

# Measurement of Embodied Carbon Emission of Trade and Responsibility Sharing Mechanism design: a case of Six Central Provinces of China

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**Abstract:** In the face of the “30-60” target, the task of carbon emission reduction in China is particularly arduous. Due to factors such as energy resource endowment and economic and industrial structure, there are large spatial differences in carbon emission levels among regions in China. As a representative region of the traditional energy industrial structure, the huge energy consumption of the industrial sector in the central region has caused a large amount of carbon emissions. Based on the MRIO model, this paper measures the embodied carbon emissions of trade and the amount of carbon emissions that the regions should bear in 2012 and 2017 for the eight major regions in China. We found that there is large difference in carbon emissions among the eight regions in China, with the central region ranking first in the country, and this difference is also manifested in the provinces of the central region. In addition, under the producer responsibility principle, the problem of carbon leakage between developed and less developed regions is becoming more prominent, with the central and western regions acting as a “pollution haven”. Further, to rationalize the carbon emission responsibilities of each region, this paper proposes a shared responsibility scheme and compares it with the producer and consumer responsibility systems. This paper is of practical and theoretical reference significance for the scientific delineation of carbon emission reduction responsibilities and the effective promotion of the overall carbon peaking goal.

## 1. Introduction

As the global climate change problem intensifies, the world is under severe pressure to reduce carbon emissions. China is the world's largest carbon emitter<sup>[1]</sup>. In 2019, China's total carbon emissions were 100.24 tons, accounting for 28% of global carbon emissions, meaning that China's carbon emissions are more than twice the total carbon emissions of any other country in the world, making it one of the world's largest carbon polluters. To ensure that the global carbon emission reduction process is moving forward properly, the Chinese government has committed to peak CO<sub>2</sub> emissions in 2030 and strives to achieve CO<sub>2</sub> emissions neutrality by 2060. Therefore, China needs to further decompose the responsibility of carbon emission reduction to each region and province in the country.

With the development of economic integration, the links of trade and economics between regions have become increasingly close, thus also bringing about the flow of products and services, the separation of where goods are produced and consumed, and the massive transfer of carbon emissions between regions. In addition, due to the differences in economic

development level, energy resource endowment, and industrial structure, the degree of decoupling between economic development and carbon emissions varies among regions, which also leads to uneven carbon emission levels among regions. Specifically, carbon emissions from less developed regions, represented by the central region, are often higher than those from developed coastal regions, and the transfer of a large amount of carbon emissions from economically developed regions to the central region has increased the burden of carbon emission reduction in that region. Therefore, the scientific approval of inter-regional carbon emission reduction responsibilities is of great significance for the implementation of energy saving and emission reduction initiatives in the central region and the achievement of China's overall carbon peak target, and is also a major practical issue that needs to be urgently addressed and discussed at present.

## 2. Review of the literature

In the measurement of carbon emissions, the multi-regional input-output approach is mostly used in academia. The multi-region input-output approach can compensate for the shortcomings of the single-

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region input-output approach, which is based on the assumption of technological homogeneity, and can better measure the carbon emissions generated in the whole production process of products or services. Manli Guo<sup>[2]</sup> et al. applied the multi-regional input-output method to measure the embodied carbon emissions from trade in six central provinces, and found that Henan Province ranked first in both production and consumption side carbon emissions among the six central provinces; Kang Yanxia et al.<sup>[3]</sup> et al. measured the trade embodied carbon emissions and transfer from the production side and consumption side in nine provinces in the Yellow River Basin based on the MRIO model, and found that the overall embodied carbon in the Yellow River Basin showed a net carbon transfer; Zhang Tianjiao et al.<sup>[4]</sup> et al. estimated the trade-embodied carbon emissions and intensity of the Yangtze River Economic Belt using the multi-regional input-output method, and found that the trade-embodied carbon emissions of the Yangtze River Economic Belt increased year by year from 2012 to 2017, and showed a net carbon transfer outward. Most of the existing literature only measures the embodied carbon emissions of trade in domestic regions, but lacks research on the determination of regional carbon emission allowances; moreover, the current research data have a lag, mostly using data before 2015, which is not conducive to the formulation of current carbon emission reduction policies.

