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The Imbalance of Embodied CO_2 in China's Imports, Exports and Its Causes

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Abstract: Constraining the embodied CO_2 from international trade is a crucial part of China's efforts to achieve emission peak and carbon neutrality. By referring to the WIOD, this article applies the Global Multi-Regional Input-Output (GMRIO) Model and the Value-added Trade Accounting Method to calculate the amount of embodied CO_2 in China's international trade from 2000 to 2014. Results indicate that China's embodied CO_2 in imports and exports is imbalanced in three dimensions: product, region, and industry. One direct cause of this phenomenon is China's higher carbon emission factors compared to its trading partner. However, the real cause is the global relocation of energy-intensive industries, which leads China to undertake the production of high-carbon industries. To achieve the 3060 Dual Carbon Goal and high-quality economic development, China needs comprehensive and systematic reforms in its economic structure.

Keywords: embodied CO_2; trade value-added; GMRIO model; GVCs

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1. Introduction

Since the beginning of the 1980s, a new international demarcation of the global value chains (GVCs) has gradually taken place, and countries at different degrees of economic development have been integrated into the global production network. The production processes have been characterized by fragmentation, with countries participating in different production segments according to their natural advantages. During the reform and opening-up period, China has actively participated in it. With the advantages of labor and resources, China has become the world factory for manufacturing and processing trade. After joining WTO in 2001, China's exports have been driven rapidly by the global market and China became the world's largest exporter in 2009. However, China did not have many advantages in terms of industrial knowledge and leading technology in the GVCs; hence, the exported products were mainly in the labor-intensive and Capital-intensive industries [1]. Accordingly, this has led to certain drawbacks in China's trade model. First, relying on the ever-increasing scale of exportation could boost China's economic growth in the short term; however, this would not drive the quality of the economy concurrently. Moreover, the long-term exportation of low value-added products would also lead to environmental damages and an excessive consumption of resources [2].

With global warming and frequent extreme weather events, there has also been greater concerns over the severity of China's climate change issues. According to the International Energy Agency (IEA) accessed on 6 May 2022 (IEA: https://www.iea.org/data-and-statistics, accessed on 1 May 2020), China's CO_2 emissions totaled 5449.5 Mt in 2005, surpassing the United States; hence China has become the world's top carbon emitter, accounting for 20.12% of the world's total emissions. In 2019, China's total carbon emissions rose to 9919.1 Mt, equivalent to 29.50% of the world's total emissions. The continuous expansion of CO_2 emissions has posed challenges to China, facing public pressures from the international society for emission reduction as well as balancing domestic economic development and environmental protection. To mitigate it, China has proposed emission peak and carbon neutrality goals

(3060 Dual Carbon Goal) in 2020 (The 3060 dual carbon goal is that China achieve carbon peaking by 2030 and carbon neutrality by 2060. Source: Central People's Government of the People's Republic of China accessed on 6 May 2022, "China will adopt stronger policies and measures to peak CO_2 emissions by 2030 and strive to achieve carbon neutrality by 2060", http://www.gov.cn/gongbao/content/2020/content_5549875.htm, accessed on 1 May 2020). Achieving reduction in carbon emission requires a systematic approach and restraining the embodied CO_2 from international trade is crucial. Excessive embodied CO_2 emission in exports and its substantial imbalance with imports have been a realistic issue. In 2014, China's embodied CO_2 in exports were as high as 2035.22 Mt, accounting for 21.95% of China's total CO_2 emissions. In comparison, embodied CO_2 in imports were only 652.05 Mt, equivalent to only 7.03%. Therefore, it is necessary to research the imbalance of embodied CO_2 in China's imports, exports and the causes.

2. Literature Review

CO_2 emissions are caused by production and consumption activities such as the combustion of fossil fuels. Although international trade does not directly generate CO_2 except for transportation, there is still a strong correlation between international trade and carbon emissions in real life [3]. The rationale is that international trade separates the production and consumption systems of products, making carbon emissions transferable and reallocated across borders. International trade leads to the international demarcations based on comparative advantages, which in turn change the distribution of production activities on a global scale. Thus, it indirectly changes the geographical distribution of CO_2, shifting them from countries with comparative advantages in clean industries to those with comparative advantages in high pollution industries.

This phenomenon has long received academic attention. Baumol and Oates (1988) [4] proposed the pollution haven hypothesis (PHH), which believes that asymmetric environmental policies leads to the international migration of industries. To reduce the costs of environmental management, countries with strict environmental regulations tend to move high-carbon industries to those regions with less strict environmental regulations and then import back the desired goods. This often makes the countries and regions with less strict environmental regulations a haven of pollution. In general, developed countries are highly concerned about the environment and they will tighten the pollution regulations. In contrast, developing countries are more willing to ease environmental regulations to boost their economies, leading them to produce products in pollution-extensive industries. Data supporting this hypothesis have been provided by Robinson (1988) [5], who examined data over the period of 1973–1982 and found that the United States tended to import rather than produce pollution-intensive products. Lee and Roland-Holst (1993) [6] used a dual-country CGE model for trade between Japan and Indonesia and it appears that their bilateral trade effects a net transfer of environmental costs from the former to the latter. Copeland and Taylor (1994) [7,8] constructed a North-South model that demonstrated that trade mitigates environmental pollutions in the North (developed countries) and increases pollution levels in the South (developing countries). Mani and Wheeler (1998) [9] showed that pollution-intensive outputs as a percentage of total manufacturing had fallen consistently in the OECD countries and they had risen steadily in the developing world.

In addition to the theoretical and data support above, there are also literatures that use the Input-Output Analysis (IOA) approach to study the relationship between international trade and environment [10,11]. This method is more intuitive and it directly reveals the impacts of international trade on environment by calculating embodied CO_2. With the improvement of technical tools and database, the method has changed from the initial Single-Region Input-Output (SRIO model) (Machado, 2001 [12]; Chen et al., 2008 [13]) through the Bilateral Region Input-Output (BRIO model) (Peters 2008 [14]) and the Multi-Region Input-Output (MRIO model) (Wiedmann, 2009 [15]; Ma et al., 2015 [16]), to the Global Multi-Region Input-Output (GMRIO model) (Xie et al., 2016 [17], Yuan et al., 2014 [18]). The I-O approach is still an effective tool for studying environmental economics.

However, due to the fragmentation of production, countries around the world are included in the GVCs with intermediate goods being traded across borders often. Therefore, if the traditional trade accounting method is followed, it will result in a double counting of trade volume, which makes the accounting of embodied CO_2 biased.

