Generating or Receiving Carbon Leakages?

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Generating or Receiving Carbon Leakages? An Examination of China's CO_2 Emissions in Asia

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Abstract

Along with increased international trade, the production of goods and services has become multinational, which indicates the possibility of environmental pollution being exported overseas as well. China is the world's factory and the largest CO_2 emitter in the world. This study examines whether China has been transferring CO_2 emissions to Asian countries through bilateral trade or receiving CO_2 emissions overseas into its own country. Further, it investigates whether such a pattern has changed from 2005 to 2015. The examination was based on China's bilateral trade with Vietnam, Indonesia, India, Japan, and South Korea in 2005, 2010, and 2015. The results show that (i) Japan and South Korea avoided domestic CO_2 emissions by importing goods and services from China from 2005 to 2015; (ii) net bilateral emission exports from China to Vietnam and India shrank from 2005 to 2015. The mining and electricity sectors have contributed. This shows that China has caused the rise of emissions in these two countries; and (iii) net bilateral emissions exports from China to Indonesia shrank and reversed from 2005 to 2015, and China became a net importer of emissions from Indonesia. However, this shrinkage can only be observed using the multi-region input–output approach rather than the single-region input–output approach.

Keyword

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

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1. Introduction

After the opening up and economic reforms in 1978, China's development was remarkable with a 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 the increase in international trade, the production of goods and services has become multinational, which indicates the possibility of environmental pollution also being exported overseas.

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

Conventionally, PHH and carbon leakage were terms related to environmental regulation and production activities. When the environment regulation is relatively strict in developed countries, entrepreneurs are forced to save energy and introduce energy-saving technology. This will raise the cost of the product produced in developed countries. As a result, multinational companies try to reduce cost 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 regarding pollution in a country. The research found that enterprises in highly regulated systems such as the United States or Canada had a direct competition with those operating in poorer countries with weak environmental standards like Mexico. Therefore, in the globalization and liberalization era, developing countries could become pollution havens for the pollution-intensive industries of advanced countries. Therefore, carbon leakage occurs because of the trade between developing countries and developed countries.

In other researches, Dietzenbacher and Mukhopadhyay (2007) examined the PHH for India. In this study, the researchers estimated the CO_2 and SO_2 emissions released into the environment when they assumed that exports and imports will increase in the same amount of one billion rupees. The authors expected that India would export pollution-intensive goods because it is considered to have relatively lenient emission permits. However, the findings for India revealed opposite results. The amount of CO_2 and SO_2 emissions generated although the extra exports were smaller than the decrease in pollution from additional imports. As a consequence, Indian exports relatively clean goods and gains from extra trade. This means that India was not a polluter in the 1990s.

Jayanthakumaran and Liu (2016) employed the sectoral input–output model to calculate the CO_2 emissions embodied in bilateral 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 Australia 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 more trade with composition may help reduce global emissions.

Carbon relocation is another environmental term. It occurs through foreign direct investment (FDI). Research from Shahbaz et al. (2015) showed the change in emissions through FDI. This paper determines the effects of FDI on the environment of low-, middle-, and high-income countries. The author used panel data from 1975 to 2012 and employed panel cointegration techniques. The results indicated that when economic growth gains 1%, there is a 0.07% and 0.65% increase in energy use and environmental pollution, respectively. In turn, FDI decreased the CO_2 emissions in high-income countries in every period, but this has not happened in low-income countries. In the case of 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.

This study focuses on the emissions induced by international trades. It aims to examine 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 patterns changed from 2005 to 2015. The examination was conducted on the basis of China's bilateral trade with Vietnam, Indonesia, India, Japan, and South Korea in 2005, 2010, and 2015. This study contributes to a better understanding of the historical pattern of emissions and international trade.

2. Methodology

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

The structure of a single-region input–output (SRIO) table is shown in Figure 1.

	Intermediate demand	Final demand	Total output
Intermediate demand	$\mathbf{A}_{\mathrm{r}}\widehat{\mathbf{x}_{\mathbf{r}}}$	$\mathbf{y}_{\mathrm{r}}$	$\mathbf{x}_{\mathbf{r}}$
Value added	$\mathbf{V}_{\mathrm{r}}$		
Total input	$\mathbf{x}'_{\mathbf{r}}$		

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

Source: Authors.

The vector $\mathbf{x}_{\mathbf{r}}$ represents the total input (output) for all sectors in region r. The matrix $\mathbf{A}_{\mathrm{r}}\widehat{\mathbf{x}_{\mathbf{r}}}$ displays the flow between domestic sources (row) and domestic destinations (column) by sectors in region r and the import intermediate demand. The matrix $\mathbf{y}_{\mathrm{r}}$ represents the final demand for goods and services in region r. The matrix $\mathbf{V}_{\mathrm{r}}$ represents the value added in region r.

2.2. Structure of the Multi-Region Input–Output Table

The structure of a multi-region input–output (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., $\mathbf{x}_{\mathrm{k}}$ represents the total input (output) for all sectors in region k.

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

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

Source: Authors.

