Research on global carbon emission flow and unequal environmental exchanges among regions

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Abstract. Global carbon emissions have become a huge problem, which greatly accelerates the process of global warming. However, the flow and exchange of carbon emissions caused by international trade has further increased the difficulty of determining carbon emissions responsibilities and advancing world's emission reductions. Based on the multi-regional input-output (MRIO) model, this study analysed the flow and outsourcing of carbon emissions among six regions of the world in 2014, and applied the regional environmental inequality (REI) index to measure the unequal environmental exchanges among regions. We found that global carbon emissions reached nearly 35Gt, of which more than 20% were outsourced to other regions. Especially developed regions, such as EU 28, USA and Japan, had significantly higher consumption-based carbon emissions than production-based carbon emissions. The unequal environmental exchanges mainly occurred between developed regions and underdeveloped regions. This paper can help to distinguish emission responsibilities of various regions of the world, and contribute to world emission reduction policies.

1. Introduction
After hundreds of years of rapid development, global industry has brought highly modern civilization to all countries in the world, but also brought catastrophic damage to the natural ecological environment. The environmental assessment report of Intergovernmental Panel on Climate Change (IPCC) pointed out that the global average temperature has risen by nearly 1 degree in the past 100 years. An abnormal increase in global temperature will not only lead to the melting of polar glaciers and sea level rise, but also more serious ecological problems. Climate warming has become a huge problem that all mankind has to face. Studies have shown that the main cause of global warming is greenhouse gas emissions caused by human activities.

Therefore, in order to cope with climate change and severe carbon emissions problem, international community has taken active measures. Various international conventions and documents related to emission reduction have been continuously introduced. However, the leading framework for these conventions to measure the responsibilities of various countries’ industrial greenhouse gas emissions is the production-based accounting [1, 2], which largely ignores the transfer of emissions responsibilities hidden in international trade [3, 4].
International trade separates consumers and producers of goods, which allows consumers to transfer carbon emissions related to their consumption to other regions [5]. At the same time, underdeveloped regions can also gain value added inflows to stimulate local economic growth in the process of exporting products. Therefore, for international trade and emission reduction policies, it is necessary to consider economic benefits and carbon emissions together. In the context of the international division of production, the quantification of the unequal exchange of carbon emissions and value added can not only provide a basis for measuring emission reduction responsibilities of various regions of the world, but also contribute to world emission reduction policies and international trade cooperation.

At present, many studies have focused on economic benefits or environmental losses in international trade. But there are few studies that comprehensively measure the exchanges between environment and economy, and also there is a lack of global regional analysis. For example, Wang et al. used the multi-regional input-output (MRIO) model to calculate the carbon emissions and total emission intensity of India’s exports and imports [6]; Wang and Yang used the MRIO model and structural decomposition analysis (SDA) method to research the temporal changes and driving forces of carbon emissions in China-India trade from 2000 to 2015 [7]; Wang and Liu studied the evolution and driving factors of net carbon emissions in Sino-German trade [8]; Yu and Luo analyzed the benefits of China’s participation in global value chains through the calculation and decomposition of China’s total exports [9].

Also, some studies have analysed environmental and economic inequality hidden in trade. Wu et al. discussed the imbalance of carbon emissions and currency transferred through the global supply chain in 2012 [10]; Zhao et al. regarded value-added and employment as economic benefits, carbon emissions as environmental costs, and then analyzed the economic and environmental impacts of the trade between China and the Asia-Pacific region [11]; Zhang et al. calculated the carbon emissions and energy per unit of value added, and analyzed the carbon footprint and value added flow among BRICS group [12]. However, few studies focused on inequality at the global trade level, and did not quantify the degree of inequality among regions on the same dimension.

Therefore, this paper calculated the carbon emissions and value added embodied in global trade in 2014 through MRIO model. The regional environmental inequality index proposed by Zhang et al. was used to quantify the inequality of environmental and economic exchanges among regions [13].

2. Methods and data sources

2.1. Multi-regional input-output model

Environmentally-extended input-output (EEIO) model introduces the direct emission coefficients of various economic sectors into the input-output model, to reflect the impact of final demand and input-output structure on emissions in a certain region [14]. On this basis, considering the economic and technological structure of different countries, such as the pollutant emission coefficient of different country, the Multi-regional input-output (MRIO) model was further developed.

\[
C_{ij} = f_i (I - A)^{-1} y_i \tag{1}
\]

\[
NC = C_{ij} - C_{ji} \tag{2}
\]

\[
f_i = \frac{e_i}{x_i} \tag{3}
\]

Where the matrix \( C_{ij} \) represents the carbon emissions in the region \( j \) caused by the consumption of region \( i \), and \((I - A)^{-1}\) is the Leontief inverse matrix. \( y_i \) is the final demand vector of region \( i \); \( f_i \) is the carbon emission intensity vector. \( e_i \) and \( x_i \) respectively represent the direct carbon emissions and total output of region \( i \), and the matrix NC represents the net flow of carbon emissions between regions \( i \) and \( j \).

