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Embodied Carbon Transfer in China's Bilateral Trade with Belt and Road Countries from the Perspective of Global Value Chains

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Abstract: In the context of global value chains (GVCs), the impact of the Belt and Road Initiative (BRI) on China's bilateral trade with Belt and Road countries (BRCs) is controversial. This study constructed a GVC accounting framework based on a multiregional input–output model, aiming to clarify the trends and transfer characteristics of the value added (VA) and the embodied carbon emissions (ECEs) in China–BRCs bilateral trade from 2000 to 2018 at the overall country, Belt and Road region (BRR), and typical country levels. The relevant results are threefold. (1) At the overall country level, the BRCs VA and ECEs imports and exports have shown overall increasing trends. (2) Most BRRs are net ECE exporters to China. Southeast Asia and Northeast Asia are the main ECEs destinations and sources. (3) In China–typical BRCs bilateral trade, China is a net ECEs exporter to most typical BRCs, and the net ECE transfers through route 1 (onefold value chain) are all positive, implying that route 1 can reduce ECEs in BRCs. These findings can help formulate policies and measures to reduce carbon emissions and provide a scientific basis for realizing the coordinated development of carbon emission reduction and economy in China and BRCs.

Keywords: Belt and Road Initiative; embodied carbon emissions; global value chain; multi-regional input–output model

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1. Introduction

Trade in intermediate goods is growing rapidly, and factor contents appear to travel back and forth across borders and reach final destinations through multiple value chain routes [1]. Moreover, based on the number of intermediate goods crossing borders, GVCs can be categorized as simple and complex GVCs, with different scales and trends [2]. Under the global value chain (GVC) system, the embodied carbon emission (ECE) from the production activities in any one country can affect and be affected by production activities in other countries [3]. Therefore, in the context of GVCs, it is important to clarify the ECE transfer process in international trade to achieve global carbon reduction.

In 2013, China proposed the Belt and Road Initiative (BRI) to promote international economic cooperation and facilitate regional economic integration [4–6]. Since its proposal, the BRI has received a wide response from Belt and Road countries (BRCs). The implementation of the BRI has assisted the participation of BRCs in global trade, effectively promoting their economic development [7]. However, because of the geospatial separation of production and consumption, ECEs have shifted along with the international trade of the BRCs, thereby exacerbating the unbalanced distributions of ECEs and economic benefits among the different Belt and Road regions (BRRs) [8]. In 2021, the China International Cooperation Committee for Environment and Development proposed that the BRI must balance the relationship between economy and climate [9]. Therefore, it is necessary to assess not only the economic impacts of the BRI but also the ECE transfers of the BRCs.

Recently, some scholars focused on certain BRCs to explore the influence of BRI on their ECEs as well as the characteristics of the ECE transfers [10–16], whereas other scholars divided the BRCs into different regions according to geographic location and conducted studies on the ECE trends of inter-regional trade [17–21]. In addition, some scholars analyzed the factors affecting the trade-ECEs of BRCs [15,19,22–24]. However, although the aforementioned studies on the issue of trade-ECEs of BRCs have achieved certain results, most of them utilize the total trade value accounting method to measure the ECEs, which not only fails to consider the ECE composition and sources but also fails to distinguish whether exported ECEs originate from domestic or foreign sources. This results in double-counting trade-ECEs and in an inability to accurately assess the real situation of a country's trade-ECE transfer [25,26].

The GVC theory is developing rapidly, and some scholars have begun to study ECEs from a GVC perspective [27–30]. Meng et al. [31] combined GVCs and embodied content to develop an accounting framework for tracking ECEs through eight value chain routes. Miroudot and Ye [32] broke down value added in total exports at the national and bilateral levels, which can track the destination of VA flows embodied in gross exports. Their innovative research is relevant to the study of ECEs from a value chain perspective. Since the implementation of the BRI, BRCs have become deeply involved in GVCs. Ali et al. [33] examined the impacts of the participation in GVCs and the participation mode of 82 BRCs on their ECEs from 2000 to 2018 based on the GVCs and evaluated the quality of the economic environments of the BRCs. Shi et al. [34] focused on carbon-intensity BRCs to explore whether and how the GVC participation mode affected their carbon intensities. Zhang et al. [35] investigated the ECE transfer of BRCs based on GVCs. Xiong et al. [36] categorized GVCs as simple and complex according to the number of times the intermediates cross borders and explored the impacts of the two routes on the ECE transfer of BRCs. However, although the above studies analyzed the characteristics of the ECE transfer of BRCs from the perspective of GVCs, only a few have measured and analyzed the ECE sources and transfer routes based on the GVC decomposition framework. Moreover, many studies have defined value chain routes mainly from a single perspective of the ECE sources and destinations or the number of times ECEs cross borders. This study combines the ECE sources and destinations and different types of GVC activities to investigate more thoroughly the ECE transfer issues of BRCs by combining different value chain routes.

Against this backdrop, this study addresses the following questions. What are the changing trends of the value added (VA) and the ECEs in the China and BRC trade? How do ECEs in the VA trade flow along GVCs among BRRs? What is the situation of ECE transfer in China's bilateral trade with the BRCs? What are the different impacts of different value chain routes on ECE transfer? Answering these questions can help formulate policies related to carbon emission reduction and realize the coordinated development of carbon emission reduction and economic growth. Therefore, based on the total export decomposition method of GVCs, in this study, we decomposed and measured the VA and ECEs in the China and BRC trade in detail from 2000 to 2018 and analyzed their characteristics and changing trends. Subsequently, based on the above decomposition results, the BRCs were divided into nine regions according to geographical location, and the ECE transfer in the BRRs was tracked. Finally, 10 high-carbon-emitting countries among the BRCs were selected as typical countries to analyze in detail the ECE transfer in the China and typical BRC trade as well as the impacts of five value chain routes on ECEs.

This study makes the following contributions: First, it constructs an accounting framework for tracking the ECE transfer in the China and BRC trade based on the total export decomposition method of GVCs. By employing this framework, this study measures the ECEs of BRCs and BRRs, clarifies the sources and destinations of ECEs in the China and BRC trade, and traces the ECE transfer in BRRs. Meanwhile, the framework is not only applicable to this study but also to studies related to the transfer of trade-ECE in other countries or regions when data are available. Second, this study constructs five different value chain routes that consider both the sources and destinations of ECEs from trade and GVC activities when analyzing the ECE transfer issue in the BRCs. The results of this study not only elucidate the influence of various value chain routes on the ECEs of the BRCs but also provide a scientific basis for carbon reduction in the BRCs.

2. Methods and Data

2.1. Decomposition of ECEs in Exports Based on VA Trade

The methodology of this study was based on a multi-region input–output (MRIO) model. The MRIO model can reflect the inputs and uses of each country in the production process and track the trade-embodied content along the GVCs. It has been typically utilized for investigating the VA and the ECEs of inter-country (inter-regional) trade [37–39]. Equation (1) is the MRIO model with G countries (regions) based on the equilibrium equation:

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

where X_s is the total output vector for country s, A_{ss} is the matrix of the direct consumption coefficients for country s, and Y_{ss} is the final domestic demand of country s. $A_{rs} = Z_{rs}/(\hat{X}_s)$ denotes the direct consumption coefficient matrix, $\hat{X}_s$ denotes the diagonal matrix of the composition of the total output of country s, and Y_{sr} represents the final goods exports from country s to country r. Equation (1) can be expressed as follows:

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

where

$$\begin{bmatrix} B_{11} & B_{12} & \dots & B_{1G} \\ B_{12} & B_{22} & \dots & B_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ B_{G1} & B_{G2} & \dots & B_{GG} \end{bmatrix} = \begin{bmatrix} I - A_{11} & -A_{12} & \dots & -A_{1G} \\ -A_{12} & I - A_{22} & \dots & -A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{G1} & -A_{G2} & \dots & I - A_{G} \end{bmatrix}^{-1}$$

denotes the global Leontief inverse matrix.

