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# Will China's trade restructuring reduce $CO_2$ emissions embodied in international exports?

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A B S T R A C T

China's $CO_2$ emissions exports embodied in international trade has recently attracted more attention and raises questions on the liability and responsibility for environmental costs associated with Chinese-produced goods. Given that embodied emissions exports and imports are normal phenomena during international trade, the key question focuses on China's reduction of embodied emissions exports via trade restructuring. A trade restructuring optimization model combined with input-output analysis and multi-objective programming was established in this study, in order to analyze the maximum volume of embodied emissions reduction within bearable cost constraints. The results suggest that the trade-off cost for China to reduce embodied emissions exports is very high. Additionally, the net exports of China's embodied $CO_2$ emissions under a reasonable scenario can only be reduced by 3.26%. Previous policy suggestions on import-export structure adjustments have limited effects on the reduction of China's embodied emission exports, and unemployment is an important constraint on embodied $CO_2$ emissions export reduction. Even so, China can still take advantage of various positive factors that have emerged in recent years to improve the industrial and energy consumption structures given that the increasing trend of China's embodied $CO_2$ emission exports has already changed gradually.


## 1. Introduction

Embodied emissions refers to the direct and indirect emissions throughout the life cycle of a product or service (Wyckoff and Roop, 1994; Machado et al., 2001). As international trade has developed, $CO_2$ emissions embodied in international exports have also received increasing attention (Su et al., 2010; Xu and Erik, 2014).

The total amount of China's foreign trade exceeded that of the United States in 2012 for the first time, making China the largest global trading nation. As the "world factory," China exports a large volume of "Made in China" products and services. In recent years, emissions embodied in China's foreign trade have been widely studied. Research shows that rapid growth in China's exports has been a key determinant in China's rising $CO_2$ emissions (Zhang et al., 2014), and that Chinese consumption-based $CO_2$ emissions are much less than production-based emissions (Chen et al., 2011; Lin and Sun, 2010; Yan and Yang, 2010; Ma and Chen, 2011; Xu et al., 2011; Erik et al., 2012), which indicate that China is a net exporter of embodied emissions.

In the current global supply chain context, production methodologies encourage leakages of emissions through trade (Pan et al., 2008). Research-related interest has recently escalated regarding the shared responsibility of embodied emissions between the producer and consumer (Rodrigues et al., 2006; Lenzen et al., 2007; Peters, 2008; Rodrigues and Domingos, 2008). The exports of China's embodied emissions effectively reduced the direct carbon emissions and other environmental costs of China's main trade partners, which raises the issue of whose responsibility it should be to bear the cost of China's carbon emissions embodied in export goods, and the Chinese government wants importers to cover some, if not all, of these costs (Zhang, 2012). Guan et al. (2009) indicated China's willingness to play an active role in post-Kyoto climate commitments if the net embodied emission importers accepted partial responsibility.

From China's perspective, it is easy to understand the motivation for responsibility sharing of these embodied emissions exports. Qi et al. (2014) showed that 22% of China's $CO_2$ emissions are embodied in China's net exports. Some trading partners can gain direct environmental benefits from importing goods produced in

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China rather than in their own country (Liu et al., 2016). However, China will have difficulty in convincing other countries to cover these costs (Zhang, 2012). Tang et al. (2016a) pointed out that the large volumes of embodied emissions exports are not forced on China by other countries, but rather a result of China's chosen export-oriented development model. Therefore, China's responsibility-sharing request is unrealistic without a global agreement, and the more practical approach for China is to change the current trade model and reduce the embodied emissions exports directly. Zhao et al. (2016) suggested that China can adjust its trade structure to reduce the exports of embodied emissions. However, there is a lack of quantitative consideration of the detailed consequences. Will China's trade restructuring reduce the emissions embodied in international exports? The present study will address this research gap and will focus on the effects of China's export restructuring on the reduction of embodied $CO_2$ emissions exports.

## 2. Methodology and data

### 2.1. Methodology

Most previous studies on consumption-based environmental accounting use some form of input-output model. Wiedmann (2009) provided an in-depth review of these input-output models. In this study also, an input-output model was used for trade-embodied $CO_2$ emissions accounting and the calculation of employment and GDP created by international exports in sections 2.1.1 and 2.1.2 respectively. The trade restructuring optimization model was created from a combination of the input-output analysis and multi-objective programming in section 2.1.3.

#### 2.1.1. Accounting of trade-embodied $CO_2$ emissions

The present study focuses on energy-related $CO_2$ emissions - given that $CO_2$ emissions are mainly caused by energy consumption. This will also benefit the analysis of the embodied $CO_2$ emissions change from the Chinese energy structure perspective. Since coal dominates China's energy consumption, the energy structure will affect China's $CO_2$ emissions embodied in international trade. Therefore, China's embodied energy exports and imports will be calculated and converted to embodied emissions by considering the $CO_2$ emission factors of different kinds of energy.