Regarding the allocation of carbon credits, the existing research results mainly focus on the attribution of responsibility to producers and consumers. The producer responsibility system advocated by the Kyoto Protocol has the following shortcomings: first, it has given rise to the problem of “carbon leakage”, which makes less economically developed countries or regions become “pollution havens” for economically developed regions and is not conducive to the sustainable development of less economically developed regions. Secondly, the “producer responsibility principle” to account for carbon emissions is unfair to large exporting countries such as China.<sup>[5]</sup> Second, accounting for carbon emissions under the producer responsibility principle is unfair to large exporters such as China. Therefore, some scholars believe that the responsibility for carbon emissions should be determined by “whoever consumes, whoever is responsible”, and Wang Zhen et al.<sup>[6]</sup> Wang Zhen et al. constructed a regional carbon emission rights allocation model from the perspective of consumers and assigned China's 2020 carbon emission reduction target to each province. Although this accounting reflects fairness, it lacks the necessary constraints on carbon emission producers because the exporting regions ultimately pass the responsibility of carbon emissions to consumers. Neither the producer responsibility system nor the consumer responsibility system takes into account the impact of regional carbon transfer on carbon emission responsibility. Only by fully considering the regional

trade value flow and carbon transfer factors, and formulating a reasonable carbon credit allocation mechanism, can we ensure the sustainable development of inter-regional trade. In the study of carbon emission rights and responsibilities under the perspective of “shared responsibility”, Kondo et al.<sup>[7]</sup> et al. constructed a carbon emission responsibility-sharing mechanism based on the principle of “who benefits, who is responsible”, and introduced responsibility-sharing factors to allocate the embodied carbon in export trade, but did not define the sources of responsibility-sharing factors; Wang Yubao and He Yupeng<sup>[8]</sup> et al. propose to use the value added of domestic outflow trade as the responsibility sharing factor, and stipulate that inter-provincial carbon transfer should be shared by the place of production and the place of consumption. Wang Wenzhi<sup>[9]</sup> et al. also based on the “benefit principle”, determine the responsibility-sharing factor by the added value embedded in the commodity flow, and build a mechanism to share the responsibility of carbon emission between the producing and consuming places.

Based on the above realistic background and problems, and because of the old data used in previous studies and the inconsistent research standards, this paper adopts the latest multi-regional input-output table to focus on measuring the production-side and consumption-side trade embodied carbon in six central provinces, and on this basis, constructs the carbon emission responsibility sharing factor according to the principle of regional benefit and clarifies the carbon emission responsibility to be borne by each region. This is of strong practical significance to fairly and reasonably stipulate the carbon emission reduction tasks of each region and promote the achievement of the carbon peak target, and also provides a theoretical reference for the study of regional carbon emission accounting and responsibility division.

### 3. Methods and data sources

#### 3.1 Research Methodology

(1) Trade embodied carbon measurement model construction

The multi-regional input-output approach is a common model for measuring the embodied emissions of trade between different industrial sectors, which overcomes the limitation of “technical homogeneity” of the single-region input-output approach and can examine the economic linkages between different regions and sectors, and thus can measure the embodied carbon emissions of trade in the whole process of commodity flow more accurately.

The hypothetical research object has  $m$  regions, where each region consists of  $n$  sectors. A multi-regional input-output model is constructed for this study object:

$$X_i^r = \sum_{s=1}^m \sum_{j=1}^n X_{ij}^{rs} + \sum_{s=1}^m Y_i^{rs} + EX_i^r + R_i^r \quad (1)$$

$X_i^r$  in equation (1) denotes the total output of sector  $i$  of region  $r$ , where  $X_{ij}^{rs}$  denotes the amount of intermediate goods input by the sector  $i$  of  $r$  region to the sector  $j$  of region  $r$ ,  $Y_i^{rs}$  denotes the final goods input by sector  $i$  of region  $r$  to region  $s$ ,  $EX_i^r$  denotes the export component of sector  $i$  region  $r$ , and  $R_i^r$  is the adjustment factor to adjust the balance between total sector output and total input.

Further, equation (2) can be reduced to

$$X^r = (I - A^{rr})^{-1} \left( \sum_{s=1, s \neq r}^m A^{rs} X^s + \sum_{s=1, s \neq r}^m Y^{rs} + Y^{rr} + EX^r \right) \quad (2)$$

$$= L^{rr} \sum_{s=1, s \neq r}^m A^{rs} X^s + L^{rr} \sum_{s=1, s \neq r}^m Y^{rs} + L^{rr} Y^{rr} + L^{rr} EX^r$$

