How Does Trade Adjustment Influence National Inventory of Open Economies? Accounting embodied carbon based on multi-region input-output model

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ABSTRACT *Current national GHG accounting which does not consider emissions embodied in trade may cause issues such as carbon leakage from Annex I to non-Annex I countries through trade of carbon-intensive goods. Among other measures to address this issue such as border carbon adjustment, this paper presents an alternative approach by trade adjustment to national* CO_2 *accounting with application to ten regions (Indonesia, Malaysia, the Philippines, Singapore, Thailand, China, Taiwan, the Republic of Korea, Japan and USA) for 2000 based on two responsibility allocation schemes: i) consumer responsibility and ii) shared producer and consumer responsibility. Multi-region input-output model is applied to calculate embodied emissions. Based on consumer responsibility, embodied carbon of ten regions accounted for 3% of their total emissions, with significant amount in USA (163 Mt-*CO_2*) and Japan (82 Mt-*CO_2*). Trade adjustments make significant changes to current national inventories, ranging from (-262Mt, 212Mt) and (-63Mt, 56Mt) of* CO_2 *particular for China and USA based on two responsibility allocation schemes. In terms of trade balance of embodied carbon, USA, Japan and Singapore had deficit while developing countries especially China had trade balance.*

KEY WORDS: embodied emissions, national emission accounting, trade adjustment, carbon leakage, multi-region input-output model, production-based vs. consumption-based responsibility

1. Introduction

World merchandise trade grew twice the rate of world GDP for 2000-2006 (WTO, 2008). Contributing to economic growth by global specialisation and efficient resource allocation, world trade however impacts regional disparity negatively and contributes to the degradation and depletion of natural resources because social and environmental externality costs are not properly internalised in the trade system. Moreover, emissions are embodied in goods which are shipped to destination countries but leave their impacts to exporting countries or on the global environment. “Embodied carbon” refers to CO_2 emitted from each upstream stage of the supply chain of a product, which is used or consumed by the downstream stages or consumers.

The issue of embodied carbon has profound implications for the international climate regime however yet received proper consideration by the United Nations Framework Convention on Climate Change (UNFCCC). First, the Kyoto Protocol sets targets for industrialized countries to collectively reduce 5% in their 1990 GHG emissions for 2008-2012. With the mitigation commitments by only a subset of all emitting parties, carbon leakage could happen through trade of carbon intensive goods from non-Annex I countries to Annex I countries. This will undermine the effectiveness of achieving the Kyoto target. Second, current national GHG inventory adopted by the UNFCCC accounts “all greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction” (IPCC, 1996). The equity of this production-based allocation approach has been argued by major exporting countries, which produce goods that are consumed by other countries but carbon emissions are charged to their national GHG accounts. This also becomes one of the barriers keeping developing nations from participation because many of them like China, India and ASEAN countries, among others, have experienced rapid economic development largely owing to steady growth in exports, which contributes to an increase in their national GHG emissions.

Several articles indicate a significant amount of CO_2 embodied in international trade. CO_2 emitted inside Japan was estimated to be 304 Mt-C in 1990, however carbon embodiments in imports to Japan was 68 Mt-C, surpassing those embodied in Japan's exports (46.4 Mt-C) (Kondo & Moriguchi, 1998), . For Denmark, CO_2 trade balance changed from a surplus of 0.5 Mt in 1987 to a deficit of 7 Mt in 1994 (Munksgaard & Pedersen, 2001). Norwegian household consumption induced CO_2 emitted in foreign countries represented 61% of its total indirect CO_2 emissions in 2000 (Peters & Hertwich, 2006). For the U.S., the overall CO_2 embodied in U.S. imports grew from 0.5-0.8 Gt-CO_2 in 1997 to 0.8-1.8 Gt-CO_2 in 2004, representing 9-14% and 13-30% of U.S. national emissions in 1997 and 2004, respectively (Webber & Mattews, 2007). At multi-region level, about 13% of the total carbon emissions of six OECD countries (Canada, France, Germany, Japan, the UK and the USA) were embodied in their manufactured imports in mid 1980s (Wyckoff & Roop, 1994). More recent research shows that around 5Gt-CO_2, of 42Gt-CO_2 equivalent of global GHG emissions in 2000 (Stern, 2007), are embodied in international trade of goods and services, most of which flow from non-Annex I to Annex I countries (Peters & Hertwich, 2008).

