An Examination of China's CO2 Emissions: Generating or Receiving Carbon Leakages

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ASSIA Working Paper Series 21-01

June, 2021

Applied Social System Institute of Asia (ASSIA)
Nagoya University

名古屋大学 アジア共創教育研究機構

An Examination of China's CO2 Emissions in Asia: Generating or Receiving Carbon Leakages

Vo Tuyet Le* and Ju Yiyi⁑

Abstract

Along with the increasingly multinational production of goods and services in the global value chain, the potential relocation of environmental pollution overseas has been attracting attention. This study examines whether China has been causing CO2 emissions to rise in its bilateral trade partners. We selected five Asian countries (Vietnam, Indonesia, India, Japan, and South Korea) and examined the problem using two approaches (single- and multi-region input–output analyses) in 2005 and 2015. This study obtained three findings: (1) the carbon leakage from Japan to China decreased, however, China increased domestic CO_2 emissions and exports to Vietnam, Indonesia, and India from 2005 to 2015; (2) such increases were related less to the upgrade of production technology in China, but more to China's growing net trade surplus; and (3) different from other China's trade partners, Vietnam's export of emission-intensive goods and services to China have increased during 2005-2015. We further looked into input coefficients from the electricity supply sector in all sectors. The improvement in power generation technologies does not only contribute to the national-level emission reduction directly, but other sectors may also benefit from a greener power generation mix (e.g., the petrochemical industry in China, the textile industry in Vietnam in a reverse way). Importing more emission-intensive goods from other countries instead of domestic production does not help global emission reduction.

Keywords

Green Leontief paradox, pollution haven hypothesis, carbon leakages, carbon relocation

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1. Introduction

After opening up and economic reforms in 1978, China's development was remarkable with a gross domestic product (GDP) growth rate of almost 10% per year, and it became the world's second-largest economy. In 2018, China became the world's number-one export country and was second in imported goods. In the meantime, decades of rapid economic growth have dramatically expanded China's energy needs. As a result, China is now the world's largest CO_2-generating country. China's fossil fuel consumption accounted for 87.6% of total energy consumption in 2014 (China Energy Group at Lawrence Berkeley National Laboratory, 2014). Along with increased international trade, the production of goods and services has become multinational. This indicates the possibility of environmental pollution also being exported overseas.

In the context of globalization's remarkable rise, the relationship between trade and the environment has also been discussed in the literature. Among the debates on the impact of trade globalization on the environment, there are discussions on the pollution haven hypothesis (PHH) and carbon leakage terms (Cole, 2004; Dietzenbacher & Mukhopadhyay, 2007; Gill et al., 2018; Mani & Wheeler, 1998; Taylor, 2004; Wiebe & Yamano, 2016).

Conventionally, the PHH and carbon leakage were terms related to environmental regulation and production activities. Relatively strict environment regulation in developed countries forced entrepreneurs to save energy and to introduce energy-saving technology, which raised the cost of the product when produced in developed countries. As a result, multinational companies tried to reduce costs by moving production bases to developing countries with lax environmental policies. Carbon leakage refers to the movement of carbon through the market mechanism. For instance, Copeland and Taylor (1994) considered the PHH in north-south trade under the North American Free Trade Agreement. Their research showed the connection between stringent environmental regulations and trade patterns in terms of a country's pollution. The research found that enterprises in highly regulated systems such as the U.S. or Canada were directly competitive with those operating in poorer countries with weak environmental standards like Mexico. In the globalization and liberalization era, developing countries could become PHHs for the pollution-intensive industries of advanced countries. Therefore, carbon leakage occurs because of the trade between developing countries and developed countries.

Yang (2001) tested the impacts on Taiwan's environment and CO_2 emissions after Taiwan joined the World Trade Organization (WTO). The author applied computable general equilibrium (CGE) to see the interaction among the economic sectors and then employed the Laspeyres index to decompose the change in CO_2 emissions after Taiwan joined the WTO in 1996. The results showed that, along with trade liberalization, CO_2 emissions also increased. The net change in emissions was focused on some carbon-intensive sectors such as on-metallic mineral products, metal products, and electricity sectors. Yang's (2001) paper supported the PHH in Taiwan after it joined the WTO.

Dietzenbacher and Mukhopadhyay (2007) examined India's PHH. Their study estimated CO_2 and SO_2 emissions released into the environment when they assumed that exports and imports would increase by the same amount of 1 billion rupees. Although the authors expected that India would export pollution-intensive goods, they found the opposite results in the case of India. The amount of CO_2 and SO_2 emissions generated to produce one unit of exports were smaller than the pollution amounts avoiding being generated by one unit of imports. Consequently, India exports relatively clean goods and gains from the extra trade. This means that India was not a pollution haven in the 1990s.

Similar to Dietzenbacher and Mukhopadhyay (2007), Temurshoev (2011) employed the same methodology to examine the PHH or the factor endowment hypothesis for the U.S. and China for 1992 and 1997. This empirical research examined three cases of trade: (1) China's trade with the rest of the world; (2) U.S. trade with the rest of the world; and (3) the bilateral trade between China and the U.S. It was revealed that a PHH does not exist in the case of bilateral trade and that China gained in terms of emissions. The author also found that, over time, the gains from trade with the U.S. are more beneficial in terms of CO_2 emissions than the same increase in trade with the rest of the world.

Chen et al. (2011) found that China's export-oriented economy from 1993 to 2007 was good for the environment. Employing the simultaneous equation model, the authors investigated the interaction among economic growth, foreign trade, foreign direct investment (FDI), and the environment. The results of this research did not support the PHH. However, it could be interpreted that China was causing the rise of CO_2 emissions in the rest of the world under its export-oriented economy.

On the other hand, in Jayanthakumaran and Liu's (2016) research, the result was the opposite for bilateral trade between China and Australia. Using the sector input–output (IO) model to calculate the CO_2 emissions embodied in trade between China and Australia, the net CO_2-embodied emissions transferred from Australia to China had a negative value. It can be shown that the Australian trade caused the rise of Chinese emissions in the period 2008–2011. This research found that global CO_2 emissions could increase by 39.13 million tons when Australia consumes China's export goods, but China's consumption of Australia's products could slow world emissions by 20.19 million t-CO_2. The authors suggested that the composition of more bilateral trade may help reduce global emissions.

Fan et al. (2019) also tested the CO_2 embodied in Chinese trade in 2010 and 2011. The author created a panel data model to examine the impact of trade on CO_2 emissions, using the single-region input–output (SRIO) model to decompose the industrial sector and carbon dioxide emissions. In general, the more open the trade, the more reduction in carbon intensity and gross emissions.

Carbon relocation is another environmental term. It occurs through FDI. Shahbaz et al. (2015) showed the change in emissions through FDI. The paper demonstrated the effects of FDI on the environments of low-, middle-, and high-income countries. The author used panel data from 1975 to 2012 and employed panel co-integration techniques. The results when economic growth gains 1%, energy use and environmental pollution increase by 0.07% and 0.65%, respectively. In turn, FDI decreases the CO_2 emissions in high-income countries in every period, but this does not happen in low-income countries. In low-income countries, FDI speeds environmental degradation. The result supports the PHH. Carbon leakage is the movement of carbon through the market mechanism, but carbon relocation refers to the redirection of carbon according to policies of carbon-intensive countries like China. There is a significant difference between carbon leakage and carbon relocation. However, carbon leakage and carbon relocation cannot be distinguished in terms of phenomena.

