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The Impact of Trade on Carbon Emissions and Employment from the Perspective of Global Value Chains—A Case Study of Chinese–Japanese–Korean Trade

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Abstract: While international trade drives countries' economic growth and promotes employment, it also has some environmental impact. To investigate the impact of trade on carbon emissions and employment, this study performs a detailed decomposition and measurement of embodied carbon emissions and employment in value-added trade between China, Japan, and Korea from 2007–2019. The current study established that, while China's trade with Japan and Korea created many domestic jobs, it also resulted in significant domestic carbon emissions. While Japan and Korea's trade with China reduced carbon emissions, employment in their own countries was reduced and replaced by employment in China. At the value chain route level, trade among the three countries through each value chain route either achieves employment promotion at the cost of increased carbon emissions or promotes domestic emissions reduction at the cost of employment loss. However, it is worth noting that, when trade between Japan and Korea was conducted through simple GVCs (route 2), it not only helped reduce Japan's carbon emissions, but also effectively promoted employment. This is the ideal trade route. The results of this study can provide useful reference information for developing countries such as China, to achieve sustainable economic growth, carbon emission reduction, and employment promotion in the context of trade globalization.

Keywords: carbon emissions; international trade; employment; GVCs; input–output models

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1. Introduction

With the advancement of trade globalization, countries participate in the international division of labor by virtue of their factor endowments and comparative advantages, playing different roles in the global value chain (GVC), which has led to a significant improvement in overall global economic efficiency [1]. The development of international trade and verticalized professional division of labor has led to a geographical separation of production and consumption. International trade has led to "environmental improvements" in developed countries, but to a large extent, these countries only transferred carbon emissions and environmental pollution to developing countries without solving the pollution problem [2]. Similarly, the transfer of environmental pollution from developed countries such as Europe, the United States and Japan have transferred a large number of labor-intensive industries to developing countries. This not only drives the employment of low-skilled labor in developing countries such as China, but also creates the problem of "industrial hollowing out" in the originating countries [3]. The transfer of employment is at the forefront of the debate on the impact of international trade, as is the displacement of carbon emissions. This is equally important for countries at different stages of development.

China, Japan, and South Korea are representatives of developing countries, developed economies, and emerging industrial countries in the Asian region, respectively [4]. According to the WTO's statistics, in 2020, China's total exports and imports increased to 14.74% and 11.69% of the world's exports and imports of products, respectively, with total import and export trade reaching US$4.7 trillion, making it the world's largest trading country. China has been actively integrated into the GVC with its own labor and resource advantages; Japan and South Korea are China's second and third largest trading partners, respectively, and the countries with which China has the most intensive trade transactions. These three countries have participated in international trade using the developed country's technological and capital advantages. All of these factors have greatly contributed to the development of trade globalization. However, an increasing number of trade disputes and trade frictions have arisen against developing countries. On the one hand, developed economies, such as the USA and Japan, accuse trade surplus developing countries of exporting large quantities of cheap products and depriving them of employment opportunities, especially for low-skilled labor in manufacturing [5], and the resulting large carbon emissions pose a serious threat to the global environment. On the other hand, developing countries argue that their taking over of labor-intensive industries creates employment for low-skilled workers while also importing large quantities of important parts and components, driving high-skilled employment in trading partner countries [3]. Developed countries achieve emission reductions through trade and investment at the expense of developing countries [6]. In contrast, while developing countries gain significant employment from the low- and medium-skill industries they assume, they gain very little profit through the value chain.

Taken together, the impact of foreign trade on a country has two sides, namely, positive benefits and negative costs, such as increased employment or increased pollution. China, Japan, and Korea are representatives of developing countries, developed economies, and emerging industrial countries, respectively, in the Asian region. Measuring and analyzing the embodied carbon emissions and employment in trade between the three countries can help to explain the impact of trade on carbon emissions and employment in different types of countries. Therefore, this paper takes trade between China, Japan and Korea as an example and analyzes the following issues from a GVC perspective: What are the characteristics of embodied carbon emissions and embodied employment in Chinese–Japanese–Korean trade? How do embodied carbon emissions and employment in Chinese–Japanese–Korean trade flow along the value chains? What is the impact of different value chain routes on carbon emissions and employment? The answers to these questions can help to understand the impact and differences of different types of countries' participation in the division of labor in GVCs on their carbon emissions and employment. This study can also provide information that is useful for China in achieving sustainable economic growth, carbon emission reduction, and employment promotion in the context of open transition.

Based on the multi-regional input–output model constructed by the GVC accounting framework, this study applies the Asian Development Bank (ADB) input–output tables and the corresponding carbon emission and employment data to decompose and measure in detail the carbon emissions and employment embodied in the value-added trade of China, Japan, and South Korea from 2007–2019. Five value chain routes are constructed, and the flows of carbon emissions and employment embodied in trade through different routes are analyzed in detail. Finally, the balance of domestic embodied emissions (BEE) and balance of domestic embodied labor (BEL) are calculated to discuss the environmental and employment impacts of Chinese–Japanese–Korean trade through different value chain routes from the perspective of embodied factor transfers.

This paper is divided into five main sections. Section 2 presents the literature review, Section 3 presents the methodology and data of the study, Section 4 presents the results and discussion, and Section 5 is the conclusion section.

2. Literature Review

In the context of GVCs, the traditional trade statistics method with the total value of products as the caliber can no longer reflect the real international trade situation. The new method with the caliber of value-added provides a new perspective to reconceptualize the trade and distribution of trade benefits under the international division of labor [7]. Researchers have studied the value-added trade by constructing different input–output models that can accurately answer the different impacts that occur when a country or region is involved in various trade activities. The relevant input–output models have gone through three stages of development, from single-region input–output models based on "domestic technology assumptions," to bilateral trade input–output models that do not consider intermediate inputs, to multi-region input–output (MRIO) models that consider both technological heterogeneity and intermediate inputs [8]. The most representative models are the HIY method of Hummels, et al. [9], the DRS method of Daudin [10], and the gross exports decomposition (KWW) method of Koopman, et al. [11,12]. Wang, et al. [13] extend the KWW approach to the bilateral/sectoral level and further decompose total trade into 16 terms. Meng, et al. [14,15] and Pan, et al. [16] refer to the analysis at the country/bilateral level using the KWW approach. Wang, et al. [17] further elaborated the total trade accounting approach by reinterpreting the traditional indicators of trade balance, vertical specialization, and revealed comparative advantage.

In recent years, environmental and climate change issues have become a global concern. CO_2 is the most important greenhouse gas, so carbon emissions embodied in foreign trade have become the main research direction of environmental and trade-related topics. Meng, et al. [18] constructed a new environmental accounting system in the framework of value-added trade accounting by integrating the method of calculating trade implied emissions in value-added trade accounting with GVCs. A framework was proposed for tracking carbon emissions along GVCs through eight pathways. Using this framework, value-added and carbon emissions can be systematically tracked and analyzed along different GVC routes at the national, bilateral and sectoral levels. Wang, et al. [19], and Bai, et al. [20] distinguish between simple and complex GVCs and analyze their embodied carbon emissions. Their innovative study provides a new approach to the role of GVC routes in emissions transfer. The continuous innovation in the methodology for the study of trade-embodied carbon emissions has led to the development of studies, such as emissions balancing (net emissions transfer: the difference between the emissions embodied in a country's exports and imports). Peters et al. [21] and Jiang, et al. [22] have studied the net emissions transfer from trade. The results of Duan, et al. [23] indicate that global CO2 emissions would be seriously reduced if there was anti-globalization with the reflow of MNEs. López, et al. [24] argue that, as international trade deepens, a geographical division of production is achieved, which in turn leads to regional transfers in global carbon emissions. Specifically, developed economies in the upper reaches of GVCs outsource high-emission production to countries with lax environmental standards. While this approach can achieve carbon reductions in their own countries, it risks leading to increased global emissions.

The impact of international trade on employment is likewise an important topic, and many researchers have studied the employment embodied in trade. Feenstra [25] established that the growth of exports creates a great deal of employment in the exporting countries. Los, et al. [26], and Ge, et al. [27] explored the impact of foreign demand on employment in China using the global MRIO model. Zhang, et al. [28] analyzed the impact of foreign demand and FDI on employment promotion. Timmer, et al. [29] analyzed changes in factor content, such as employment created in the GVC division of labor production using a multi-country input–output model with an analytical approach similar to that of embodied carbon emissions. Lin, et al. [30] decomposed employment embodied in a country's exports (similar to the decomposition of value added) into 12 terms by referring to the total export decomposition method of Wang, et al. [13]. Representing the flows and transfers of employment embodied in trade, Alsamawi, et al. [31] quantified the flows of employment embodied in international trade. Feenstra and Hong [32] and Ben Salha [33] analyzed the impact of international trade on net employment in the home country. In the context of global production fragmentation, the labor force involved in trade may come from multiple countries, and the labor mobility involved in trade becomes more complex. Therefore, it has become increasingly important to analyze and discuss the impact of different GVCs routes on employment. However, the current studies related to employment embodied in trade comprise less research on value chain routes.

In summary, the available studies have focused more on the single effect of trade on carbon emissions or employment, but few studies have included carbon emissions and employment in the same framework. The current study mostly uses data published in the WIOD database in 2016, and its input–output tables, carbon emissions, and employment data are updated only to 2014. Meanwhile, existing studies focus on the impact of a single country's export trade, and fewer comparative studies are conducted for different types of countries and different bilateral trade. This study selects three countries at different development stages, China, Japan, and Korea, to study carbon emissions and employment in the same framework. The relationship between value-added trade and embodied carbon emissions and employment in the three countries from 2007–2019 is analyzed, as well as the impact of different value chain routes on embodied carbon emissions and employment.