To address the impacts of trade on climate policy, adjustment of national GHG inventory for trade is one policy option among others such as border carbon adjustment. Several articles proposed alternative accounting methods including consumption-based accounting and shared responsibilities between exporting and importing countries (Kondo & Moriguchi; Ferng, 2003; Peters, 2008) or among upstream and downstream agents in a supply chain (Bastianoni et al., 2004; Gallego & Lenzen, 2005; Lenzen et al., 2007).

The purpose of this work is to calculate carbon embodied in trade using multi-region input-output (MRIO) model and then adjust current national inventory for trade based on two responsibility allocation schemes. One is consumer responsibility and the other is shared producer and consumer responsibility. Ten regions are selected for application, including three OECD countries, Japan, KOR and USA, five ASEAN countries, Indonesia, Malaysia, the Philippines, Singapore and Thailand, and China and Taiwan.

Several authors calculating embodied carbon based on input-output analysis applied either single-region model or multiple single-region model. Single-region model (Kondo & Moriguchi, 1998; Munksgaard & Pedersen, 2001) assumes that domestic production recipe and emission intensity are applied to the country's imports no matter from which countries the goods are made. Estimation error due to this simplicity is obvious when trading parties have large difference in their productivity and emission intensity. As an improvement of the single-region model to emphasize emissions embodied in bilateral trade, multiple single-region model (Peters & Hertwich, 2006; Webber & Mattews, 2007; Wyckoff & Roop, 1994; Peters & Hertwich, 2008) uses production recipe and emission intensity of each trading parties for their exports of both final goods and intermediate products. Treating exports of intermediate commodities exogenously however fails to account feedback impacts associated with the use of intermediate commodities by a downstream production. MRIO applies technical input coefficients with identification of source countries. Intermediate commodities both for domestic production and for exports are endogenously accounted in multiplier analysis. Compared with other two models, MRIO is more appropriate to calculate consumption-based emissions at multi-region level (Turner et al., 2007; Wiedmann et al., 2007).

In addition, previous works focused only on developed countries and few of them measure the impacts of embodied carbon on developing nations' emission inventory. They also hardly tell the source and destination countries of embodied emissions. This paper could be used to inform the impacts of trade on climate policy for multilateral negotiations under the UNFCCC. From a specific country standpoint, it also provides breakdowns in sources and destinations accounting for embodied carbon, which could help select trading partners.

Rest of this paper is organized as follows. Section 2 explains the accounting methodology emphasizing the differences of MRIO from other two input-output models. Two responsibility allocation schemes, viz. consumer responsibility and shared producer and consumer responsibility, are provided and discussed. Section 3 presents the results on trade adjustment to national emission account and bilateral trade balance of embodied carbon. Section 4 provides policy implications and concludes the paper.

2. METHODOLOGY

2.1. MRIO Model

This work applies MRIO to calculate CO_2 emissions embodied in trade. In the structure of a MRIO (see an example of two-sector and two-region model in Table 1), interregional trade of both intermediate and final goods are made explicit by sector in the supplying region and by sector in the receiving region.

<Insert Table 1>

The following are two types of Leontief multipliers. One is multi-region type, B_{mrio}, two-sector and two-region in this case (*Eq.1*). The other is single-region type, B^{1}_{single} for Region 1 (*Eq.2*) and (B^{2}_{single}) for Region 2 (*Eq.3*).

$$B_{\mathrm{mrio}} = \left[I - \begin{pmatrix} a^{11}_{11} & a^{11}_{12} & a^{12}_{11} & a^{12}_{12} \\ a^{11}_{21} & a^{11}_{22} & a^{12}_{21} & a^{12}_{22} \\ a^{21}_{11} & a^{21}_{12} & a^{22}_{11} & a^{22}_{12} \\ a^{21}_{21} & a^{21}_{22} & a^{22}_{21} & a^{22}_{22} \end{pmatrix} \right]^{-1} = \begin{pmatrix} b^{11(2)}_{11} & b^{11(2)}_{12} & b^{12(2)}_{11} & b^{12(2)}_{12} \\ b^{11(2)}_{21} & b^{11(2)}_{22} & b^{12(2)}_{21} & b^{12(2)}_{22} \\ b^{21(2)}_{11} & b^{21(2)}_{12} & b^{22(2)}_{11} & b^{22(2)}_{12} \\ b^{21(2)}_{21} & b^{21(2)}_{22} & b^{22(2)}_{21} & b^{22(2)}_{22} \end{pmatrix} \qquad (1)$$