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

2.3. Examination 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 the i^{th} sector. x_i represents the total output of the i^{th} sector. c_{ir} is one of the elements of the direct emission coefficient vector $\mathbf{c}_\mathrm{r}$ for all n sectors in the r^{th} region; it 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 of all n sectors in the r^{th} region, $\mathbf{x}_\mathrm{r}$, meets the production balance in Equation 2,

$$\mathbf{x}_\mathrm{r} = [\mathbf{I} - \mathbf{A_r}]^{-\mathbf{1}}\mathbf{y}_\mathrm{r}, \tag{2}$$

where $\mathbf{A_r}$ represents the $n \times n$ intermediate input coefficient matrix of the r^{th} region and $\mathbf{y}_r$ represents the final demand of the r^{th} region. 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 fewer disposals of valuables.

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

$$\mathbf{ce}_\mathrm{rs} = \hat{\mathbf{c}}_\mathrm{r}[\mathbf{I} - \mathbf{A}_\mathrm{r}]^{-\mathbf{1}}\mathbf{e}_\mathrm{rs}, (r = 1, \cdots, k; \; s = 1, \cdots, k), \tag{3}$$

where the direct emission coefficient vector in the rth region $\mathbf{c}_\mathrm{r}$ is diagonalized, $\mathbf{e}_\mathrm{rs}$ represents the goods and services exported from region r to region s, and both intermediate exports and final exports are included.

Total CO_2 emissions induced by the imported goods of region r from region s can be calculated as Equation 4, which is similar to that of Dietzenbacher and Mukhopadhyay (2007):

$$\mathbf{cm}_\mathrm{rs} = \hat{\mathbf{c}}_\mathrm{r}[\mathbf{I} - \mathbf{A}_\mathrm{r}]^{-\mathbf{1}}\mathbf{e}_\mathrm{sr}, (r = 1, \cdots, k; \; s = 1, \cdots, k), \tag{4}$$

where $\mathbf{e}_\mathrm{sr}$ represents the goods and services exported from region s to region r. However, in this equation, the direct emission coefficient vector in the r^{th} region $\mathbf{c}_\mathrm{r}$ is utilized, which means Dietzenbacher and Mukhopadhyay assumed that imported goods from the rest of the world have the same technology with that of region r. Thus, the result indicates the total CO_2 avoided in region r through its imports. This can be improved with Equation 5.

In Equation 5, total CO_2 emissions induced by importing from region s to region r can also be calculated by

$$\mathbf{cm}^*_\mathrm{rs} = \hat{\mathbf{c}}_\mathrm{s}[\mathbf{I} - \mathbf{A}_\mathrm{s}]^{-\mathbf{1}}\mathbf{e}_\mathrm{sr}, (r = 1, \cdots, k; \; s = 1, \cdots, k), \tag{5}$$

where the direct emission coefficient vector in the s^{th} region $\mathbf{c}_\mathrm{s}$ is utilized.

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

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

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

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

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

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 input-output table, it is not possible to obtain the direct emission coefficient vector $\mathbf{c}_{\mathrm{s}}$ and matrix $\mathbf{A}_{\mathrm{s}}$; therefore, the second examination can be improved with a multi-region approach, as shown in Section 2.4.

2.4. Examination Through a Multi-Region Approach

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

$$\begin{bmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_{\mathrm{k}} \end{bmatrix} = \left[\mathbf{I} - \begin{bmatrix} \mathbf{A}_{11} & \cdots & \mathbf{A}_{1\mathrm{k}} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{\mathrm{k}1} & \cdots & \mathbf{A}_{\mathrm{kk}} \end{bmatrix} \right]^{-1} \begin{bmatrix} \mathbf{y}_{11} + \cdots + \mathbf{y}_{1\mathrm{k}} \\ \vdots \\ \mathbf{y}_{\mathrm{k}1} + \cdots + \mathbf{y}_{\mathrm{kk}} \end{bmatrix} \tag{8}$$

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 all n sectors in all k regions, $\mathbf{ct}$, can be formulated as

$$\mathbf{ct} = \hat{\mathbf{c}} \left[\mathbf{I} - \begin{bmatrix} \mathbf{A_{11}} & \cdots & \mathbf{A_{1k}} \\ \vdots & \ddots & \vdots \\ \mathbf{A_{k1}} & \cdots & \mathbf{A_{kk}} \end{bmatrix} \right]^{-1} \begin{bmatrix} \widehat{\mathbf{y_{11}}} & \cdots & \widehat{\mathbf{y_{21}}} \\ \vdots & \ddots & \vdots \\ \widehat{\mathbf{y_{k1}}} & \cdots & \widehat{\mathbf{y_{kk}}} \end{bmatrix}, \tag{9}$$

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

The total CO_2 emission in trade between regions r and s, $\mathbf{ct}$, can be considered as

$$\mathbf{ct} = \begin{bmatrix} \mathbf{ct_{rr}} & \mathbf{ct_{rs}} \\ \mathbf{ct_{sr}} & \mathbf{ct_{ss}} \end{bmatrix} \tag{10}$$

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

$$tb_{rs} = \boldsymbol{\iota}[\mathbf{ct_{rs}} - \mathbf{ct_{sr}}]\boldsymbol{\iota}' < 0\ (r = 1, \cdots, k;\ s = 1, \cdots, k), \tag{11}$$

region r caused the rise of emissions in region s.