From the research objects and areas of concern, many scholars have paid higher attention to the embodied CO_2 between specific countries [19,20]. Yan et al., 2017 [21] and Liu et al., 2020 [22] focused on the China-US trade, Pan et al., 2018 [23] and Jin et al., 2018 [24] studied the embodied CO_2 in the trade between China and Japan. Zheng et al., 2018 [25] and Meng et al., 2019 [26] studied the issue of embodied CO_2 from China-BRICS and China- "Belt and Road" countries, respectively. In addition, there are also some papers that focus on the embodied CO_2 in foreign trade of a certain country [27]. For example, Tolmasquim and Machado, 2003 [28] analyzed the embodied CO_2 in Brazil's international trade in the 1990s and argued that the increase of CO_2 emissions in the country was closely related to its specialization in energy-intensive industries. Whan-Sam Chung et al., 2011 [29] analyzed CO_2 emissions and the affecting factors in South Korea from 1985 to 2005, and the findings proved that national energy policies such as those pertaining to the diversification of energy sources are effective. Numerous scholars have studied the issue of embodied CO_2 in China from a particular perspective. Wang, 2010 [30] accounted for the embodied CO_2 of exports in China's industrial sector from 2003 to 2007, and he concluded that the expansion of exports was the main reason for the increase in the size of embodied CO_2. Dai et al., 2015 [31] studied the embodied CO_2 of Chinese agriculture from 1990 to 2010, and he used the Kaya constant equation decomposition principle to determine its driving factors. Fei et al., 2020 [32] measured embodied CO_2 emissions of Chinese exports from 1995 to 2011 and found that the trade in intermediate goods was the main reason. However, due to the complexity of calculation, literatures about the issue of embodied CO_2 across all industries and its imbalance between imports and exports are relatively limited. That is why we have conducted the research.

The marginal contributions of this article are explained below. First, with the inclusion of value-added trade in the GMRIO model, double counting has been removed and the heterogeneity of carbon emissions across countries has been considered. Hence, the calculation accuracy has been improved. Second, this paper focuses on the imbalance of embodied carbon in China's imports and exports with an innovative approach. The following chapters of this paper is organized as follows: Part III introduces the accounting method of embodied CO_2 emissions; Part IV describes the situation of imbalance of China's embodied CO_2 in imports and exports from three dimensions: product, industry and regional; Part V explains the causes of this Phenomenon; Part VI is the conclusion of this article.

3. Research Methodology

The traditional trade accounting method only takes the total amount of trade into consideration, without distinguishing the original country of a certain part of production in the commodity. In other words, if the final exporter is China, all the trade value of this commodity is counted as China's exports. However, China has a large share of manufacturing and processing trade, importing many intermediate products, processing them into final consumer goods before exporting them worldwide. Accordingly, by using the traditional trade accounting method, the value of China's export trade is overestimated as is the amount of embodied CO_2 emissions, because the value of intermediate goods produced in other countries have not been removed from the equation [33].

Therefore, in order to improve the accuracy of calculation in embodied CO_2, improvements in two aspects have been made in this article. First, we have adopted the value-added trade accounting method and decomposed the trade volume into three components: importing country, exporting country, and third-party country according to the place of origins. By doing so, the overestimation of trade volume caused by double counting of intermediate products has been mitigated. Second, the differences in carbon emission factors across countries have been considered (some previous literature assumed that the importing countries have the same carbon emission factors as their own countries). By identifying the source countries of production for each part of trade and correlating to their respective carbon emission factors, the accuracy of calculation has been significantly improved.

3.1. Data Source and Data Processing

The world input-output tables (WIOTs) and the CO_2 data in various industries were obtained on 20 April 2022 from WIOD 2016, published by Groningen Growth and Development Centre (world input-output Database: https://www.rug.nl/ggdc/valuechain/wiod/wiod-2016-release, accessed on 27 March 2022) [34]. The reason for the choice is that it contains the annual data and trading trends for major trading countries of China. WIOD has two types of WIOTS, in current year's prices and in previous year's prices. We chose the latter because it allows for comparison of the annual data. The data has been processed as follows:

First, referring to the industry classification of Rahman and Zhao, 2013 [35] (Rahman, Zhao, 2013, Export Performance in Europe: What Do We Know from Supply Links? IMF Working Paper.), the 56 sectors were categorized into eight major industries: primary resource industry(P); labor-intensive manufacturing(L-M); capital-intensive manufacturing(C-M); knowledge-intensive manufacturing(K-M); labor-intensive services(L-S); capital-intensive services(C-S); knowledge-intensive services(K-S); and other services industries(O-S). It can also be categorized into three major industries: a primary resource industry, a manufacturing industry and a service industry. L-M, C-M, K-M are manufacturing industries, L-S, C-S, K-S and O-S are service industries. The detailed methodology of industry classification and combination is showed in the Appendix A at the end of article. Second, for the decomposition of data for trade value-addition, we used the codes provided by the Global Value Chain Institute of the University of International Business and Economics (UIBE) accessed on 20 April 2022 (RIGVC UIBE, 2016, UIBE GVC Indicators, http://rigvc.uibe.edu.cn/english/D_E/database_database/index.htm, accessed on 27 March 2022) and it was obtained using R Studio. The calculations involving embodied CO_2 were obtained using Matlab2016b according to the equations provided below.

3.2. Construction of the Model

3.2.1. Value-Added Trade Accounting Method

The value-added trade accounting method (WWZ 2015) allows for the decomposition of trade volume (E_{sr}) from country s to country r into 16 portions (refer to the original literature for derivation). The specific decomposed portions are as follows:

$$
\begin{aligned}
E_{sr} = {} & (V_s B_{ss})^T \# Y_{sr} + (V_s L_{ss})^T \#(A_{sr} B_{rr} Y_{rr}) + (V_s L_{ss})^T \#(A_{sr} B_{rt} Y_{tt}) + (V_s L_{ss})^T \# \\
& (A_{sr} B_{rr} Y_{rt}) + (V_s L_{ss})^T \#(A_{sr} B_{rt} Y_{tr}) + (V_s L_{ss})^T \#(A_{sr} B_{rr} Y_{rs}) + (V_s L_{ss})^T \#(A_{sr} B_{rt} Y_{ts}) + \\
& (V_s L_{ss})^T \#(A_{sr} B_{rs} Y_{ss}) + (V_s L_{ss})^T \#[(A_{sr} B_{rs}(Y_{sr} + Y_{st})] + (V_s B_{ss} \\
& - V_s L_{ss})^T \#(A_{sr} X_r) + (V_r B_{rs})^T \# Y_{sr} + (V_r B_{rs})^T \#(A_{sr} L_{rr} Y_{rr}) + (V_r B_{rs})^T \#(A_{sr} B_{rr} E^r) + \\
& (V_t B_{ts})^T \# Y_{sr} + (V_t B_{ts})^T \#(A_{sr} L_{rr} Y_{rr}) + (V_t B_{ts})^T \#(A_{sr} L_{rr} E^r)
\end{aligned}
$$

where # represents the multiplication of the matrix and T represents the transpose of the matrix. L_{ss}, L_{rr} represent the Leontief inverse matrix of countries s and r; V_s, V_r, V_t represent the vectors of the value-added coefficients of the countries s, r and t; X_r, E_{r*} represent the vectors of the total output and the total exports of country r. Each part of the above formula corresponds to T1 to T16.

Table 1 gives the specific meanings of the 16 decomposed components (from T1 to T16) of the gross exports from country s to country r (among them T9, T10, T13 and T16 are purely double-counted components hence they have been excluded).