Defining VA_s as the vector of VA for each sector of country s, the vector of VA coefficients is $V_s = VA_s(\hat{X}_s)^{-1}$, where $\hat{X}_s$ is the diagonal matrix of the total output vector. In this study, the total exports of country s to country r are decomposed into the following 17 VA and double-counting terms according to the total export decomposition method proposed by Wang Z et al. [26]:

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

In Equation (3), "#" denotes the chunked matrix dot product; country t is a third party different from countries s and r; V_t is the vector of VA coefficients for that country; $L_{ss} = (I - A_{ss})^{-1}$ is the local Leontief inverse matrix for country s (similarly); X_r is the vector of total output for country r; and E_{r*} is the vector of total exports for country r. In Equation (3), four terms, namely T10, T11, T14, and T17, are duplicate statistics, whereas the remaining thirteen terms are the real VA embodied by exports corresponding to actual production activities. With Equation (3), we can obtain the results on the VA in both the China–BRCs and the China–BRRs trade from 2000 to 2018.

Depending on the source, VA can be categorized as the domestic VA, T1–T9; the importing country's VA, T12–T13; and the third-party VA, T15–T16.

Depending on the type of export, VA can be categorized as VA embodied in trade in intermediate goods, namely T2–T6, T8–T9, T13, and T15–T16; and VA embodied in trade in final goods, namely T1, T7, and T12.

The meanings of the 17 items are as follows:

T1: Domestic VA in the form of final goods exported and absorbed by direct trading partners;

T2: Domestic VA in the form of intermediate exports absorbed by direct trading partners;

T3: Domestic VA exported to direct trading partners in the form of intermediate goods and then exported to third parties in the form of intermediate goods and absorbed by third parties;

T4: Domestic VA exported to direct trading partners in the form of intermediate goods and then exported to third parties by final goods;

T5: Domestic VA exported to direct trading partners by intermediate goods and then exported by intermediate goods to third parties and utilized for their exports of final goods;

T6: Domestic VA exported to the direct trading partner by intermediate goods, then intermediate goods exported to a third party, and ultimately back to the direct trading partner and absorbed by the direct trading partner;

T7: Domestic VA exported to direct trading partners by intermediate goods and returned to the home country by final goods absorbed by the home country;

T8: Domestic VA exported to direct trading partners by intermediate goods, then exported to third parties, and returned to the home country by final goods absorbed by the home country;

T9: Domestic VA exported to direct trading partners by intermediate goods and returned to the home country by intermediate goods absorbed by the home country;

T10: Domestic VA double-counted in trade in the statistics of final goods;

T11: Domestic VA double-counted in trade in the statistics of intermediate goods;

T12: VA of trading partner countries whose exports are absorbed by direct trading partners by final goods;

T13: VA in trading partner countries whose exports are absorbed by direct trading partners by intermediate goods;

T14: Double-counted foreign VA in the accounting for trade of final goods;

T15: VA in other countries whose exports are absorbed by direct trading partners by final goods;

T16: VA in other countries whose exports are absorbed by direct trading partners by intermediate goods;

T17: Double-counted foreign VA in the accounting for trade of intermediate goods.

Regarding the ECE calculation, unlike the total VA accounting method, this study calculates the ECE exports by the actual VA from trade. Of these 17 components, 13 components, namely T1–T9, T12–T13, and T15–T16, are VA in the total exports from region s to r, while T10–T11, T14, and T17 are double-counting terms that do not involve production and are not related to ECEs. Therefore, the decomposition of ECEs in exports involves 13 VA components. $F_s = CE_s(\hat{X}_s)^{-1}$ is the direct carbon emission intensity of region s, where CE_s is the carbon emission vector of region s. Replacing F_s with the direct VA coefficients in Equation (3) yields EEC_{sr}, which is decomposed into 13 terms:

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

With Equation (4), we can obtain the impact of the ECE on both the China–BRCs and the China–BRRs trade from 2000 to 2018. In Equation (4), T1–T9 are the domestic ECEs in exports, of which T1–T6 are the domestic ECEs absorbed abroad, and T7–T9 are the domestic ECEs exported and then returned. T10–T11 are the ECEs of the direct-importing countries, and T12–T13 are the ECEs of third parties. Thus, we can obtain the ECE source structure from exports. The domestic ECEs absorbed by foreign countries reflect the real amount of export ECEs, which is entirely driven by foreign final demand and facilitates the allocation of responsibility for ECEs. Meng et al. [31] argued that ECEs from total bilateral trade must be tracked through domestic ECEs absorbed abroad. Therefore, this study focuses on the gross domestic ECEs absorbed abroad and herein discusses how they are absorbed abroad along five value chain routes. The five value chain routes are rearranged and divided by EEX_{sr} (denoted by T1–T6 in Equation (4)), which is defined based on the decomposition framework proposed by Wang Z et al. [3]:

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

GVC activities are production-oriented, and their factor contents are traded across national borders. Based on the number of times the intermediates cross borders, they can be further categorized as simple (crossing borders once) and complex (crossing borders at least twice) GVCs. This study considers the number of times a factor content crosses national borders as well as its final destination to delineate the value chain routes. The criteria for delineating the value chain routes are listed in Table 1.

Table 1. Five value chain routes.

Value Chain Routes	Meaning
Route 1	Onefold value chain Factor contents of final exports cross national borders once and are absorbed by direct trading partners
Route 2	Simple global value chain Factor contents of intermediate exports cross national borders once and are absorbed by direct trading partners
Route 3	Complex global value chains Factor contents of intermediate exports cross borders twice and are absorbed by direct trading partners
Route 4	Simple global value chain Factor contents of intermediate exports cross national borders once and are absorbed by third parties
Route 5	Complex global value chains Factor contents of exports of intermediates cross national borders at least twice and are absorbed by third parties

Route 1 (onefold value chain) is trade associated with traditional final goods, and route 2 through route 5 are trade associated with GVCs. Route 2 (absorption by direct trading partners in simple GVCs) and route 4 (absorption by third parties in simple GVCs) are simple GVC routes. Route 3 (absorption by direct trading partners in complex GVCs) and route 5 (absorption by third parties in complex GVCs) are complex routes.

2.2. Data Sources

Comparing with other widely used databases, we chose the Organization for Economic Cooperation and Development (OECD) because it includes 67 economies covering 45 sectors, among which 40 economies have signed the BRI with China. Moreover, the OECD data cover a long-time span from 1995 to 2018 and include the input–output data and CO_2 emission data. Because the data sample includes China and 40 BRCs, the amount of data is relatively large; therefore, to facilitate the discussion and analysis, in this study, we divided the 40 BRCs into nine regions according to geographical location (Northeast, Southeast, Central, South, and West Asia; North Africa; Russia; Europe; Oceania; and the Americas). From these nine regions, 10 countries with high ECEs (India, Vietnam, Italy, South Africa, Russia, Turkey, Kazakhstan, South Korea, Peru, and New Zealand) were selected. The regional division of the BRCs is presented in Table 2. The software used to derive the results is MATLAB R2022a.