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

2.5. Data Sources

This paper employs the Input Output Tables from the Eora Global Supply Chain Database (EORA database) for the years 2005, 2010, and 2015 with the basic price. The EORA database is the global supply chain database that provides the time series input/output tables of 190 countries with environmental satellite accounts. This database currently has three formats, which are the individual country input/output tables, EORA26, and full EORA. In the context of this paper, EORA26 will be employed because all industries were aggregated into 26 sectors. Because of the different number 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 as it has already deducted the tax payable and included the subsidy for one unit of output of goods and services. This keeps the transaction value between producers and consumers as homogenous as possible.

In terms of sector-level emissions, the paper also includes the CO_2 emissions from EORA26 for the years 2005, 2010, and 2015.

There are three data providers, which are Emission Database for Global Atmospheric Research (EDGAR), Carbon Dioxide Information Analysis Center (CDIAC), and the PRIMAPHIST model, used to create the CO_2 and greenhouse gas satellite account rows in the EORA database. However, this paper used the PRIMAP to obtain the total CO_2 generated by sectors in all countries because it included EDGAR and CDIAC data.

3. Results and Discussion

3.1. National CO_2 Emissions during 2005–2015

Figure 3 represents 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 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. In Vietnam and India, national CO_2 emissions are relatively insignificant compared with those of China; however, they increased significantly from 2005 to 2015. Vietnam's CO_2 doubled from 99 million tons of CO_2 in 2005 to 203 million tons of CO_2 in 2015. Similarly, India's emissions increased from 1.200 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, with a 4% drop over 10 years.

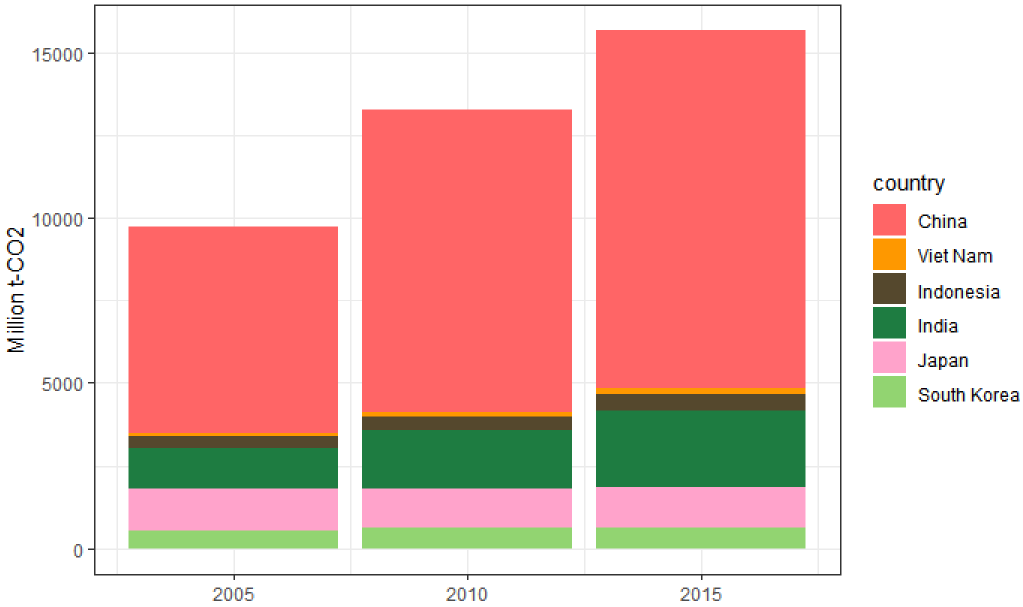

Figure 3. Total national CO_2 emissions, 2005–2015.

Source: EORA database.

The direct emission coefficients of the main sectors are shown in Figure 4. The results were divided into 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 USD. However, while China and India decreased their emission coefficients by year and by sector, Vietnam tended to enhance its emission coefficients from 2005 to 2015, especially in the mining sector.

