	33.52
2010	15.97	26.57	10.59	57.05
2012	19.18	23.58	4.40	75.09
2015	11.64	16.09	4.45	63.55

Source: Own elaboration.

Moreover, China’s net export trade embodied carbon was dropped from 13.21 Mt in 2007 to 4.45 Mt in 2015. Therefore, less and less amounts of CO₂ were transferred from Russia to China. The reason for this phenomenon is that the level of production technology of China has increased significantly. As can be seen from Table 3, the CO₂ emission intensity of all sectors in China has been decreasing year by year, indicating that the CO₂ emission reduction technology and energy utilization efficiency have been continuously improved.

3.2 CO₂ emissions embodied in China-Russia trade by sector

According to the sectoral division above, we will make a comparative analysis on the embodied carbon emissions of 12 sectors in China-Russia trade. From the perspective of carbon emissions embodied in imports from Russia, Figs. 2–5 show that sector 3 (oil and natural gas extraction), sector 6 (wood and wood products), sector 8 (chemical industry and manufacturing industry) and sector 10 (metal manufacturing industry) play a dominating role in embodied carbon emissions. To be specific, sector 3, accounting for 43.86%, 40.15%, 58.87%, and 60.28% of the total CO₂ emissions in 2007, 2010, 2012, and 2015, respectively, was the first rank

Table 3 Carbon emission coefficients of sectors in China

Sector	2007	2010	2012	2015
1	0.049	0.024	0.018	0.015
2	3.704	1.555	1.230	0.991
3	0.068	0.069	0.074	0.109
4	0.078	0.029	0.025	0.023
5	0.071	0.025	0.027	0.024
6	0.032	0.018	0.015	0.012
7	0.235	0.124	0.084	0.059
8	0.445	0.187	0.109	0.077
9	0.489	0.366	0.191	0.203
10	0.303	0.154	0.116	0.083
11	0.037	0.024	0.025	0.018
12	0.096	0.035	0.026	0.017

Note: Unit (kt/per million US dollar).
Source: Own elaboration.

among 12 sectors. Moreover, the proportion of embodied carbon emissions in the imports of sector 3 from Russia to China presented a significant growing trend, which indicated that China’s demand for energy imports from Russia was rapidly increasing. Embodied carbon emissions of sector 10 (metal manufacturing industry)

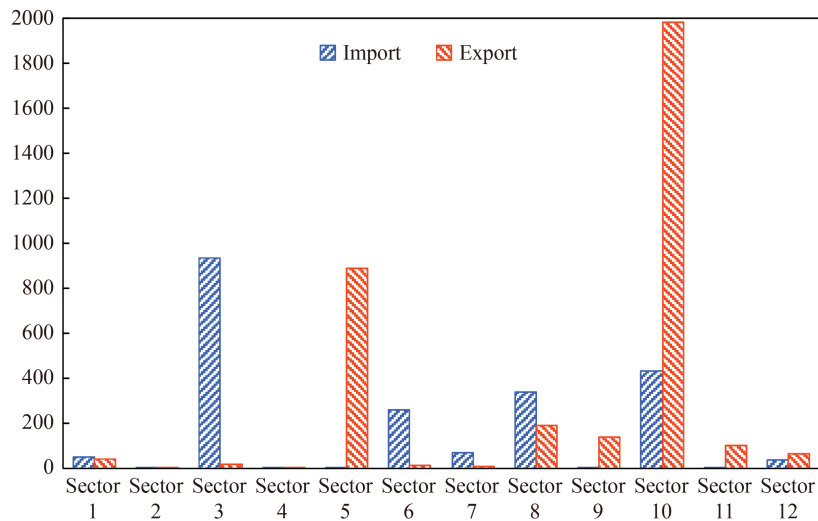


Fig. 2 CO₂ emissions embodied in China-Russia trade in 2007 (unit: 1 × 10⁴ t CO₂).