Table 2. Breakdown of BRCs situation.

Region	Nations	Quantities
Northeast Asia	Korea *, Russia *	2
Central Asian	Kazakhstan *	1
South Asia	India *	1
Southeast Asia	Singapore, Malaysia, Indonesia, Myanmar, Thailand	10
West Asia and North Africa	Morocco, Tunisia, Turkey *, Israel, Saudi Arabia	5
South Africa	South Africa *	1
European	Slovakia, Poland, Malta, Portugal, Romania, Luxembourg, Greece, Slovenia, Cyprus, Lithuania, Latvia, Italy *, Czech Republic, Hungary, Croatia, Estonia, Bulgaria	17
America	Peru *, Costa Rica	2
Oceania	New Zealand *	1

Note: Countries marked with an asterisk are typical BRCs.

3. Results and Discussion

3.1. Overall Analysis of VA and ECEs in the Trade between China and BRCs

Figure 1 shows the VA changes in the trade between China and the BRCs from 2000 to 2018. Among them, China's VA grew rapidly from 2000 to 2008, with the VA exports increasing from USD 4.07 billion to USD 36.73 billion and the VA imports increasing from USD 5.64 billion to USD 31.57 billion. Owing to the global economic crisis, the VA of both imports and exports declined significantly during 2008–2009. The year 2010 saw a rebound and steady growth, with minor fluctuations during 2014–2016 and steady growth during 2017–2018. Furthermore, the share of exported intermediates in China's trade with BRCs reached 55.25–64.52%, and the share of imported intermediates reached 75.62–82.35% during 2000–2018. This result is in agreement with Damoah K et al. [40], who found that trade in intermediate goods accounted for approximately 71% of the total VA exports and 64% of the total VA imports of the BRCs and that the BRCs exported more intermediate goods to China in their bilateral trade with China. This may be due to the fact that because of the implementation of the BRI, China imported actively a large number of intermediate goods from BRCs to stimulate their export potential, striving to provide development opportunities for BRCs. In terms of the domestic VA component (the sum of the orange, green, and purple parts in Figure 1), China's domestic VA growth rate was 26.73%, driven by the final demand of the BRCs during 2013–2018, while China's final demand led to a 46.83% growth rate of domestic VA in the BRCs. This shows that since the implementation of the BRI, China has endeavored to promote the "connectivity" of the BRCs by expanding the scale of its imports and exports.

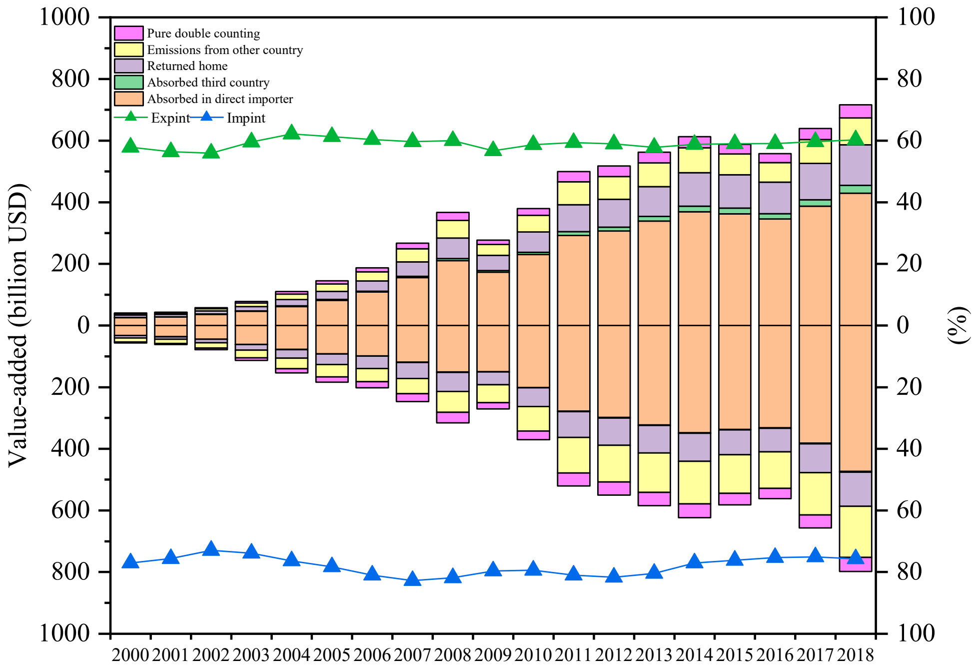

Figure 1. Changes in value-added (VA) import and VA export between China and the Belt and Road countries (BRCs) during 2000–2018. The upper-half axis shows China's VA exports, and the lower-half axis shows China's VA imports.

Using Equation (4), the ECE in a country's exports, divided into 13 parts, can be estimated. The changes in China's ECE trade with the BRCs from 2000 to 2018 are shown in Figure 2. China joined the WTO in 2001; since then, the volume and quality of its economy have improved significantly, and the ECEs of China and the BRCs have changed significantly. From 2000 to 2008, China's ECE exports to the BRCs increased by 337.48%. During 2008–2009, the global financial crisis led to a brief decline in China's ECE exports, which began to rebound during 2009–2010. From 2011 to 2018, China's ECE exports showed a relatively stable trend. From an import trade perspective, China's ECE imports showed an overall upward trend from 2000 to 2015, increasing from 95.68 to 447.05 Mt. China's ECE imports fluctuated slightly in 2016 and then grew steadily during 2017–2018. Since the implementation of the BRI, China has actively expanded its scale of imports and exports to the BRCs. In terms of domestic ECEs (the sum of the orange, green, and purple parts in Figure 2), China's final demand during 2013–2018 led to an overall ECE increase in the BRCs. The domestic ECEs of the BRCs increased from 226.80 to 286.19 Mt during 2013–2018, with a growth rate of 26.18%. The final demand of the BRCs resulted in China's domestic ECEs reaching 509.94–565.50 Mt during 2013–2018, which is 1.52–1.91 times more than China's final demand, resulting in ECEs generated by BRCs. This result is in agreement with Xiong et al. [36], who found that the ECEs exported by China to the BRCs were 2.04 times those imported from the BRCs in 2017, suggesting that China has been generating more ECEs to meet the final demand of the BRCs. This is consistent with the economic development situation. Since the implementation of the BRI, China's economic contribution to the BRCs has been greater than the latter's contribution to China, which has led to the growth of China's domestic ECEs.