3. Methodology and Data

3.1. Embodied Factor Content Decomposition of Exports Based on Value-Added Trade

This study is based on the MRIO model. According to the equilibrium equation, the MRIO model consisting of G countries (regions) can be expressed as:

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \ldots A_{1G} \\ A_{12} & A_{22} & \ldots A_{2G} \\ \vdots & \vdots & \ddots \quad \vdots \\ A_{G1} & A_{G2} & \ldots A_{GG} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} + \begin{bmatrix} Y_{11} & Y_{12} & \ldots Y_{1G} \\ Y_{12} & Y_{22} & \ldots Y_{2G} \\ \vdots & \vdots & \ddots \quad \vdots \\ Y_{G1} & Y_{G2} & \ldots Y_{GG} \end{bmatrix} \tag{1}$$

For any country s (s = 1, . . . , G), X_s and A_{ss} denote the country's gross output vector and direct consumption coefficient matrix, respectively, and Y_{ss} is the product produced by the country and satisfying domestic final demand. A_{rs} (r = 1, . . . , G and $r \neq s$) denotes the matrix of mutual demand coefficients between country s and any other country r, which portrays the activity of trade in intermediate products between the two countries. Y_{sr} is the product produced by country s and satisfying the final demand of country r. It reflects the final product exports from country s to country r. From Equation (1), we have:

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & \ldots B_{1G} \\ B_{12} & B_{22} & \ldots B_{2G} \\ \vdots & \vdots & \ddots \quad \vdots \\ B_{G1} & B_{G2} & \ldots B_{GG} \end{bmatrix} \begin{bmatrix} Y_{11} & Y_{12} & \ldots Y_{1G} \\ Y_{12} & Y_{22} & \ldots Y_{2G} \\ \vdots & \vdots & \ddots \quad \vdots \\ Y_{G1} & Y_{G2} & \ldots Y_{GG} \end{bmatrix} \tag{2}$$

where B denotes the Leontief inverse matrix.

Based on the MRIO model, VA_s is defined as the value-added vector ($1 \times N$ row vector) of country s. The value-added coefficient vector of that country can then be expressed as $V_s = VA_s(\hat{X_s})^{-1}$, $\hat{X_s}$ is the diagonal matrix of output vector X_s; similarly, the value-added coefficient vector V_r of country r is obtained. In this study, according to the decomposition framework used by Zhang, et al. [34], the export E_{sr} of country s to country r is decomposed into the following 17 parts according to the total trade accounting method:

$$
\begin{aligned}
E_{sr} = \; & \underbrace{(V_s B_{ss})^{\mathrm{T}} \# Y_{sr}}_{\mathrm{T1}} + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# (A_{sr} B_{rr} Y_{rr})}_{\mathrm{T2}} + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tt} \right)}_{\mathrm{T3}} \\
& + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} B_{rr} \sum_{t \neq s,r}^{G} Y_{rt} \right)}_{\mathrm{T4}} + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} \sum_{u \neq s,r,t}^{G} B_{rt} Y_{tu} \right)}_{\mathrm{T5}} \\
& + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tr} \right)}_{\mathrm{T6}} + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# (A_{sr} B_{rr} Y_{rs})}_{\mathrm{T7}} \\
& + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{ts} \right)}_{\mathrm{T8}} + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# (A_{sr} B_{rs} Y_{ss})}_{\mathrm{T9}} \\
& + \underbrace{(V_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rs} Y_{st} \right)}_{\mathrm{T10}} + \underbrace{(V_s B_{ss} - V_s L_{ss})^{\mathrm{T}} \# (A_{sr} X_r)}_{\mathrm{T11}} \\
& + \underbrace{(V_s B_{rs})^{\mathrm{T}} \# Y_{sr}}_{\mathrm{T12}} + \underbrace{(V_r B_{rs})^{\mathrm{T}} \# (A_{sr} L_{rr} Y_{rr})}_{\mathrm{T13}} + \underbrace{(V_r B_{rs})^{\mathrm{T}} \# (A_{sr} L_{rr} E_{r^*})}_{\mathrm{T14}} \\
& + \underbrace{\left(\sum_{t \neq s,r}^{G} V_t B_{ts} \right)^{\mathrm{T}} \# Y_{sr}}_{\mathrm{T15}} + \underbrace{\left(\sum_{t \neq s,r}^{G} V_t B_{ts} \right)^{\mathrm{T}} \# (A_{sr} L_{rr} Y_{rr})}_{\mathrm{T16}} \\
& + \underbrace{\left(\sum_{t \neq s,r}^{G} V_t B_{ts} \right)^{\mathrm{T}} \# (A_{sr} L_{rr} E_{r^*})}_{\mathrm{T17}}
\end{aligned} \quad (3)
$$

In Equation (3), the superscript "T" and the symbol "#" denote the transpose of the matrix and the chunk matrix dot product, respectively; country t ($t = 1, \ldots, G$ and $t \neq s, r$) represents country s and the third country outside country r; V_t denotes the value-added of the country coefficient vector; $L_{ss} = (I - A_{ss})^{-1}$ is the Leontief inverse matrix of country s (similar to L_{rr}); X_r and E_{r^*} are the total output vector and total export vector of country r (both are $N \times 1$ column vectors), respectively. To facilitate the analysis, the 17 terms on the right side of the equal sign of Equation (3) are set as T1–T17 (all are $N \times 1$ column vectors) in this study. T10, T11, T14, and T17 are pure double-counting parts, and the remaining 13 terms are the implicit value-added in exports; these 13 correspond to the actual production activity of each country.

The model framework for the detailed decomposition of the 17 items is shown in Figure 1.

This study calculates the carbon emissions embodied in a country's exports based on the value-added of trade. The pure double-counting section (T10, T11, T14, T17) does not correspond to the actual production or carbon emission process, therefore, it was removed in this study. We defined $F_s = CE_s(\hat{X}_s)^{-1}$ as the direct carbon emission intensity of region s, where CE_s is the carbon emission vector of region s. The direct carbon emission intensity F_s is replaced by the direct value-added factor content V_s in Equation (3) to obtain the traded embodied carbon emission EEC_{sr}, which is decomposed into 13 terms as shown below.

$$
\begin{aligned}
EEC_{sr} = & \underbrace{(F_sB_{ss})^{\mathrm{T}}\#Y_{sr}}_{\mathrm{T1}} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rr}Y_{rr})}_{\mathrm{T2}} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}B_{rt}Y_{tt}\right)}_{\mathrm{T3}} \\
& + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}B_{rr}\sum_{t\neq s,r}^{G}Y_{rt}\right)}_{\mathrm{T4}} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}\sum_{u\neq s,r,t}^{G}B_{rt}Y_{tu}\right)}_{\mathrm{T5}} \\
& + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}B_{rt}Y_{tr}\right)}_{\mathrm{T6}} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rr}Y_{rs})}_{\mathrm{T7}} \\
& + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}B_{rt}Y_{ts}\right)}_{\mathrm{T8}} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rs}Y_{ss})}_{\mathrm{T9}} \\
& + \underbrace{(F_sB_{rs})^{\mathrm{T}}\#Y_{sr}}_{\mathrm{T10}} + \underbrace{(F_rB_{rs})^{\mathrm{T}}\#(A_{sr}L_{rr}Y_{rr})}_{\mathrm{T11}} \\
& + \underbrace{\left(\sum_{t\neq s,r}^{G}F_tB_{ts}\right)^{\mathrm{T}}\#Y_{sr}}_{\mathrm{T12}} + \underbrace{\left(\sum_{t\neq s,r}^{G}F_tB_{ts}\right)^{\mathrm{T}}\#(A_{sr}L_{rr}Y_{rr})}_{\mathrm{T13}}
\end{aligned}
\quad (4)
$$

In Equation (4), the first nine terms represent domestic carbon emissions embodied in exports, where terms T1–T6 are domestic carbon emissions absorbed by foreign countries (*EC*_1), and terms T7–T9 are domestic carbon emissions that are exported and then returned to the country. Items T10 and T11 are carbon emissions from direct importing countries (*EC*_2), and items T12 and T13 are carbon emissions from third parties (*EC*_3). This defines the source structure of carbon emissions embodied in exports. Meng, et al. [18] established that the domestic CO_2 emissions generated from China's gross exports production account for a relatively large share (more than 90%), and they believe that domestic emissions absorbed abroad are the only measure of emissions trading and are always correlated with total bilateral trade. Therefore, in order to track emissions from total bilateral trade, we focus on total domestic emissions absorbed abroad (*EC*_1). Embodied domestic emissions from exports in region s to region r are represented by EEX_{sr} as follows:

$$
\begin{aligned}
EEX_{sr} &= \underbrace{(F_s B_{ss})^{\mathrm{T}} \# Y_{sr}}_{\mathrm{T1}} + \underbrace{(F_s L_{ss})^{\mathrm{T}} \# (A_{sr} B_{rr} Y_{rr})}_{\mathrm{T2}} + \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tr} \right)}_{\mathrm{T6}} \\
&+ \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} B_{rr} \sum_{t \neq s,r}^{G} Y_{rt} \right)}_{\mathrm{T4}} \\
&+ \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tt} \right) + (F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} \sum_{u \neq s,r,t}^{G} B_{rt} Y_{tu} \right)}_{\mathrm{T3+T5}} \\
&= \underbrace{(F_s B_{ss})^{\mathrm{T}} \# Y_{sr}}_{(Route\ 1)} + \underbrace{(F_s L_{ss})^{\mathrm{T}} \# (A_{sr} B_{rr} Y_{rr})}_{(Route\ 2)} + \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tr} \right)}_{(Route\ 3)} \\
&+ \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} B_{rr} \sum_{t \neq s,r}^{G} Y_{rt} \right)}_{(Route\ 4)} \\
&+ \underbrace{(F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} B_{rt} Y_{tt} \right) + (F_s L_{ss})^{\mathrm{T}} \# \left(A_{sr} \sum_{t \neq s,r}^{G} \sum_{u \neq s,r,t}^{G} B_{rt} Y_{tu} \right)}_{(Route\ 5)}
\end{aligned}
\tag{5}
$$

To assess the impact of different value chain routes on carbon emissions and employment, this study defines five value chain routes based on the decomposition framework proposed by Wang, et al. [35]. The content of the factor is available in both GVCs and non-GVCs activities. The embodied factor content in GVCs activity will be traded across national borders. We further classify it into simple and complex GVCs. The five value chain routes are defined as shown in Figure 2.