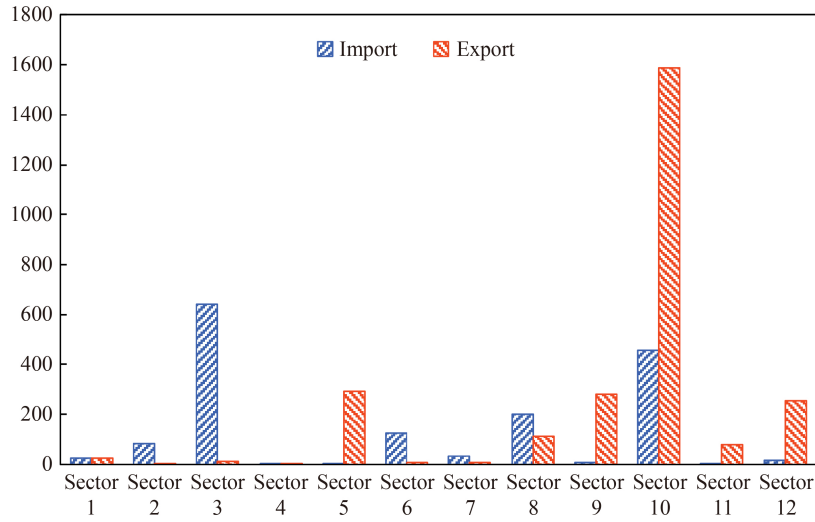


Fig. 3 CO₂ emissions embodied in China-Russia trade in 2010 (unit: 1 × 10⁴ t CO₂).

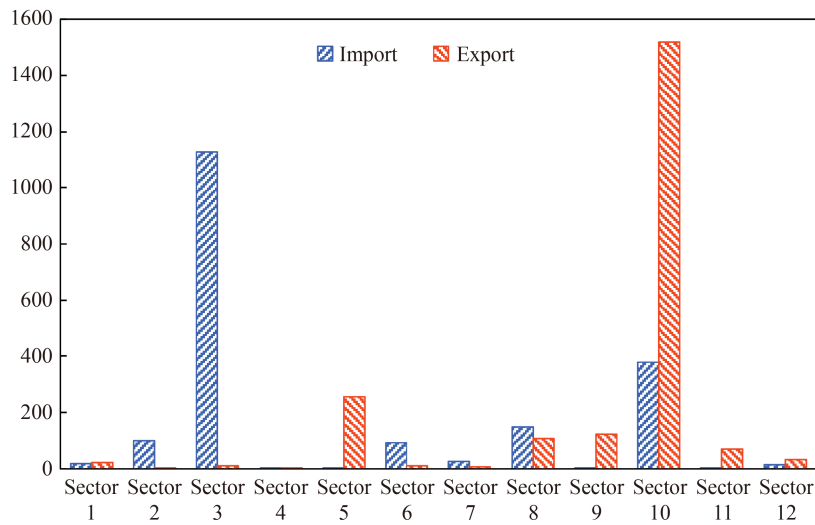


Fig. 4 CO₂ emissions embodied in China-Russia trade in 2012 (unit: 1 × 10⁴ t CO₂).

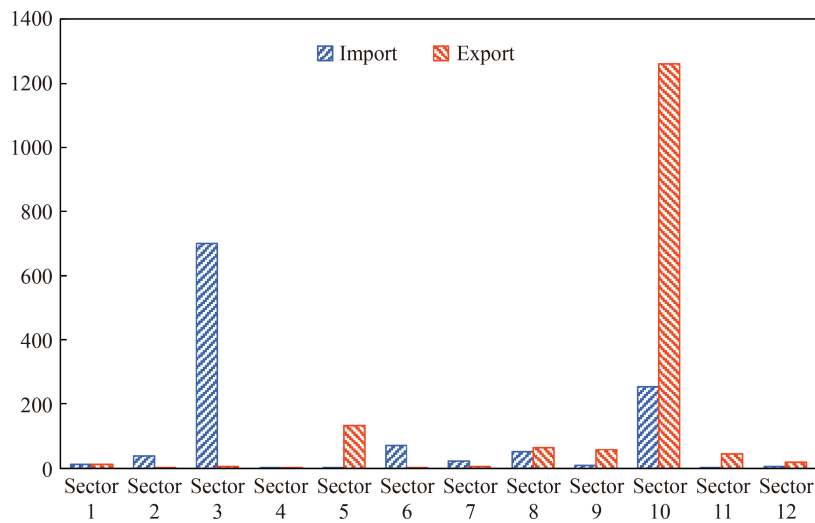


Fig. 5 CO₂ emissions embodied in China-Russia trade in 2015 (unit: 1 × 10⁴ t CO₂).

ranked the second place among all sectors and the respective proportion of embodied carbon was 20.32%, 28.54%, 19.73%, and 21.67% of total in 2007, 2010, 2012, and 2015, which was approximately stable during this period.