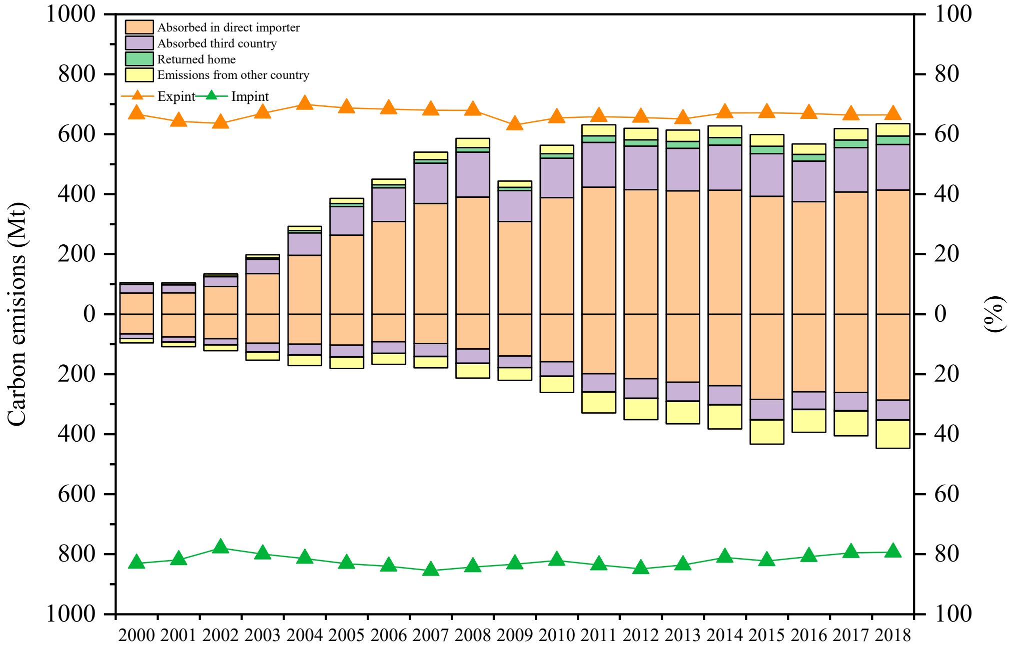

Figure 2. Changes in China's embodied carbon emission (ECE) import and export with the BRCs during 2000–2018. The top-half axis shows China's ECE exports, and the bottom-half axis shows China's ECE imports.

3.2. Analysis of VA and ECEs between China and the BRRs

Figure 3 shows the VA of China's trade with the nine BRRs. Among the nine BRRs, Northeast Asia, Southeast Asia, and Europe are the top three regions for China's VA trade. Regarding China's VA trade with BRCs from 2000 to 2018, 70.23–83.16% of the VA trade was generated by trade with these three regions. Northeast and Southeast Asia are the top two regions in terms of China's VA trade, probably due to the fact that Northeast and Southeast Asia, as China's neighboring regions, have convenient diplomatic and trade exchanges, which help promote bilateral trade. While Europe is the third-largest region for China's VA trade, this may be due to the fact that the opening of the China–Europe liner train has improved the transportation infrastructure between China and Europe, shortened the transportation time, and reduced the trade cost, thereby increasing the trade flow between China and Europe [41]. Since the implementation of the BRI, besides the three regions of Northeast Asia, Southeast Asia, and Europe, China has also been proactively expanding its import and export trade with other BRRs. On the one hand, the proportion of China's export trade to South Asia, Oceania, and the Americas is increasing; the growth rate of China's VA export to South Asia is 58%, ranking first among the BRRs and growing from USD 61.63 billion in 2013 to USD 97.27 billion in 2018. On the other hand, China's VA imports to West Asia and North Africa, Oceania, South Africa, and other regions has grown at a larger rate. In 2013, China's VA imports to West Asia and North Africa amounted to USD 54.48 billion and grew to USD 79.82 billion in 2018, with West Asia and North Africa surpassing Europe, making it only the third-largest region in terms of China's VA imports.

The ECE transfers between China and the BRRs in 2000 and 2018 are shown in Figure 4a,b, respectively. In 2000, the world's total ECE exports amounted to 3742.61 Mt, and the proportion of ECE outflows from China and BRRs was 79%. Northeast Asia, Southeast Asia, Europe, and China were the main ECE outflow regions. Compared to 2000, the total global ECE export (6872.70 Mt) increased by 84% in 2018, and the proportion of ECE outflow from China and the BRRs (76%) was relatively stable. The main regions of ECE outflows are still Northeast Asia, Southeast Asia, Europe, and China. However, China and Southeast Asia surpass Northeast Asia and are the top two regions in terms of ECE exports. China's ECE exports grew from 105.17 Mt in 2000 to 634.96 Mt in 2018—a fivefold increase. Specifically, China's ECEs in 2000 went to Northeast Asia (112.82 Mt), Southeast

Asia (46.12 Mt), and Europe (44.58 Mt). Compared to 2000, the increase in China's ECE exports to Southeast Asia (242.04 Mt) in 2018 was fourfold, surpassing Northeast Asia as the top destination for China's ECE exports. The increase in China's ECE exports to South Asia (91.67 Mt) was twofold, surpassing Europe and making it the third-largest destination for China's ECE exports. Conversely, China's ECE imports with BRRs accounted for 43% of the world's total ECE imports in 2000. Europe, Southeast Asia, Northeast Asia, and China were the main ECE import regions. Compared with 2000, Southeast Asia, China, Europe, and Northeast Asia were still the main ECE import regions for China and the BRRs in 2018. China's ECE imports were particularly prominent, increasing from 95.68 Mt in 2000 to 447.05 Mt in 2018—a fourfold increase—and surpassing Europe, which became the second-largest region in ECE imports. This shows that although China is a net ECE outflow country, it also bears the problem of ECE transfer from the BRRs. The BRI proposed by China aims to achieve a win–win cooperation rather than unilateral ECE transfer to BRCs.

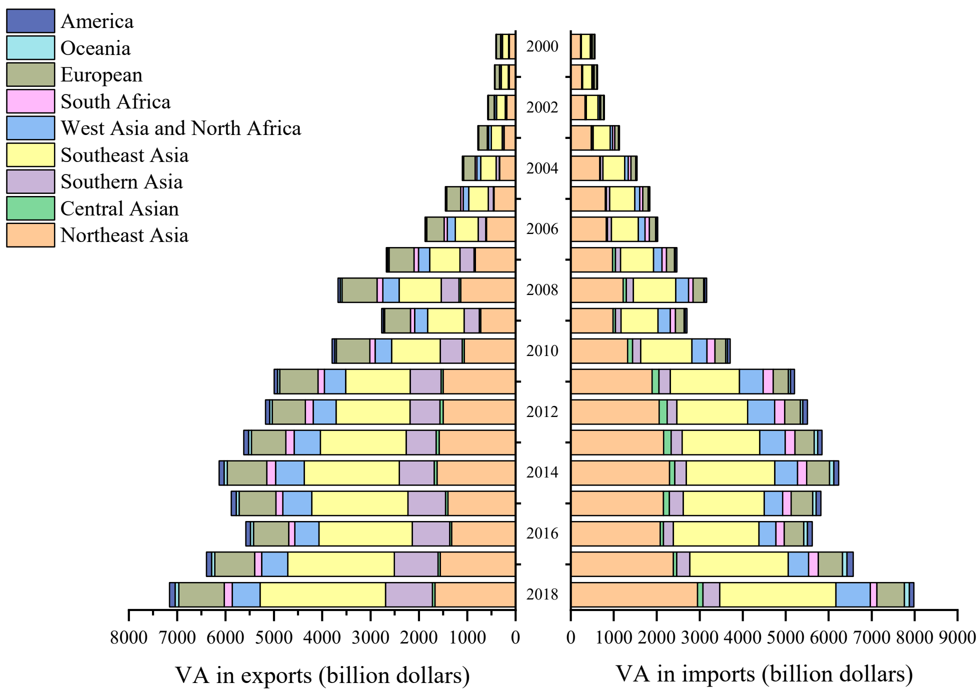

Figure 3. VA trade between China and the BRRs. VA exports shown on the left; VA imports shown on the right.