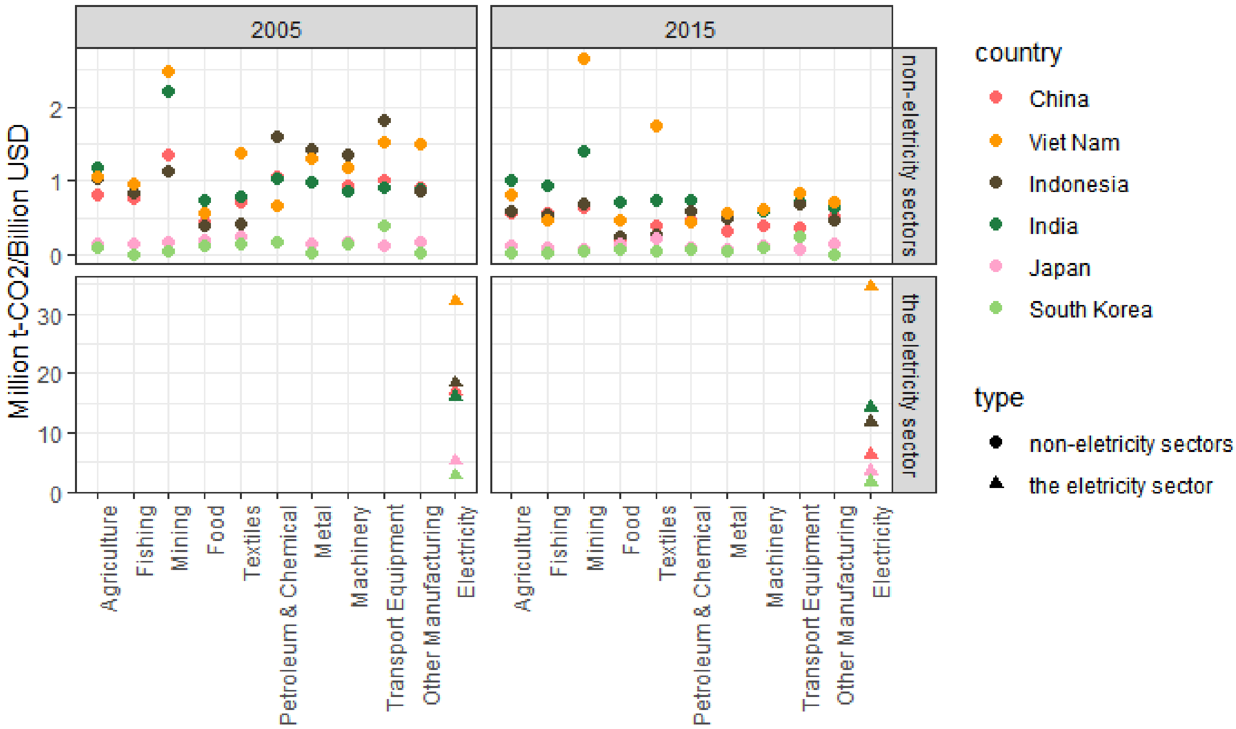

Figure 4. Direct emission coefficients of main industrial sectors in selected Asian countries.

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

The emission coefficient expresses the volume of emissions per unit of GDP in USD. The reduction of this coefficient can be interpreted as less pollution released per unit of GDP. Those countries with a small emission coefficient may have better technology or more efficient energy consumption than those with a high coefficient.

3.2. Bilateral CO_2 Trade during 2005–2015

Figures 5 and 6 show the trade balance and corresponding embodied emission between China and the selected Asian countries. The results are listed using both SRIO and MRIO approaches. With a same trade balance in Figures 5 and 6, the corresponding embodied emission results are different on the basis of the two methods.

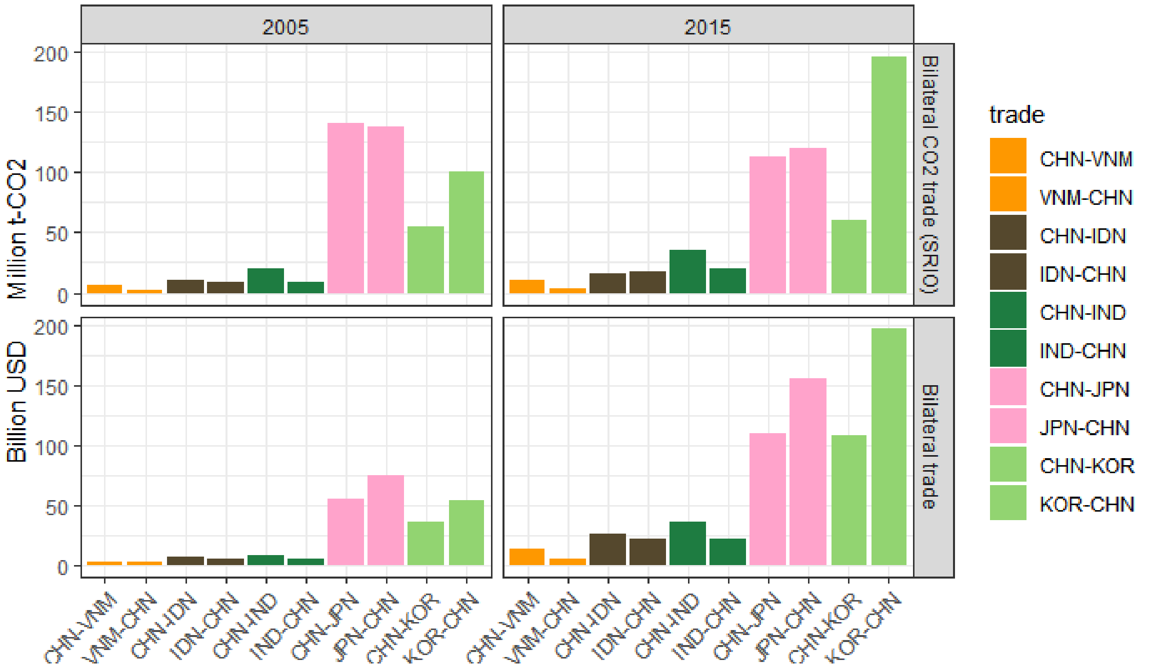

Figure 5. China's bilateral trade with selected Asian countries and the corresponding embodied emissions using the single-region input–output (SRIO) approach.