Tang et al. (2011, 2012, 2013a) presented an input-output model to calculate the energy embodied in international exports and imports, that was later revised specifically for China (Tang et al., 2016b). In the revised model, the embodied energy was divided into embodied coal, embodied oil, and embodied gas, wherein their respective exports and imports were calculated separately. Therefore, the differences in coal and oil consumption intensity among China and its trade partners can be considered. China's top 15 trade partners were selected and the remaining smaller trade partners were aggregated as the "rest of the world" in this revised model to calculate the average energy content for China's imports. By importing goods from other countries, China can avoid a proportion of domestic energy consumption dedicated to the manufacturing of these goods. This study adopted the same method to update China's embodied energy export and import calculations. The equations to calculate China's embodied $CO_2$ emissions exports (*EEE*) and embodied $CO_2$ emissions imports (*EEI*) are established as follows:

$$EEE = \sum_{k=1}^{3}\sum_{j=1}^{n} EX_j \times b_{kj} \times \frac{E_k}{Y_k} \times C_k \tag{1}$$

$$EEI = \sum_{k=1}^{3}\sum_{j=1}^{n}\left(IM_j \times b_{kj} \times \frac{E_k}{Y_k} \times C_k\right)\sum_{R=1}^{K}\sum_{L=1}^{S}\left(\frac{V_R}{V} \times \frac{V_{RL}}{V_R} \times \frac{Q_{RL-k}}{Q_{CL-k}}\right) \tag{2}$$

where, $EX_j$ is China's exports in sector $j$; $IM_j$ is China's imports in sector $j$; $b_{kj}$ is the complete consumption coefficient in sector $j$ from the energy $k$ sector, such that the energy sector will be coal, oil, and gas when $k$ equal to 1, 2, and 3, respectively; $E_k$ is China's consumption of energy sector $k$; $Y_k$ is the output of energy sector $k$ in China, in monetary units; $C_k$ is the $CO_2$ emissions factor of energy sector $k$; $\sum_{k=1}^{3}\sum_{j=1}^{n}\left(IM_j \times b_{kj} \times \frac{E_k}{Y_k} \times C_k\right)$ measures China's $CO_2$ emissions imports embodied in international trade, assuming that any imports produced elsewhere generate the same amount of $CO_2$ emissions as they would if they were produced in China; $\sum_{R=1}^{K}\sum_{L=1}^{S}\left(\frac{V_R}{V} \times \frac{V_{RL}}{V_R} \times \frac{Q_{RL-k}}{Q}\right)$ is the adjustment factor and reflects the difference in energy consumption intensity among China and its main trade partners at the sectoral level; $V_R$ is China's total imports from country $R$; $V$ is China's total imports; $V_{RL}$ is China's total imports from sector $L$ in country $R$; and $Q_{RL\text{-}k}$ and $Q_{CL\text{-}k}$ are the energy $k$ consumption intensities of sector $L$ in country $R$ and China, respectively.

#### 2.1.2. Employment and GDP creation from international trade

Embodied $CO_2$ emissions imports and exports are normal economic phenomena caused by international trade. Global trade has been a primary driver for China's economic growth, especially since its accession to the World Trade Organization in 2001. This development model has created many job opportunities and increased GDP in China. The present study considers the total employment opportunities and GDP growth provided by international trade as a part of the embodied $CO_2$ emissions exports' contribution. The Leontief inverse matrix is usually adopted to measure indirect effects. Tang et al. (2016b) also adopted a similar method:

$$TE_j = \theta_j \times EX_j = \left(\sum_{i=1}^{n}\frac{N_i}{Y_i} \times L_{ij}\right) \times EX_j \tag{3}$$

where, $TE_j$ is the total employment creation of the embodied $CO_2$ emissions exported in sector $j$; $\theta_j$ is the complete employment coefficient of sector $j$; $N_i$ is the direct level of employment in sector $i$; $Y_i$ is the total output of sector $i$; $L_{ij}$ is the corresponding element in the Leontief inverse matrix $(I\text{-}A)^{-1}$ and indicates the direct and indirect inputs required from sector $i$ to produce one unit of final demand in sector $j$; and $EX_j$ is the volume of export in sector $j$.

The total GDP creation of embodied $CO_2$ emissions exports in sector $j$, $TG_j$, can also be expressed as follows:

$$TG_j = \left(\sum_{i=1}^{n}\frac{G_i}{Y_i} \times L_{ij}\right) \times EX_j \tag{4}$$

where, $G_i$ is the GDP in sector $i$.

#### 2.1.3. Trade-restructuring optimization model

The trade-restructuring optimization model was established to study China's maximum potential embodied emissions reduction within bearable costs, particularly considering economic losses and unemployment. The main objective of the trade-restructuring optimization model is the minimization of net embodied $CO_2$ emissions exports. The model simultaneously accomplishes the objectives of GDP and unemployment loss minimization after trade