In Eq.(2),  $L = (I - A^{rr})^{-1}$  is the Leontief inverse matrix,

$L^r \sum_{s=1, s \neq r}^m A^{rs} X^s$ 、 $L^{rr} \sum_{s=1, s \neq r}^m Y^{rs}$  denote the portion of the

$$CE_{produce}^r = CI^r X^r$$

$$= CI^r (I - A^{rr})^{-1} \left( \sum_{s=1, s \neq r}^m A^{rs} X^s + \sum_{s=1, s \neq r}^m Y^{rs} + Y^{rr} + EX^r \right) \quad (3)$$

$$= CI^r L^{rr} Y^{rr} + CI^r L^{rr} \sum_{s=1, s \neq r}^m A^{rs} X^s + CI^r L^{rr} \sum_{s=1, s \neq r}^m Y^{rs} + CI^r L^{rr} EX^r$$

In Eq. (3),  $CI^r L^{rr} Y^{rr}$  denotes the domestic emissions from meeting local demand in region  $r$ ,  $CI^r L^{rr} \sum_{s=1, s \neq r}^m A^{rs} X^s$  denotes the carbon emissions caused by meeting the demand for intermediate products in region  $s$  in region  $r$ ,  $CI^r L^{rr} \sum_{s=1, s \neq r}^m Y^{rs}$  denotes the

total output of region  $r$  used to meet the demand for intermediate goods and final goods in region  $s$ , respectively;  $L^{rr} Y^{rr}$  denotes the portion of the total output of region  $r$  used to meet the demand for final goods in this region;  $L^{rr} EX^r$  denotes the portion of the total output of region  $r$  used to meet the demand for exports.

Further, the implicit carbon measurement model will be constructed from two perspectives of producer responsibility and consumer responsibility respectively, and  $CI^r$  is defined as the diagonal matrix of carbon emissions per unit of total output of each production sector in region  $r$ , which consists of the ratio of total direct carbon emissions output of each sector in province  $r$ . The expression of production-side carbon emissions of province  $r$  is:

carbon emissions caused by meeting the demand for final products in region  $s$  in region  $r$ , and  $CI^r L^{rr} EX^r$  is the carbon emissions from exports in region  $r$ .

Drawing on Shuijun Peng<sup>[10]</sup> et al.'s approach to delineating consumption-side carbon emissions in China, the expression for provincial  $r$  consumption-side carbon emissions are:

$$CE_{consume}^r = CI^r L^{rr} Y^{rr} + \sum_{s=1, s \neq r}^m CI^s L^{ss} (Y^{sr} + A^{sr} X^r) + CI^r L^{rr} IM^r \quad (4)$$

In Eq. (4),  $CI^r L^{rr} Y^{rr}$  represents the carbon emissions from local production of intermediate and final products to meet local demand, which is inter-

provincial emissions;  $\sum_{s=1, s \neq r}^m CI^s L^{ss} Y^{sr}$ 、

$\sum_{s=1, s \neq r}^m CI^s L^{ss} A^{sr} X^r$  represent the direct spillover carbon emissions from the procurement of final and intermediate products from other provinces to meet local consumption in the province; and  $CI^r L^{rr} IM^r$  represents the carbon emissions from imports.

The net carbon transfer between provinces and regions can be expressed by the difference between the production side carbon emission and consumption side carbon emission of provinces and regions A-B. A positive difference means that the embodied product outflow of provinces is greater than the embodied product inflow carbon, which is a net carbon transfer into provinces; conversely, a negative difference is a net carbon transfer out of regions.

(2) Regional carbon responsibility sharing mechanism model construction

Based on the beneficiary principle, a regional net carbon transfer responsibility allocation model is constructed based on the real level of regional benefits through product or service flows. And according to the composition of beneficiary subjects of product or service flow, the regional carbon emission responsibility is divided into three parts:

$$CE = CE_1^{PRO} + \alpha \cdot CE_2^{PRO} + (CE_2^{CON} - \alpha^* \cdot CE_2^{CON}) \quad (5)$$

$$= CE_1^{PRO} + \alpha \cdot CE_2^{PRO} + (1 - \alpha^*) \cdot CE_2^{CON}$$

$CE_1^{PRO}$ 、 $CE_2^{PRO}$  Where  $CE_1^{PRO}$  and  $CE_2^{PRO}$  denote the embodied carbon transferred from the production of products to meet the consumption demand of local and foreign provinces respectively, and  $CE_2^{CON}$  denotes the embodied carbon of trade from the consumption of products or services from foreign provinces.  $\alpha$  denotes the share of local trade value added;  $\alpha^*$  denotes the share of trade value added of products from the inflowing provinces.