CO₂ emissions embodied in exports of sector 5 (textile, leather, and clothing), sector 8 (chemical industry and manufacturing industry), sector 9 (non-metallic mineral manufacturing) and sector 10 (metal manufacturing industry) from China to Russia accounted for a larger proportion than others. In detail, sector 10 (metal manufacturing industry) accounted for the largest proportion and its respective ratio was 57.46%, 59.78%, 70.38%, and 78.35% in 2007, 2010, 2012, and 2015, which showed an increasing trend. The main reason is that Russia's domestic industry is dominated by the energy industry, and the manufacturing industry is relatively backward. China's manufacturing industry is one of the most developed in the world, especially because of the policy of Made in China 2025. Embodied carbon emissions in exports of sector 5 (textile, leather,

and clothing) accounted for 25.74%, 11.06%, 11.80%, and 8.36% of the total in 2007, 2010, 2012, and 2015, respectively. The share of embodied carbon emissions in exports from China to Russia of sector 5 presented a downward trend.

3.3 SDA results

In this section, SDA was adopted to analyze the driving factors of carbon emissions embodied in bilateral trade between China and Russia. Figures 6 and 7, respectively, show the influence of the carbon emission coefficient (*C*), intermediate technology (*L*), trade scale (*F*), and trade structure (*S*) on the embodied carbon emissions in imports and exports. In addition, the contribution rates of all factors to the embodied carbon emissions are calculated (Tables 4 and 5).

Figure 6 demonstrates that the carbon emission coefficient exerted a negative effect on embodied carbon emissions in imports from Russia to China during the period from 2007 to 2015. Furthermore, embodied CO₂

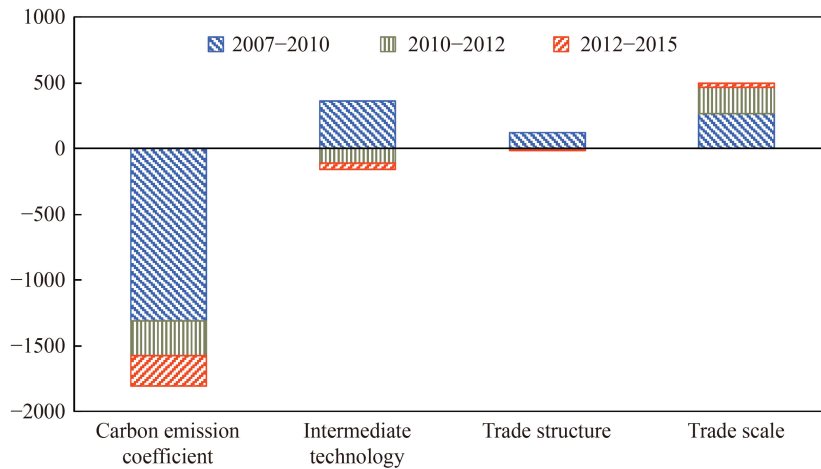


Fig. 6 Decomposition analysis of imported carbon emissions (unit: 1 × 10⁴ t CO₂).