Trade through route 1 is also referred to as traditional trade in final products, and trade through other routes is trade associated with global value chains. The simple GVCs-related trade includes route 2 and 4. The complex GVCs-related trade includes route 3 and 5. We can interpret the physical meaning as the more complex the GVC production activity, and the longer the length of the production chain, the more the value-added sector is in the downstream production stage of the economic activity, which means that the domestic production stage of intermediate products is closer to the upstream of the production chain [36]. Similarly, to estimate the total embodied employment in a region's exports, we use LE_s to denote the vector of employment in region s, so $L_s = LE_s(\hat{X_s})^{-1}$ is defined as the direct labor input coefficient for region s. The employment embodied in trade (EEL_{sr}) is obtained by replacing the direct carbon emission intensity F_s in Equation (5) with the direct labor input coefficient L_s. Based on this framework, we can also track trade-related employment.

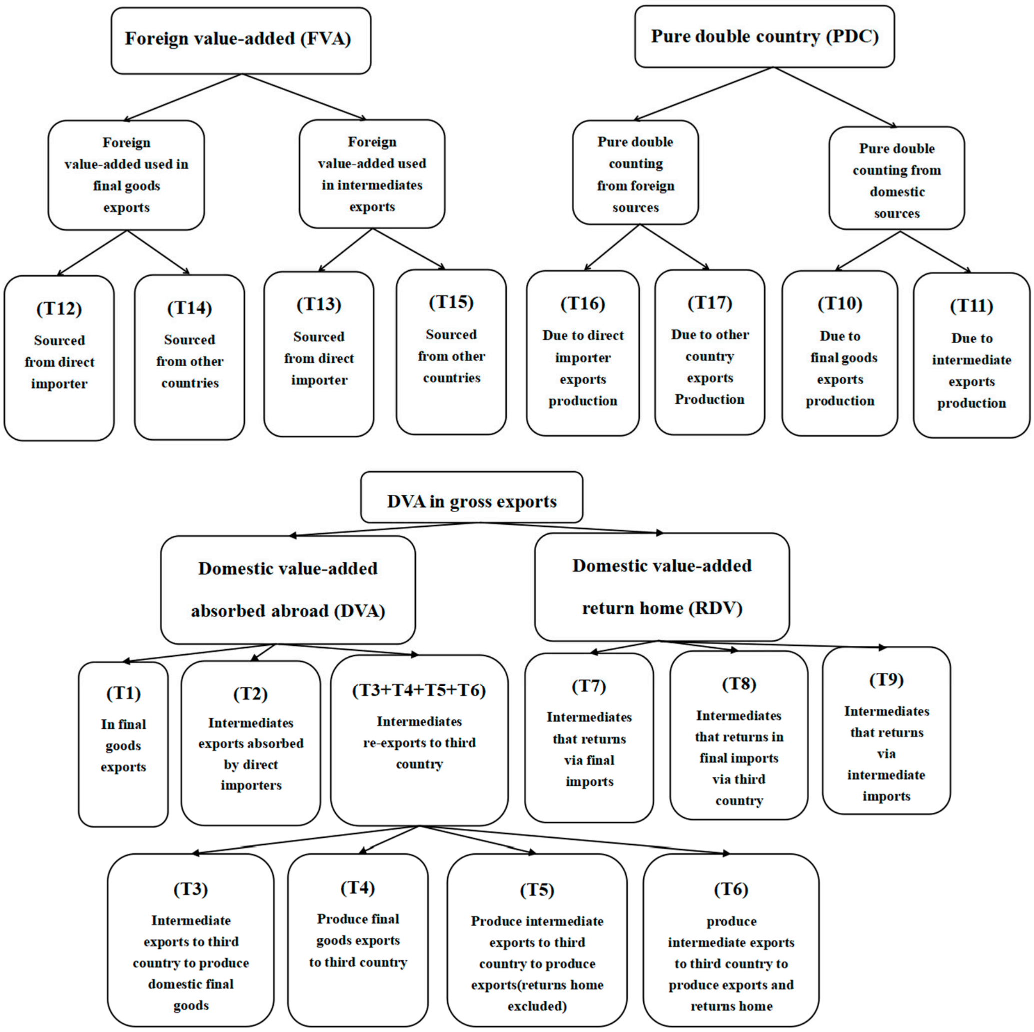

Figure 1. Decomposition framework of value-added embodied in a country's exports.

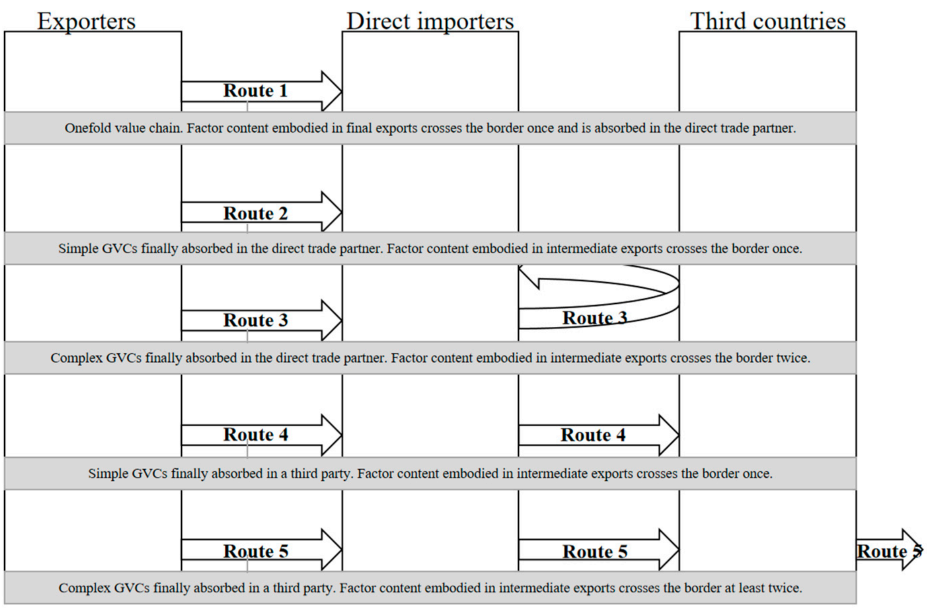

Figure 2. The five value chain routes.

$$
\begin{aligned}
EEL_{sr} &= \underbrace{(L_sB_{ss})^{\mathrm{T}}\#Y_{sr}}_{\mathrm{T1}} + \underbrace{(L_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rr}Y_{rr})}_{\mathrm{T2}} + \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G} B_{rt}Y_{tr}\right)}_{\mathrm{T6}} \\
&+ \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}B_{rr}\sum_{t\neq s,r}^{G} Y_{rt}\right)}_{\mathrm{T4}} \\
&+ \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G} B_{rt}Y_{tt}\right) + (L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}\sum_{u\neq s,r,t}^{G} B_{rt}Y_{tu}\right)}_{\mathrm{T3+T5}} \\
&= \underbrace{(L_sB_{ss})^{\mathrm{T}}\#Y_{sr}}_{(Route\ 1)} + \underbrace{(L_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rr}Y_{rr})}_{(Route\ 2)} + \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G} B_{rt}Y_{tr}\right)}_{(Route\ 3)} \\
&+ \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}B_{rr}\sum_{t\neq s,r}^{G} Y_{rt}\right)}_{(Route\ 4)} \\
&+ \underbrace{(L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G} B_{rt}Y_{tt}\right) + (L_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}\sum_{u\neq s,r,t}^{G} B_{rt}Y_{tu}\right)}_{(Route\ 5)}
\end{aligned} \tag{6}
$$