Based on Koopman<sup>[11]</sup> et al. study, the value-added decomposition method of international trade is applied to the domestic regional level to construct a

provincial outflow trade value decomposition framework. First, the matrix  $V$  of direct output value-added coefficients; the matrix  $Z$  of total product outflows from each province to foreign provinces are defined, where  $Z^{r*}$  denotes the total outflows from province  $r$  to meet the demand for intermediate and final products from foreign provinces, i.e.,

$$Z^{r*} = \sum_{s=1, s \neq r}^m Z^{rs} = \sum_{s=1, s \neq r}^m (A^{rs} X^s + Y^{rs}).$$

Further, the direct output value-added coefficient matrix ( $V$ ), the Leontief inverse matrix ( $L$ ), and the total product outflow matrix ( $Z$ ) are operated to obtain the provincial product outflow value-added matrix:

$$V \cdot L \cdot Z = \begin{bmatrix} V^1 \cdot L^1 \cdot Z^{1*} & V^1 \cdot L^{12} \cdot Z^{2*} & \dots & V^1 \cdot L^m \cdot Z^{m*} \\ V^2 \cdot L^{21} \cdot Z^{1*} & V^2 \cdot L^{22} \cdot Z^{2*} & \dots & V^2 \cdot L^m \cdot Z^{m*} \\ \vdots & \vdots & \ddots & \vdots \\ V^m \cdot L^{m1} \cdot Z^{1*} & V^m \cdot L^{m2} \cdot Z^{2*} & \dots & V^m \cdot L^{mm} \cdot Z^{m*} \end{bmatrix} \quad (6)$$

In Eq. (6), the diagonal elements of the matrix denote the local increase in the total outflow of province  $r$  ( $DV^r$ ), denoted  $DV^r = V^r L^{rr} Z^{r*}$  denotes the increase in the total outflow of province  $r$  containing province  $s$ , denoted  $OV^{sr}$ ;

Drawing on Wang Zhi<sup>[12]</sup> et al. and Wang Quing<sup>[13]</sup> et al. to decompose the sources of provincial  $r$  domestic outflow value added:

$$Z^r = DV^r + OV^r \quad (7)$$

In Eq. (7),  $Z^r$  is the total value of domestic outflow trade for province  $r$ . Further, using the share of local value added as the responsibility sharing factor, the net carbon transfer responsibility sharing factor for province  $r$  ( $\alpha^r$ ) is

$$\alpha^r = \frac{DV^r}{Z^r} = \frac{DV^r}{DV^r + OV^r} \quad (8)$$

In Eq. (8),  $DV^r$ 、 $OV^r$ 、 $Z^r$  are the total value added and value of intra-provincial and extra-provincial domestic outflow trade in the provincial domain  $r$ . Therefore, the standard accounting formula for sharing the responsibility of net carbon transfer in the provincial domain  $r$  is constructed as

$$SR^r = CE_{PRO1}^r + \alpha^r \cdot CE_{PRO2+PRO3}^r + \sum_{s=1, s \neq r}^m (1 - \alpha^s) \cdot CE_{CON2+CON3}^r + CE_{Export}^r \quad (9)$$

In Eq. (9),  $\alpha^r$ 、 $\alpha^s$  are the responsibility sharing factors of provincial domain  $r$  and  $s$ .  $\alpha^r = 0$ 、 $\alpha^r = 1$  indicates that the responsibility of outflow trade embodied carbon is entirely borne by the place of consumption and the place of production;  $0 < \alpha^r < 1$  indicates that the responsibility of outflow trade embodied carbon is shared by the place of production and the place of consumption.

### 3.2 Data sources

Due to the lack of data from the Hong Kong and Macao Special Administrative Regions, Macao Special

Administrative Region and Taiwan, this paper only collects multi-regional input-output table data from 42 sectors of 31 provinces in China in 2012 and 2017, and carbon emission data of each province are obtained from the China Energy Statistical Yearbook and Shan<sup>[14]</sup>, etc. measured by China's 2012 and 2017 carbon emission inventory data of China's end-use energy consumption in each province. And regarding the reference to Guo Zhengquan<sup>[15]</sup> et al.'s study, China is divided into eight regions.