Source: Authors' calculations are based on the EORA database

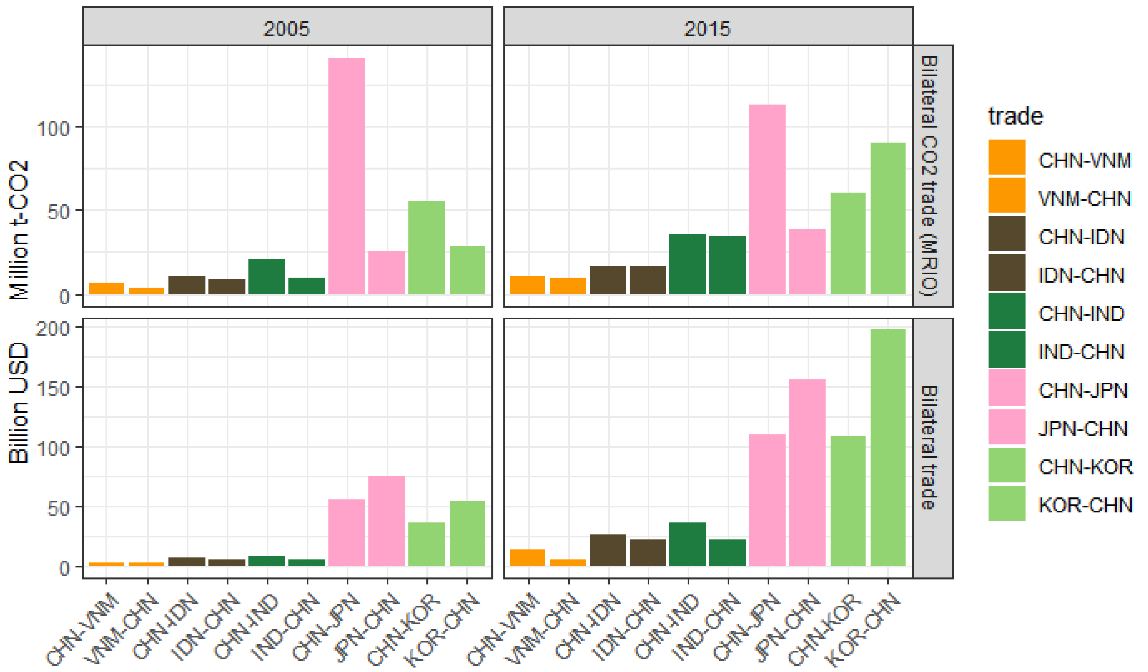

Figure 6. China's bilateral trade with selected Asian countries and the corresponding embodied emissions using the multi-region input–output (MRIO) approach.

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

In 2005, China was a net exporter to Vietnam, India, and Indonesia, and a net importer from Japan and South Korea. The emissions that China transferred to other countries through export were also more significant than those that arrived through imported goods. Only the case of Japan was the opposite when China was a net importer of final goods and services but a net exporter of emissions, as China has been exporting more “dirty goods” (pollution-intensive goods) to Japan. Moreover, in 2005, China was causing emissions to rise in South Korea through trade. In 2015, the role of China in the trade balance is still the same. However, China began to increase embodied emissions in Indonesia through trade. In contrast, Japan had transferred more CO_2 emissions to China through exports.

Figure 6 displays results similar to Figure 5. In general, China exports more environmentally unfriendly goods to Vietnam, India, and Indonesia. The difference is that the magnitude of embodied emissions generated by goods exported from Vietnam, India, and Indonesia is more extensive than that calculated using the SRIO approach. In the SRIO approach, the emission coefficient was based on China's coefficient. On the other hand, the MRIO approach employed the emission coefficients of importing countries. Therefore, it can be interpreted that China's technology may be better than the technologies of importing countries.

In contrast, according to the MRIO approach, the embodied emissions in the case of Japan are smaller than those based on the SRIO approach. This means that Japan is using energy more efficiently than China. In 2015, China had started to raise the embodied emissions in South Korea through trade when MRIO was employed. As a result, the emissions from Indonesia were also rising in 2015.

The difference in total net bilateral CO_2 trade results based on single-region and multi-region approaches is shown in Figure 7. Employing the SRIO approach, carbon leakage may have happened in South Korea from 2005 to 2015 because the CO_2 trade balance has a negative value. Japan and Indonesia also tended to enhance their CO_2 emissions in 2015. When MRIO was used, South Korea and Indonesia had begun to export more dirty goods to China in 2015. Carbon leakage may have happened in that case.