After specifying the differences in carbon leakage and carbon relocation definitions, this study supplemented the previous literature on regional carbon leakage by improving the examination approach. Previous literature used the SRIO table (Dietzenbacher and Mukhopadhyay, 2007; Temurshoev, 2011) to calculate the embodied emissions and further reviewed the international carbon leakages pattern. This was limited because of the unavailableness of international intermediate trades. In these studies. The technology levels of imported goods and services were assumed to be the same as in the home countries, as well as in the rest of the world. The results calculated by such an SRIO approach referred to the CO_2 emissions that were avoided by importing goods and services, rather than to the exact value of CO_2 emissions embodied in the imports.

Against this backdrop, this study applied both the SRIO and multi-region input–output (MRIO) approaches to achieve a more accurate estimation of embodied emissions and to determine a more accurate examination of international carbon leakages. This is one of our contributions to improved methodology.

This study focuses on the emissions induced by international trade. It examines whether China has been transferring CO_2 emissions to Asian countries through bilateral trade or receiving overseas CO_2 emissions. Further, the study investigates whether the pattern of China's bilateral emissions transfer has changed from 2005 to 2015. We selected five trade partner countries in Asia to use when considering the range of economic development level, specifically by the indicator GDP per capita (China US $4,550 in 2010). These countries include Vietnam (US $1,318), India (US $1,358), and Indonesia (US $3,122), the ones smaller than China; as well as Japan (US $44,508) and South Korea (US $23,087, GDP per capita in 2010, World Bank, 2016), the ones larger than China. This study contributes to a better understanding of the role of one country in the global carbon transaction. It clarifies how different empirical examination results support different theorical hypotheses of carbon leakages due to the application of examination approaches. Such approaches include MRIO analysis distinguishing emission intensities of imports and domestic production, a feature of international trade that has not received enough attention in the previous literature.

2. Methodology

This study adopts input–output methodology to calculate embodied emissions and to further examine whether China has been transferring CO_2 emissions to Asian countries through bilateral trade or has been receiving overseas CO_2 emissions. The literature has applied various methodologies to evaluate the interaction between global business and the environment, such as CGE (Yang, 2001) and econometric models (Chen et al., 2011). However, use of the econometric models may involve the endogeneity of explanatory variables. In addition, the model may test for only a single country and may lack data for developing countries. One of the advantages of input–output (IO) analysis is that it does not depend on the availability of long-term series data to track emissions. Moreover, it can also distinguish the demand for various fuel types in economic sectors that show the interrelation of production sectors in the economy. Computer generated equilibrium models can also become the extension of IO models. However, the disadvantage of CGE is the complexity of their computation and the validation difficulty. Therefore, the IO approach can be considered as appropriate.

We further applied both the SRIO and MRIO approaches to cover the importance of intermediate goods and services in this study.

2.1. The Structure of the Single-Region Input–Output Table

The structure of an SRIO table is shown in Figure 1. The vector $\mathbf{x}_r$ represents the total input (output) for all sectors in region r. The matrix $\mathbf{A}_r\widehat{\mathbf{x}_r}$ displays the flow between domestic sources (rows) and domestic destinations (columns) by sectors in region r and the import intermediate demand. The matrix $\mathbf{y}_r$ represents the final demand for goods and services in region r. The matrix $\mathbf{V}_r$ represents the value added in region r.

	Intermediate demand	Final demand	Total output
Intermediate input	$\mathbf{A}_r\widehat{\mathbf{x}_r}$	$\mathbf{y}_r$	$\mathbf{x}_r$
Value added	$\mathbf{v}_r$		
Total input	$\mathbf{x}'_r$		

Figure 1 Structure of a single-region input–output table in region *r*.

Source: Authors.

2.2. The Structure of the Multiple-Region Input–Output Table

The structure of an MRIO table is shown in Figure 2. Compared with that of the SRIO table, the total input (output) for all sectors is expanded to all k regions; e.g., $\mathbf{x}_k$ represents the total input (output) for all sectors in region k.

The intermediate demand matrix is expanded to all k regions; e.g., $\mathbf{A}_{k2}\widehat{\mathbf{x}_k}$ represents the input of intermediate goods and services for all sectors from region k to region 2. Similarly, the final demand matrix and the value-added matrix are also expanded to all k regions; e.g., $\mathbf{y}_{k2}$ represents the input of final products and services for all sectors from region k to region 2, and $\mathbf{v}_k$ represents the value-added in region k.

		Intermediate demand				Final demand				Total Demand	Total Output
		Region 1	Region 2	…	Region k	Region 1	Region 2	…	Region k	$\mathbf{y}$	$\mathbf{x}$
Intermediate input	Region 1	$\mathbf{A}_{11}\widehat{\mathbf{x}_1}$	$\mathbf{A}_{12}\widehat{\mathbf{x}_1}$		$\mathbf{A}_{1k}\widehat{\mathbf{x}_1}$	$\mathbf{y}_{11}$	$\mathbf{y}_{12}$		$\mathbf{y}_{1k}$	$\mathbf{y}_1$	$\mathbf{x}_1$
	Region 2	$\mathbf{A}_{21}\widehat{\mathbf{x}_2}$	$\mathbf{A}_{22}\widehat{\mathbf{x}_2}$		$\mathbf{A}_{2k}\widehat{\mathbf{x}_2}$	$\mathbf{y}_{21}$	$\mathbf{y}_{22}$		$\mathbf{y}_{2k}$	$\mathbf{y}_2$	$\mathbf{x}_2$
	: :			…				…			
	Region *k*	$\mathbf{A}_{k1}\widehat{\mathbf{x}_k}$	$\mathbf{A}_{k2}\widehat{\mathbf{x}_k}$		$\mathbf{A}_{kk}\widehat{\mathbf{x}_k}$	$\mathbf{y}_{k1}$	$\mathbf{y}_{k2}$	…	$\mathbf{y}_{kk}$	$\mathbf{y}_k$	$\mathbf{x}_k$
Value Added	$\mathbf{v}$	$\mathbf{v}_1$	$\mathbf{v}_2$	…	$\mathbf{v}_k$						
Total Input	$\mathbf{x}$	$\mathbf{x}'_1$	$\mathbf{x}'_2$	…	$\mathbf{x}'_k$						

Figure 2 Structure of a multi-region input–output table.

Source: Authors.

2.3. Analysis by a Single-Region Approach

The emission coefficient of the ith sector in the rth region, c_{ir}, is formulated in Equation 1.

$$c_{ir} = p_{ir}/x_{ir}\ (\ i = 1, \cdots, n;\ r = 1, \cdots, k\ ), \tag{1}$$

where p_{ir} represents the direct CO_2 emissions of sector i; x_i represents the total output of sector i; c_{ir} is one of the elements of the direct-emission coefficient vector $\mathbf{c}_r$ for all n sectors in region r; and $\mathbf{c}_r$ is also one of the elements of the direct-emission coefficient vector $\mathbf{c}$ for all n sectors in all k regions.