3.2. Embodied Factor Content Transfer in Value-Added Trade

To analyze the transfer of carbon emissions and employment along GVCs, this study uses the balance of domestic embodied factor content to evaluate the domestic impacts of value-added trade, following the idea of Bai, et al. [20]. In the case of carbon emissions, the balance of domestic embodied carbon emissions (BDE) is the difference between domestic emissions embodied in exports and in imports. It can be used to evaluate the impact of international trade on the direct emissions of a region. The BDE for region s to region r (BEE_{sr}) can be expressed as follows:

$$
\begin{aligned}
BEE_{sr} &= EEC_{sr} - EEC_{rs} \\
&= \underbrace{(F_sB_{ss})^{\mathrm{T}}\#Y_{sr} - (F_rB_{rr})^{\mathrm{T}}\#Y_{rs}}_{(Route\ 1)} + \underbrace{(F_sL_{ss})^{\mathrm{T}}\#(A_{sr}B_{rr}Y_{rr}) - (F_rL_{rr})^{\mathrm{T}}\#(A_{rs}B_{ss}Y_{ss})}_{(Route\ 2)} \\
&+ \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G} B_{rt}Y_{tr}\right) - (F_rL_{rr})^{\mathrm{T}}\#\left(A_{rs}\sum_{t\neq s,r}^{G} B_{st}Y_{ts}\right)}_{(Route\ 3)} \\
&+ \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}B_{rr}\sum_{t\neq s,r}^{G} Y_{rt}\right) - (F_rL_{rr})^{\mathrm{T}}\#\left(A_{rs}B_{ss}\sum_{t\neq s,r}^{G} Y_{st}\right)}_{(Route\ 4)} \\
&+ \underbrace{(F_sL_{ss})^{\mathrm{T}}\#\left(A_{sr}\sum_{t\neq s,r}^{G}\sum_{u\neq s,r}^{G} B_{rt}Y_{tu}\right) - (F_rL_{rr})^{\mathrm{T}}\#\left(A_{rs}\sum_{t\neq s,r}^{G}\sum_{u\neq s,r}^{G} B_{st}Y_{tu}\right)}_{(Route\ 5)}
\end{aligned} \tag{7}
$$

In region s, if $BEE_{sr} > 0$, it indicates that value-added trade leads to an increase in carbon emissions in region s. If $BEE_{sr} < 0$, it indicates that value-added trade helps to reduce carbon emissions in region s. The analysis of the five GVC routes helps us to measure the impact of different forms of trade on regional emissions. Using similar ideas, we derived the BEL to assess the impact of value-added trade on regional employment.

3.3. Data

The input–output data used in this study were sourced from the Asian Development Bank's Input–Output Table published in 2021. The database provides world input–output tables for 2000 and from 2007–2020, including 62 economies and rest of the world (ROW), covering 35 sectors. This study focused on China, Japan, and Korea, so the 59 additional economies were combined into the ROW. CO_2 emissions data were sourced from WIOD environmental accounts [37]. Employment data were obtained from the national statistical offices of China, Japan, and Korea, and the ROW employment data was obtained according to the method of Stadler, et al. [38] and Wood, et al. [39], combined with the world employment data from the ILO. To harmonize input–output tables, employment, and CO_2 emission data, eight sectors were classified according to the International Standard Industrial Classification (Rev.4) of the statistical services of the United Nations Department of Economic and Social Affairs by labor-, knowledge-, and capital-intensive options, as shown in Table 1.

Table 1. Eight sectors.

No.	Sector
A	Primary and natural resources
M1	Labor-intensive manufacturing
M2	Knowledge-intensive manufacturing
M3	Capital-intensive manufacturing
S1	Labor-intensive service
S2	Knowledge-intensive service
S3	Capital-intensive service
O	Health/education/public/other service

4. Results and Discussion

4.1. Bilateral Trade between China, Japan, and Korea

China, Japan, and Korea are the world's second, third, and twelfth largest economies, respectively, and the three countries account for more than one-fifth of the world's gross domestic product and total foreign trade. Figure 3 shows the bilateral trade volume between China, Japan, and South Korea in 2007 and 2019. From 2007–2019, the bilateral trade volume between China and Japan, and China and South Korea increased by 75.4% and 135.6%, respectively, while the bilateral trade volume between Japan and South Korea increased by 17.5%. In terms of sectors, trade among the three countries was dominated by knowledge-intensive manufacturing (M2), followed by capital-intensive manufacturing (M3). The share of labor-intensive manufacturing (M1) in China's export trade was significantly higher than that of Japan and Korea. This is in line with the resource endowment advantages of China, Japan, and Korea. Compared with 2007, the growth of knowledge-intensive services (S2) in bilateral trade between China, Japan, and South Korea was more pronounced in 2019. As seen in Figure 3, China had a trade surplus with Japan in 2019 of $34.53 billion, and Japan had a trade surplus with South Korea, of $20.28 billion. There was an increase of 415% and 14.9% from 2007, respectively. China had a trade deficit with Korea in 2019, with a deficit of $62.585 billion, representing an increase of 116% from 2007. In terms of trade types, China's exports to Japan are mainly final products, and the remaining exports are mainly intermediate products trade. China, Japan, and South Korea are not only the main engines of innovative economy, science, and technology in Asia and the world, but they also have their own advantages in economic, trading, and science and technology structures, complementarity, dependence, and close trade relations, and are important mutual trading partners [40].

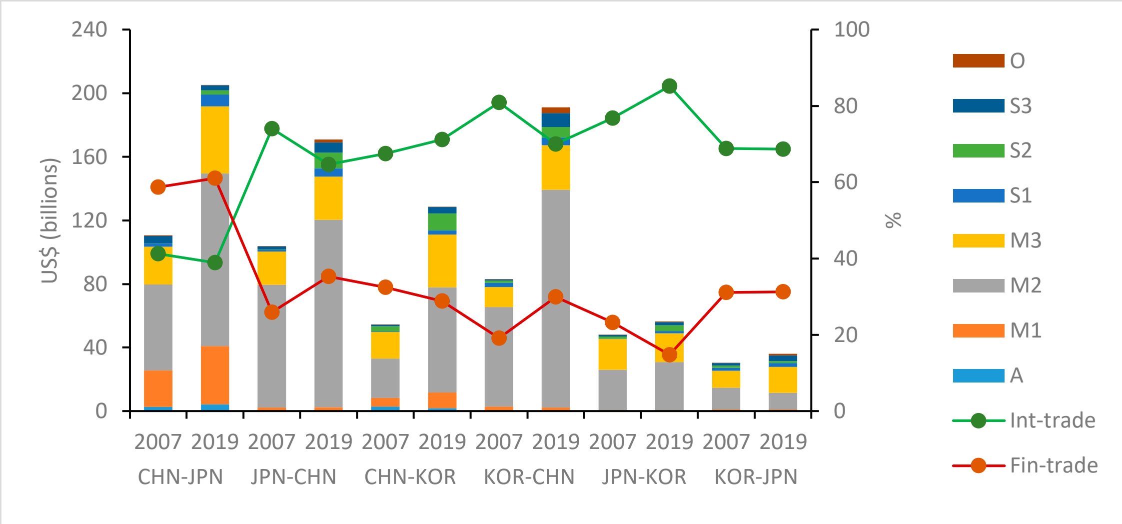

Figure 3. Bilateral trade between China, Japan, and Korea, 2007 and 2019. Source: Author's calculations based on ADB Database (https://mrio.adbx.online, accessed on 1 November 2021).

4.2. Embodied Carbon Emissions in Chinese–Japanese–Korean Trade

Figure 4 shows the carbon emissions embodied in the bilateral trade between China, Japan, and Korea, and the general trend is roughly similar. Due to the global financial crisis, trade displayed a low value in 2009 and then began to rebound, attaining a peak in 2011. This growth was mainly due to stimulus measures by governments targeting the economy and exports, as well as the recovery of overseas demand, especially the increase in demand from Japan to China. These trends led some observers at the time to believe that export emissions from China, for example, would return to the strong growth seen before the financial crisis [41,42]. However, the data derived from our analysis for the years 2011–2017 show that the emissions embodied in the trade of the three countries were not increasing rapidly after 2011; they were decreasing. This is due to the potential structural trend impact of declining export emissions that began in 2008 [43]. From the structural point of view, the carbon emissions embodied in the bilateral trade between China, Japan, and Korea are mainly from domestic carbon emissions (T1–T6). Except for the direct final products trade from China to Japan, which embodied the highest proportion of carbon emissions (T1), the rest were embodied in the intermediate products trade absorbed by the direct importing countries (T2), which had the highest proportion. China, Japan, and Korea differ significantly in the form of trade. Intermediate product trade accounts for about 50% of the embodied carbon emissions in China's exports to Japan, and the share of trade in intermediate products and trade in final products is similar. In the bilateral trade between China and Korea, and Japan and Korea, the carbon emissions embodied in the trade of intermediate products account for approximately 75% and 78%, respectively, which was significantly higher than that in the trade of final products. These results indicate that the carbon emissions embodied in China's exports to Japan are relatively balanced between the trade of intermediate and final products, while those in the trade between Japan and Korea were dominated by the trade of intermediate products. This is created by the different trade structures among China, Japan, and Korea.

