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Input–output analysis of CO_2 emissions embodied in trade: A multi-region model for China

Bin Su [a,*], B.W. Ang [a,b]

[a] Energy Studies Institute, National University of Singapore, Singapore
[b] Department of Industrial and Systems Engineering, National University of Singapore, Singapore

HIGHLIGHTS

- We combine the HEET approach and SWD-EET analysis for regional emission modeling.
- A comprehensive study of China's regional emission embodiments is presented.
- How interregional and international trade affect China's regional CO_2 are explained.
- Developed regions are generally net importers of embodied emissions from trade.
- Developing regions are generally net exporters of embodied emissions from trade.

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ABSTRACT

Energy-related CO_2 emissions embodied in international trade have been widely studied at the national level in recent years. The embodiment estimates help to explain the "weak carbon leakage" between industrial and developing countries and to reveal the so-called "consumption-based" emissions (or carbon footprint). These findings have implications on national climate policy and international negotiations. For a large country like China, spatial aggregation issues are important in embodied emission studies. Dividing the country into several regions, previous studies propose the hybrid emissions embodied in trade (HEET) approach for regional emission studies and use step-wise distribution of emissions embodied in trade (SWD-EET) analysis to explain indirect absorption patterns. In this paper, we combine the HEET approach and SWD-EET analysis to conduct a comprehensive study of China's regional emission embodiments. We explain how inter-regional trade and international trade affect China's regional domestic emissions, and present the resulting regional carbon footprint. Policy implications from the empirical results obtained are discussed.

1. Introduction

The measurement of CO_2 emissions embodied in international trade using the environmental input–output (I–O) framework has been an actively-researched area [37,36].[1] The "consumption-based" emission (or carbon footprint) accounting has also received much attention.[2] The trade balance of embodied emissions has been used by researchers as a proxy to reveal the "carbon leakage" between Annex B and non-Annex B countries [23]. The mechanisms of direct and indirect absorption patterns of embodied emissions clarify the sources of resulting "consumption-based" emissions [27]. Total CO_2 emissions embodied in world international trade have been found to be increasing in the last two decades [24]. All these studies are important to national climate policy and international climate negotiations.

To substantiate the policy implications of the empirical results reported in embodied emission studies, a reasonable emission accounting system is needed. Although both single-region and multi-region I–O models can be applied [37], more recent studies show a preference towards the multi-region I–O models because of its ability to account for different emission technologies associated with different countries' products. See, for example, Minx et al. [16], Su and Ang [26], Su and Ang [27], Su et al. [31], Davis and Caldeira [3], Atkinson et al. [1], Davis et al. [4], Peters et al. [24], Gavrilova and Vilu [6] and Wiebe et al. [35]. Two general approaches to multi-region emission studies are the emissions embodied in bilateral trade (EEBT) approach and the multi-regional I–O (MRIO) approach [21]. The main differences between the two lie on the treatment of the feedback effect [27].

* Corresponding author. Tel.: +65 6601 2075; fax: +65 6775 1831.
E-mail addresses: subin@nus.edu.sg, subin.nus@gmail.com (B. Su).

[1] Details about the environmental I–O framework for single-region and multi-region analyses can be found in Leontief [12] and Miller and Blair [15].

[2] The "consumption-based" emissions are computed using the "production-based" emissions minus the emissions embodied in exports and plus those in imports [21,27].

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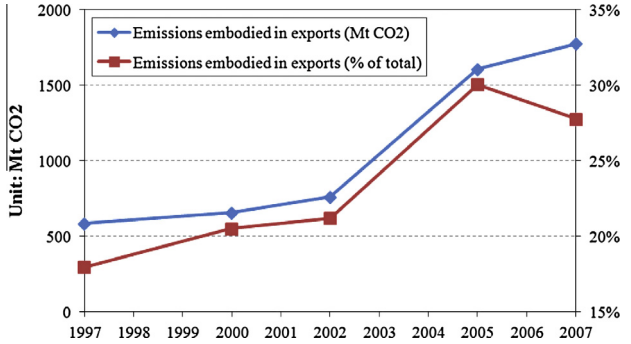

Fig. 1. Estimates of CO_2 emissions embodied in China's exports for selected years from 1997 to 2007 [30].

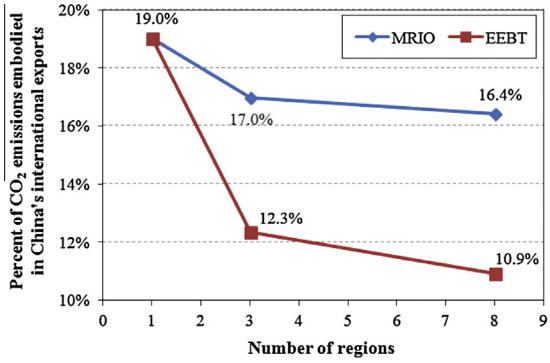

Fig. 2. Total emissions embodied in China's exports estimated at three different spatial aggregation levels using the MRIO and EEBT approaches, 1997 [26].