The total output $\mathbf{x}_\mathrm{r}$ of all n sectors in region r meets the production balance in Equation 2.

$$\mathbf{x}_r = [\mathbf{I} - \mathbf{A}_r]^{-1}\mathbf{y}_r, \quad (2)$$

where $\mathbf{A}_r$ represents the $n \times n$ intermediate input coefficient matrix of region r and $\mathbf{y}_r$ represents the final demand of region r. The final demand consists of household (and non-profit institutions serving households) final consumption, final government consumption, gross fixed-capital formation, changes in inventories, and the acquisitions less disposals of valuables.

Total CO_2 emissions induced by the export from region r to region s, $\mathbf{ce}_{rs}$, are formulated as

$$\mathbf{ct}_{rs} = \hat{\mathbf{c}}_r[\mathbf{I} - \mathbf{A}_r]^{-1}\mathbf{y}_{rs} \ (r = 1, \cdots, k;\ s = 1, \cdots, k), \quad (3)$$

where the direct-emission coefficient vector in the rth region $\mathbf{c}_r$ is diagonalized; $\mathbf{e}_{rs}$ represents the goods and services exported from region r to region s, and both intermediate and final exports are included. Total CO_2 emissions induced by the imported goods of region r from region s can be calculated in Equation 4, which is similar to that of Dietzenbacher and Mukhopadhyay (2007):

$$\mathbf{ct}_{rs} = \hat{\mathbf{c}}_r[\mathbf{I} - \mathbf{A}_r]^{-1}\mathbf{y}_{sr} \ (r = 1, \cdots, k;\ s = 1, \cdots, k), \quad (4)$$

where $\mathbf{y}_{sr}$ represents the export of final demands from region s to region r. However, in this equation, the direct-emission coefficient vector in the rth region $\mathbf{c}_r$ is utilized, which means Dietzenbacher and Mukhopadhyay (2007) assumed that imported goods from the rest of the world have the same technology as that of region r. Thus, the result indicates that the total CO_2 is avoided in region r through its imports. This estimation approach is limited by the data access at the time and may lead to large uncertainties in results. This can be improved with Equation 5, where total CO_2 emissions induced by importing from region s to region r can also be calculated by

$$\mathbf{ct}^*_{rs} = \hat{\mathbf{c}}_s[\mathbf{I} - \mathbf{A}_s]^{-1}\mathbf{y}_{sr} \ (r = 1, \cdots, k;\ s = 1, \cdots, k), \quad (5)$$

where the direct-emission coefficient vector in region s, $\mathbf{c}_s$, is utilized.

In this paper, both intensity vectors, namely, the vector of the receiving regions of the imported goods (used in $\mathbf{ct}_{rs}$) and the vector of the original regions of the imported goods (used in $\mathbf{ct}^*_{rs}$), were examined.

For the trade balance of total CO_2 emissions, tb_{rs}, if

$$tb_{rs} = \boldsymbol{\iota}[\mathbf{ct}_{rs} - \mathbf{ct}_{rs}] < 0 \ (r = 1, \cdots, k;\ s = 1, \cdots, k), \quad (6)$$

region r caused the rise of emissions in region s. Also, if

$$tb_{rs} = \boldsymbol{\iota}[\mathbf{ct}_{rs} - \mathbf{ct}^*_{rs}] < 0 \ (r = 1, \cdots, k;\ s = 1, \cdots, k), \quad (7)$$

region r avoided domestic CO_2 emissions by the imports from region s. In other words, region r caused the rise of emissions in region s.

However, in a one-country IO table, it is not possible to obtain the direct-emission coefficient vector $\mathbf{c}_s$ and matrix $\mathbf{A}_s$. Therefore, the second examination can be improved with a multi-region approach, as shown in the next section.

2.4. Analysis Through a Multi-Region Approach

The total output of all n sectors in all k regions, $\mathbf{x}$, meets the production balance in Equation 8,

$$\begin{bmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_k \end{bmatrix} = \left[\mathbf{I} - \begin{bmatrix} \mathbf{A}_{11} & \cdots & \mathbf{A}_{1k} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{k1} & \cdots & \mathbf{A}_{kk} \end{bmatrix} \right]^{-1} \begin{bmatrix} \mathbf{y}_{11} + \cdots + \mathbf{y}_{1k} \\ \vdots \\ \mathbf{y}_{k1} + \cdots + \mathbf{y}_{kk} \end{bmatrix} , \qquad (8)$$

where $\mathbf{A}_{rs}$ represents the $n \times n$ intermediate coefficient matrix of region r's imports from region s. The final demands for goods and services are separated by country and sector in $\mathbf{y}$ (e.g., $\mathbf{y}_{1k}$ represents the $n \times 1$ vector of final goods and services from region 1 to region k).

The total CO_2 trade emissions in all n sectors in all k regions, $\mathbf{C^t}$, can be formulated as

$$\mathbf{C^t} = \hat{\mathbf{c}} \left[\mathbf{I} - \begin{bmatrix} \mathbf{A}_{11} & \cdots & \mathbf{A}_{1k} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{k1} & \cdots & \mathbf{A}_{kk} \end{bmatrix} \right]^{-1} \begin{bmatrix} \widehat{\mathbf{y}_{11}} & \cdots & \widehat{\mathbf{y}_{1k}} \\ \vdots & \ddots & \vdots \\ \widehat{\mathbf{y}_{k1}} & \cdots & \widehat{\mathbf{y}_{kk}} \end{bmatrix}, \qquad (9)$$

where the direct-emission coefficient vector of all k regions $\mathbf{c}$ is diagonalized.

The total CO_2 trade emissions between regions r and s, $\mathbf{C^t}$, can be considered as

$$\mathbf{C^t} = \begin{bmatrix} \mathbf{C}_{11}^t & \cdots & \mathbf{C}_{1k}^t \\ \vdots & \ddots & \vdots \\ \mathbf{C}_{k1}^t & \cdots & \mathbf{C}_{kk}^t \end{bmatrix}. \qquad (10)$$

For the trade balance of total CO_2 emissions from region r to region s, tb_{rs}, if

$$tb_{rs} = \boldsymbol{\iota}[\mathbf{C}^t{}_{rs} - \mathbf{C}^t{}_{sr}]\boldsymbol{\iota}' < 0 \; (r = 1, \cdots, k;\; s = 1, \cdots, k), \qquad (11)$$

region r caused the rise of emissions in region s.

In this study, the k regions include Vietnam, Indonesia, India, Japan, South Korea, and the rest of the world. All 26 n sectors include agriculture, mining and quarrying, and electrical and machinery, as shown in Table-Appendix, Sectors.

2.5. Data Sources

This study employs the IO tables from the Eora Global Supply Chain Database (EORA database) for the years 2005, 2010, and 2015 with the basic prices. The EORA database is the global supply chain database that provides the time series IO tables for 190 countries with environmental satellite accounts. Currently, this database has three formats: the individual country IO tables, EORA26, and full EORA. EORA26 will be employed in this study because all industries were aggregated into 26 sectors. With the different numbers of industries or commodities among 190 countries, using EORA26 will be more suitable and easier to analyze and compare among country sectors.