Table 1. The Decomposition of Country s' Gross Exports.

Value-Added Parts	Contents of Value-Add	Specific Meaning	Producing Country	Consuming Country
T1	DVA_FIN	Domestic value-addition by direct importer	s	r
T2	DVA_INT	Domestic value-addition by direct importer	s	r
T3 + T4 + T5	DVA_INTRE X	Domestic value-addition by other countries	s	t
T6 + T7 + T8	RDV	Domestic value-addition returns home	s	s
T11 + T12	MVA	Foreign value-addition from direct importer	r	r
T14 + T15	OVA	Foreign value-addition from other countries	t	r

Note: The meanings of DVA_FIN and DVA_INT are the same, but the former is the final product and the latter is the intermediate product. Besides, s, r and t represent exporting country, importing country and third country, respectively.

In addition, we distinguish different product types in Table 1, where T2, T3, T4, T5, T8, T12 and T15 are intermediate products, whereas T1, T6, T7, T11 and T14 are final products. Meanwhile, we also distinguish the actual producing and consuming countries of the products.

3.2.2. GMRIO Model Based on Heterogeneity

1. GMRIO model

$$x_i = \sum_j a_{ij} x_j + y_i$$

where $a_{ij}x_j = z_{ij}$ and z_{ij} is the intermediate product of industry i consumed by industry j.

The matrix can be expressed as $X = AX + Y$, X and Y are the column vectors of total output and the final demand of each industry. A is the matrix of the direct consumption coefficient.

The calculation yields:

$$X = (I - A)^{-1} Y = LY \tag{1}$$

wre L is the Leontief inverse matrix.

If there are G countries (regions), according to the GMRIO model, the output of each country can be expressed as:

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_G \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1G} \\ A_{21} & A_{22} & \cdots & A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ A_{G1} & A_{G2} & \cdots & A_{GG} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_G \end{bmatrix} + \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1G} \\ y_{21} & y_{22} & \cdots & y_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ y_{G1} & y_{G2} & \cdots & y_{GG} \end{bmatrix}$$

that is:

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_G \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} & \cdots & L_{1G} \\ L_{21} & L_{22} & \cdots & L_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ L_{G1} & L_{G2} & \cdots & L_{GG} \end{bmatrix} \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1G} \\ y_{21} & y_{22} & \cdots & y_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ y_{G1} & y_{G2} & \cdots & y_{GG} \end{bmatrix}$$

where the subscript G represents the number of countries that have trade with each other. For country s (s = 1, ... , G), vector x_s represents the country's total outputs, A_{ss} is the coefficient matrix of direct consumption, and vector y_{ss} represents the final products that are being produced and consumed to meet final domestic demands.

2. Calculation equation of embodied CO_2

First, the embodied CO_2 concept is introduced into Equation (1), and the output is substituted by CO_2 to obtain Equation (2).

$$C = f(I - A)^{-1} Y \tag{2}$$

where f is the direct CO_2 emission factor, which is the directly consumed CO_2 emissions divided by the total output of the industry.

Second, the final demand Y of Equation (2) is substituted by EX which yields the equation for the measurement of the embodied CO_2 in a country's exports.

$$C_{ex} = f(I - A)^{-1}EX \tag{3}$$

where EX is the export trade volume and C_{ex} is the embodied CO_2 in exports.

3. Equation for the embodied CO_2 decomposition in the perspective of heterogeneity

Embodied CO_2 generated by exporting country:

$$C_{ex1} = f_s(I - A)^{-1} * (DVA + RDV) \tag{4}$$

Embodied CO_2 generated by importing country:

$$C_{ex2} = f_r(I - A)^{-1} * MVA \tag{5}$$

Embodied CO_2 generated by third country:

$$C_{ex3} = f_t(I - A)^{-1} * OVA \tag{6}$$

where f_s, f_r, f_t are the diagonal matrices of the direct CO_2 factors of the exporting country, importing country, and third country, respectively.

Similarly, the equation for the embodied CO_2 of imports can be obtained by replacing the export value with the import value to correspond to the respective CO_2 emission factors.

4. The Imbalance of China's Embodied CO_2 in Imports and Exports

4.1. Imbalance in Product Amount and Product Type

First, during the period this study focuses on, China's total embodied CO_2 emissions in exports were much higher than that of imports and the imbalance has clearly indicated that China is clearly in the position of carbon transfer-in (Figure 1). From 2001 to 2007, the gap was widening. In 2001, the embodied CO_2 emissions in exports was higher than that in imports by 432.53 Mt, and it reached a peak of 1590.93 Mt in 2007, which means that the amount of transferred carbon emission into China was from 432.53 Mt to 1590.93 Mt. From 2008 to 2010, the gap showed a V-shaped change of falling and then rising. This is mainly due to the financial crisis in 2008; the decline in exports led to the decline in embodied CO_2, but after 2009, it gradually recovered. From 2010 to 2014, the difference tended to be stable, basically between 1300 and 1400 Mt.

Second, the types of imported and exported products with embodied CO_2 are also imbalanced (Figure 2). The main source of embodied carbon in imports is from trade of intermediate goods, which accounts for more than 70%. However, more than 50% of the embodied carbon in exports trade is from final goods, although the trend is weakening slightly. In 2001, 53.1% of the embodied carbon in exports was generated from final goods. In 2014, the proportion dropped to 49.6%. In general, the difference of embodied carbon in various product types is consistent with China's long-established manufacturing and processing trade pattern of importing intermediate goods and exporting final goods. It has indicated that the trade pattern has a great impact on carbon emissions.

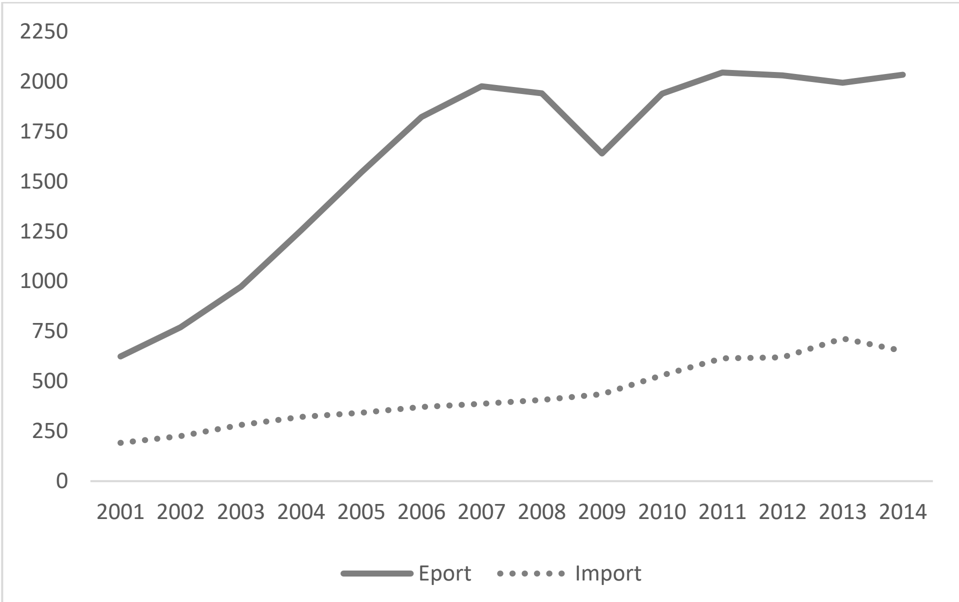

Figure 1. The embodied CO_2 in China's import and export from 2001 to 2014 (Unit: Mt). Source: The figure in this article is plotted by the calculations.