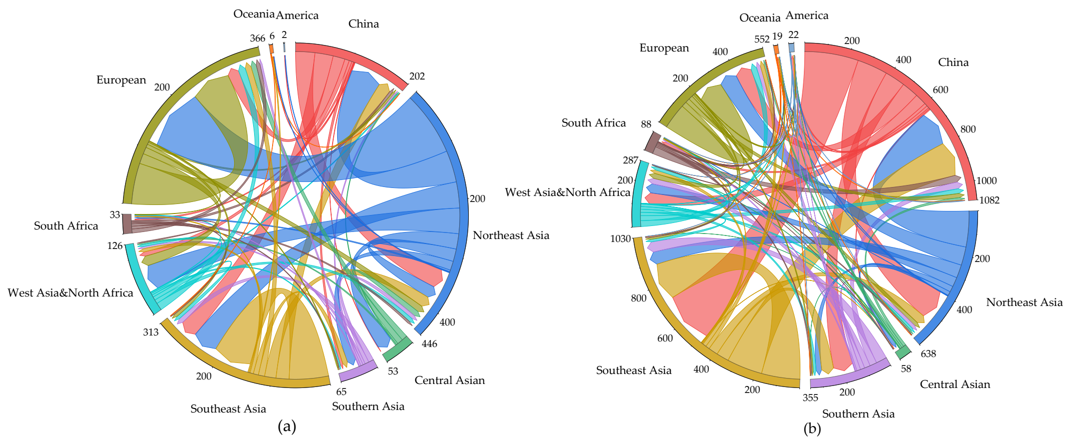

Figure 4. ECE transfers between China and the Belt and Road regions (BRRs). (**a**) ECE transfers in 2000; (**b**) ECE transfers in 2018.

Using Equation (5), GVC activities can be further categorized as five value chain routes. Figure 5 shows the share of the five value chain routes in China's ECE trade with the BRRs in 2018. The share of China's ECE exports to each BRR is shown in Figure 5a. Regarding China's domestic ECEs absorbed by the BRRs, China mainly exported ECEs to the BRRs through route 1 (one fold value chain) and route 2 (absorbed by direct trading partners in simple GVCs), whereas the proportion of ECEs exported through route 3 (absorbed by direct trading partners in complex GVCs) was less than 1%. Regarding China's domestic ECEs absorbed by third parties, the share of China's ECEs exported to Northeast Asia, Southeast Asia, and Europe through route 4 (absorbed by third parties in the simple GVC) and route 5 (absorbed by third parties in the complex GVC) reached 22.23–38.52%, thereby being more significant than those exported to the other BRRs. The share of China's ECE imports from each BRR is shown in Figure 5b. Unlike exports, China's ECE imports from each BRR relied more on the simple GVC activities of route 2. For example, Northeast Asia—China's main import region—accounted for 66.26% of China's ECEs from Northeast Asia through route 2 in 2018, which is much higher than those of the other routes. This finding is in agreement with Xiong et al. [36], who found that the share of China's domestic ECEs exported to BRRs through onefold value chain routes and simple GVC routes was 79.86% in 2017, whereas that of ECEs imported through simple GVC routes was 68.82%.

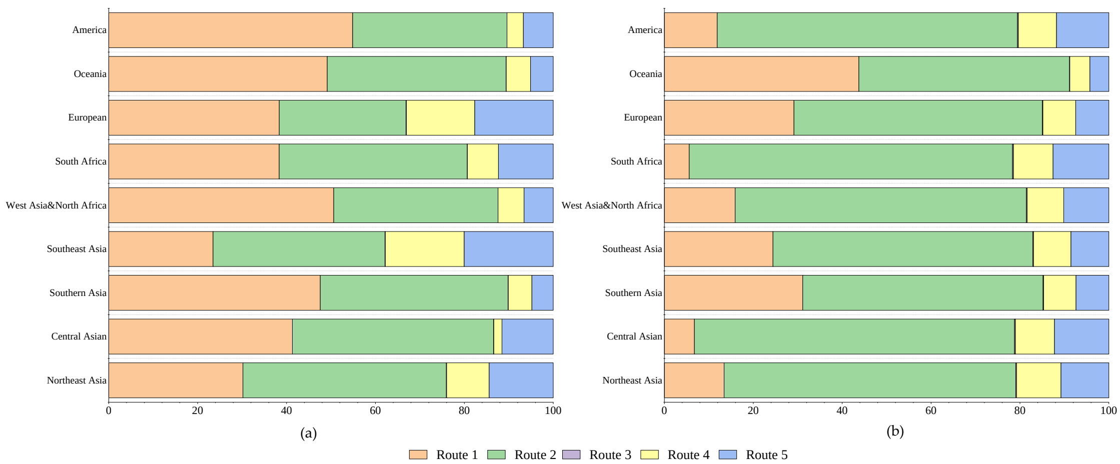

Figure 5. Shares of five routes in China's ECE trade with the BRRs. (**a**) ECE exports in 2018; (**b**) ECE imports from each BRR in 2018.

3.3. Analysis of ECEs in China's Trade with Typical BRCs

Table 3 shows the ECE transfers in China–typical BRCs bilateral trade in 2000 and 2018. In 2000, China's ECE exports to typical BRCs (62.62 Mt) accounted for 60.12% of the total ECE exports to the BRCs (105.17 Mt), whereas China's ECE imports from typical BRCs reached 70.34 Mt, accounting for 74.02% of the total ECE imports from BRCs (95.68 Mt). In 2018, China's ECE imports and exports with typical BRCs amounted to 367.77 and 288.64 Mt, a six- and four-times increase, respectively, compared with those in 2000. Regarding exports, China's ECE exports to South Korea were the highest in 2000 and much higher than those of other typical BRCs. In 2018, the situation did not change; however, it was less prominent than in 2000. After the implementation of the BRI, China's ECE exports to other typical BRCs grew rapidly. Among them, China's ECE exports to India are particularly prominent, having grown 18 times from 4.73 Mt in 2000 to 91.67 Mt in 2018. Regarding imports, South Korea surpassed Russia as the country importing the most ECEs from China in 2018. This may be due to the geographical proximity of China and South Korea and strong complementarities in natural resources, labor resources, industrial structure, and trade cooperation between the two sides under the promotion of the BRI, which has led to an increase in ECEs [42]. In terms of net ECE transfer, China is a net ECE importer in trade with Russia, South Korea, South Africa, and Kazakhstan, which is conducive to China's ECE reduction. Conversely, China has always been a net ECE exporter in its bilateral trades with India, Vietnam, Italy, Turkey, Peru, and New Zealand. This means that China generates more ECEs in these bilateral trades, which is conducive to helping the BRCs reduce carbon emissions.

Table 3. ECE transfer between China and typical Belt and Road countries (BRCs).