The EORA database also offers both basic and purchase prices. However, in this research, the basic price will be used because it has already deducted the tax payable and has included the subsidy for one unit of goods and services output. This keeps the transaction value between producers and consumers as homogenous as possible. In terms of sector-level emissions, the study also includes the CO_2 emissions from EORA26 for the years 2005, 2010, and 2015.

Three data providers were used to create the CO_2 and greenhouse gas satellite account rows in the EORA database: the Emission Database for Global Atmospheric Research (EDGAR), the Carbon Dioxide Information Analysis Center (CDIAC), and the PRIMAPHIST model. However, this study used the Potsdam Real-time Integrated Model for the Probabilistic Assessment of Emission Paths (PRIMAP) to obtain the total CO_2 generated by sectors in all countries because it included the EDGAR and CDIAC data.

3. Results

3.1. National CO_2 Emissions During 2005–2015

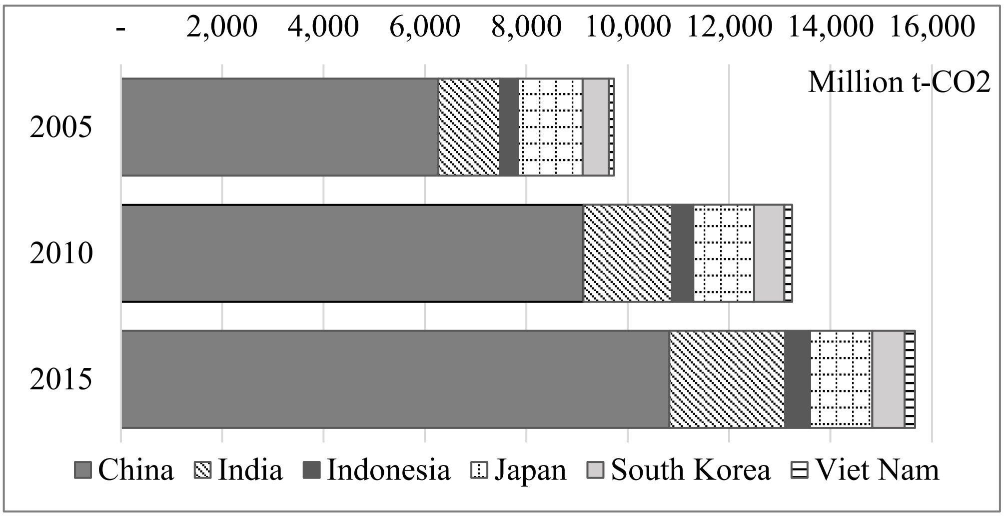

Figure 3 Total national CO_2 emissions, 2005–2015.

Source: EORA database.

Figure 3 shows the total national CO_2 emissions of China and selected Asian countries (Japan, South Korea, India, Vietnam, and Indonesia) from 2005 to 2015 based on the EORA database. In general, China is the highest CO_2 emitter among the six countries. China's carbon emissions increased from 6.2 billion t-CO_2 in 2005 to 10.8 billion t-CO_2 in the period from 2005 to 2015. National CO_2 emissions in Vietnam and India are relatively insignificant compared with China's; however, they increased significantly from 2005 to 2015. Vietnam's CO_2 doubled from 99 million t-CO_2 in 2005 to 203 million t-CO_2 in 2015. Similarly, India's emissions increased from 1.2 billion t-CO_2 to 2.3 billion t-CO_2 in the same period. Emissions in Indonesia and South Korea also increased by 36% and 24%, respectively, from 2005 to 2015. The only decrease in total national CO_2 occurred in Japan, which had a 4% drop over 10 years.

The direct-emission coefficients of the main sectors are shown in Table 1. The results were divided into the non-electricity sectors and the electricity sector from 2005 to 2015. Generally, the direct-emission coefficient slowed from 2005 to 2015. However, there are some differences in outcomes among these countries. Among the main sectors, the electricity sector has the highest emission coefficient, followed by the mining sector. Japan and South Korea have a low direct-emission coefficient in both the electricity sector and the non-electricity sectors. In contrast, China, Vietnam, India, and Indonesia have a relatively large volume of emissions per monetary unit. However, China and India decreased their emission coefficients by year and by sector, but Vietnam tended to enhance its emission coefficients from 2005 to 2015, especially in the mining sector.

The emission coefficient expresses the volume of emissions per unit of GDP, the reduction of which can be interpreted as less pollution released per unit of GDP. Countries with small emission coefficients may have better technology or more efficient energy consumption than those with high coefficients.

Table 1 Direct emission coefficients of main industrial sectors in selected Asian countries.

(Unit: Million t-CO2/US$ Billion)

	2005						2015					
	CHN	IDN	IND	JPN	KOR	VNM	CHN	IDN	IND	JPN	KOR	VNM
Agriculture	0.81	1.03	1.20	0.16	0.10	1.06	0.58	0.59	1.00	0.12	0.04	0.82
Fishing	0.77	0.84	0.83	0.15	0.01	0.97	0.58	0.55	0.95	0.10	0.02	0.47
Mining	1.35	1.12	2.22	0.18	0.06	2.49	0.63	0.70	1.40	0.08	0.05	2.66
Food	0.44	0.40	0.75	0.20	0.13	0.57	0.22	0.24	0.72	0.16	0.08	0.48
Textiles	0.71	0.41	0.79	0.25	0.15	1.38	0.40	0.29	0.75	0.23	0.07	1.75
Pet. & Chemical	1.07	1.61	1.03	0.17	0.17	0.67	0.48	0.60	0.73	0.10	0.08	0.45
Metal	0.99	1.44	0.99	0.15	0.03	1.31	0.32	0.49	0.56	0.08	0.06	0.58
Machinery	0.93	1.35	0.87	0.18	0.16	1.19	0.39	0.61	0.58	0.14	0.10	0.62
Transport Eqp.	0.20	0.09	0.12	0.07	0.02	0.37	0.13	0.04	0.09	0.05	0.01	0.15
Other Mfg.	0.91	0.86	0.90	0.18	0.02	1.51	0.52	0.47	0.65	0.14	0.01	0.71
Electricity	17.01	18.27	16.11	5.13	2.69	32.12	6.28	11.60	14.18	3.50	1.51	34.54

Source: Authors' calculations are based on the EORA database

Table 2. China's bilateral trade with selected Asian countries and the corresponding embodied emissions using the single-region I-O (SRIO) and multi-region I-O (MRIO) approach.