## 4. Analysis of results

### 4.1 Analysis of trade embodied carbon emission measures

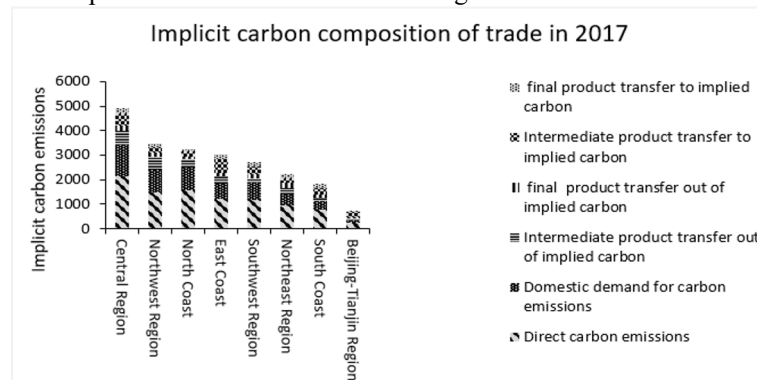
(1) Analysis of direct carbon emissions, production-side and consumption-side embodied carbon

Compared with 2012, the total domestic direct carbon emissions and bilateral carbon emissions have increased in 2017, which is caused by the rapid development of China's economy, the current industrial structure, and the energy consumption structure. To promote the process of reducing pollution and carbon emissions and ensure the achievement of China's "double carbon" target, the country has continued to adjust the industrial structure, with the proportion of primary industry decreasing year by year and the proportion of tertiary industry increasing year by year, but high energy-consuming industries still occupy a large proportion. And China's "coal-rich, oil-poor, gas-poor" energy resources endowment also determines the consumption structure of coal-based consumption, although the country continues to optimize the energy consumption structure, the coal-based energy consumption structure is still difficult to change in the short term. Therefore, the total domestic carbon emissions are still on an upward trend.

As is shown in Figure 1, at the regional level, the total carbon emission in the central region is always in the first place in the country, and the difference between regions is obvious. 2017, the direct carbon emission level of each region in the country is: central region > northwest region > north coast > east coast > southwest region > northeast region > south coast > Beijing-Tianjin region, and the overall pattern is "low in the south and high in the north", and the difference between the direct carbon emission level of the central region and Beijing-Tianjin region is 1985.37Mt CO<sub>2</sub>. In addition, compared with the production side and consumption side, the embodied carbon emission level and ranking of trade in each region are increasing and decreasing. The regional ranking of embodied carbon on the production side is the same as the regional ranking of direct carbon emissions, while the ranking of embodied carbon in trade for each region on the consumption side is, in descending order: central region > east coast > northwest region > north coast > southwest region > south coast > northeast region > Beijing-Tianjin region. Compared with the production side, the trade embodied carbon emissions on the consumption side in the central

region have decreased, but still ranked first in the country; among them, the difference in carbon emission levels between the two sides in Beijing and Tianjin is the most significant, with the consumption side being 187.75Mt CO<sub>2</sub> higher than the production side. The

differences in energy endowment and consumption structure, economic development level, and regional conditions are the main reasons for the differences in carbon emission levels and carbon emissions between the regions and the two sides.



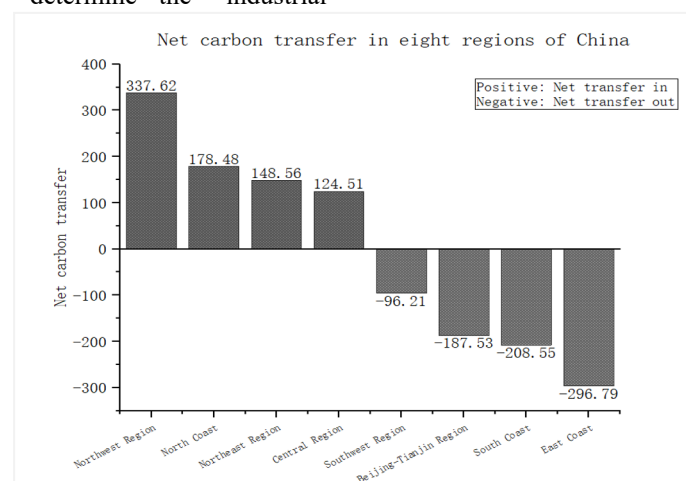
**Figure1.** Implicit carbon measures for eight regions in China in 2017 (Unit: Mt CO<sub>2</sub>)

The provinces in the central region show consistent carbon emission characteristics, with resource-intensive provinces emitting significantly more carbon than other provinces. Specifically, Henan and Shanxi provinces have higher carbon emission levels, with the total direct carbon emissions of the two provinces accounting for 44.4% of the total in the central region, while the province with the lowest carbon emission level is Jiangxi, accounting for only 10.1% of the total in the central region. The reasons for this are: Henan Province is a large population, agricultural production, and a new industrial province, energy consumption is still dominated by coal, the amount of carbon dioxide emitted per unit of production is high, and the energy demand is still in a high growth state, so the task of reducing pollution and carbon is a long way to go; in addition, Shanxi Province's natural energy resource endowment and rich mineral resources determine the heavy industry in Shanxi Province with huge industrial energy consumption. In addition, Shanxi Province's natural energy resources endowment and rich mineral resources determine the industrial

structure of Shanxi Province, which is dominated by heavy industry with huge industrial energy consumption.