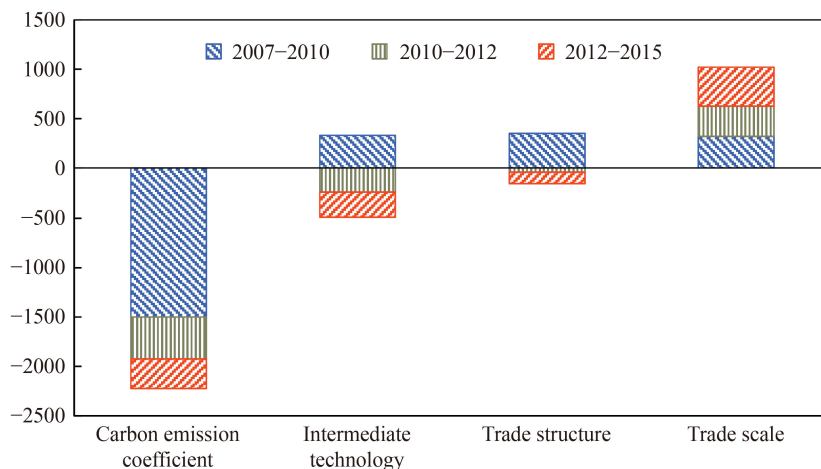


Fig. 7 Decomposition analysis of exported carbon emissions (unit: 1 × 10⁴ t CO₂).

Table 4 Contribution rate of indexes in reducing imported carbon

Year	Contribution rate/%			
	Carbon emissions coefficients	Intermediate technology	Trade structure	Trade scale
2007–2010	231.09	–63.14	–21.01	–46.94
2010–2012	143.10	61.31	2.21	–106.34
2012–2015	95.26	17.51	2.03	–14.80

Source: Own elaboration.

Table 5 Contribution rate of indexes in reducing exported carbon

Year	Contribution rate/%			
	Carbon emissions coefficients	Intermediate technology	Trade structure	Trade scale
2007–2010	303.48	–67.38	–70.94	–65.17
2010–2012	108.22	61.95	8.60	–78.76
2012–2015	108.36	92.61	43.54	–144.50

Source: Own elaboration

emissions were decreased by approximately 180.83 Mt during three research periods. During 2007–2010, the intermediate technology and trade structure presented a positive correlation with the embodied carbon emissions in the imports from Russia to China, and had a negative impact on embodied CO₂ emissions during 2010–2012 and 2012–2015. Furthermore, the contribution rate of the intermediate technology to embodied CO₂ emissions reduction was 61% and 17.5% during 2010–2012 and 2012–2015, respectively. In regard to trade structure, its contribution rates were 2.2% and 2.0% during 2010–2012 and 2012–2015, respectively.

The analysis above showed that the carbon emission coefficient was the main factor for the reduction of embodied carbon emissions in imports at this stage. With the progress of technology, the effect of intermediate technology on the reduction on embodied carbon emissions in the imports from Russia to China will become more and more significant. In terms of trade structure, China has gradually increased the proportion of imports of energy-saving and low-carbon goods and has reduced the proportion of imports of high-energy and high-emission commodities. Therefore, the changes of the trade structure will gradually promote the reduction of embodied carbon emissions in imports.

Figure 7 describes the contribution values of the carbon emission coefficient, intermediate technology, trade structure, and trade scale to embodied carbon emission in the exports from China to Russia. The carbon emission coefficient was negatively correlated with the embodied carbon emissions in the exports from China to Russia, and embodied carbon emissions were reduced by 22.25 Mt from 2007 to 2015. With respect to the trade scale, it significantly contributed to the growth of carbon emissions, and the embodied carbon emissions were increased by 10.27 Mt. Intermediate technology exerted a

positive effect on embodied carbon emissions in the exports from 2007 to 2010. However, the intermediate technology had a negative correlation with embodied carbon emissions in the exports during 2010–2012 and 2012–2015, and the contribution rate of intermediate technology to carbon emission reduction was 61.95% and 92.61%, respectively (Table 5), the reason of which was mainly due to the growth of China's research and development investment (R&D) and foreign direct investment (FDI), contributing to the improvement of the technical level (Zhu and Jeon, 2007; Khachoo and Sharma, 2016). Unusually, trade structure had a positive effect on embodied carbon emissions from 2007 to 2010, while had a negative effect from 2010 to 2015. The contribution of trade structure to carbon emission reduction embodied in China's export trade was increased rapidly from 8.60% to 43.74%. This may be due to the optimization of China's trade structure. China has reduced exports of carbon-intensive goods, such as glass, steel, and aluminum.

3.4 Policy implications

In this section, we investigated the impact of the current embodied carbon emissions in trade on the China-Russia economies and ecology, as well as proposed specific policy implications.