	Bilateral trade, Unit: US$ Billion									
	2005					2015				
	VNM	IDN	IND	JPN	KOR	VNM	IDN	IND	JPN	KOR
CHN's export to	0.9	2.3	3.1	49.4	8.3	5.2	9.3	12.9	99.0	30.9
CHN's import from	0.4	0.9	0.5	16.3	8.3	0.9	5.9	3.1	53.1	32.1
	Bilateral CO_2 trade (SRIO base), Unit: Million t-CO_2									
	2005					2015				
	VNM	IDN	IND	JPN	KOR	VNM	IDN	IND	JPN	KOR
CHN's export to	1.7	4.6	7.2	105.2	18.3	4.7	9.1	14.6	105.6	33.7
CHN's import from	0.5	0.2	0.8	4.7	3.5	1.4	0.3	4.3	12.0	13.0
	Bilateral CO_2 trade (MRIO base), Unit: Million t-CO2									
	2005					2015				
	VNM	IDN	IND	JPN	KOR	VNM	IDN	IND	JPN	KOR
CHN's export to	1.9	5.1	8.2	116.3	20.5	5.1	9.8	15.9	113.5	36.4
CHN's import from	0.6	1.1	0.9	8.1	6.8	1.6	3.4	4.7	20.4	21.6

Source: Authors' calculations are based on the EORA database

3.2. Bilateral CO_2 Trade During 2005–2015

Table 2 shows the trade balance and corresponding embodied emissions between China and the selected Asian countries. The results are listed using both the SRIO and MRIO approaches.

According to the IO table, China was the net exporter of final demands to Vietnam, India, Indonesia, and Japan in both selected years and the net importer of final demands from South Korea. Following a similar pattern, the emissions that China transferred to Vietnam, India, Indonesia, and Japan through the export of final demands also overweighed those that arrived through imported goods. However, in the case of South Korea, China was not only a net importer of final goods and services but also a net exporter of emissions. Similarly, the gaps between the bilateral emission export and import between China and Japan (105.6 vs. 12.0 million t-CO_2 by the SRIO approach or 113.5 vs. 20.4 million t-CO_2 by the MRIO approach) were far larger than the gaps between the bilateral export and import (US$99.0 billion vs. US$53.1 billion). China has been exporting more "dirty goods" (pollution-intensive goods) to Japan and Korea.

Comparing the results in 2005 and 2015, the emissions that China transferred to Vietnam, India, Indonesia, and South Korea largely increased (by 176.5%, 97.8%, 102.8%, and 84.2%, respectively, using the SRIO approach). The bilateral emissions exported from China to Japan over those 10 years remained nearly the same. On the other hand, the emissions that China imported from Vietnam, India, Japan, and South Korea largely increased (by 180.0%, 437.5%, 155.3%, and 271.4%, respectively, using the SRIO approach). The increase in bilateral emissions imported from Indonesia to China during those 10 years was slight.

When the results of the SRIO and MRIO approaches are compared, the bilateral emission trade results calculated by the MRIO approach are larger than the results calculated by the SRIO approach. All indirect emissions, namely, the emissions generated in the domestic production activities in all sectors, are considered. Moreover, under the SRIO approach, the emissions that China transferred to Japan slightly increased from 105.2 to 105.6 million t-CO_2; however, under the MRIO approach, such an increase turned into a slight decrease from 116.3 to 113.5 million t-CO_2. The SRIO approach, without considering intermediate imports and indirect domestic emissions, underestimated such growth. This can only be revealed by conducting the MRIO approach.

The difference in total net bilateral CO_2 trade results based on the single-region and multi-region approaches is shown in Figure 4.

Under both approaches, China was net exporting CO2 induced by final demand exports to all selected countries in both 2005 and 2015, especially to Japan. Japan has been causing the rise in emissions in China. However, the number has decreased from 2005 to 2015 (−6.9 million t-CO2 by the SRIO approach and −7.4 million t-CO2 by the MRIO approach). The rise in emissions in China caused by Japan has slowed. On the other hand, according to the results of this study, China has not been causing the emission rises in Vietnam, India, or Indonesia.

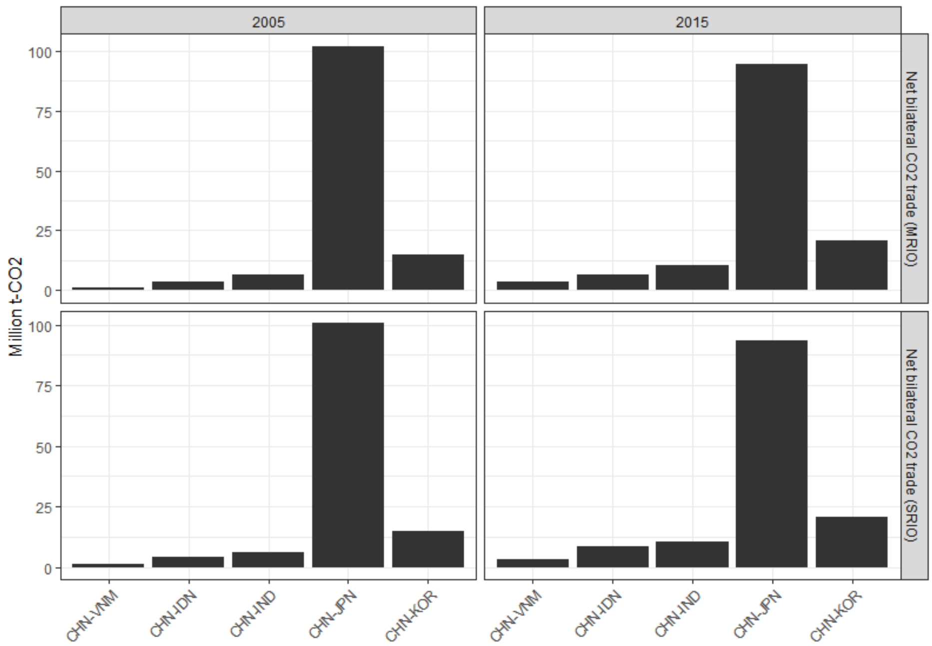

Figure 4 Total net bilateral emissions trade of China with selected Asian countries using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

Table 3 Emissions embodied per unit of bilateral trade.

	Emissions embodied per unit of bilateral trade Unit: Million t-CO2/US$ Billion									
	2005					2015				
	VNM	IDN	IND	JPN	KOR	VNM	IDN	IND	JPN	KOR
CHN's export to	1.8	2.0	2.4	2.2	2.2	0.9	1.0	1.1	1.1	1.1
CHN's import from	1.3	1.0	1.6	0.3	0.4	1.4	0.5	1.4	0.2	0.4

Source: Authors' calculations based on the EORA database.

Emissions embodied per unit of export from China decreased from 2005 to 2015 with all the selected countries, as shown in Table 3. This indicates that more low-emission technologies have been adopted in the production activities in China over 10 years. In 2005, in all selected bilateral trade partners, the emissions embodied per unit of exports from China were larger than the emissions embodied per unit of imports from Vietnam (1.8 vs. 1.3 million t-CO_2/US$ billion) and India (2.4 vs. 1.6 million t-CO_2/US$ billion). However, in 2015, the balance has reversed. The emissions embodied per unit of exports from China became smaller than the emissions embodied per unit of imports from Vietnam (0.9 vs. 1.4 million t-CO_2/US$ billion) and India (1.1 vs. 1.4 million t-CO_2/US$ billion). The structure of bilateral export from China to these countries has been switched to a smaller weight of pollution-intensive goods and services. If the China–Vietnam or China–India trade balance keeps growing according to this trend, China will cause emissions to rise in these countries. Moreover, on the import side, in all selected bilateral trade partners, the emissions embodied per unit of China's imports increased in the case of Vietnam. Vietnam was exporting more pollution-intensive goods and services to China from 2005 to 2015.