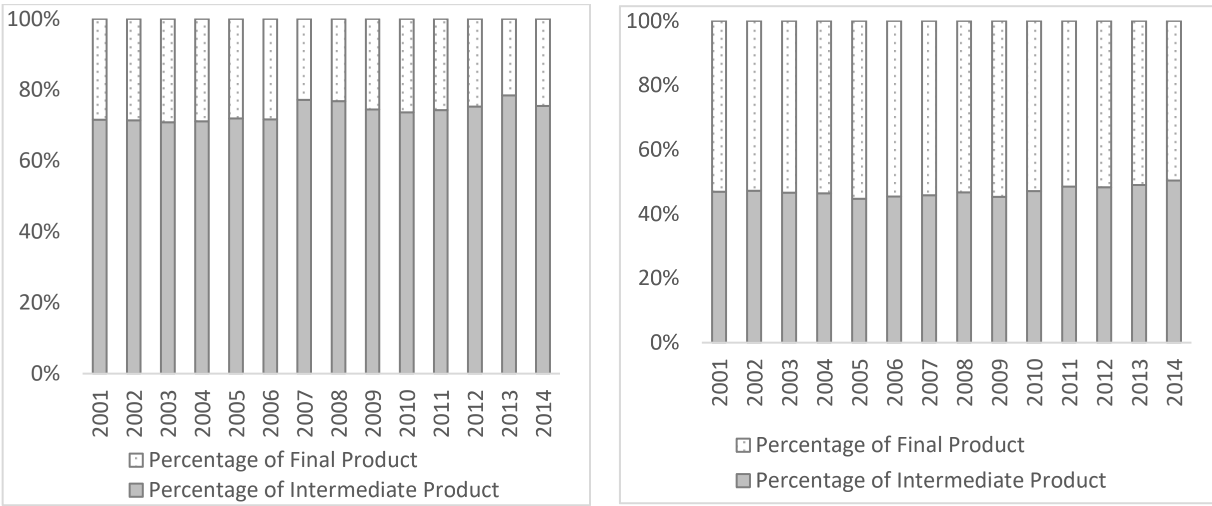

Figure 2. The product type of embodied CO_2 in China's import and export from 2001 to 2014. Note: The left one is embodied CO_2 in import and the right is in export.

4.2. Imbalance in Regions

China's embodied CO_2 in imports and exports have been in great imbalance with the major regions of the world and there have been significant differences among these regions. There have been no substantial changes in the characteristics during the study interval; hence 2010 has been chosen as an example for illustration (Figure 3). According to the geographical and economic development characteristics, the 43 countries and regions in the WIOD excluding China have been divided into six major regions (Euro Zone; Non-Euro Zone; BRIIAT; East Asia; NAFTA and ROW).

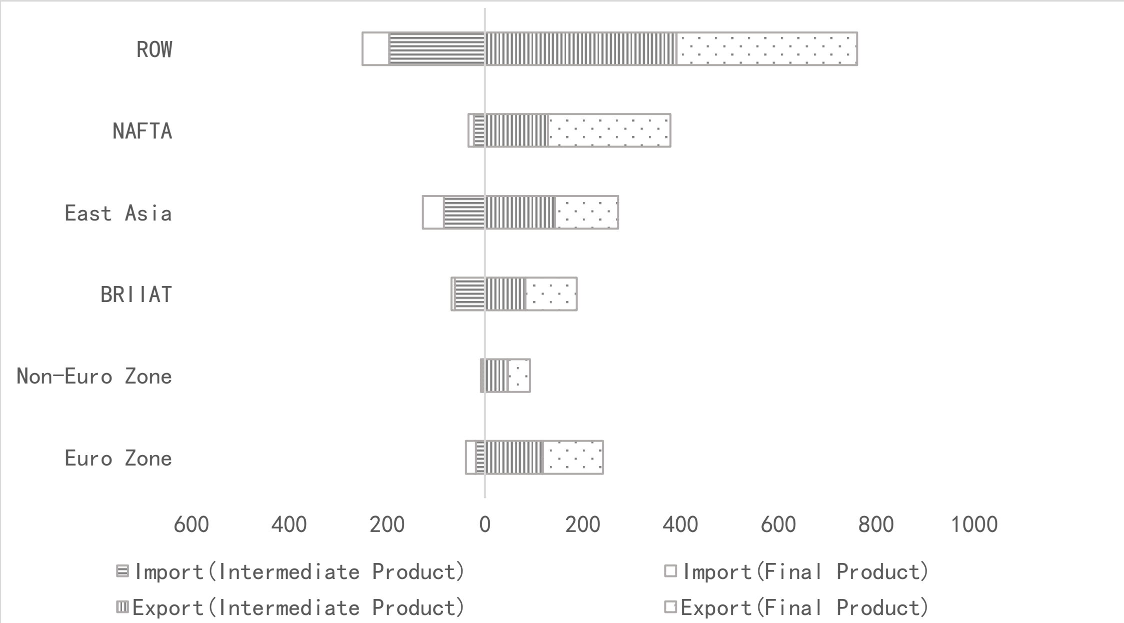

Figure 3. Region distribution of China's embodied CO_2 in import and export in 2010. (Unit: Mt). Note: (1) NAFTA refers to North American Free Trade Area, BRIIAT includes Brazil, Russia, India, Indonesia, Australia and Turkey, East Asia includes Japan, South Korea and Taiwan (China), and ROW refers to the rest of the world. Since the rest of the world ROW is counted as a whole, the description of this article does not include ROW. (2) This table divides the EU into the Euro Zone and Non-Euro Zone. The former contains Austria, Belgium, Cyprus, Germany, Spain, Estonia, Finland, France, Greece, Ireland, Italy, Luxembourg, Malta, the Netherlands, Portugal, Slovakia and Slovenia. Non-Euro Zone contains Bulgaria, the Czech Republic, Denmark, the United Kingdom, Croatia, Hungary, Lithuania, Latvia, Poland Romania and Sweden. Since Switzerland CHE and Norway NOR are not part of the EU, they are not included in the statistical results.