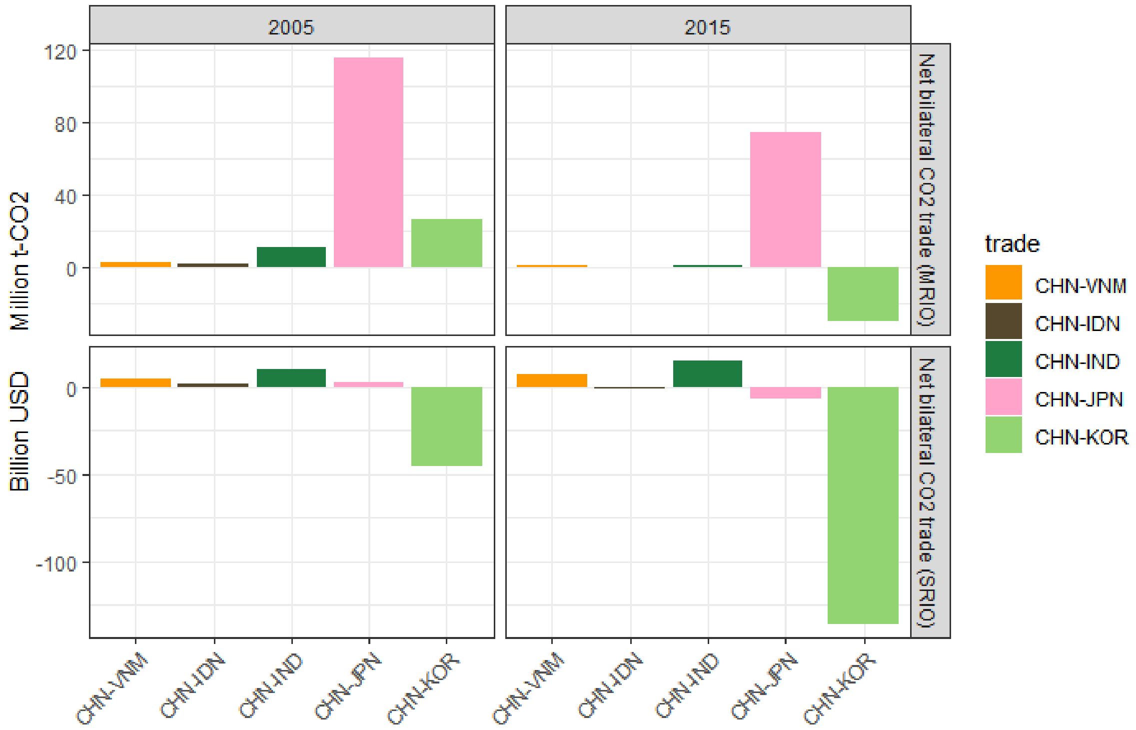

Figure 7. Total net bilateral emissions trade of China with selected Asian countries using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches.

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

According to both approaches, the net bilateral emission exports from China to Indonesia shrank and reversed from 2005 to 2015, indicating that China has caused an increase in emissions in Indonesia and has become a net importer of embodied emissions. The net bilateral emission export from China to Vietnam and India also shrank from 2005 to 2015; however, this can be only observed using the MRIO approach rather than the SRIO approach.

Figure 8 shows the emissions embodied per unit of bilateral trade, namely, how much CO_2 emissions are generated per one unit of export scale. There may be a difference between the technologies that exporting and importing countries use. In the bilateral CO_2 trade, the embodied emissions per unit of China's bilateral exports are higher than those for all receiving countries in 2005. However, the situation reversed in China–Vietnam, China–Indonesia, and China–India in 2015. China turned to importing more emission-intensive goods and services from these three countries. For instance, in 2005, in the case of bilateral trade between China and Japan, if China's export scale was enlarged by 1 billion USD, the embodied emissions generated by China's goods will be 325.3 million t-CO_2. Conversely, there were only 29 million t-CO_2 released into the environment when Japan's export increased by 1 billion USD. These results can reveal dissimilar technologies between Japan and China. In general, China seemed to use more inefficient technology than that used in other countries in 2005. However, in 2015, Vietnam, India, and Indonesia generated more CO_2 emissions per 1 billion USD of exports.