In the same way, the value added coefficient is introduced:

\[
V_{ij} = e_i (I - A)^{-1} y_i \tag{4}
\]

\[
NV = V_{ij} - V_{ji} \tag{5}
\]
\[ e^i = \frac{\nu^i}{x^i} \]  

(6)

Where the matrix \( V^{ij} \) represents the value added in region \( j \) caused by the consumption of region \( i \); \( e^i \) is the value added coefficient vector, and \( \nu^i \) represents the direct value added of region \( i \). The matrix \( NV \) represents the net flow of value added between regions \( i \) and \( j \).

2.2. Regional environmental inequality index

The study used the Regional environmental inequality (REI) index to quantify the inequality of environmental and economic exchanges in the same dimension between regions [13]. If \( \bar{n}e^{ij} \) and \( \nu v^{ij} \) are corresponding elements in matrix \( NC \) and \( NV \) respectively, and \( NC \) is the matrix with all positive value of emission flows between regions. So the element \( r^{ij} \) of REI index can be calculated as follows:

\[
r_{ij} = \begin{cases} 
  f\left(\frac{\bar{n}e^{ij}}{\nu v^{ij}}\right), & \text{if } \bar{n}e^{ij} > 0 \text{ and } \nu v^{ij} > 0 \\
  f\left(\bar{n}e^{ij}\right) + f\left(\nu v^{ij}\right) + 1, & \text{if } \bar{n}e^{ij} > 0 \text{ and } \nu v^{ij} < 0 
\end{cases}
\]  

(7)

\[
f(z) = \frac{z - z_{\min}}{z_{\max} - z_{\min}}
\]  

(8)

Where \( f(z) \) is a normalization function, which can make each element \( z \) in the matrix \( Z \) lie between 0 and 1. And \( z_{\max} \) and \( z_{\min} \) are the maximum and minimum values in \( Z \), respectively.

When \( 1 > r^{ij} > 0 \), it indicates that both carbon emissions and value added are transferred from region \( i \) to region \( j \); when \( r^{ij} > 1 \), it indicates that while region \( i \) transfers carbon emissions to region \( j \), it also received value added from region \( j \). Therefore, \( r^{ij} \) represents the quantification of environmental inequality between two regions, and the larger \( r^{ij} \) indicates the higher the inequality.

2.3. Data sources

In this study, we adopt the Eora MRIO database in 2014 to conduct the analysis, as it includes the most updated environmental satellite accounts. The Eora provides annual multi-country input-output tables, which includes data for 26 industries, covers 189 countries. And according to the world’s major trade regions, we aggregate the 189 countries into 6 regions (China, USA, Japan, 28 EU countries, 10 ASEAN countries and 148 countries of rest of the world). Therefore, subsequent calculations and analysis are based on the integrated MRIO table of 6 regions and 26 industries.

3. Results and discussion

3.1. Outsourcing of carbon emissions and value added

In 2014, global consumption-based carbon emissions reached nearly 35Gt, of which more than 7Gt (about 20%) of carbon emissions were outsourced to other regions, and 15% of the corresponding value added was transferred.
As shown in Figure 1, EU 28, USA and Japan outsourced 28%-38% of consumption-based carbon emissions to other regions, but only transferred about 15% of consumption-based value added. For example, EU 28 outsourcing 1550Mt (36%) of consumption-based carbon emissions by purchasing products and services from other regions of the world, but only transferred 1900 billion dollars (11%) of consumption-based value added.

In contrast, ASEAN 10 and RoW 148 outsourced 33% and 16% of consumption-based carbon emissions, while transferring a similar proportion (25% and 15%, respectively) of value added. However, China outsourced 728Mt (8%) of consumption-based carbon emissions, but transferred twice the value added (16%).

3.2. Consumption-based and production-based carbon emissions and value added

Figure 2 compares consumption-based and production-based carbon emissions and value added in various regions of the world. The consumption- and production-based carbon emissions of ASEAN 10 are almost equal, and similar in RoW 148.

Figure 2. Consumption-based and production-based carbon emissions and value added in different regions of the world. The number on the right side of each bar represents the ratio of consumption-based to production-based.