The embodied CO_2 in China's exports to all these regions are much higher compared with that in imports. Among them, NAFTA, Euro Zone and Non-Euro Zone are the three regions with the most substantial imbalanced. Reflected in data, embodied CO_2 emissions from China's exports to these regions are 11.23 times, 11.00 times and 6.18 times of that from imports, respectively. Moreover, the embodied CO_2 in exports to these regions were dominated by final products. From the specific countries in Table 2 below, the US is the country with the largest imbalance of NAFTA, accounting for 81.03% of the total imbalance, mainly because China exports a large amount of embodied CO_2 in final goods to the US, reaching 214.58 Mt. Germany, France, Italy and the Netherlands are the main imbalanced countries in the Euro Zone, and China's exports to them are also quite large; the difference of product type is not very obvious, but in general the final products are higher than the intermediate goods. The UK is the country with the largest imbalance in the Non-Euro Zone, accounting for 51.03% of the region. A distinctive feature is that China imports very little from the UK, only 2.79 Mt, and exports 45.26 Mt (mainly final goods).

East Asia and BRIIAT belong to the zone with an intermediate imbalance, where the embodied CO_2 in exports is 2.73 times and 2.13 times than that in imports, respectively. Moreover, it is observed that the CO_2 in imports of the two regions is mainly from intermediate products. Among them, there is little difference in BRIIAT countries, with about 90% of the imported embodied CO_2 from intermediate goods in the four countries (Australia, Brazil, India, and Russia). Japan is the country with the largest imbalance in East Asia, accounting for 88.01% of the total imbalance CO_2. A relatively large share of China's imports of embodied CO_2 to Japan comes from intermediate goods, about twice as much as final goods. Besides, for embodied CO_2 in exports, immediate goods carry less weight compared with final goods.

Table 2. China's Embodied CO_2 of Import and Export to Major Countries by Region in 2010 (Unit: Mt).

Region	Country	Immediate Product (Import)	Final Product (Import)	Immediate Product (Export)	Final Product (Export)
Euro	Germany	9.05	11.43	35.72	44.38
Euro	France	2.28	1.95	21.29	21.25
Euro	Italy	1.56	2.24	17.05	17.09
Euro	The Netherlands	1.49	1.16	14.70	12.71
Non-Euro	UK.	1.29	1.51	19.69	25.58
East Asia	Japan	26.58	13.09	74.40	92.37
NAFTA	US	17.33	9.08	91.41	214.58
BRIIAT	Australia	11.54	1.36	19.45	20.81
BRIIAT	Brazil	7.06	0.66	13.49	13.68
BRIIAT	India	11.09	1.34	20.78	17.40

To summarize, the main source of China's embodied CO_2 in imports is intermediate products, basically from East Asia and BRIIAT, whereas the main source of embodied CO_2 in exports is final goods, mainly from NAFTA and Euro Zone, followed by East Asia and BRIIAT, with the least inflow to Non-Euro Zone. Therefore, it is further clear that China, as the world factory, operates a typical triangular trade, importing intermediate goods from East Asia and emerging economies to meet the consumption demand of final goods in developed economies in Europe and the US.

4.3. Imbalance in Industries

As shown in Figure 4, in 2005, all industries had higher exported embodied CO_2 than that from importation, dominated by the products of capital-intensive manufacturing industry and capital-intensive service industry. The total imbalance from all industries was 1203.49 Mt and the primary resources industry, manufacturing industry, and service industry accounted for 2.45%, 59.87% and 37.68%, respectively. The primary resources industry is the industry with the least imbalance with exports of embodied CO_2 only 29.46 Mt higher than that from importation. This is mainly because of China's dependence on imports for direct extraction of raw materials, fuels, etc. Manufacturing industries are with the most substantial imbalance. Further breakdown shows labor-intensive manufacturing, capital-intensive manufacturing, and knowledge-intensive manufacturing industry are out of balance by 69.89 Mt, 494.54 Mt and 156.14 Mt, respectively. Service industries are out of balance by a total of 453.46 Mt, mainly generated by the imbalance of capital-intensive service (439.36 Mt), with very few in labor-intensive service, knowledge-intensive service, and other services.

In 2014, the situation remained that all industries had higher exported embodied CO_2 than that from importation, with a difference of 1383.17 Mt, although the share of each individual industry has changed. With the increase of imports in the primary resources industry, its imbalance of embodied CO_2 decreased significantly and the proportion fell to 0.45%, which was the least imbalanced industry. The manufacturing industry still had the largest imbalance and the proportion rose to 65.81%. Among them, the imbalance of capital-intensive manufacturing is the largest, which is 696.39 Mt. Inevitably, it drove the rise of the imbalance of the whole manufacturing industry. The embodied CO_2 in exports of knowledge-intensive manufacturing was higher than that from imports by 169.41 Mt. Labor-intensive manufacturing has the lowest imbalance (44.48 Mt). Thus, it can be seen that the structure of China's embodied CO_2 in exports has been optimized to a certain extent, with increase in the knowledge-intensive manufacturing exports and decrease in the labor-intensive manufacturing exports. However, as exports of capital-intensive manufacturing remain large, they still contribute to increased CO_2. The imbalance proportion in the service sector has decreased slightly, from 37.68% of the total imbalance in 2005 to 33.74% in 2014. The imbalance in the capital-intensive services still dominates with relatively low imbalance in the other three services industries.

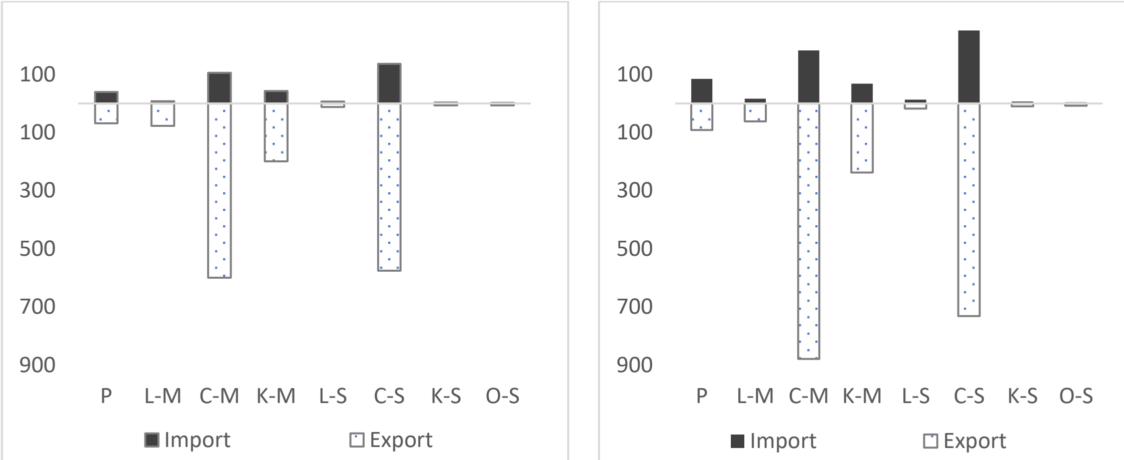

Figure 4. Industry distribution of China's imports and exports of embodied CO_2 in 2005 and 2014 (Unit: Mt). Note: (1) The left one is industry distribution of embodied CO_2 in 2005 and the right is in 2014. (2) P, L-M, C-M, K-M, L-S, C-S, K-S, O-S represent primary industries, labor-intensive manufacturing, capital-intensive manufacturing, knowledge-intensive manufacturing, labor-intensive services, capital-intensive services, knowledge-intensive services and other services, respectively.