(2) Net carbon transfer from provincial trade and its direction

As is shown in Figure 2, International carbon transfer shows a net carbon transfer in. in 2017, China's embodied carbon emissions from export trade were greater than those from import trade, and carbon was transferred from abroad to China, with a net carbon transfer of 151.49 Mt CO<sub>2</sub>. among them, at the regional level, the northwest region, the northern coast, the central region, and the northeast region were net carbon transfer-in regions, and the northwest region had the largest net carbon transfer-in volume, at 36.43 Mt CO<sub>2</sub>, and the smallest net carbon transfer from the central region is 124.51 Mt CO<sub>2</sub>; the eastern coast, southern coast, Beijing-Tianjin region, and southwest region are net carbon transfer regions, and the eastern coast and southwest region are the largest and smallest net carbon transfer regions respectively.



**Figure2.** Net carbon transfer in eight regions of China

Among the provinces in the central region, Shanxi Province, Anhui Province, Jiangxi Province and Hunan Province are net carbon transfer provinces in 2017, Shanxi Province, as a large resource province, has the

highest mineral reserves, coal-bed methane and bauxite reserves in China, Shanxi Province has been developing high energy-consuming industries mainly with coal resources for a long time, so its net carbon

transfer is the first in the central region, accounting for 68.7% of the total net carbon transfer in the central region; Jiangxi Province is the smallest net carbon transfer-in province with only 3.04 Mt CO<sub>2</sub>. Henan Province and Hubei Province have negative net carbon transfer-in and are net carbon transfer-out provinces, and Henan Province has the largest net carbon transfer-out with 59.5 Mt CO<sub>2</sub>, transferring carbon emission responsibility to other provinces.

#### 4.2 Measurement of Embodied Carbon Responsibility Sharing of Provincial Trade

As shown in Figure 3, it shows the carbon emission responsibilities of each region under different responsibility perspectives. In this section, we will discuss in detail the differences in the amount of regional carbon responsibility between different responsibility perspectives.

##### (1) Measurement of production-side trade embodied carbon responsibility

The embodied carbon responsibility of production-side trade between regions and provinces is densely distributed. Among the regions, the central region requires the most carbon emission responsibility, which is 2107.49 Mt CO<sub>2</sub>, accounting for 23.5% of the total production-side carbon emission responsibility; while the Beijing-Tianjin region has the smallest production-side carbon emission responsibility, which is only 195.87 Mt CO<sub>2</sub>, accounting for 2.19%. Because most of the provinces in the central region are mainly manufacturing industries and rich in resource endowment and energy consumption, they continuously export or export a large amount of intermediate and final products for foreign provinces and abroad, so the production side carbon emission responsibility is the largest in the central region; while in Beijing-Tianjin region, the economic level is higher, the ability to consume the imported products from each province are stronger, the industrial production capacity is weaker, and the production side carbon emission responsibility is smaller.

The production-side carbon emission responsibility in the central region is dominated by resource-concentrated provinces and heavy industry provinces. In 2017, the production-side carbon emission responsibility in the central region is larger, from largest to smallest, in the following order: Shanxi Province, Henan Province, Anhui Province, Hubei Province, Hunan Province, and Jiangxi Province. Shanxi Province has 474.69 Mt CO<sub>2</sub> in production side carbon emission responsibility, and Henan Province is second only to Shanxi Province with 472.32 Mt CO<sub>2</sub>; Jiangxi Province is the smallest with 207.01 Mt CO<sub>2</sub> in production side carbon emission responsibility. Shanxi Province and Henan Province, with the advantages of resource endowment, transportation location conditions, and human resources, vigorously develop high energy consumption industries and heavy industry industries, and have larger direct carbon emissions. Therefore, under the limited conditions of the producer

responsibility system, these provinces need to take more responsibility for carbon emission reduction.