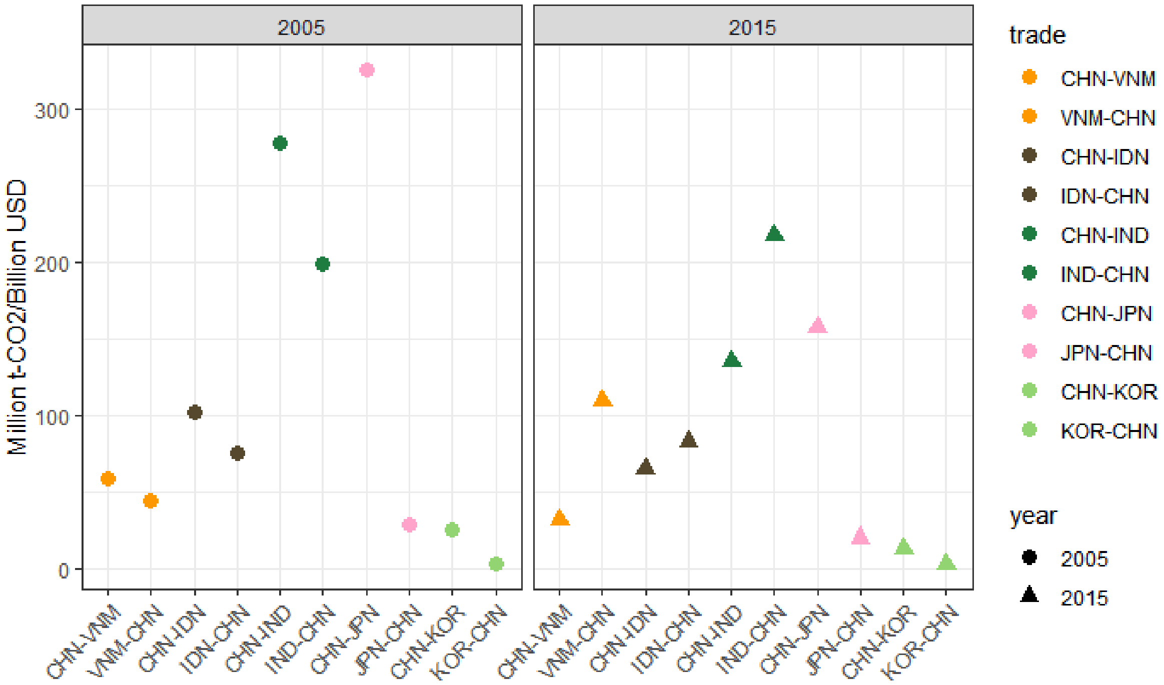

Figure 8. Emissions embodied per unit of bilateral trade.

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

3.3. Bilateral CO_2 Trade at the Sector Level

The differences in the bilateral CO_2 emissions based on single-region and multi-region approaches are decomposed into sectors in this section. Figures 9–11 show the net trade balance of total emissions between China–Vietnam, China–Indonesia, and China–Japan, respectively. These are three representative cases that show the diversity in the patterns of net CO_2 embodied emissions from China to other countries. If the net CO_2 emissions transferred from China to other countries have a negative value, it can be interpreted that China is causing an increase of CO_2 emissions in its counterparts. In that case, carbon leakage occurs in trade partner countries. In Figure 9, China may have caused the emission rise in the mining sector in Vietnam, no matter which approach is used.

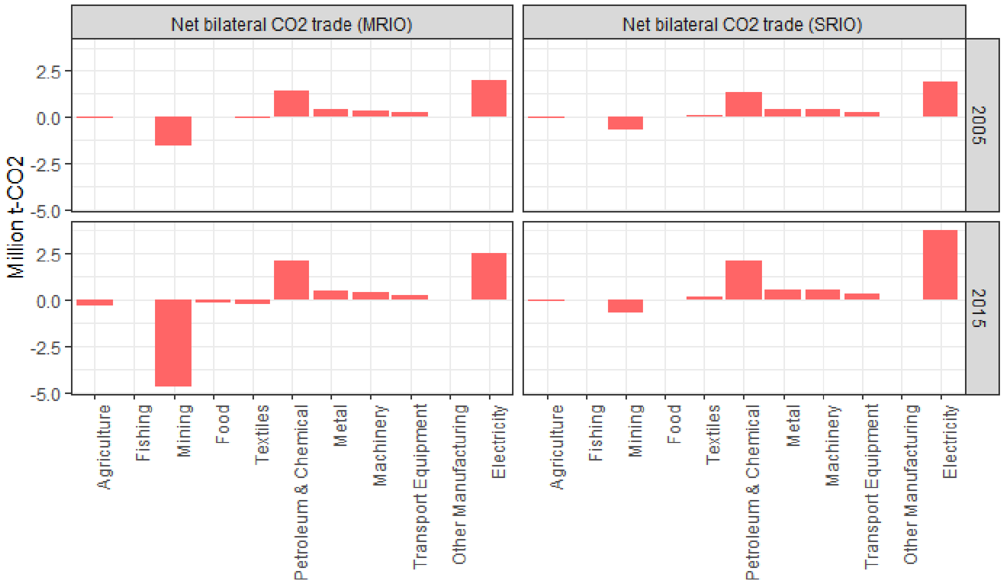

Figure 8. China's net bilateral CO_2 trade with Vietnam at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches in 2005 and 2015.

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

Figure 10 shows the result of the net CO_2 emissions transferred from China to Indonesia. Besides the mining sector similar to the Vietnam case, the MRIO approach shows that China became a net importer of emissions in machinery and in petroleum and chemical goods.