To summarize, the structure of China's imports and exports of embodied CO_2 has constantly been optimized, but the current imbalance is still substantial. As exports of labor-intensive manufacturing have declined and exports of knowledge-intensive manufacturing have increased, the shift towards knowledge-based manufacturing is beneficial to China's reduction in emissions. However, the capital-intensive industries still have the biggest share of embodied CO_2 emissions from exports. Capital-intensive industries have been labeled by high-carbon content; hence, they should be the focus of reducing carbon emissions in the future. In addition, the knowledge-intensive service industries and other service industries are low-carbon industries. The inclination towards such industries will help a great deal for achieving the overall emission reductions.

5. The Main Reasons for the Imbalance in China's Embodied CO_2

5.1. China's Higher Carbon Emission Factor Compared to Its Major Trading Partner

One direct cause of the imbalance in embodied CO_2 between imports and exports is that China produces higher CO_2 per unit of output than its major trading countries in Europe, the US, and the developed East Asian countries. For instance, in 2002, China yielded 1.014 t of CO_2 per thousand dollars of output compared to 0.255 t in the US, 0.245 t in Germany, and 0.152 t in Japan in the same year (Table 3). In other words, with the same amount of exports, China consumed 0.759 t, 0.769 t and 0.862 t of CO_2 more than the US, Germany, and Japan, respectively. In particular, the carbon emission factors of capital-intensive manufacturing and capital-intensive services was as high as 1.460 and 3.926 (Figure 5), which were the leading products of China's exports. However, due to improving environmental standards and emission reduction technologies, China's carbon emission levels increased. For instance, the 2014 overall carbon emission factors fell to 0.312, already lower than India (0.505). At the same time, there were still noticeable differences compared to developed countries and even some developing countries. The differences in carbon emission levels between China and its major trading countries contribute directly to the imbalance of China's embodied CO_2 in imports and exports.

Table 3. Direct carbon emission factors of China and its' major trading countries.

Region	Country	2002	2004	2006	2008	2010	2012	2014
Euro	Germany	0.245	0.184	0.149	0.112	0.106	0.098	0.097
Euro	France	0.127	0.092	0.074	0.060	0.055	0.049	0.046
Euro	Italy	0.161	0.125	0.104	0.086	0.075	0.069	0.064
Euro	Netherlands	0.196	0.151	0.117	0.098	0.098	0.085	0.087
Non-Euro	UK	0.165	0.136	0.107	0.085	0.095	0.088	0.074
East Asia	Japan	0.152	0.142	0.127	0.129	0.106	0.101	0.121
NAFTA	US	0.255	0.234	0.199	0.181	0.177	0.149	0.142
BRIIAT	Australia	0.466	0.330	0.243	0.195	0.194	0.128	0.124
BRIIAT	Brazil	0.318	0.308	0.196	0.140	0.130	0.095	0.116
BRIIAT	India	0.980	0.825	0.658	0.545	0.560	0.456	0.505
East Asia	China	1.014	1.014	0.842	0.625	0.502	0.384	0.312

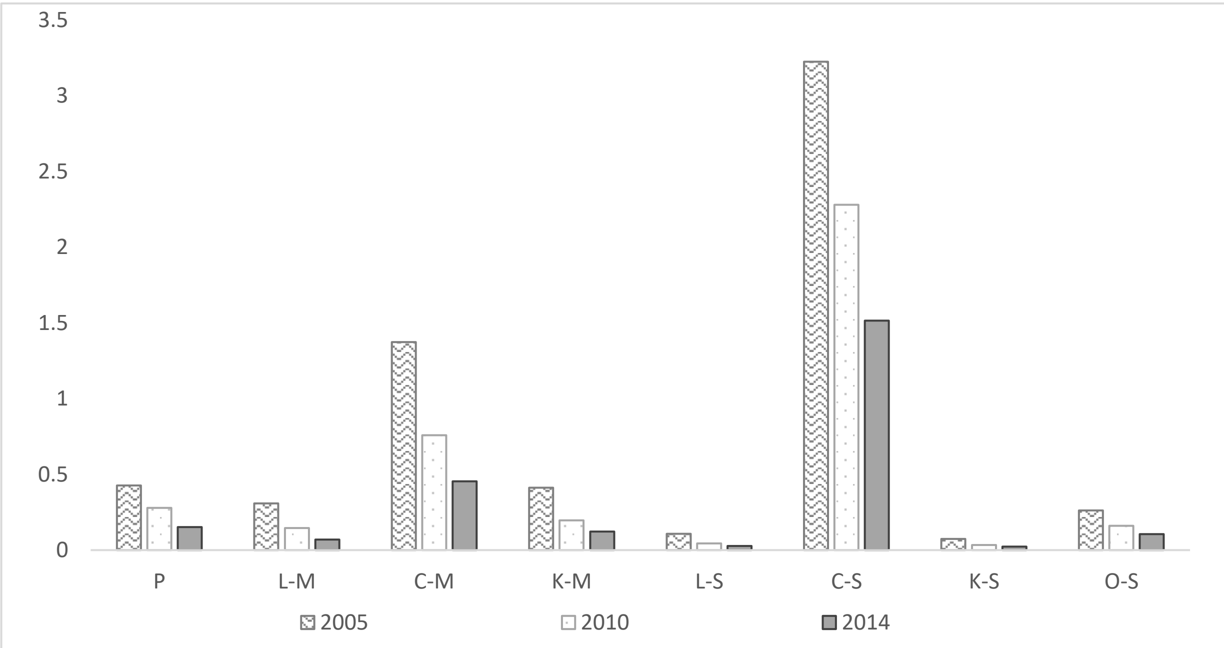

Figure 5. China's direct carbon emission factors of specific industries in 2005, 2010 and 2014. Note: P, L-M, C-M, K-M, L-S, C-S, K-S, O-S represent primary industries, labor-intensive manufacturing, capital-intensive manufacturing, knowledge-intensive manufacturing, labor-intensive services, capital-intensive services, knowledge-intensive services and other services, respectively.

5.2. Global Relocation of Energy-Intensive Industries to China

Global relocation of manufacturing has a stepwise nature. According to the life cycle theory, the stages of industrial development include a start-up period, a growth period, a maturity period, and a decline period. An industry that enters the final stage will spread outward by seeking a transfer location. The differences in the economic development level of countries leads to the existence of gradient. The general rule is that when an industry in a country with a large economy of scale enters a period of decline, it will seek a new location and move to a country with a relatively small economy of scale. The world has experienced five major global manufacturing relocations involving changes in the geographic location of the world's factories [36]. The fourth relocation was to China in the 1980s, which is one key factor in China's imbalance of embodied CO_2 in imports and exports. In this process, advanced East Asian nations such as Japan, Korea, Taiwan (China), and developed countries in Europe and NAFTA relocated their mature, labor-intensive, and capital-intensive industries to China, and created space for them to focus on knowledge-intensive industries. Although the transfer drove China's economic development, many drawbacks followed. First, there is a large proportion of capital-intensive industries in China's industrial structure. These industries tend to be energy-intensive and have high-carbon emission factors, as described above. In short, a drastic increase in carbon emissions can be excepted. The second drawback is carbon leakage from developed countries to China, meaning production in China and consumption in developed countries. In other words, after receiving the relocations from developed countries, China needs to produce and export those products. This process consumes energy and increases carbon dioxide emissions.