##### (2) Measurement of embodied carbon responsibility of trade on the consumption side

Some regions or provinces have large differences between production-side and consumption-side carbon liabilities. Among the major regions, the six central provinces still have the highest embodied carbon responsibility for trade on the consumption side in China, with 1982.96 Mt CO<sub>2</sub>, accounting for 22.1% of the total. Among other regions, Beijing and Tianjin are also required to bear the least carbon responsibility, with only 383.4 Mt CO<sub>2</sub>, but the difference is larger compared with the production side, with an increase of 187.53 Mt CO<sub>2</sub>, with the most obvious difference in Beijing. Among the provinces, Shandong, Jiangsu, Guangdong, Hebei, and Henan are in the top5, accounting for 33.1% of the total; Tibet, Hainan, Qinghai, Gansu, and Tianjin are in the bottom 5, accounting for only 4.49%. In addition, Inner Mongolia, Zhejiang, Guangdong, Beijing, Hebei, Shanxi, Liaoning, and other provinces' production side and consumption side carbon emission responsibility gaps are more than 100 Mt CO<sub>2</sub>.

The consumption-side carbon emission responsibility is lower than the production-side carbon emission responsibility in the central region, and there are differences among provinces. The amount of consumption-side trade embodied carbon responsibility is larger in the central region, but compared with the production side, the amount of carbon emission responsibility is reduced by 124.53 Mt CO<sub>2</sub>. Among the provinces in the central region, Henan Province needs to bear the most consumption-side trade embodied carbon responsibility, which is more than 500 Mt CO<sub>2</sub>, accounting for 26.8% of the total in the central region, followed by Hubei, Shanxi, Hunan, Anhui, and Jiangxi.

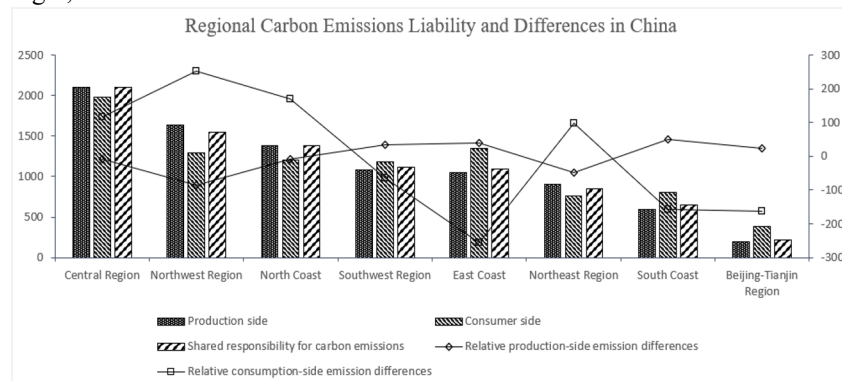
##### (3) Measuring the implicit carbon responsibility of provincial trade from the perspective of shared responsibility

In 2017, the total "shared responsibility" carbon emission of 31 provinces in China was 8959.49 Mt CO<sub>2</sub>, which is the same as the domestic carbon emission excluding the embodied carbon of import and export on the production and consumption sides. Among them, Shandong, Hebei, Jiangsu, Inner Mongolia, and Henan ranked in the top five in "shared responsibility" carbon emissions, with a total of 3037.3 Mt CO<sub>2</sub>, accounting for 33.9% of the total, which is 0.02% lower than the production side and 0.1% higher than the consumption side; Tibet, Hainan, Qinghai, Beijing, and Tianjin ranked the bottom five, accounting for only 3.64% of the total. 3.64%, 10.4% higher than the production side, and 36% lower than the consumption side.

The total carbon emission responsibility of "shared responsibility" in the central region still leads the country, with the carbon emission responsibility of 2098.49 Mt CO<sub>2</sub>, which is 8.97 Mt CO<sub>2</sub> lower than that of the production side and 115.54 Mt CO<sub>2</sub> higher than that of the consumption side. The responsibility

of carbon emission in the following order: northwest region, north coast, southwest region, northeast region, south coast, and Beijing-Tianjin region. Under different responsibility perspectives, the ranking positions of carbon emission responsibility of each province are basically the same. Compared with the production side carbon emission responsibility, provinces such as Hubei and Hunan have increased compared with the production side; provinces such as Shanxi, Anhui, Jiangxi, and Henan have decreased

compared with the production side. In addition, compared with the consumption-side carbon emission responsibility, Anhui, Hunan and Shanxi provinces increased compared with the consumption-side carbon emission responsibility, with Shanxi province increasing the most, reaching 125.18 Mt CO<sub>2</sub>; while Henan, Hubei and Jiangxi decreased compared with the consumption side, and Henan province decreased the most, with 60.07 Mt CO<sub>2</sub>.