3.3. Bilateral CO_2 Trade at the Sector Level

The changes from 2005 to 2015 in bilateral CO_2 emissions based on the single-region and multi-region approaches are decomposed into sectors in this section. Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9 show the changes in the net trade balance of total emissions in the China–Vietnam, China–Indonesia, China–India, China–Japan, and China–Korea trade, respectively. There are three representative cases that show the diversity in the change patterns of net CO_2-embodied emissions. Because the net CO_2 emissions transferred from China to other countries were all positive, it can be interpreted that bilateral trade partners have caused the increase of CO_2 emissions in China. However, the trends—namely, the changes in net bilateral emissions from 2005 to 2015—follow different patterns.

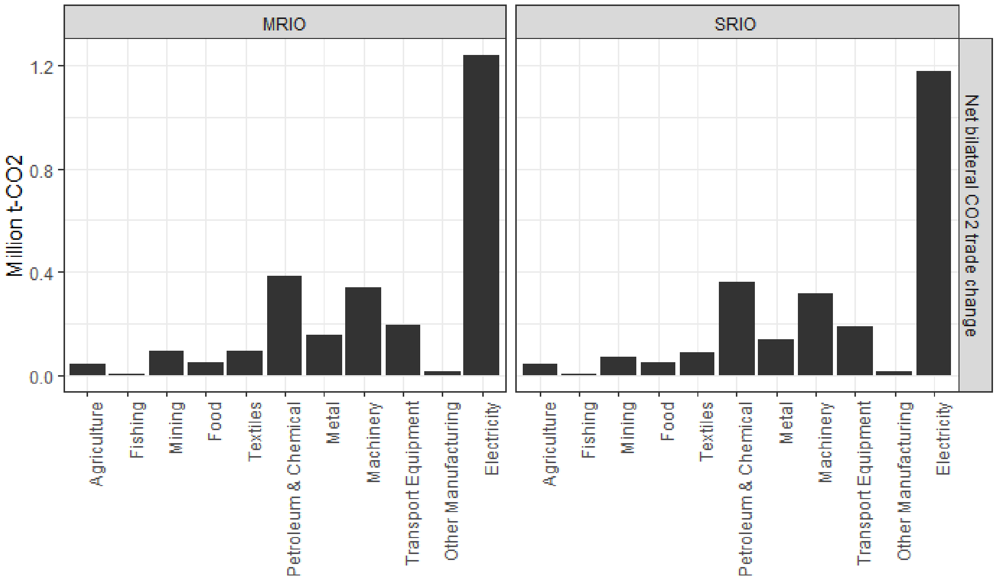

Figure 5 Changes from 2005 to 2015 in China's net bilateral CO_2 export with Vietnam at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

Under both approaches, Figure 5 shows that China's net bilateral CO_2 export with Vietnam has largely grown from 2005 to 2015, especially in electricity supply, petrochemical products, and machinery sectors. The SRIO approach cannot cover the indirect emissions embodied in the domestic production activities induced by international trade, and therefore, such growth was underestimated compared with that under the MRIO approach.

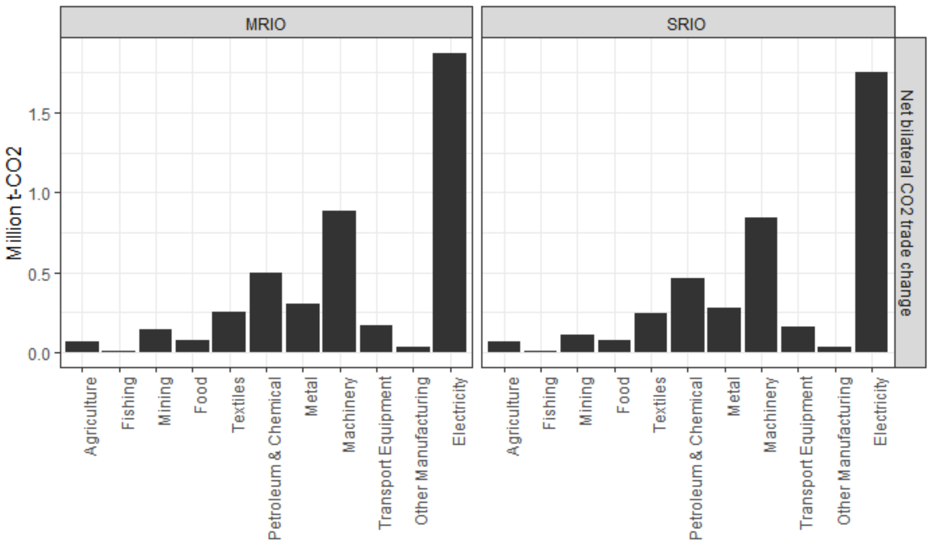

Figure 6 Changes from 2005 to 2015 in China's net bilateral CO_2 export with Indonesia at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

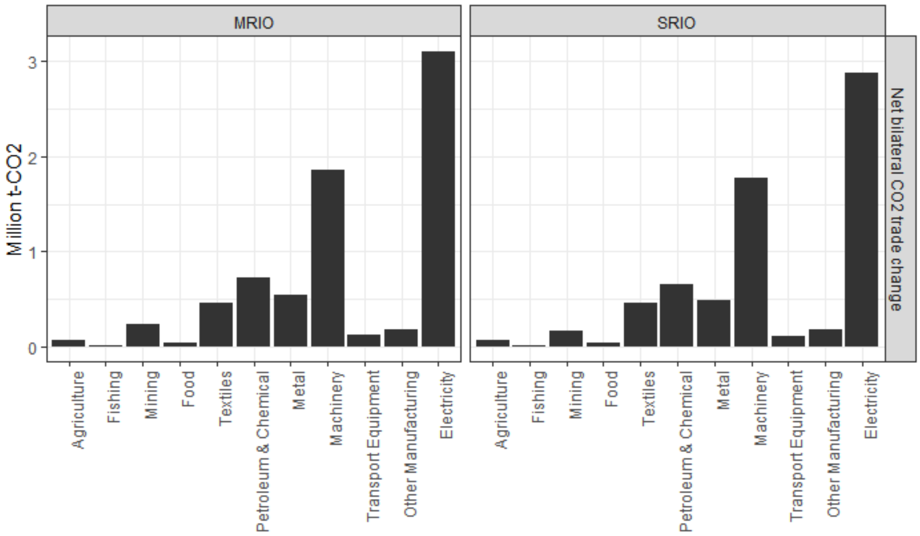

Figure 7 Changes from 2005 to 2015 in China's net bilateral CO_2 export with India at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

In Figure 6 (China–Indonesia) and Figure 7 (China–India), similar to the China–Vietnam case, China's net bilateral CO2 export has largely grown from 2005 to 2015. The top three sectors were the electricity supply sector, the machinery sector, and petrochemical products sector under both approaches.