Data from 2005 and 2014 are used to illustrate the phenomenon. On the demand side, the 2005 shares of consumption, fixed capital, and inventory in China's imported embodied CO_2 were 36.27%, 60.24%, and 3.49% (Table 4). More than half of the imported embodied CO_2 was used for fixed capital, indicating that imports dominated by capital goods. Moreover, the data also shows that China's imported CO_2 indicates investment dependence. In terms of regions, the main source of fixed capital was East Asia (31.90%), followed by Euro Zone (10.13%), NAFTA (6.24%) and BRIIAT (4.45%).

Table 4. Demand-side 2005 imports and exports of regional distribution of China's embodied CO_2 (Unit: Mt).

Import					Export				
Consumption	27.37 36.27%	Euro	1.55	5.68%	Consumption	612.21 63.03%	Euro	76.74	12.54%
		Non-Euro	0.51	1.87%			Non-Euro	35.44	5.79%
		BRIIAT	2.42	8.84%			BRIIAT	36.49	5.96%
		East Asia	4.49	16.41%			East Asia	99.16	16.20%
		NAFTA	1.82	6.64%			NAFTA	164.36	26.85%
		ROW	16.48	60.22%			ROW	196.92	32.17%
Fixed Capital	45.45 60.24%	Euro	4.60	10.13%	Fixed Capital	345.80 35.60%	Euro	44.09	12.75%
		Non-Euro	0.74	1.63%			Non-Euro	10.59	3.06%
		BRIIAT	2.02	4.45%			BRIIAT	23.40	6.77%
		East Asia	14.50	31.90%			East Asia	61.89	17.90%
		NAFTA	2.92	6.42%			NAFTA	113.73	32.89%
		ROW	20.56	45.23%			ROW	90.50	26.17%
Inventories	2.63 3.49%	Euro	0.18	6.79%	Inventories	13.31 1.37%	Euro	3.91	29.33%
		Non-Euro	0.03	1.17%			Non-Euro	0.57	4.31%
		BRIIAT	0.14	5.42%			BRIIAT	1.90	14.25%
		East Asia	0.80	30.59%			East Asia	1.81	13.59%
		NAFTA	0.16	5.98%			NAFTA	5.03	37.80%
		ROW	1.31	49.91%			ROW	0.00	0.00%

As for China's embodied CO_2 in exports, the proportions of consumption, fixed capital, and inventory were 63.03%, 35.60% and 1.37%, respectively. The data shows that consumer demand is the main dominant factor in China's exports. In other words, exported CO_2 indicates consumption dependence. In terms of regions, NAFTA is the main outflow region (26.85%), followed by East Asia (16.20%), Eurozone (12.54%), BRIIAT (5.96%) and non-Eurozone (5.79%), which shows that China exports a large amount of final products to meet the consumer demands from developed NAFTA countries, East Asia, and Euro Zone.

In addition, the main sources were China's imported embodied CO_2 from the industry include capital-intensive services, capital-intensive manufacturing, and knowledge-intensive manufacturing on the investment side (Figure 6). By contrast, the main destinations of China's exported embodied CO_2 include products of capital-intensive services, capital-intensive manufacturing, and labor-intensive manufacturing on the consumption side. Therefore, since the import and export industries are the same but from different sides, these industries can indicate that the global relocation of energy-intensive industries has imbalanced China's embodied carbon.

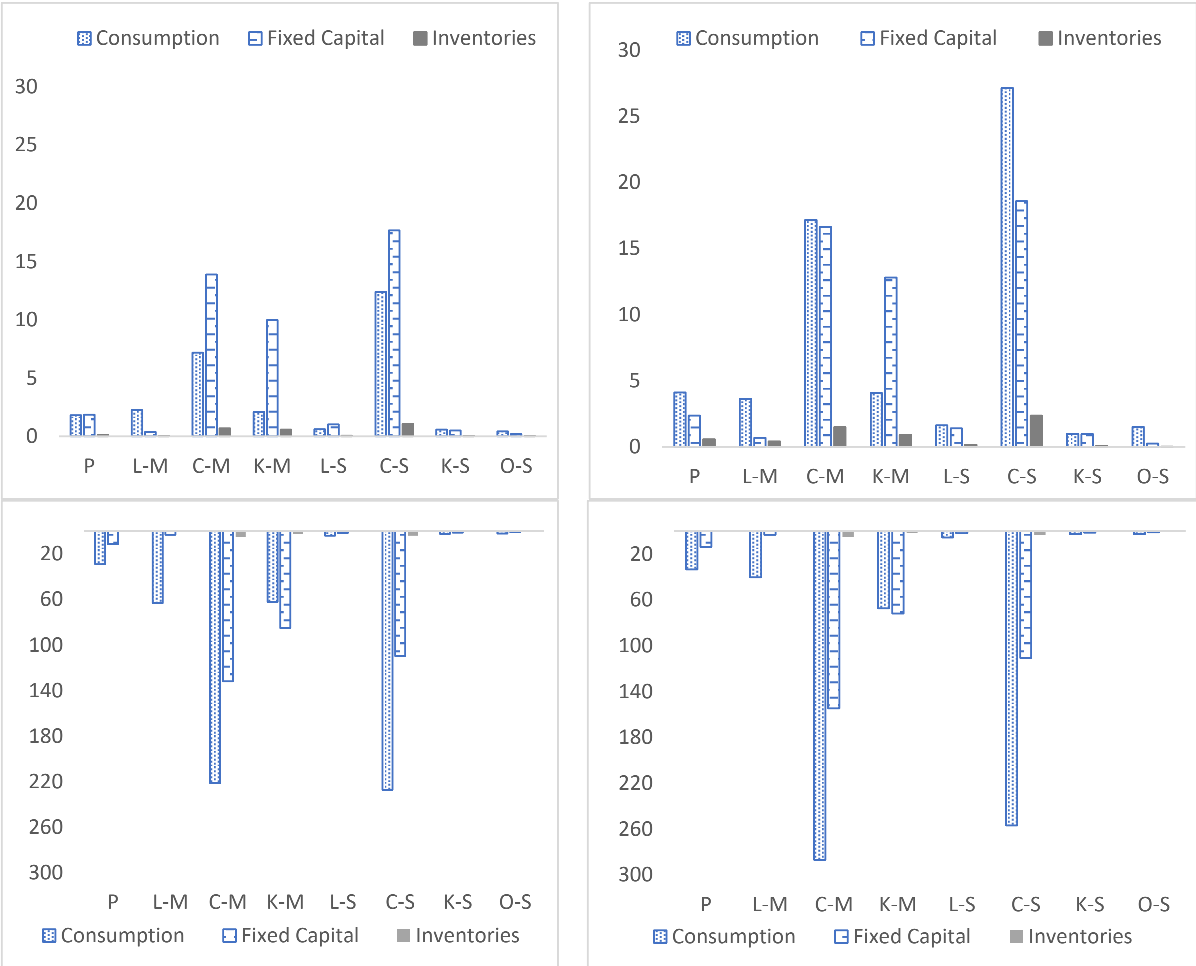

Figure 6. Demand-side imports and exports of industry distribution of China's embodied CO_2. (Unit: Mt). Note: (1) The upper left one is import in 2005, the lower left one is export in 2005, The upper right one is import in 2014, the lower right one is export in 2014. (2) P, L-M, C-M, K-M, L-S, C-S, K-S, O-S represent primary industries, labor-intensive manufacturing, capital-intensive manufacturing, knowledge-intensive manufacturing, labor-intensive services, capital-intensive services, knowledge-intensive services and other services, respectively.