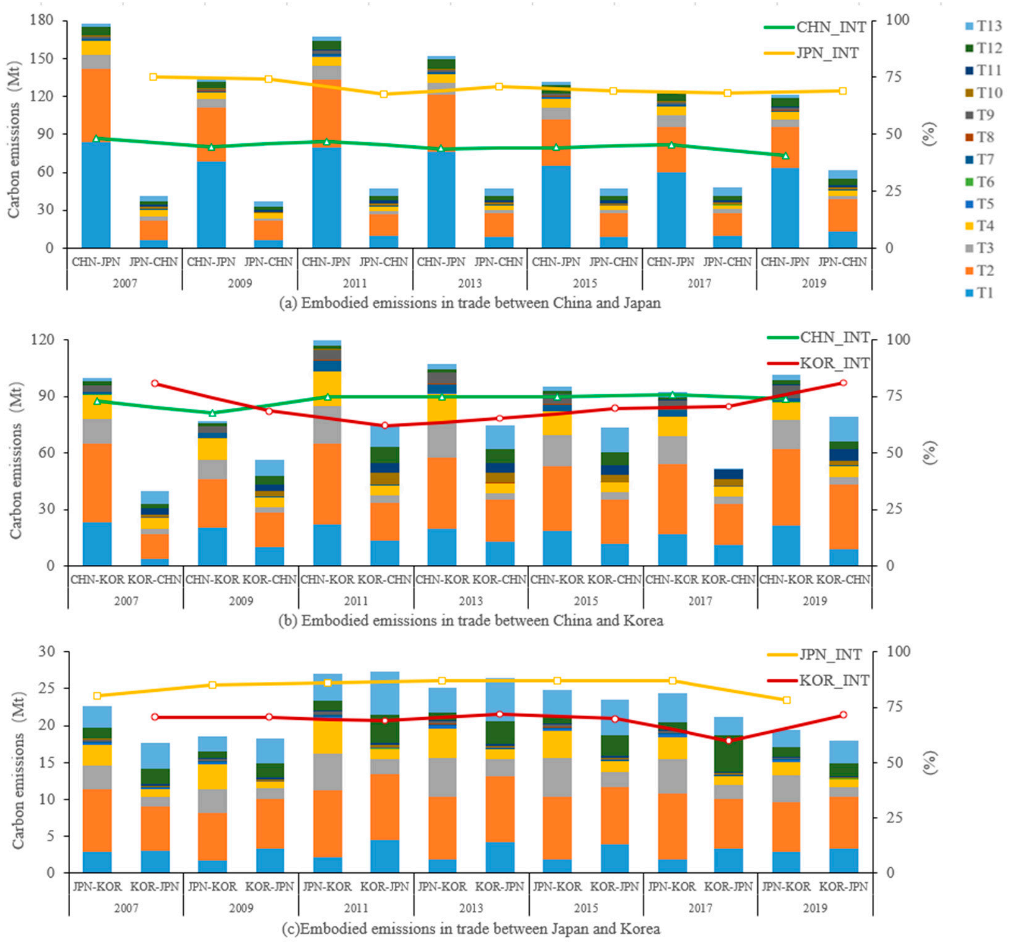

Figure 4. Carbon emissions embodied in bilateral trade between China, Japan, and Korea, 2007–2019.

Table 2 shows the sectoral and source structure of carbon emissions embodied in bilateral trade between China, Japan and Korea. The previous 13 terms are classified into three types of sources: *EC*_1 (emissions from exporting countries), *EC*_2 (emissions from direct importing countries), and *EC*_3 (emissions from third countries). Regarding the sectoral structure, in general, the carbon emissions embodied in China's export trade to Japan and South Korea mainly originate from M2 (knowledge-intensive manufacturing) (49.2% and 43.4% in 2019, respectively) and M3 (capital-intensive manufacturing) (31.13% and 43.35% in 2019, respectively). The main origin of carbon emissions embodied in the export trade of Japan and South Korea to China was the M2 sector (62.3% and 57.1%, respectively, in 2019). The share of M1 (labor-intensive manufacturing) in trade between Japan and Korea was significantly lower than its share in trade with China, and the share of carbon emissions embodied in the service sector was higher. In terms of changes, the share of agriculture and natural resources and M1 sectors in bilateral trade among China, Japan, and Korea decreased, while the service sector share increased. In China's foreign trade, the M2 sector rose, indicating that the share of high technology sector in China's foreign trade increased. The M2 sector share in Japan and Korea's foreign trade decreased, while the services share increased significantly. This indicates that there was a tendency for Japan and Korea to transfer their high-emissions manufacturing sector to China and to focus on developing their services trade. The main source of embodied carbon emissions in China's exports to Japan and South Korea was *EC*_1 (92.64–95.53%), while *EC*_2 and *EC*_3 accounted for relatively small shares. In contrast, the share of *EC*_1 in exports from Japan and South Korea to China was significantly less than the exports from China and the share was continuing to decrease (from 82.44% and 78.22% in 2007 to 81.17% and 73.95% in 2019 in Japan and South Korea, respectively). This was due to the transfer of technology and capital from Japan and Korea to developing countries, such as China, particularly in sectors with high environmental costs [44]. Japan and Korea account for significantly more *EC*_2 and *EC*_3 in exports to China (about 15.29% and 17.81%, respectively, of third-country embodied carbon emissions in 2019). In Japanese–Korean bilateral trade, the share of domestic carbon emissions from Japanese exports to South Korea decreased significantly (from 93.90% in 2007 to 83.66% in 2019); however, it was still higher than the share of domestic emissions from South Korean exports to Japan (about 73%). The increase in carbon emissions from third countries was higher in the mutual export trade between Japan and Korea (from 14.79% and 17.81% in 2007 to 17.81% and 25.66% in 2019, respectively).

Table 2. Sectoral and source structure of carbon emissions embodied in bilateral trade between China, Japan and Korea (%).

Sector	China to Japan								Japan to China							
	Percentage by Sector		*EC*_1		*EC*_2		*EC*_3		Percentage by Sector		*EC*_1		*EC*_2		*EC*_3	
	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019
A	1.70	1.44	96.04	94.51	0.25	0.20	3.71	5.29	0.63	0.29	80.66	78.26	1.69	2.36	17.65	19.38
M1	16.97	14.15	93.69	92.58	0.45	0.33	5.86	7.09	1.29	0.93	82.65	82.52	6.46	4.94	10.89	12.54
M2	46.16	49.12	92.47	89.05	0.66	0.63	6.87	10.32	62.31	62.30	72.19	70.56	10.34	7.82	17.48	21.62
M3	29.18	31.13	96.30	95.02	0.25	0.20	3.45	4.78	31.21	24.99	80.32	78.56	4.34	3.90	15.34	17.55
S1	1.16	1.36	95.82	92.89	0.24	0.29	3.94	6.82	0.69	2.02	84.78	82.73	3.54	2.68	11.68	14.58
S2	0.02	0.59	92.97	88.95	0.55	0.47	6.48	10.58	0.02	2.31	82.53	81.61	4.16	3.16	13.31	15.24
S3	4.69	2.15	96.96	96.10	0.19	0.14	2.85	3.75	3.73	6.48	90.74	91.60	1.54	0.93	7.72	7.47
O	0.12	0.07	93.90	91.98	0.48	0.37	5.62	7.65	0.13	0.67	85.66	83.51	3.29	2.55	11.06	13.94
GROSS	100.00	100.00	94.77	92.64	0.38	0.33	4.85	7.04	100.00	100.00	82.44	81.17	4.42	3.54	13.14	15.29
Sector	China to Korea								Korea to China							
	Percentage by Sector		*EC*_1		*EC*_2		*EC*_3		Percentage by Sector		*EC*_1		*EC*_2		*EC*_3	
	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019
A	3.58	0.76	97.08	95.42	0.17	0.23	2.76	4.35	0.11	0.16	90.89	86.43	2.46	3.51	6.65	10.06
M1	7.05	5.26	94.41	93.39	0.43	0.38	5.15	6.23	3.13	0.88	75.33	64.06	10.55	14.56	14.12	21.39
M2	38.94	43.40	93.99	92.50	0.44	0.53	5.58	6.98	66.26	57.11	62.47	62.06	14.60	13.98	22.94	23.96
M3	45.82	43.35	97.44	96.90	0.12	0.14	2.44	2.96	25.23	26.09	67.69	69.79	8.29	7.74	24.03	22.47
S1	0.29	0.63	95.90	94.39	0.22	0.31	3.88	5.30	2.11	1.91	85.27	71.37	3.34	8.79	11.39	19.85
S2	2.76	3.30	93.89	89.84	0.41	0.61	5.70	9.55	0.72	1.57	74.55	74.38	8.17	7.59	17.28	18.03
S3	1.54	3.16	97.22	96.81	0.18	0.18	2.60	3.01	2.32	10.87	89.07	86.52	2.09	2.62	8.84	10.87
O	0.02	0.14	94.30	91.93	0.40	0.49	5.30	7.58	0.12	1.40	80.53	77.02	6.39	7.10	13.08	15.88
GROSS	100.00	100.00	95.53	93.90	0.30	0.36	4.18	5.74	100.00	100.00	78.22	73.95	6.99	8.24	14.79	17.81
Sector	Japan to Korea								Korea to Japan							
	Percentage by Sector		*EC*_1		*EC*_2		*EC*_3		Percentage by Sector		*EC*_1		*EC*_2		*EC*_3	
	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019
A	0.60	0.45	95.42	82.14	0.23	0.58	4.35	17.28	0.34	1.12	86.43	78.53	3.51	0.92	10.06	20.55
M1	0.46	0.64	93.39	82.28	0.38	0.65	6.23	17.07	2.87	1.06	64.06	60.17	14.56	2.04	21.39	37.78
M2	40.04	42.34	92.50	75.15	0.53	0.98	6.98	23.87	32.33	17.74	62.06	59.72	13.98	2.46	23.96	37.82
M3	54.00	47.42	96.90	83.90	0.14	0.52	2.96	15.58	49.96	55.67	69.79	70.35	7.74	1.24	22.47	28.40
S1	0.32	1.47	94.39	84.22	0.31	0.55	5.30	15.23	3.00	4.23	71.37	75.46	8.79	0.98	19.85	23.56
S2	0.80	2.26	89.84	83.22	0.61	0.65	9.55	16.14	1.79	1.10	74.38	74.65	7.59	1.19	18.03	24.16
S3	3.67	5.19	96.81	93.46	0.18	0.29	3.01	6.25	9.22	17.46	86.52	86.98	2.62	0.47	10.87	12.55
O	0.10	0.24	91.93	84.94	0.49	0.60	7.58	14.47	0.49	1.63	77.02	78.48	7.10	1.09	15.88	20.43
GROSS	100.00	100.00	93.90	83.66	0.36	0.60	5.74	15.74	100.00	100.00	73.95	73.04	8.24	1.30	17.81	25.66

Note: *EC*_1 is emissions from exporting countries in trade; *EC*_2 is emissions from direct importing countries in trade; *EC*_3 is emissions from third countries in trade.