In contrast to the cases for Vietnam, Indonesia, and India, China's net bilateral CO_2 export with Japan shrank in most sectors from 2005 to 2015 (Figure 8), especially in the electricity supply, petrochemical products, and transportation equipment sectors. The net bilateral CO_2 trade increased in the textiles and other manufacturing sectors.

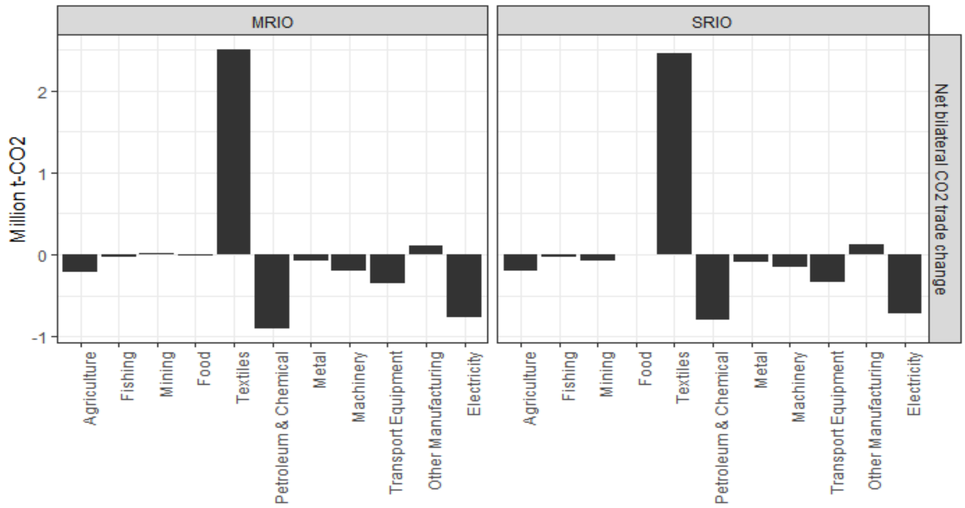

Figure 8 Changes from 2005 to 2015 in China's net bilateral CO_2 export with Japan at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

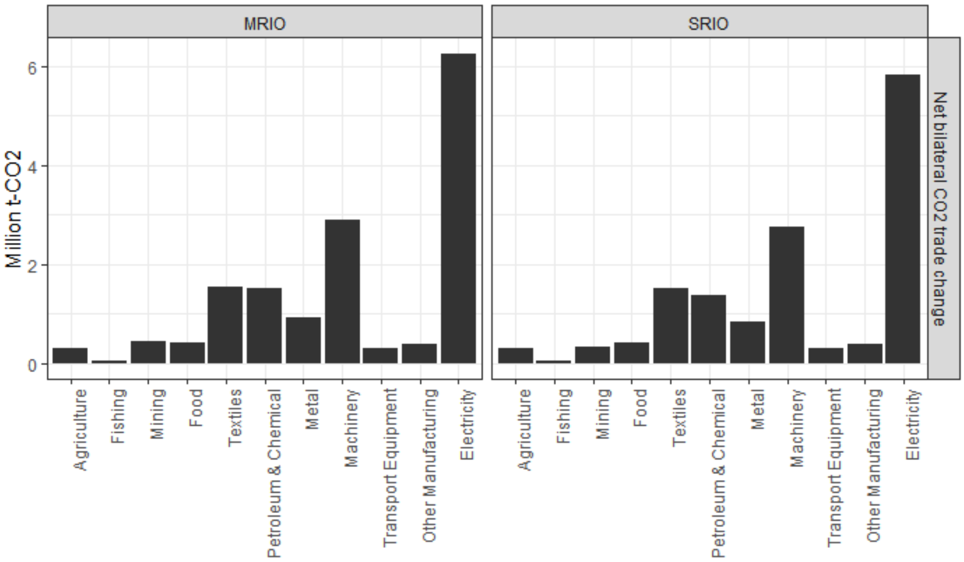

Figure 9 Changes from 2005 to 2015 in China's net bilateral CO_2 export with Korea at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

Source: Authors' calculations are based on the EORA database.

Similar to the case of Japan, Figure 9 shows that China was a net exporter of emissions to Korea despite the net import of final goods and services. Moreover, the net export of emissions in 2015 increased compared to those in 2005 despite the increasing net import of final goods and services at the same time. The electricity supply sector contributed 5.83 million t-CO_2 to the growth in the SRIO approach and 6.26 million t-CO_2 in the MRIO approach.

4. Discussion

In the bilateral CO_2 trade, China has been net exporting CO_2 through final demand exports. Emissions embodied per unit of export from China decreased from 2005 to 2015 with all selected countries, indicating an improvement at the low-emission technology level in domestic production in China. However, the emissions embodied per unit of China's imports increased in the case of Vietnam. This implies that emission-intensive goods and services exported from Vietnam to China have increased during 2005-2015.

Such an increase can be related to changes in both the amount of bilateral trade (scale factor) and emission intensity (intensity factor). First, the exports of intermediate and final goods have significantly increased in many sectors, while the structure of bilateral export, especially the top 5 sectors were relatively stable from 2005 to 2015 (Table 4). Especially, mining, the largest export sector, increased from 1.71 to 3.82 US$ billion. Second, the change in the emission intensity varies by sector. While the agriculture and the food sector actually became less emission-intensive 2005-2015, the textile sector largely increased from 1.38 to 1.75 Million t-CO_2/US$ billion. This can be related to the large increase in the intermediate input of electricity in the textile sector (third largest sector in 2015 with an input coefficient of 0.0326, shown in Table 4). The electricity supply sector was exactly the most emission-intensive sector in Vietnam, and the most emission-intensive sector in all countries discussed in this study. The energy mix in power generation in Vietnam from 2005 to 2015 has changed from hydropower to natural gas and then to coal. The ratio of coal power in installed capacity rose from 20% to around 35% in the 2005–2015 period. Driven by both bilateral trade amount (scale factor) and emission intensity (intensity factor), emission-intensive goods and services exported from Vietnam to China increased during 2005-2015.

Table 4 2005-2015 changes in Vietnam: input coefficients from the electricity supply sector and exports from Vietnam to China

2005		2015	
Direct emission intensity of the electricity supply sector in Vietnam (Million t-CO2/US$ Billion)			
32.12		34.54	
Input coefficients from the electricity supply sector (top 5 of all sectors) in Vietnam			
Top 5 sectors	Value	Top 5 sectors	Value
Mining	0.0457	Petroleum & Chemical	0.0367
Metal	0.0398	Wood and Paper	0.0360
Wood and Paper	0.0276	Textiles	0.0326
Other Manufacturing	0.0249	Metal	0.0315
Petroleum & Chemical	0.0246	Other Manufacturing	0.0258
Export as intermediate and final goods from Vietnam to China (top 5 of all sectors, unit: US$ Billion)			
Top 5 sectors	Value	Top 5 sectors	Value
Mining	1.71	Mining	3.82
Agriculture	0.40	Agriculture	0.77
Machinery	0.21	Food	0.35
Textiles	0.18	Textiles	0.32
Petroleum & Chemical	0.10	Machinery	0.30

Source: Authors' calculations based on the EORA database.
Notes: Note: The input coefficient from the electricity supply sector refers to the monetary unit of electricity intermediate input to produce one unit of final product in each sector.