However, this pattern of imbalance had eased primarily due to changes in the share of embodied CO_2 in imports, the decreasing percentage of fixed capital, and increasing consumption. In 2014, the proportion of fixed capital decreased to 44.79%, while consumption increased to 50.23% (Table 5). This indicated that demand in China was shifting from investment-led to consumption-led scenarios, which would contribute to China's industrial restructuring and reduce the embodied CO_2 of exports.

Table 5. Demand-side 2014 imports and exports of regional distribution of China's embodied CO_2 (Unit: Mt).

Import					Export				
Consumption	60.17 50.23%	Euro	4.71	7.82%	Consumption	696.03 65.29%	Euro	68.29	9.81%
		Non-Euro	1.58	2.63%			Non-Euro	28.08	4.04%
		BRIIAT	5.95	9.89%			BRIIAT	68.45	9.83%
		East Asia	7.95	13.21%			East Asia	66.33	9.53%
		NAFTA	5.36	8.90%			NAFTA	127.65	18.34%
		ROW	34.42	57.21%			ROW	334.70	48.09%

Table 5. *Cont.*

Import					Export				
Fixed Capital	53.66 44.79%	Euro	7.13	13.29%	Fixed Capital	359.26 33.70%	Euro	42.85	11.93%
		Non-Euro	1.21	2.25%			Non-Euro	14.70	4.09%
		BRIIAT	1.50	2.79%			BRIIAT	40.79	11.35%
		East Asia	22.17	41.32%			East Asia	63.43	17.65%
		NAFTA	5.77	10.74%			NAFTA	91.48	25.46%
		ROW	15.70	29.27%			ROW	103.70	28.86%
Inventories	5.97 4.98%	Euro	0.41	6.94%	Inventories	10.84 1.02%	Euro	2.26	20.88%
		Non-Euro	0.08	1.39%			Non-Euro	0.85	7.85%
		BRIIAT	0.43	7.21%			BRIIAT	3.13	28.87%
		East Asia	2.01	33.63%			East Asia	0.79	7.28%
		NAFTA	0.49	8.29%			NAFTA	3.48	32.11%
		ROW	2.53	42.34%			ROW	0.00	0.01%

6. Conclusions

The pattern of embodied CO_2 emissions in China's trade is closely linked to its natural advantages and the extent of its participation in the international demarcation. Since its accession to WTO, China has been integrated into the GVCs, and developed countries in Europe, NAFTA, and East Asia have relocated their industries without competitive advantages to China through foreign direct investment. As a result, China has become the world factory and has been vigorously developing its manufacturing industries regardless of the consumption of resources and damage to its environment, relying on an export-oriented economy [37,38]. However, nowadays China is seeking a balance between economic growth and environment protection. Seemingly as a problem between trade and environment, the imbalance of embodied CO_2 in China's imports and exports actually reflects China's economic structure. The most crucial thing is the development of technology and knowledge, hence changing the way China participates in the GVCs, although it is not an easy task. Due to decades of reliance on labor and resources to drive its economy and its engagement in the production of energy-intensive industries, China is facing great difficulties in energy transition and emission reduction. A comprehensive and systematic change in its economic structure is crucial to achieve the 3060 Dual Carbon Goal.

First, it is important to realize that trade is one of the important drivers of China's economic growth. The development of a high-quality economy is not to reduce the volume of trade, but to control the exports of high-energy-consuming, high-polluting, and resource-based products, while increasing the proportion of low-energy-consuming and low-emission goods and services in international trade. By doing so, a transition from a large trading country to a strong trading country can be achieved.

Second, industrial relocation is one of the causes of growth of carbon emissions; however, it is also one of the driving forces of economic growth. What China should do is not to deny or restrict the development of foreign investment, but to attract high-quality foreign investment, especially those focusing on the introduction of knowledge, technology, and other core elements in the GVCs. Ultimately, the upgrade and optimization of China's industrial structure can be achieved.

Lastly, the Chinese government should formulate reasonable and effective policies to strengthen the regulations for pollution control and to support clean production. For example, environmental regulations can be tightened by establishing a unified carbon trading market system to raise the production costs of polluting industries, hence eventually removing them from the market. Another possibility is to strengthen financial support to clean technology and to guide local companies to engage in cleaner production.

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Appendix A

Table A1. Classification of Sector.

Categories	Sector Number	Sector Name
Primary and Natural Resources	r1, r2, r3, r4	Agriculture, Hunting, Forestry, Fishing, Mining and Quarrying
Labor-Intensive Manufacturing	r6, r7, r22	Textiles and Textile Products, Leather, Leather and Footwear Wood and Products of Wood and Cork, Manufacturing
Capital-Intensive Manufacturing	r5, r8, r9, r10, r13, r14, r15, r16, r18	Food, Beverages and Tobacco Paper and Paper Products, Printing and Publishing Coke, Refined Petroleum and Nuclear Fuel Rubber and Plastics Other Non-Metallic Mineral Basic Metals and Fabricated Metal Electrical equipment
Knowledge-Intensive Manufacturing	r11, r12, r17, r19, r20, r21	Chemicals and Chemical Products Machinery Electronic and Optical Equipment Transport Equipment
Labor-Intensive Service	r27, r28, r29, r30, r34, r36	Construction Sale, Maintenance and Repair of Motor Vehicles Wholesale Trade except of Motor Vehicles Retail Trade except of Motor Vehicles and Motorcycles; Other Supporting and Auxiliary Transport Activities Accommodation and food service activities
Capital-Intensive Service	r23, r24, r25, r26, r31, r32, r33, r35, r39, r44	Repair and installation of machinery and equipment Electricity, Gas and Water Supply Inland Transport, Water Transport, Air Transport Post and Telecommunications Real Estate Activities
Knowledge-Intensive Service	r40, r41, r42, r43, r45, r46, r47, r48, r49, r50	Computer programming, consultancy, Financial Intermediation, Architectural and engineering activities, Scientific research and development, Advertising and market research, Other professional, scientific and technical activities, Administrative and support service activities
Other Service	r37, r38, r51, r52, r53, r54, r55, r56	Publishing activities, Public Admin and Defence, Compulsory Social Security Education Health and Social Work Other Community, Activities of households as employers Activities of households as employers

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