China undertakes a significant amount of carbon emissions in its bilateral trade with Japan. This is partly due to the higher carbon intensity per unit of output in China, and partly due to China's greater involvement in the high-emission production chain of basic industrial and technology-intensive products. Therefore, the bilateral trade between China and Japan will have "carbon leakage", that is, Japan will transfer high pollution, high energy-consumption and resource-consumption sectors to China, and then import low value-added products from China. In this way, Japan reduces its own carbon emissions, which helps to achieve their emission reduction targets, but increases China's carbon emissions. In bilateral trade between China and Korea, although Korea has a trade surplus with China ($62.585 billion in 2019, according to Korea Customs), Korea's technological and capital advantages place it higher up the value chain. The share of carbon emissions originating from third countries in Korea's exports has increased significantly, indicating that Korea has transferred its high-emission, high-pollution production to China. This practice results in China being the main source of embodied carbon emissions in bilateral trade between China and Korea. Expanded trade openness will significantly promote CO_2 emissions in region of China, Japan, and Korea [45].

Figure 5 shows how the embodied emissions in China's exports to Japan and South Korea flowed along the GVC in 2019. It can be seen that Japan and Korea have absorbed 194.6 Mt of China's domestic emissions, of which 44% (84.7 Mt) flow through trade in intermediate products, while 56% (109.9 Mt) flow through trade in final products. For the destination, 157.9 Mt was absorbed by direct importers and 36.7 Mt was absorbed by third parties. The domestic emissions absorbed by Japan and Korea can be further divided into five value chain routes. Of these, 53.6% of domestic carbon emissions absorbed by direct trading partners were through a single value chain (route 1), 46.3% through simple-GVCs (route 2), and approximately 0.1% through complex-GVCs (route 3). Of the domestic emissions absorbed by indirect trading partners (third parties), 39.8% were absorbed through simple-GVCs (route 4), and 60.2% were absorbed through complex-GVCs (route 5). Finally, 107.5 Mt of domestic carbon emissions were absorbed by Japan, and 87.1 Mt of domestic carbon emissions were absorbed by Korea.

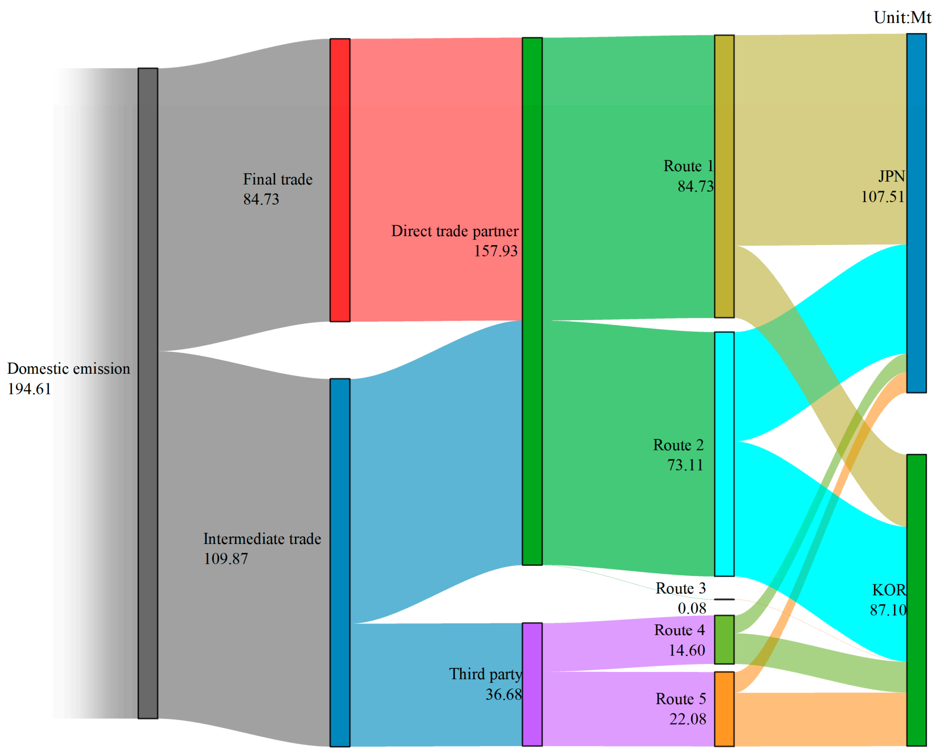

Figure 5. Carbon emissions flow embodied in China's exports.

To assess the impact of different value chain routes on carbon emissions in Chinese–Japanese–Korean trade, the BEE of bilateral trade between China, Japan, and Korea was calculated. Table 3 shows the BEE of trade between China, Japan and Korea in 2007 and 2019.

Table 3. Domestic embodied emissions balance in China, Japan and Korea, 2007 and 2019.

	BEE (Mt)											
	Route 1		**Route 2**		**Route 3**		**Route 4**		**Route 5**		**Total**	
	2007	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**
CHN to JPN	77.18	50.32	42.82	7.12	0.02	−0.06	5.46	1.20	8.06	3.04	133.49	61.62
CHN to KOR	19.46	12.46	28.65	6.33	0.01	−0.01	7.03	3.21	10.26	11.86	65.41	33.85
CHN to ROW	827.89	666.59	561.27	249.21	1.80	1.28	−6.65	−5.21	−4.33	3.56	1379.98	915.44
GROSS	924.53	729.37	632.73	262.66	1.79	1.21	5.84	−0.80	13.98	18.47	1578.88	1010.91
JPN to CHN	−77.18	−50.32	−42.82	−7.12	0.02	0.06	−5.46	−1.20	−8.06	−3.04	−133.49	−61.62
JPN to KOR	−0.10	−0.46	2.41	−0.22	0.01	0.01	1.66	0.84	2.17	2.40	6.14	2.57
JPN to ROW	73.99	50.38	−69.04	−93.00	0.68	0.47	−1.71	−3.24	−4.95	−6.89	−1.03	−52.27
GROSS	−3.29	−0.39	−109.45	−100.34	0.71	0.55	−5.51	−3.60	−10.84	−7.53	−128.38	−111.32
KOR to CHN	−19.46	−12.46	−28.65	−6.33	−0.01	0.01	−7.03	−3.21	−10.26	−11.86	−65.41	−33.85
KOR to JPN	0.10	0.46	−2.41	0.22	−0.01	−0.01	−1.66	−0.84	−2.17	−2.40	−6.14	−2.57
KOR to ROW	13.82	−7.85	−5.63	0.35	0.43	0.56	−2.34	−3.23	−7.30	−11.96	−1.01	−22.14
GROSS	−5.54	−19.85	−36.68	−5.77	0.41	0.57	−11.03	−7.28	−19.73	−26.23	−72.57	−58.56

In terms of bilateral net emissions transfer (total BEE), as the world's factory, China was the largest net carbon exporter among the three countries. This suggests that international trade increases China's direct carbon emissions. In 2019, China's trade with Japan and Korea increased net domestic emissions by 61.62 Mt and 33.85 Mt, respectively. China's significant carbon intensity and large trade surplus led to carbon leakage from developed countries to China through international trade [46]. China's foreign trade caused a net domestic emission of 1010.91 Mt, representing a decrease of 567.79 Mt compared to 2007. Japan was a net emission transferer to Korea, and the net emission transfer from Japan to Korea was 2.57 Mt, representing a decrease of 3.57 Mt compared to 2007. The data show that trade with China is beneficial to Japan and South Korea in reducing their domestic carbon emissions. With the improvement of technology and production processes, the intensity of carbon emissions is decreasing, and there is a trend toward decreases in carbon emissions created by trade. Considering the value chain routes, it is clear that trade in final products through route 1 plays a major role in bilateral net emissions transfers. It shows that China's final products exports create more domestic emissions. Trade in intermediate products through route 2 also plays a key role in the bilateral net emissions transfer. It is worth noting that there is a relatively large reduction in carbon emissions embodied in trade in China's intermediate exports through route 2 (from 632.73 Mt in 2007 to 262.66 Mt in 2019). There is also a significant weakening of the effect of Japan's and South Korea's trade with China through route 2 on their emission reductions. Compared to trade with Japan, China's trade with South Korea has a more pronounced effect on domestic emissions through route 2. Japan's trade with South Korea through both routes 1 and 2 can contribute to Japan's reduction of carbon emissions. BEE was negative when trading bilaterally with Japan and Korea through complex GVCs (route 3), i.e., domestic emissions could be reduced by trading with Japan and Korea through route 3. However, the actual impact was limited due to its small absolute value. China's net transfer emissions to Korea were higher when trading with indirect trading partners through simple GVCs (route 4) and through complex GVCs (route 5), indicating that more processing trade in intermediate products takes place between China and Korea. The absolute value of BEE for each route in the bilateral trade between Japan and Korea was small, and the route that created relatively large impact was route 5. A separate analysis of each route showed that China's bilateral trade with Japan was primarily through final products trade and generated more carbon emissions in China, while China's bilateral trade with South Korea was primarily through GVCs for intermediate products trade and generated less carbon emissions in China.