However, EU 28, USA and Japan had significantly higher consumption-based carbon emissions than production-based carbon emissions, which was 1.24, 1.20, and 1.23 times respectively. These richer developed countries produced high value-added and low-emission goods and services, and imported carbon-intensive products from other regions to outsource large amounts of carbon emissions. Therefore, a large part of their consumption-based emissions occurred in other regions. In contrast, China produced high-emission products for other regions through international trade, greatly increasing its own carbon emissions. As one of the largest carbon emitters, China generated 1655Mt of carbon emissions due to consumption in other countries and regions, accounting for 15% of its total carbon emissions.

For value added, the consumption- and production-based were almost equal in all regions of the world. As shown in Figure 2, it can be seen that the difference between consumption- and production-based carbon emissions was more significant than value added. The ratio of consumption-based to production-based carbon emissions in each region ranged from 0.85 to 1.24, while the value-added ratio ranged from 0.95 to 1.07. This difference between ratios is mainly caused by the international trade of products with high-carbon emission but low-value added among regions with different economic structures.
3.3. Imbalance of economic gains and environmental losses among regions

We used REI index to measure the unequal transfer of carbon emissions and value added among regions in global trade. Figure 3 shows the REI index among the 6 regions (including 15 pairs of regions) in the world.

![Figure 3. The REI index matrix of 6 regions of the world in 2014.](image)

REI>1 means that net carbon emissions are transferred from importing regions to exporting regions, but net value added is transferred from exporting regions to importing regions. The larger the REI value, the more unequal the transfer of carbon emissions and value added. The regions with higher REI index values were EU 28-RoW 148 (REI=2.84) and EU 28-China (REI=2.02). It can be concluded that the environmental inequality embodied in the international trade between developed and underdeveloped regions was the most serious. In addition, there was also inequality among developed regions, such as EU 28 -USA (REI = 1.49), EU 28 -Japan (REI = 1.01). Similarly, inequality existed among underdeveloped regions, such as ASEAN 10-China (REI=1.23), ASEAN 10- RoW 148 (REI=1.13).

When 1>REI>0, it means that carbon emissions and value added are both transferred from importing area to exporting area. But there was still inequality, such as EU 28 -ASEAN 10 (REI= 1.00), Japan-China (REI=0.36). It means that the ASEAN 10 and China received carbon emissions from EU 28 and Japan in international trade, and as a compensation, they gained a certain amount of value added. However, the economic benefits and carbon emissions pollution were not equal.

In the 6 regions, EU 28 greatly promoted this inequality in international trade. In the process of trading with other 5 regions, EU 28 not only transferred carbon emissions, but also did not make any economic compensation for the pollution outsourcing. Instead, it gained value added inflows from other regions. In contrast, China was the region that suffered the most in global trade. In the trade with the other 5 regions, China was always the region receiving carbon emissions, but hardly obtained the equivalent inflow of value added. For example, in trade with Japan, China has only obtained economic benefits far less than carbon emissions pollution; while in trade with EU 28 and ASEAN 10, China not only failed to obtain economic benefits, but suffered a large outflow of value added.

4. Conclusion

We used the MRIO model to quantify the carbon emissions and value added embodied in international trade in 2014. By constructing REI index, we measured the degree of unequal exchange between economic gains and environmental losses in global trade. The main conclusions and policy recommendations are as follows:

(1) There were huge differences between production-based and consumption-based carbon emissions among regions. In global trade, the net flow of carbon emissions was mainly from developed regions to underdeveloped regions. Therefore, when considering international carbon emissions and emission reduction policies, more consideration should be given to consumption-based emissions. This will help
clarify the transfer of emissions embodied in global trade, and also reduce carbon leakage and make more effective division of responsibilities for emission reduction issues.

(2) China and other underdeveloped regions received a net inflow of carbon emissions, but didn’t obtain equivalent value added. From the perspective of environmental and economic benefits, these regions suffered serious inequalities in international trade. Therefore, while pursuing economic development in international trade, underdeveloped regions should pay attention to the impact on their own environment. Try to broaden the areas of cooperation, and actively participate in international cooperative emission reduction actions, and obtain more technical and financial support from developed countries and regions.

(3) The environmental inequality in global trade was mainly due to the uneven economic development among regions. For relatively underdeveloped regions, products with high-value added and low-carbon emissions accounted for a low proportion of the export structure. Also, their emission reduction technologies were backward, so more carbon emissions were generated. Therefore, for regions suffering from severe inequality, especially China, it is necessary to optimize the import and export structure, and increase the proportion of green industries in exports, and promote trade transformation and upgrading. At the same time, they should improve energy efficiency and the use of renewable clean energy, and strengthen technological innovation to achieve emission reduction in high-polluting industries.

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