**Figure3.** embodied carbon for trade by region under different responsibility perspectives(Unit: Mt CO<sub>2</sub>)

## 5. Conclusion and Policy Recommendations

### 5.1 Conclusion

(1) Influenced by energy resource endowment, industrial structure and energy consumption characteristics, the central region has huge direct carbon emissions, production-side carbon emissions and consumption-side carbon emissions, which are among the highest in China. The Beijing-Tianjin region, as a representative of economically developed regions, has the smallest carbon emissions. In addition, the central region is a net carbon transfer region, and under the traditional responsibility principle, the central region needs to bear excessive carbon emission reduction responsibilities for other regions. The Beijing-Tianjin region and some economically developed coastal regions show a net carbon transfer out, transferring their own carbon emission reduction pressure to the central and western regions.

(2) The ranking of embodied carbon in trade by provinces in the central region is Henan Province, Shanxi Province, Anhui Province, Hubei Province, Hunan Province, and Jiangxi Province in order. Henan Province and Shanxi Province, as large carbon-emitting provinces, have more energy-consuming industries, higher total industrial energy consumption than other industries, and lower energy use efficiency, resulting in large CO<sub>2</sub> emissions. At the level of net carbon transfer, Shanxi, Anhui, Jiangxi, and Hunan provinces are net carbon transfer provinces, among which Shanxi, as a major energy province, has the largest net carbon transfer, accounting for 68.7% of the total in the central region, while Jiangxi has the lowest net carbon transfer, accounting for only 1.5%. Henan Province and Hubei Province have a large scale

of product transfer and strong consumption-ability of residents, which are net carbon transfer out regions.

(3) Through the comparative analysis of the three responsibility schemes, the shared responsibility scheme is better than the producer and consumer responsibility schemes. Specifically, the shared responsibility for carbon emissions in the northwest, northeast, central and north coastal regions is lower than the responsibility for carbon emissions on the production side and higher than the responsibility for carbon emissions on the consumption side. Among them, the central region requires the largest amount of carbon emission responsibility, but the difference is smaller compared with the production side and the consumer side, while the northwest region requires a lower amount of carbon emission responsibility than the central region, but the largest decrease compared with the production side and the consumer side carbon emission reduction responsibility. In addition, the carbon emission responsibilities of the six central provinces are, from largest to smallest, Henan Province, Shanxi Province, Anhui Province, Hubei Province, Hunan Province, and Jiangxi Province. At the province level, the comparative analysis also proves the conclusion that the shared responsibility scheme is better than the producer and consumer responsibility scheme. Therefore, the shared responsibility perspective can effectively balance the carbon emission reduction responsibilities among regions and make up for the shortcomings of the producer and consumer responsibility system. However, the variation behind the responsibility for carbon emission reduction in a particular region still needs to be explored in more depth.

### 5.2 Insights

(1) To set regional carbon emission peaking targets in batches according to local conditions. In the context of

the 2030 carbon peak target, and taking into account the actual problems of carbon emissions in each region, we can set the carbon peak target for each region according to the degree of decoupling between regional economic development and carbon emissions, implement differentiated carbon emission reduction measures, and promote each region to achieve the carbon peak target in batches in an orderly manner.

(2) Promote the carbon market and force traditional industries to transform and upgrade. Traditional energy industries in the central and western regions are predominant, and the production technology of enterprises is relatively backward, producing a large amount of carbon dioxide emissions in the process of energy or product production and utilization. For such problems, it is recommended to be led by the government promote carbon marketization, accelerate the construction of carbon trading mechanisms, and enhance the awareness and enthusiasm of enterprises in carbon emission reduction, so as to force high energy-consuming and high-polluting enterprises to transform and upgrade, low-carbon technology innovation, improve the efficiency of energy resources utilization, and reduce the dependence on traditional energy sources such as coal and thermal power, and reduce carbon dioxide emissions in the production stage. At the same time, for enterprises with backward technology and low energy utilization efficiency, it is recommended to strengthen the supervision and assessment of regional carbon emission reduction from the government level and use their emission reduction effect as the assessment index of corporate social responsibility to strengthen the social responsibility of carbon emission reduction of enterprises.

(3) Implement the responsibility-sharing scheme and scientifically delineate the responsibility for carbon emission reduction. Scientific and reasonable carbon emission reduction responsibilities are conducive to more effective promotion of the reasonable distribution and balanced development of carbon emission reduction actions of all parties. It is also conducive to reducing the burden of carbon emission reduction in less developed regions, enhancing the awareness of carbon emission reduction in developed regions, and stimulating the vitality of energy conservation and emission reduction in each region, so as to achieve the goal of carbon peaking and carbon neutrality for the whole society.

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