4.3. Employment Embodied in Chinese–Japanese–Korean Trade

Figure 6 shows the employment embodied in bilateral trade between China, Japan, and Korea. There was a significant reduction in total employment embodied in bilateral trade between China, Japan, and Korea in 2009 due to the financial crisis. The slowdown in global economic and trade growth after the crisis has also had an important impact on trade-led labor employment [47]. At the same time that China's economic development has entered the "new normal", the economic growth rate has slowed down due to the downward pressure of the economy and the transformation and upgrading of the economic structure, and the labor force employment situation has become more severe. Regarding the employment embodied in China's exports to Japan and South Korea, although it rebounded in 2011, it soon began a steady decline, dropping to the lowest point in 2017 (7,832,000 and 4,663,000 respectively). It can be seen that, as the comparative cost advantage of low-skilled labor in China diminished, the model of "low-end embedding" for economic and social benefits became increasingly unsustainable [27]. Some researchers also argue that the reduction in the employment intensity of exports [48] has made exports less powerful in driving employment. Similar to the embodied carbon emissions, the embodied employment composition of bilateral trade between China, Japan, and Korea differs significantly. China's trade with Japan was driven by approximately 70% of employment in final products trade and approximately 30% in intermediate products, while the opposite was true for Japan and Korea. This was due to the high share of China's trade with Japan in the textile, clothing, and leather products manufacturing sector, which is dominated by trade in final products and is a labor-intensive manufacturing sector with a high employment intensity per unit of value-added. It is worth noting that the ability of China's final products exports to drive domestic employment (T1) has been declining continuously due to, among other things, China's weakening comparative cost advantage in low-skilled employment [27]. Thus, although the share of final products trade-driven employment in China's trade with Japan remained stable at around 70% from 2007–2019, total Chinese–Japanese trade-driven employment decreased. Chinese–Korean trade slowly decreased in the share of final products trade from 2007–2019, keeping the total employment driven by Chinese–Korean trade relatively stable.

Table 4 shows the sectoral and source structure of embodied employment in bilateral trade between China, Japan, and Korea in 2007 and 2019. Overall, trade embodied employment in Chinese and Korean exports was mainly derived from M2 (knowledge-intensive manufacturing) (both at around 50% in 2019), followed by M3 (capital-intensive manufacturing). In contrast, the embodied employment in Japan's export trade to China and South Korea was mainly derived from M1 (labor-intensive manufacturing) (61.23% and 51.24% in 2019). Specifically, the employment embodied in China's exports to Japan and South Korea remained the main source of employment in the exporting countries (with a share of about 90.70–94.78%), while the share of employment in the exporting countries was significantly lower in Japan and South Korea's exports to China (75.53% and 64.46%, respectively, in 2019). In terms of third-country employment embodied in exports, Japan and South Korea had a significantly higher share of third-country employment in exports to China (approximately 13.44% and 18.95%, respectively, in 2019) than China (4.32% and 3.68%). In addition to Japan and South Korea's deeper participation in GVCs, China's more complete industrial chain compared to Japan and South Korea was also an important factor in this phenomenon. As the only country with all industrial sectors in the United Nations Industrial Classification, China has the world's largest, most comprehensive, and most complete manufacturing system. In manufacturing production, China can better play the advantage of a stable local supply chain, which has obvious advantages for boosting employment in the country.

From 2007–2019, the share of domestic employment driven by China's exports decreased slightly but remained the main beneficiary (China's exports to Japan and South Korea $EL\_1 > 90\%$). The ability of China's export trade to Japan and South Korea to drive employment in importing and third countries increased. The current results also confirmed

Akira's [49] view that the increase in labor productivity weakened China's export-led domestic employment, however, with China's deeper participation in the division of labor in GVCs, the ability of China's foreign trade to drive employment in other countries increased. China created more jobs in bilateral trade between itself, Japan, and Korea. Imports from Japan and Korea also created many jobs in other countries (about 13.44% and 18.95% of employment in third countries, respectively, in 2019).

Figure 6. Employment embodied in bilateral trade between China, Japan, and Korea, 2007–2019.

Table 4. Sectoral and source structure of employment embodied in bilateral trade between China, Japan, and Korea (%).

Sector	**China to Japan**								**Japan to China**							
	Percentage by Sector		***EL*_1**		***EL*_2**		***EL*_3**		**Percentage by Sector**		***EL*_1**		***EL*_2**		***EL*_3**	
	2007	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**
A	1.91	1.78	95.04	91.63	2.59	4.92	2.37	3.45	1.33	1.15	71.92	74.07	11.48	10.44	16.61	15.49
M1	18.61	17.20	93.86	90.67	2.69	4.98	3.44	4.35	61.24	61.23	72.91	76.20	13.86	11.73	13.23	12.07
M2	48.18	49.66	93.25	88.90	2.80	5.14	3.95	5.96	23.97	20.86	67.68	70.22	15.80	13.17	16.52	16.61
M3	23.43	24.40	95.17	91.89	2.59	4.92	2.24	3.20	2.70	3.36	71.75	74.22	12.80	11.21	15.45	14.57
S1	2.47	2.57	94.93	90.82	2.59	4.96	2.49	4.22	3.75	4.90	73.98	76.31	12.40	10.60	13.62	13.09
S2	1.62	1.90	93.50	88.85	2.74	5.05	3.76	6.09	4.99	6.37	72.85	75.75	12.71	10.84	14.44	13.41
S3	3.28	2.01	95.50	92.43	2.56	4.89	1.94	2.68	1.33	1.60	76.96	80.74	11.40	9.72	11.64	9.53
O	0.50	0.48	93.97	90.37	2.71	5.01	3.33	4.63	0.13	0.67	74.41	76.70	12.27	10.54	13.31	12.76
GROSS	100.00	100.00	94.40	90.70	2.66	4.98	2.94	4.32	100.00	100.00	72.81	75.53	12.84	11.03	14.35	13.44
Sector	**China to Korea**								**Korea to China**							
	Percentage by Sector		***EL*_1**		***EL*_2**		***EL*_3**		**Percentage by Sector**		***EL*_1**		***EL*_2**		***EL*_3**	
	2007	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**
A	2.85	1.44	95.55	92.09	2.55	4.94	1.89	2.98	0.74	0.76	73.27	70.70	12.44	14.23	14.28	15.07
M1	13.65	12.76	94.22	91.07	2.68	5.01	3.09	3.92	2.97	1.84	65.50	59.51	16.49	19.75	18.02	20.74
M2	44.57	46.80	94.01	90.63	2.69	5.08	3.30	4.29	59.85	55.27	59.07	58.51	18.51	19.46	22.43	22.03
M3	31.75	30.52	95.73	92.83	2.53	4.89	1.74	2.29	24.20	24.63	61.67	62.38	15.35	16.34	22.97	21.28
S1	2.03	2.21	94.97	91.57	2.58	4.98	2.46	3.45	3.71	3.61	70.47	63.17	12.88	16.87	16.65	19.97
S2	2.98	3.25	93.96	89.30	2.67	5.13	3.37	5.58	2.16	2.59	65.10	64.67	15.30	16.27	19.60	19.06
S3	1.71	2.51	95.62	92.78	2.56	4.91	1.82	2.31	4.49	8.77	72.37	70.74	12.26	13.78	15.38	15.48
O	0.45	0.51	94.17	90.34	2.67	5.06	3.17	4.59	1.88	2.52	68.10	65.99	14.41	16.02	17.50	17.98
GROSS	100.00	100.00	94.78	91.33	2.62	5.00	2.60	3.68	100.00	100.00	66.94	64.46	14.70	16.59	18.35	18.95
Sector	**Japan to Korea**								**Korea to Japan**							
	Percentage by Sector		***EL*_1**		***EL*_2**		***EL*_3**		**Percentage by Sector**		***EL*_1**		***EL*_2**		***EL*_3**	
	2007	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**	**2007**	**2019**
A	0.92	1.01	79.29	76.02	10.75	9.55	9.96	14.44	0.85	1.24	71.05	66.75	12.97	12.93	15.99	20.32
M1	50.10	51.25	78.28	76.08	10.82	9.58	10.90	14.33	2.84	1.93	59.86	57.57	18.49	13.50	21.65	28.94
M2	35.37	32.08	77.83	72.52	10.89	9.75	11.27	17.73	42.88	35.59	58.86	57.34	18.20	13.70	22.94	28.96
M3	2.51	3.08	80.03	76.90	10.70	9.52	9.27	13.59	36.57	39.42	62.73	62.66	15.08	13.09	22.19	24.25
S1	4.14	4.87	78.78	77.05	10.79	9.54	10.43	13.41	4.16	4.77	63.51	65.21	15.60	12.96	20.88	21.82
S2	4.96	5.72	76.50	76.55	10.94	9.58	12.56	13.86	2.70	2.35	65.02	64.81	15.01	13.07	19.97	22.12
S3	1.32	1.39	79.99	81.67	10.72	9.40	9.29	8.92	7.95	12.07	71.09	70.97	12.52	12.71	16.39	16.32
O	0.10	0.24	77.55	77.41	10.88	9.56	11.57	13.03	2.06	2.63	66.34	66.72	14.76	13.02	18.89	20.26
GROSS	100.00	100.00	78.53	76.78	10.81	9.56	10.66	13.66	100.00	100.00	64.81	64.00	15.33	13.12	19.86	22.87

Note: *EL*_1 is employment in exporting countries in trade; *EL*_2 is employment in direct importing countries in trade; *EL*_3 is employment in third countries in trade.