Bilateral Trade	2000 (Mt CO_2)			2018 (Mt CO_2)		
	Export	Import	Net Transfer	Export	Import	Net Transfer
CHN–IND	4.73	2.92	1.81	91.67	31.54	60.13
CHN–VNM	3.04	0.72	2.32	58.25	33.28	24.97
CHN–ITA	12.13	1.93	10.21	29.14	6.50	22.64
CHN–ZAF	2.79	4.88	−2.09	13.93	33.08	−19.15
CHN–RUS	4.91	32.80	−27.88	41.91	60.38	−18.47
CHN–TUR	3.33	0.39	2.95	17.16	4.70	12.45
CHN–KAZ	0.57	2.44	−1.87	4.76	12.24	−7.47
CHN–PER	0.58	0.19	0.39	9.64	2.56	7.08
CHN–KOR	29.21	23.42	5.79	95.30	101.41	−6.11
CHN–NZL	1.32	0.65	0.67	6.00	2.94	3.06

Figure 6a shows the ECE flow from China's exports to typical BRCs along the GVC in 2018. The domestic ECEs from China's exports amounted to 325.88 Mt, of which 34% (112.09 Mt) and 66% (213.79 Mt) were used in the production of final and intermediate products, respectively. In terms of the final destination, domestic ECEs were absorbed by direct-importing countries (247.83 Mt) and third parties (78.06 Mt). Domestic ECE exports can be further categorized into five value chain routes. Among these, 45.2% of China's domestic ECEs absorbed by direct-importing countries is exported through route 1 (onefold value chain), 53.6% is exported through route 2 (absorbed by direct trading partners in simple GVCs), and 0.1% is exported through route 3 (absorbed by direct trading partners in complex GVCs). Of China's domestic ECEs absorbed by third parties, 43.8% was exported through route 4 (absorbed by third parties in a simple GVC), and 56.2% was exported through route 5 (absorbed by third parties in a complex GVC). The top three final demand destinations for China's domestic ECE exports were India (83.45 Mt), South Korea (80.84 Mt), and Vietnam (50.67 Mt). Figure 6b shows the flow of China's ECEs imported from typical BRCs along the GVC in 2018. The first column shows that the top three ECE sources for import by China were South Korea, Russia, and South Africa. Considering the value chain routes, China imported foreign ECEs mainly through route 2 (152.81 Mt), which accounted for 80.6% of the ECEs imported by China, whereas the remaining 19.2% was imported through route 1, and less than 1% of the ECEs was imported through route 3. Third parties imported 45.85 Mt of ECEs, of which 47.4% was imported through route 4 and 52.6% through route 5.

Table 4 lists the net ECE transfer between China and typical BRCs through five value chain routes in 2018. Overall, the net ECE transfer between China and typical BRCs was dominated by route 1 and route 2 (absorbed by direct trading partners in simple GVCs), followed by route 4 (absorbed by third parties in simple GVCs) and route 5 (absorbed by third parties in complex GVCs), whereas the impact of route 3 (absorbed by absorbed by direct trading partners) had a very limited impact. Specifically, in China–typical BRCs trade, the net ECE transfers through route 1 are all positive, implying that the final demand of BRCs increases China's domestic direct carbon emissions. For example, in trade with India, the net ECE transfer through route 1 reaches 30.82 Mt, which is much higher than the ECE transferred through other value chain routes. Conversely, in trade with typical countries other than Italy, the net ECEs transferred through route 3 are all negative, thereby reducing China's domestic direct carbon emissions. For route 2, in trade with Russia, South Africa, Kazakhstan, and South Korea, ECE transfers dominate, reducing China's domestic direct carbon emissions. The impacts of route 4 and route 5 vary somewhat across bilateral trade. For example, the China–Vietnam bilateral trade is dominated by the two GVC routes, namely route 4 and route 5, which help Vietnam reduce its direct carbon emissions. Conversely, in trade with Russia, South Africa, and Kazakhstan, the net ECE transfer through route 4 and route 5 is negative, which can help China reduce direct carbon emissions. The above results show that China is not unilaterally transferring the responsibility of ECEs to the BRCs in the implementation of BRI and that specific value chain routes can reduce the ECEs of the BRCs while promoting the economic growth of the BRCs.

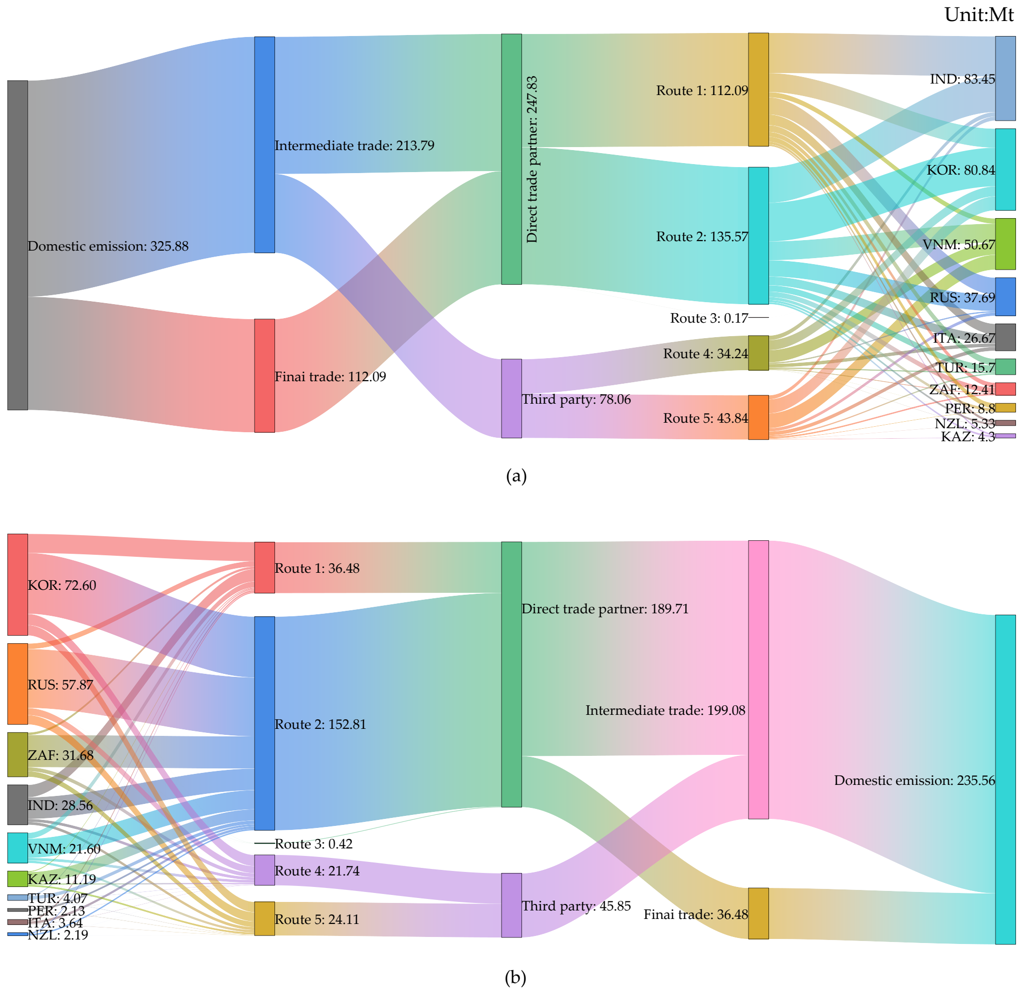

Figure 6. ECE flows in China's trade with typical BRCs along the global value chains (GVCs), 2018. (**a**) China's exports; (**b**) China's imports.

Table 4. Net ECE transfer between China and typical BRCs along five routes.