Embodied emission studies can be conducted at multiple scales, such as national, regional and worldwide [22,26]. Previous emission studies focus mainly on emissions embodied in trade at the national level without considering country size. Su and Ang [26] look into the effect of spatial aggregation on embodied emission estimates and propose the hybrid emissions embodied in trade (HEET) approach for a large country like China. Utilizing the stepwise distribution analysis proposed in Su and Ang [27], a regional emission model can be constructed to better understand the impact of CO_2 emissions embodied in interregional and international trade for each region in a country.

China, the world largest CO_2 emitter, has experienced rapid economic growth and increases in external trade volumes. Many empirical studies on its CO_2 emissions embodied in international trade at the national level have been reported [30,25].[3] Su and Ang [30] review 14 studies on estimates of China's emissions embodied in exports and reveal the impacts of imports assumptions in embodied emission studies. Fig. 1 shows China's CO_2 emissions embodied in its exports and their shares in the country's total CO_2 emissions for selected years [30]. The embodied emissions have been increasing over time, especially after 2002. Very few studies have looked into the embodied emissions at the regional level for the country.

This study is an attempt to introduce a regional emission model for a large country like China. We use China's regional data and Asian international data to illustrate the application of our proposed regional model. Some implications on China's climate policies in its "Twelfth Five-Year (2011–2015)" Plan will be discussed. Key findings and recommendations on future research are summarized.

2. Hybrid approach to regional emission study

When dividing a country into several regions, a good choice for regional emission modeling is to apply the MRIO approach. If the EEBT approach is used instead, the share of a country's emissions embodied in its international exports will drop sharply because a significant part of the national total CO_2 emissions will be allocated to interregional trade within the country [26]. However, those emissions embodied in interregional trade are not attributable to the domestic consumers in the regions due to the feedback effect [27]. The impacts of spatial aggregation on the estimates of China's emissions embodied in exports are shown in Fig. 2.[4] The MRIO approach is also used in McGregor et al. [13] to evaluate the trade balance between Scotland and the rest of the United Kingdom.

The hybrid (or HEET) approach is a combination of the MRIO approach at the regional level and the EEBT approach at the national level. This HEET approach incorporates the transparency property of the EEBT approach at the national level and the interregional feedback effect property of the MRIO approach at the regional level. The concept of the HEET approach is shown in Fig. 3, where $\overline{N}$ is the total index set, Q is the regional index set for country $(n+1)$, and P is the rest of world country index set.

For any country p in set P, its total CO_2 emissions from industry can be formulated using the following single-region I–O model:

$$C_p = f_p'(I - A_{pp})^{-1}\left(y_{pp} + \sum_{s\neq p} e_{ps}\right) = C_{pp}^{EEBT} + \sum_{s\neq p} C_{ps}^{EEBT} \quad (1)$$

where C_p is the total CO_2 emissions from production in country p, f_p is the vector of CO_2 emissions per unit of total output, A_{pp} is the matrix of domestic production coefficient, y_{pp} is the vector of domestic final consumption, e_{ps} is the vector of domestic exports from country p to country s, $C_{pp}^{EEBT} = f_p'(I - A_{pp})^{-1} y_{pp}$ is the embodied emissions with domestic final consumption in country p, and $C_{ps}^{EEBT} = f_p'(I - A_{pp})^{-1} e_{ps}$ is the embodied emissions with country p's exports to country s.

For any region r (or $\overline{n+r}$) in set Q, i.e. one of m regions in country $(n+1)$, its total CO_2 emissions from industry can be formulated using multi-region I–O model as

$$C_r = \sum_{q\in Q} \widetilde{C}_{rq}^{d} + \sum_{p\in P} \widetilde{C}_{rp}^{ex} = \sum_{q\in Q} C_{rq}^{MRIO} + \sum_{p\in P} C_{rp}^{MRIO} \quad (2)$$

where $C_{rq}^{MRIO} = \widetilde{C}_{rq}^{d}$ is region r's emissions embodied in trade to satisfy the final demands in region q in set Q, and $C_{rp}^{MRIO} = \widetilde{C}_{rp}^{ex}$ is region r's emissions embodied in country $(n+1)$'s exports to country p in set P. The proof of Eq. (2) using the stepwise distribution analysis [27] can be found in Appendix A.

With the embodied emissions in Eqs. (1) and (2), the "consumption-based" emissions of any country r in set P or region r in set Q can be formulated as

$$\widetilde{C}_r^{HEET} = \sum_{p\in P} C_{pr}^{EEBT} + \sum_{q\in Q} C_{qr}^{MRIO} \quad (3)$$

where $\widetilde{C}_r^{HEET}$ is the "consumption-based" emissions using the HEET approach, C_{pr}^{EEBT} is the estimated embodied emissions using the EEBT

[3] Some other studies further utilize decomposition techniques to derive the driving forces behind the historical changes of total emissions and embodied emissions. A review of previous decomposition studies applied to energy and emissions can be found in Su and Ang [28]. Recently, Michieka et al. [14] use the vector autoregression model to examine the relationship among exports, CO_2, coal consumption and trade openness in China for 1970–2010.

[4] Detailed explanation of three different levels of spatial aggregation, i.e. treating China as a single entity and dividing China into three and eight regions, are given in Su and Ang [26].