Figure 7 shows how the employment embodied in China's exports to Japan and South Korea flowed along the global value chain in 2019. From left to right, it can be seen that Chinese exports created employment for 11,504,900 domestic laborers for production to meet the final demand of Japan and South Korea. Of these, 58% (6,678,300 people) were involved in producing final products and 42% (4,826,600 people) were involved in producing intermediate products. Domestic labor inputs are used to meet three types of final demand: direct importer to meet their final demand; re-exported to a third party; and returned home through re-import to satisfy domestic final demand. In the figure, 9.989 million domestic jobs were created to satisfy the final demand of direct trading partners, and 1.5159 million domestic jobs were created to satisfy the final demand of third countries. Among the five value chain paths, employment creation to meet the final demand of direct importing countries was realized through a single value chain (path 1) at 66.8%, through simple GVCs (path 2) at 33.2%, and very little through complex GVCs (path 3). Domestic employment involved in meeting the final demand of third countries was realized at 41.5% through simple GVCs (path 4) and 58.5% through complex GVCs (path 5). Ultimately, 7.013 million domestic jobs were created in production to meet final demand in Japan, and 4.436 million domestic jobs were created in production to meet final demand in Korea.

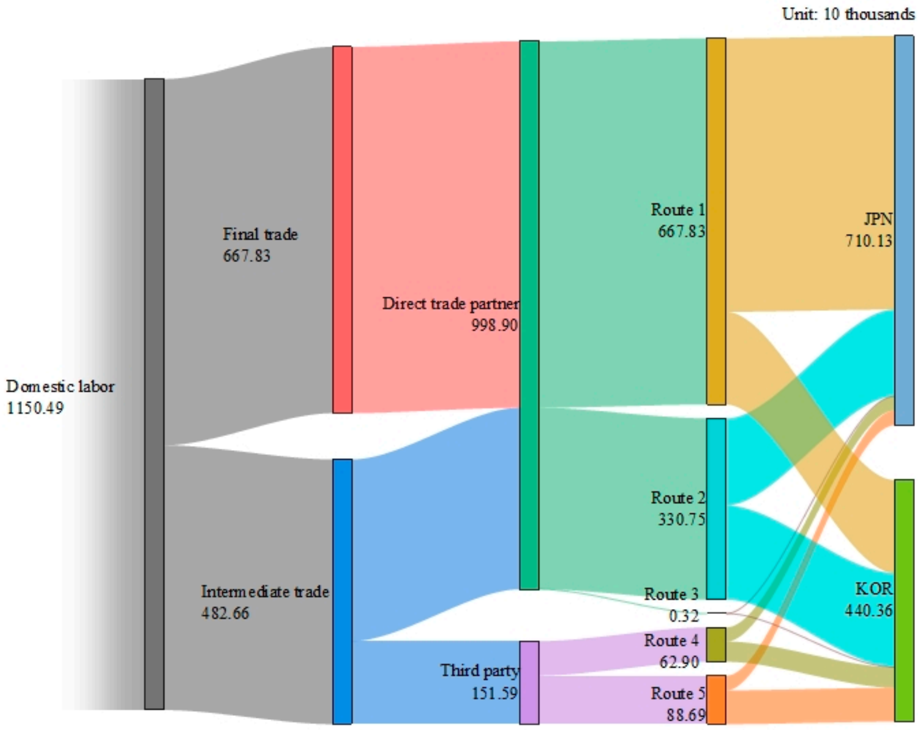

Figure 7. Flow of employment embodied in China's exports.

Table 5 presents the domestic embodied employment balance for bilateral trade between China, Japan, and Korea in 2007 and 2019. In terms of bilateral net employment transfer (total BEL), China is a net employment exporter to Japan and South Korea when they engage in bilateral trade. China's net employment exports to Japan and South Korea in 2019 were 5.005 million and 2.581 million, respectively, accounting for 24.5% of China's embodied net employment trade exports and making an important contribution to domestic job creation in China. It is important to note that the net employment exports of China decreased by 112,547,300 in 2019 compared to 2007. On the one hand, this may be due to the weakening of China's comparative cost advantage of low-skilled labor and the reduction in the employment intensity of exports, which weakens export-led employment capacity. On the other hand, it may be due to China's rising position in the GVC, with more imports of intermediate products, which implies employment in other countries. Japan was a net employment transferer to Korea, and its net employment transfer was 149,100. In terms of the value chain routes, the net employment transfer from bilateral trade between China and Japan was primarily determined by trade in final products through a single value chain, route 1, through which China and Japan created 4,263,000 jobs in China. In contrast, the net employment transfer in China's trade with Korea was dominated by three routes: trade in final products in a single value chain (route 1), and trade in intermediate products through a simple GVCs (route 2), creating 1,283,900 and 658,000 jobs in China, respectively. Direct bilateral trade with Japan and Korea through complex GVCs (route 3) created employment losses for China, but the negative effect was again limited due to the small absolute value. Japan's trade with Korea through routes 2, 4, and 5 created more jobs in Japan.

Table 5. The balance of domestic embodied labor in China, Japan and Korea, 2007 and 2019.

	BEL (10 Thousands)											
	Route 1		Route 2		Route 3		Route 4		Route 5		Total	
	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019
CHN to JPN	897.57	426.30	331.57	54.41	−0.03	0.27	49.79	6.30	55.71	13.77	1334.61	500.50
CHN to KOR	213.77	128.39	214.77	65.80	0.12	0.01	45.69	15.65	59.50	48.32	533.85	258.15
CHN to ROW	8029.77	3430.90	4482.54	−1036.12	12.89	4.80	53.06	64.02	5.92	−2.43	12,478.06	2333.14
GROSS	9141.11	3985.59	5028.88	−915.90	12.98	4.52	42.42	42.08	121.14	59.66	14,346.52	3091.79
JPN to CHN	−897.57	−426.30	−331.57	−54.41	0.03	0.27	49.79	−6.30	−55.71	−13.77	−1334.61	−500.50
JPN to KOR	−2.59	0.54	1.21	3.17	0.01	0.04	3.50	3.11	4.23	8.06	6.36	14.91
JPN to ROW	342.99	269.35	−1037.71	−934.79	1.81	1.64	14.78	24.77	−31.12	−40.85	−738.82	−729.42
GROSS	−557.17	−156.41	−1368.08	−986.03	1.86	1.95	61.07	27.96	−82.60	−46.56	−2067.06	−1215.01
KOR to CHN	−213.77	−128.39	−214.77	−65.80	−0.12	0.01	45.69	15.65	−59.50	−48.32	−533.85	−258.15
KOR to JPN	2.59	−0.54	−1.21	−3.17	−0.01	0.04	−3.50	−3.11	−4.23	−8.06	−6.36	−14.91
KOR to ROW	−82.57	−392.68	−242.32	−364.92	1.57	1.63	16.40	26.37	−36.93	−67.30	−376.65	−849.65
GROSS	−293.75	−521.61	−458.30	−433.89	1.44	1.60	65.60	45.12	−100.66	−123.68	−916.86	−1122.71

5. Conclusions and Policy Recommendations

In the context of economic globalization, this study analyzed the impact of Chinese–Japanese–Korean trade on carbon emissions and employment from 2007–2019 using the total export decomposition method based on the MRIO model. The main findings are as follows:

The results on carbon emission shows that China was the largest net exporter of trade embodied carbon emissions and was responsible for a large amount of carbon emissions in the trade among the three countries. In China's trade with Japan and Korea, the embodied carbon emissions of final products trade were relatively high, while the embodied carbon emissions in Japan and Korea trade were primarily intermediate products trade. The main source of embodied carbon emissions in China's exports to Japan and South Korea was domestic emissions, while emissions from importing countries and third countries were minimal. In contrast, the share of domestic emissions in Japan and South Korea's exports to China was significantly less than that of China, and there was a decreasing trend. The increase in carbon emissions from third countries was higher in Japan's trade with Korea.

From the findings on employment, China was the largest net exporter of trade embodied employment. In the bilateral trade among China, Japan, and South Korea, China's exports created more domestic jobs, while Japan and South Korea's exports created many jobs for other countries. The trade in final products created more employment in China, while the employment embodied in the trade of Japan and Korea was mainly derived from the trade in intermediate products. China's exports to Japan and South Korea drove a small reduction in domestic employment, although they remained the primary beneficiaries. Japanese and South Korean exports to China drove a small increase in domestic employment, much smaller than that of China. Japan's bilateral trade with Korea increased its ability to drive employment in third countries.

In general, trade between China, Japan and Korea led to an overall increase in emissions and employment in China and a decrease in Japan and Korea. For the different routes, China's trade through route 1 created a large amount of direct domestic employment at the cost of increased domestic emissions, while Japan and Korea's carbon reduction through route 2 was achieved at the cost of some job losses. However, it is worth noting that trade between Japan and South Korea through route 2 not only helped reduce Japan's direct emissions, but also promoted its employment, which is the ideal trade route. This study shows that there are specific value chain routes that can lead to a win–win situation of reduced emissions and increased employment in some bilateral trade.

Based on the results of our analysis, we have made some policy recommendations. International trade is closely related to domestic carbon emissions and employment, so policymakers need to take environmental impact into account when formulating policies to reduce emissions. Governments need to analyze environmental issues in balance with economic and social issues.

Developing countries, such as China, should continue to expand their openness to the outside world. This will drive their own economic development while creating more domestic employment demand. However, the results of the analysis of trade and carbon emissions show that as trade increases, a large amount of domestic carbon emissions are generated. Therefore, when promoting economic growth, the country must consider corresponding emission reduction policies to achieve green and sustainable economic development.

For developed countries, such as Japan and Korea, this study finds that trade in intermediate products, especially between developed countries, creates more domestic jobs. The trade between Japan and Korea through simple-GVCs helps reduce their direct emissions. Developing trade in intermediate products will help them to ensure low-carbon development while promoting more domestic employment. In addition, policymakers should use measures such as taxation to encourage the development of low-carbon technology enterprises. This will facilitate the return of manufacturing companies to create more jobs.

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