Bilateral Trade	Route1 (Mt CO_2)	Route 2 (Mt CO_2)	Route 3 (Mt CO_2)	Route 4 (Mt CO_2)	Route 5 (Mt CO_2)
CHN–IND	30.82	19.83	−0.02	2.36	1.90
CHN–VNM	0.98	4.98	−0.01	10.16	12.96
CHN–ITA	9.35	6.82	0.03	3.26	3.57
CHN–ZAF	2.99	−17.79	−0.07	−1.95	−2.45
CHN–RUS	12.98	−26.01	−0.10	−3.65	−3.41
CHN–TUR	5.77	3.72	−0.0005	1.03	1.11
CHN–KAZ	1.02	−6.12	−0.02	−0.91	−0.87
CHN–PER	4.76	1.58	−0.004	0.05	0.29
CHN–KOR	5.28	−5.37	−0.06	1.95	6.44
CHN–NZL	1.66	1.11	−0.0001	0.19	0.18

4. Conclusions

In the context of GVCs, this study constructed a GVC-accounting framework based on a multiregional input–output model and conducted research on the VA and ECEs in China–BRCs trade at three levels: the overall country, BRRs, and typical BRCs. First, the VA and ECEs of China's trade with BRCs were measured in detail. Then, based on the above decomposition results, the VA and ECEs in the China–BRR trade were analyzed by source, destination, and value chain routes. Finally, the ECE transfer between China and typical BRCs was tracked at the bilateral level along different value chain routes. The conclusions are as follows:

(1) At the overall country level, the VA and ECEs in China's trade with the BRCs showed upward trends during the study period. Regarding VA trade, China's VA grew rapidly from 2000 to 2008, with the VA imports and exports increasing by 459.76% and 802.45%, respectively. Owing to the global economic crisis, the VA of both imports and exports declined significantly during 2008–2009. The years 2010–2018 saw a rebound and steady growth. Regarding ECE, China's ECE exports to the BRCs increased by 337.48%. During 2008–2009, the global financial crisis led to a brief decline in China's ECE exports, which began to rebound during 2009–2010. From 2011 to 2018, China's ECE exports showed a relatively stable trend. From an import trade perspective, China's ECE imports showed an overall upward trend from 2000 to 2018;

(2) Among the BRRs, China, Northeast Asia, and South Asia had net ECE outflows. Southeast Asia and Northeast Asia are both the main ECE destinations and sources for China. Regarding value chain routes, their impact on the ECEs varied between China's imports and exports. For example, China's domestic ECEs, due to the final demand of the BRRs, flow mainly through route 1 and route 2. However, the ECEs from the BRRs, due to China's final demand, flow mainly through route 2. Specifically, 21.61% of China's ECEs flow to Northeast Asia, 38.12% to Southeast Asia, 14.44% to South Asia, and 11.98% to Europe through route 1 and route 2. Through route 2, the ECEs from Northeast Asia, Southeast Asia, and South Africa to China account for 38.87%, 33.55%, and 56.44% of the total domestic ECEs, respectively;

(3) In China–typical BRCs bilateral trade, China is a net ECE importer in trade with Russia, South Korea, South Africa, and Kazakhstan, which is conducive to China's ECE reduction. Conversely, China has always been a net ECE exporter in its bilateral trades with India, Vietnam, Italy, Turkey, Peru, and New Zealand. Regarding exports, China's ECE exports to South Korea were the highest in 2000 and much higher than those of other typical BRCs. After the implementation of the BRI, China's ECE exports to other typical BRCs grew rapidly. Among them, China's ECE exports to India were particularly prominent in 2018. Regarding imports, South Korea surpassed Russia as the country importing the most ECEs from China in 2018. At the same time, the share of China's ECEs imported from South Africa, Vietnam, and India also increased significantly;

(4) Through specific value chain routes, China–BRCs bilateral trade can help the BRCs reduce their ECEs while maintaining economic development. For example, the ECE transfer from the China–India bilateral trade mainly relies on route 1, while the ECE transfer from China's trade with Vietnam mainly relies on route 4 and route 5. Trade through route 2 can help China reduce its ECEs in bilateral trade with Russia, South Korea, South Africa, and Kazakhstan. Trade through complex GVCs via route 3 can also reduce ECEs; however, it accounts for less than one percent and has a limited impact on carbon reduction.

Based on the above analysis, we propose some policy implications. (1) Since Northeast and Southeast Asia are the top two regions in terms of China's VA trade, their trade policy changes will have a greater impact on China's import and export trade. Therefore, China should pay close attention to the changes in the trade policies of major BRCs and actively maintain economic and trade cooperation. (2) China should also seek to expand trade cooperation with countries outside Northeast Asia and Southeast Asia, seize the opportunity of the BRI, expand international production capacity cooperation, and strengthen its GVC ties with BRCs. (3) While strengthening trade among the BRCs, it is also necessary to pay attention to the impact of trade on the environment. Specific value chain routes can reduce the ECEs of the BRCs while promoting the economic growth of the BRCs. while actively developing economic cooperation with BRCs, China needs to work with them to formulate carbon emission reduction policies and jointly achieve carbon emission reduction goals based on the influence of different value chain routes.

This study has some limitations. First, because the OECD input–output data only include 40 economies that signed the BRI with China, it is difficult to study the ECE of all the BRCs. We expect to expand the scope of the study in future studies. Secondly, due to the limitations of the OECD data, there is a lag in the research cycle. The OECD has only updated the annual data to 2018, and future studies are expected to draw from an updated database.

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Data Availability Statement: Data are available in a publicly accessible repository. The data presented in this study are openly available in Organization for Economic Cooperation and Development (OECD) at https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm, accessed on 1 February 2023.

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References

1. Johnson, R.C.; Noguera, G. Accounting for intermediates: Production sharing and trade in value added. *J. Int. Econ.* **2012**, *86*, 224–236. [CrossRef]
2. Wang, Z.; Wei, S.J.; Yu, X.; Zhu, K. *Measures of Participation in Global Value Chains and Global Business Cycles*; National Bureau of Economic Research: Cambridge, MA, USA, 2017.
3. Zhong, Z.; Jiang, L.; Zhou, P. Transnational transfer of carbon emissions embodied in trade: Characteristics and determinants from a spatial perspective. *Energy* **2018**, *147*, 858–875. [CrossRef]
4. Liu, W.; Dunford, M.; Gao, B. A discursive construction of the Belt and Road Initiative: From neo-liberal to inclusive globalization. *J. Geogr. Sci.* **2018**, *28*, 1199–1214. [CrossRef]
5. Cheng, L.K. Three questions on China's "belt and road initiative". *China Econ. Rev.* **2016**, *40*, 309–313. [CrossRef]
6. Dunford, M.; Liu, W. Chinese perspectives on the Belt and Road Initiative. *Camb. J. Reg. Econ. Soc.* **2019**, *12*, 145–167. [CrossRef]
7. Zhang, N.; Liu, Z.; Zheng, X. Carbon footprint of China's belt and road. *Science* **2017**, *357*, 1107. [CrossRef]
8. Han, M.; Lao, J.; Yao, Q.; Zhang, B.; Meng, J. Carbon inequality and economic development across the Belt and Road regions. *J. Environ. Manag.* **2020**, *262*, 110250. [CrossRef] [PubMed]
9. Zhao, Y.; Liu, X.; Wang, S.; Ge, Y. Energy relations between China and the countries along the Belt and Road: An analysis of the distribution of energy resources and interdependence relationships. *Renew. Sustain. Energy Rev.* **2019**, *107*, 133–144. [CrossRef]
10. Ascensão, F.; Fahrig, L.; Clevenger, A.P.; Corlett, R.T.; Jaeger, J.A.; Laurance, W.F.; Pereira, H.M. Environmental challenges for the Belt and Road Initiative. *Nat. Sustain.* **2018**, *1*, 206–209. [CrossRef]
11. Lu, Q.; Fang, K.; Heijungs, R.; Feng, K.; Li, J.; Wen, Q.; Li, Y.; Huang, X. Imbalance and drivers of carbon emissions embodied in trade along BRI. *Appl. Energy* **2020**, *280*, 115934. [CrossRef]
12. Fan, J.L.; Dong, Y.; Zhang, X. How does "the Belt and Road" and the Sino-US trade conflict affect global and Chinese CO_2 emissions? *Environ. Sci. Pollut. Res.* **2020**, *27*, 38715–38731. [CrossRef] [PubMed]
13. Peng, H.R.; Qi, S.Z.; Zhang, Y.J. Does trade promote energy efficiency convergence in BRI countries? *J. Clean. Prod.* **2021**, *322*, 129063. [CrossRef]
14. Teo, H.C.; Lechner, A.M.; Walton, G.W.; Chan, F.K.S.; Cheshmehzangi, A.; Tan-Mullins, M.; Chan, H.K.; Sternberg, T.; Campos-Arceiz, A. Environmental impacts of infrastructure development under the belt and road initiative. *Environments* **2019**, *6*, 72. [CrossRef]