China's net CO_2 export largely increased in its trade with Vietnam and Indonesia in 2015 (especially in the electricity supply, petrochemical products, and machinery sectors) compared with 2005. On the other hand, it shrank in the trade with Japan (especially in petrochemical products and transportation equipment). Considering China's growing net export of final goods and services during 2005–2015 in these three countries, the shrink of net CO_2 export to Japan can be more related to the decrease in domestic emission intensity in China (intensity factor) than changes in export scale (scale factor). As shown in Table 5, the direct emission intensity of the electricity supply sector in China has dropped from 17.01 to 6.28 Million t-CO2/US$ Billion. In fact, during 2005–2015, the standard coal consumption for power supply in large thermal power plants (above 6000 kW capacity) in China decreased from 370g/kWh to 313g/kWh (China Electricity Council, 2017). Benefiting from the green power generation mix, the emission intensity of the petroleum & chemical sector in China also largely decreased, leading to a shrink of its net CO_2 export to Japan. It is also worth noting that, the share of mining goods exports from China to Japan has dropped in 2015 compared to 2005 (11.2% to 5.8%) as shown in Table 5, indicating the contribution of changes in trade structure to the reduction in China's CO_2 exports.

Table 5 2005-2015 changes in China: input coefficients from the electricity supply sector and exports from China to Japan

2005		2015	
Direct emission intensity of the electricity supply sector in China (Million t-CO2/US$ Billion)			
17.01		6.28	
Input coefficients from the electricity supply sector (top 5 of all sectors) in China			
Top 5 sectors	Value	Top 5 sectors	Value
Mining	0.0669	Mining	0.0367
Metal	0.0588	Petroleum & Chemical	0.0360
Petroleum & Chemical	0.0566	Metal	0.0326
Post & Tele	0.0357	Wood and Paper	0.0315
Wood and Paper	0.0329	Education & Health	0.0258
Export as intermediate and final goods from China to Japan (top 5 of all sectors, unit: US$ Billion)			
Top 5 sectors	Value	Top 5 sectors	Value
Textiles	24.77	Textiles	46.83
Machinery	17.86	Machinery	39.86
Mining	11.79	Petroleum & Chemical	22.17
Petroleum & Chemical	9.75	Food	16.36
Food	8.98	Transport	12.41

Source: Authors' calculations based on the EORA database.
Notes: Note: The input coefficient from the electricity supply sector refers to the monetary unit of electricity intermediate input to produce one unit of final product in each sector.

These results provide two implications. First, the result of domestic sector-level emission intensity can reveal for industry policymakers which sectors generate higher emissions and pollutants, so that mitigation actions should be taken in these sectors. Second, an increasingly low-carbon power generation mix not only contributes to the national-level emission reduction directly but also helps other sectors reduce emissions from a greener power generation mix (e.g., the petrochemical industry in China, the textile industry in Vietnam in a reverse way). Instead of domestic production, importing more emission-intensive goods from other countries does not help global emission reduction. Third, the change in export structure from China to Japan can reduce global emissions as long as it does not cause carbon relocation of non-power sectors from China to other countries.

Our analysis also shows that the results of the carbon leakage examination can vary due to the applied approaches to some extent. The differences can be caused by the different examination approaches used, the different definition of non-domestic emissions (e.g., emissions induced by the export of final goods and services in this paper, emissions induced by value-added, Meng et al., 2018), and different effort-sharing principles (van den Berg et al., 2019; Höhne et al., 2014). In our analysis, larger carbon leakages show in MRIO than SRIO examination results. In the Copenhagen Era, seven methodologies (i.e., the IPCC, G8, UNDP, OECD, Garnaut, CCCPST, Srensen approach; Ding et al., 2010) have been proposed to establish an international standard, but no consensus has been achieved so far.

This study also has some limitations regarding the raw data of the IO tables and emission data. Although the tables from 2005 and 2015 were used in this study, they were all compiled using those years' purchase prices. The accuracy of the results could be improved if a table using comparable prices was used. In terms of the raw data on emissions, the results of emissions embodied in trade can be distinguished by sector but cannot be distinguished by energy carrier sources (e.g., by coal and oil) when the current data source is used. In other words, the current results of emissions from the mining sector refer to the emissions generated when coal is produced. It does not represent the emissions caused by the use or consumption of coal. Thus, the results of this study are limited in their ability to explore the impacts of coal industry investments.

5. Conclusions

In this study, we examined whether China has been causing the rise of CO_2 emissions among its bilateral trade partners (carbon leakage through trade from China to its bilateral trade partners). We selected five Asian countries (Vietnam, Indonesia, India, Japan, and South Korea) and conducted an examination using two approaches (SRIO and MRIO analyses) in two target years (2005 and 2015).

Among all five selected bilateral trade partners, the results show that from 2005 to 2015, the carbon leakage from Japan to China decreased. On the other hand, China caused the domestic CO_2 emission levels to rise in Vietnam, Indonesia, and India in 2005 and, even more, in 2015.

Our estimation shows that China's emissions embodied per unit of bilateral trade (namely, how much CO2 emissions are generated per unit of bilateral goods and service trade) has been decreasing from 2005 to 2015. This indicates that more low-emission technologies have been adopted in domestic production activities in China over those 10 years. We further looked into input coefficients from the electricity supply sector in all sectors. The improvement in power generation technologies not only contributes to the national-level emission reduction directly but also helps other sectors reduce emissions by a greener power generation mix (e.g., the petrochemical industry in China, the textile industry in Vietnam in a reverse way).

Our examination also shows that the SRIO approach cannot cover the indirect emissions embodied in the domestic production activities induced by international trade. Thus, such growth is underestimated compared with that under the MRIO approach.

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Table Appendeix Sectors

No.	Sector	Sector abbreviation
1	Agriculture	Agriculture
2	Fishing	Fishing
3	Mining and Quarrying	Mining
4	Food & Beverages	Food
5	Textiles and Wearing Apparel	Textiles
6	Wood and Paper	Wood and Paper
7	Petroleum & Chemical	Petroleum & Chemical
8	Metal Products	Metal
9	Electrical and Machinery	Machinery
10	Transport Equipment	Transport Equipment
11	Other Manufacturing	Other Manufacturing
12	Recycling	Recycling
13	Electricity, Gas and Water	Electricity
14	Construction	Construction
15	Maintenance and Repair	Maintenance
16	Wholesale Trade	Wholesale Trade
17	Retail Trade	Retail Trade
18	Hotels and Restaurants	Hotels & Restaurants
19	Transport	Transport
20	Post and Telecommunications	Post & Tele
21	Financing	Financing
22	Public Administration	Public Administration
23	Education, Health and Other Services	Education & Health
24	Private Households	Private Households
25	Others	Others
26	Re-export & Re-import	Re-export & Re-import

Source: EORA database.