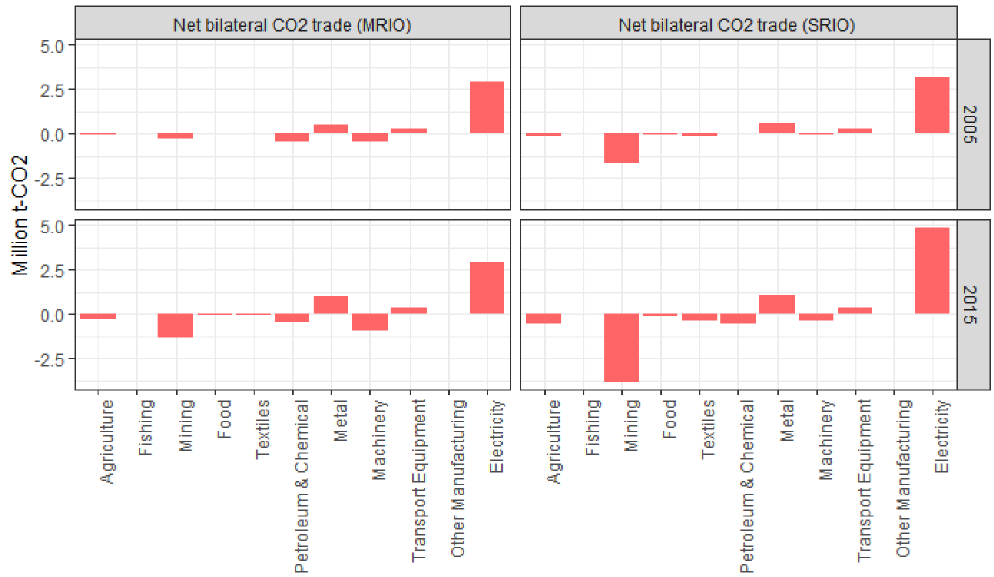

Figure 9. China's net bilateral CO_2 trade with Indonesia at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches in 2005 and 2015.

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

Figure 11 shows that Japan may have caused the rise of CO_2 emissions in China, especially in the electricity supply sector when the analysis is conducted with the MRIO approach. The emissions of the electricity supply sector induced by the export of all goods and services from China to Japan can be underestimated using the SRIO approach. Also, the emissions embodied in the metal and machinery goods made in Japan and exported to China would be overestimated.

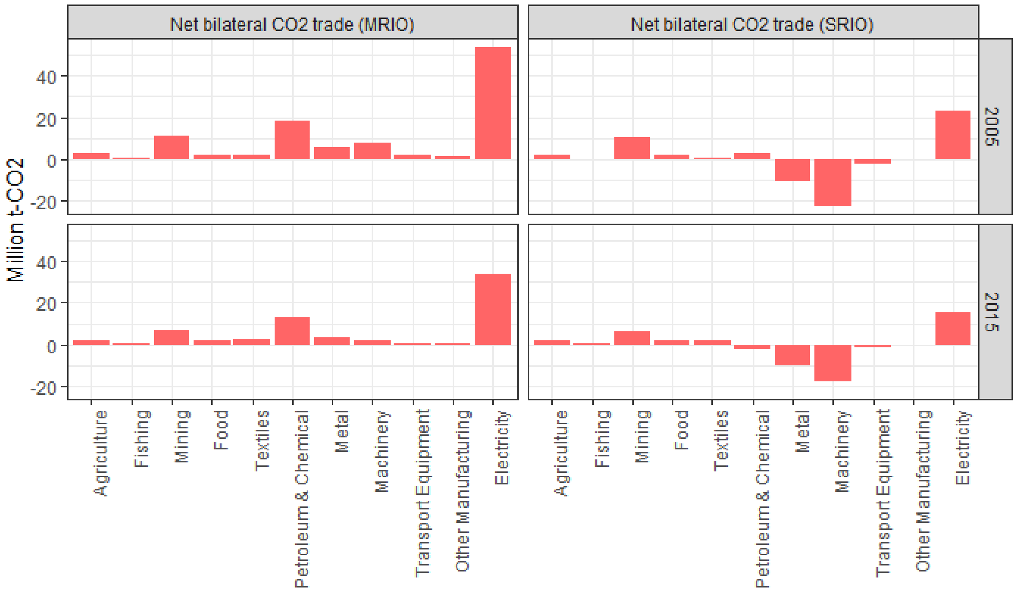

Figure 10. Net bilateral CO_2 trade of China with Japan at the sector level using the single-region input–output (SRIO) and multi-region input–output (MRIO) approaches in 2005 and 2015.

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

4. Conclusions

In this paper, the CO_2 emissions embodied in the bilateral trade between China and selected Asian countries have been examined on the basis of the SRIO and MRIO approaches. The result shows that, generally, from 2005 to 2010, China has been the largest emitter among the six selected Asian countries (Vietnam, Indonesia, India, Japan, China, and South Korea). Emission intensity in developing countries such as Vietnam, Indonesia, and India has decreased from 2005 to 2010. However, compared with developed countries such as Japan and South Korea, these emission intensities are still relatively high. In the case of Vietnam's mining sector, the direct emission coefficients increased sharply.

In the bilateral CO_2 trade, the embodied emissions per unit of China's bilateral exports were higher than all receiving countries in 2005. However, the situation was reversed in China–Vietnam, China–Indonesia, and China–India in 2015. China imported more emission-intensive goods and services from these three countries. On the other hand, using both approaches, the net bilateral export emissions from China to Indonesia shrank and reversed from 2005 to 2015, indicating that China has caused the rise of emissions in Indonesia and become a net importer of embodied emissions. The net bilateral emissions exported from China to Vietnam and India also shrank from 2005 to 2015. The mining and electricity sectors contributed to the shrinkage. However, this shrink can only be observed using the MRIO approach rather than the SRIO approach.

This paper also has some limitations regarding the raw data of the input–output tables and emission data. Although the tables from 2005, 2010, and 2015 were used in this paper, they were all compiled using the purchase prices of those years. The accuracy of the results could be improved if a table using comparable prices is used. In terms of the raw data of 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 result of emissions from the mining sector refers 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 paper are limited in their ability to explore the impacts of coal industry investments.

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