15. Sun, H.; Attuquaye Clottey, S.; Geng, Y.; Fang, K.; Clifford Kofi Amissah, J. Trade openness and carbon emissions: Evidence from belt and road countries. *Sustainability* **2019**, *11*, 2682. [CrossRef]
16. Wang, H.; Wang, X.; Zhang, X.; Liu, G.; Chen, W.-Q.; Chen, S.; Du, T.; Shi, L. The coupling between material footprint and economic growth in the "Belt and Road" countries. *J. Clean. Prod.* **2022**, *359*, 132110. [CrossRef]
17. Zou, J.; Liu, C.; Yin, G.; Tang, Z. Spatial patterns and economic effects of China's trade with BRCs. *Prog. Geogr.* **2015**, *34*, 598–605.
18. Wang, J.; Dong, K.; Dong, X.; Jiang, Q. Research on the carbon emission effect of the seven BRRs—Based on the spillover and feedback effects model. *J. Clean. Prod.* **2021**, *319*, 128758. [CrossRef]
19. Deng, X.; Du, L. Estimating the environmental efficiency, productivity, and shadow price of carbon dioxide emissions for BRI countries. *J. Clean. Prod.* **2020**, *277*, 123808. [CrossRef]
20. Wang, H.; Ang, B.W.; Su, B. Multiplicative structural decomposition analysis of energy and emission intensities: Some methodological issues. *Energy* **2017**, *123*, 47–63. [CrossRef]
21. Han, M.; Yao, Q.; Liu, W.; Dunford, M. Tracking embodied carbon flows in the Belt and Road regions. *J. Geogr. Sci.* **2018**, *28*, 1263–1274. [CrossRef]
22. Liu, Y.; Hao, Y. The dynamic links between CO_2 emissions, energy consumption and economic development in the countries along "the Belt and Road". *Sci. Total Environ.* **2018**, *645*, 674–683. [CrossRef] [PubMed]
23. Fan, J.L.; Da, Y.B.; Wan, S.L.; Zhang, M.; Cao, Z.; Wang, Y.; Zhang, X. Determinants of carbon emissions in 'Belt and Road initiative' countries: A production technology perspective. *Appl. Energy* **2019**, *239*, 268–279. [CrossRef]
24. Zhu, C.; Gao, D. A research on the factors influencing carbon emission of transportation industry in "the belt and road initiative" countries based on panel data. *Energies* **2019**, *12*, 2405. [CrossRef]
25. Koopman, R.; Wang, Z.; Wei, S.J. Tracing VA and double counting in gross exports. *Am. Econ. Rev.* **2014**, *104*, 459–494. [CrossRef]
26. Wang, Z.; Wei, S.J.; Zhu, K.F. Gross trade accounting method: Official trade statistics and measurement of the global value chain. *Soc. Sci. China* **2015**, *9*, 108–127.
27. Liu, H.; Liu, W.; Fan, X. Carbon emissions embodied in VA chains in China. *J. Clean. Prod.* **2015**, *103*, 362–370. [CrossRef]
28. Liu, H.; Lackner, K.; Fan, X. VA involved in CO_2 emissions embodied in global demand-supply chains. *J. Environ. Plan. Manag.* **2021**, *64*, 76–100. [CrossRef]
29. Wang, H.; Hu, Y.; Zheng, H.; Shan, Y.; Qing, S.; Liang, X.; Feng, K.; Guan, D. Low-carbon development via greening GVCs: A case study of Belarus. *Proc. R. Soc. A* **2020**, *476*, 20200024. [CrossRef] [PubMed]
30. Bai, S.; Zhang, B.; Ning, Y. Comprehensive assessment of the environmental and employment impacts of international trade from the perspective of global value chains. *Front. Environ. Sci.* **2023**, *10*, 1099655. [CrossRef]
31. Meng, B.; Peters, G.P.; Wang, Z.; Li, M. Tracing CO_2 emissions in GVCs. *Energy Econ.* **2018**, *73*, 24–42. [CrossRef]
32. Miroudot, S.; Ye, M. Decomposing value added in gross exports from a country and bilateral perspective. *Econ. Lett.* **2022**, *212*, 110272. [CrossRef]
33. Ali, M.U.; Wang, Y. Pollution haven or pollution halo? The role of global value chains in Belt and Road economies. *Rev. Dev. Econ.* **2024**, *28*, 168–189. [CrossRef]
34. Shi, Q.; Shan, Y.; Zhong, C.; Cao, Y.; Xue, R. How would GVCs participation affect carbon intensity in the "Belt and Road Initiative" countries? *Energy Econ.* **2022**, *111*, 106075. [CrossRef]
35. Zhang, Z.; Chen, W. Embodied carbon transfer between China and BRI countries. *J. Clean. Prod.* **2022**, *378*, 134569. [CrossRef]
36. Xiong, Y.; Xu, R.; Wu, S.; Li, S.; Li, L.; Li, Q. Evolution of the bilateral trade situation between Belt and Road countries and China. *J. Clean. Prod.* **2023**, *414*, 137599. [CrossRef]
37. Peters, G.P.; Andrew, R.; Lennox, J. Constructing an environmentally-extended multi-regional input–output table using the GTAP database. *Econ. Syst. Res.* **2011**, *23*, 131–152. [CrossRef]
38. Wang, F.; Li, Y.; Zhang, W.; He, P.; Jiang, L.; Cai, B.; Zhang, J.; Zhang, P.; Pan, H.; Jiang, H. China's trade-off between economic benefits and sulfur dioxide emissions in changing global trade. *Earth's Future* **2020**, *8*, e2019EF001354. [CrossRef]
39. Bai, S.; Ning, Y.; Zhang, B. Estimating the environmental and employment impacts of China's value-added trade from the perspective of value chain routes. *Environ. Sci. Pollut. Res.* **2022**, *29*, 73414–73443. [CrossRef]
40. Damoah, K.A.; Giovannetti, G.; Marvasi, E. Five stylized facts on Belt and Road countries and their trade patterns. *China World Econ.* **2023**, *31*, 149–181. [CrossRef]
41. Baniya, S.; Rocha, N.; Ruta, M. Trade effects of the New Silk Road: A gravity analysis. *J. Dev. Econ.* **2020**, *146*, 102467. [CrossRef]
42. Liu, W.; Ning, Y.; Bai, S.; Zhang, B. The Impact of Trade on Carbon Emissions and Employment from the Perspective of Global Value Chains—A Case Study of Chinese–Japanese–Korean Trade. *Energies* **2023**, *16*, 2378. [CrossRef]