As a result of the US-China trade war, China's trade with other countries along the "Belt and Road" region has increased significantly, especially with Russia. Trade scale and trade structure between Russia and China will change dramatically. Our study indicated that an increase in trade volume between China and Russia is accompanying with a decrease in the embodied carbon emissions of trade. It is important for China and Russia to reduce carbon emission and achieve sustainable economic

development. It was found that carbon emission coefficient was crucial for the embodied emission reduction during the observation period (2007–2015). Carbon emission coefficient was energy-based CO₂ emissions per unit of output, which essentially depends on the production technology. However, the contribution of carbon emission coefficient to CO₂ emission reduction has been gradually decreasing. While improving energy efficiency, China should also make full use of renewable energy sources such as solar, biomass, wind, and tidal energies.

Besides, in China, negative to positive impact of intermediate technology and trade structure on CO₂ emission reduction was verified. Therefore, attention should be paid to techno-economic linkages among sectors. Enterprises and governments should increase R&D investment to promote technological innovation. As for trade structure, the metal manufacturing sector is the largest net exporter, while the mining and washing of coal sector is the largest net importer of embodied carbon emissions. We can see that Sino-Russian trade relies mainly on the factor endowments that both countries

have, i.e., China has sufficient labor and Russia has abundant resources. However, China’s exports have become more diversified in recent years, such as chemical products. Optimizing trade structures is an important way to reduce carbon emissions in the future.

In terms of import, we found that the share of carbon emissions embodied in sector 3 (oil and natural gas extraction) was the largest and kept increasing. Besides, Fig. 8 shows that the trade volume of this sector ranked as the first as well as presented a growing trend. This means that trade scale was likely to be significant contributor to the carbon emissions in this sector. It was also confirmed that the carbon emission coefficient of this sector was increasing. Therefore, it is necessary for China to improve the energy efficiency in oil and natural gas extraction sector. Otherwise, the huge consumption can offset the reduction in carbon emissions from clean energy utilization.

In terms of export, Fig. 9 shows that sector 10 (metal manufacturing industries) and sector 5 (textiles, leather, and clothing) had the largest export trade, which is accompanied by large carbon emissions embodied in

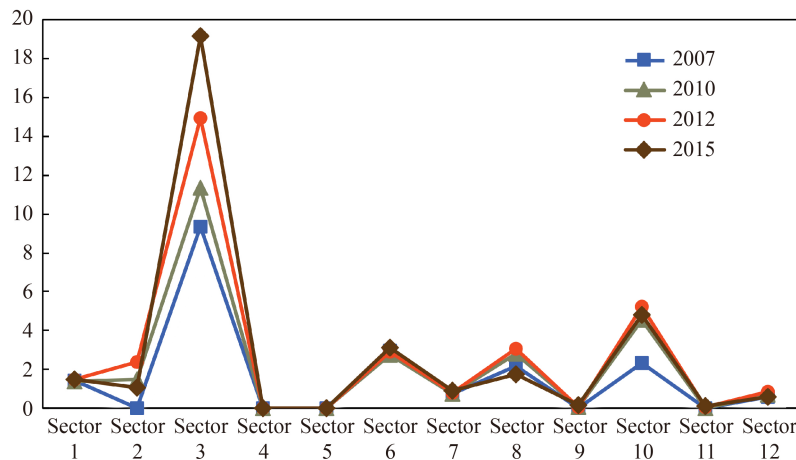


Fig. 8 Trade volume of China import from Russia (unit: billion USD).

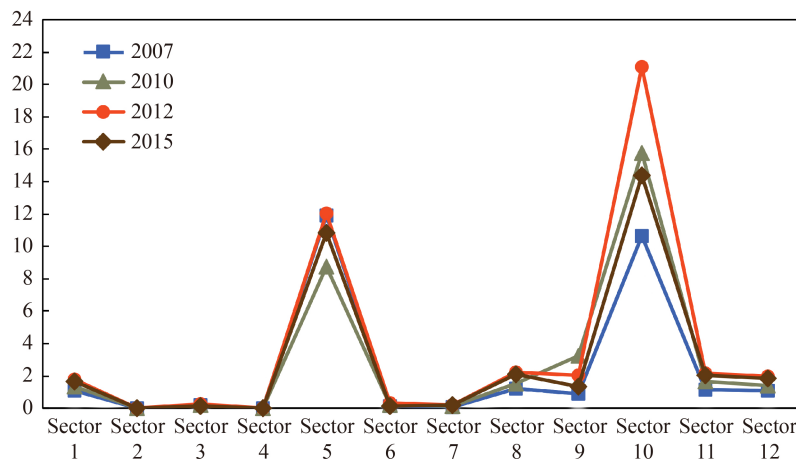


Fig. 9 Trade volume of China export to Russia (unit: billion USD).

trade. Especially, although carbon emission coefficient for both decreased, sector 10 remained significantly higher than sector 5. For China, exports from metal manufacturing industries generate a significant amount of carbon emissions. More technological innovations should be applied to this sector.

4 Conclusions

This study employed the bilateral trade input-output analysis method (EEBT) and quantified embodied carbon emissions in China-Russia trade from 2007 to 2015. In addition, the SDA method was adopted to explore the internal driving factors of embodied carbon emissions in China-Russia trade. The conclusions of this study are summarized as follows.

First, China was always a net exporter of CO₂ emissions in China-Russia trade from 2007 to 2015. In addition, with the continuous growth of the bilateral trade volume, China's net CO₂ export volume showed a declining trend, the volume of which decreased from 13.21 Mt in 2007 to 4.45 Mt in 2015. Secondly, from the perspective of the sectoral level, sectors 3 (oil and natural gas), 6 (wood and wood products), and 10 (metal manufacturing) are the principal sources of embodied carbon emissions in the imports from Russia to China. Meanwhile, embodied carbon emissions in the exports from China to Russia are concentrated in the sector 5 (textile, leather, and clothing), 8 (chemical industry), 9 (non-metallic minerals manufacturing) and 10 (metal manufacturing), which were responsible for the increase of embodied carbon emissions in the exports. Thirdly, the carbon emission coefficient is the most important factor for the embodied carbon reduction, and the contribution rate of the carbon emission coefficient to embodied carbon emission reduction in imports was more than 95.26%, as compared with 108.22% to embodied carbon emission reduction in exports. In the end, trade scale played a vital role in contributing to the increase in embodied carbon emissions. To be more specific, it contributed more than 14.80% to the growth of embodied carbon emissions in imports and more than 65.17% in the exports.

Some policy implications derived from these results mentioned above are as follows. First, China must promote the transition of its industrial structure and accelerate the adjustment of the export structure, particularly related to the sectors “textiles, leather and clothing”, “non-metallic mineral manufacturing industries” and “metal manufacturing industries”. The results of our study indicated that the contribution rate of the trade structure to the exported carbon emission reduction increased from -70.94% in 2007–2010 to 43.54% in 2012–2015, which means that the trade structure can play an important role in embodied carbon

emissions reduction. More importantly, China should increase the proportion of the low-carbon industry in the exports in China-Russia trade, so as to gradually change the status quo of net carbon export.

Secondly, it is necessary to optimize the energy utilization structure and increase the proportion of clean energy for China and Russia to reduce carbon emissions. The results of SDA show that the sectoral carbon emission coefficient has the highest contribution rate to embodied carbon emission reduction. Hence, on one hand, China should improve energy efficiency by technological innovation. On the other hand, it is also essential to reduce the share of fossil energy, especially coal, and oil, and increase the proportion of cleaner energy, like wind, solar, nuclear, and other renewable energy sources.

Finally, China should have closer collaboration with Russia in bilateral trade. In particular, it is necessary for China and Russia to give play to comparative advantages of carbon emissions in different sectors. In detail, the two countries should increase the exports of low-carbon products and reduce the production of domestic high-carbon products, which will not only significantly reduce the embodied carbon emissions in China-Russia trade, but also play a positive role in promoting global carbon emission reduction. Nowadays, in the context of One Belt One Road, the total trade volume between China and Russia shows a trend of rapid growth (Fig. 1), the growth potential of which should be taken seriously.

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