$$B^{1}_{\mathrm{single}} = \left[I - \begin{pmatrix} a^{11}_{11} & a^{11}_{12} \\ a^{11}_{21} & a^{11}_{22} \end{pmatrix} \right]^{-1} = \begin{pmatrix} b^{11(1)}_{11} & b^{11(1)}_{12} \\ b^{11(1)}_{21} & b^{11(1)}_{22} \end{pmatrix} \qquad (2)$$

$$B^{2}_{\mathrm{single}} = \left[I - \begin{pmatrix} a^{22}_{11} & a^{22}_{12} \\ a^{22}_{21} & a^{22}_{22} \end{pmatrix} \right]^{-1} = \begin{pmatrix} b^{22(1)}_{11} & b^{22(1)}_{12} \\ b^{22(1)}_{21} & b^{22(1)}_{22} \end{pmatrix} \qquad (3)$$

where I: identity matrix; $a^{rs}_{ij} = X^{rs}_{ij} / X^{s}_{j}$: transaction coefficients, for sectors i, j = 1, 2 and for regions r, s = 1, 2; $b^{rs(2)}_{ij}$: Leontief multiplier in a two-region input-output framework; $b^{rs(1)}_{ij}$: Leontief multiplier in a single-region input-output framework.

The economic impacts induced by consumption in Region 1 (*R1*) and Region 2 (*R2*) in the two-region MRIO framework are calculated as $\left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i1}^{r1(2)}\right)F_1^{11} + \left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i2}^{r1(2)}\right)F_2^{11}$ $+\left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i1}^{r2(2)}\right)F_1^{21} + \left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i2}^{r2(2)}\right)F_2^{21}$ for *R1* and $\left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i1}^{r1(2)}\right)F_1^{12} + \left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i2}^{r1(2)}\right)F_2^{12}$ $\left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i1}^{r2(2)}\right)F_1^{21} + \left(\sum_{r=1}^{2}\sum_{i=1}^{2} b_{i2}^{r2(2)}\right)F_2^{22}$ for *R2*, respectively. Because of sector-region specification on both the source and the destination of trade, interregional spillover effect, e.g. the impacts of an output change in Sector 1 (*S1*) in *R1* on two sectors in *R2*, is internalized via multiplier analysis. So is interregional feedback effect, which indicates the propagated impacts of changes in both sectors in *R2* caused by the initial change in *S1* in *R1* back onto both sectors in *R1*.

Using single-region model assuming domestic production recipe is used for imports, the economic impacts induced by consumption in *R1* and *R2* are estimated as $\left(\sum_{i=1}^{2} b_{i1}^{11(1)}\right)(F_1^{11} + F_1^{21} + X_{11}^{21} + X_{21}^{21}) + \left(\sum_{i=1}^{2} b_{i2}^{11(1)}\right)(F_2^{11} + F_2^{21} + X_{12}^{21} + X_{22}^{21})$ for *R1*, and $\left(\sum_{i=1}^{2} b_{i1}^{22(1)}\right)(F_1^{12} + F_1^{22} + X_{11}^{12} + X_{21}^{12}) + \left(\sum_{i=1}^{2} b_{i2}^{22(1)}\right)(F_2^{12} + F_2^{22} + X_{12}^{12} + X_{22}^{12})$ for *R2*, respectively. Using domestic production recipe to estimate imports could cause significant error when $\left(\sum_{i=1}^{2} b_{i1}^{11(1)}\right)$ and $\left(\sum_{i=1}^{2} b_{i1}^{22(1)}\right)$, or $\left(\sum_{i=1}^{2} b_{i2}^{11(1)}\right)$ and $\left(\sum_{i=1}^{2} b_{i2}^{22(1)}\right)$ are greatly different.

By multiple single-region model, the economic impacts induced by consumption in *R1* and *R2* are calculated as $\left(\sum_{i=1}^{2} b_{i1}^{11(1)}\right)F_1^{11} + \left(\sum_{i=1}^{2} b_{i2}^{11(1)}\right)F_2^{11} + \left(\sum_{i=1}^{2} b_{i1}^{22(2)}\right)(F_1^{21} + X_{11}^{21} + X_{12}^{21})$ $+\left(\sum_{i=1}^{2} b_{i2}^{22(2)}\right)(F_2^{21} + X_{21}^{21} + X_{22}^{21})$ for *R1*, and $\left(\sum_{i=1}^{2} b_{i1}^{22(2)}\right)F_1^{22} + \left(\sum_{i=1}^{2} b_{i2}^{22(2)}\right)F_2^{22} +$

$\left(\sum_{i=1}^{2} b_{i1}^{11(1)}\right)(F_1^{12} + X_{11}^{12} + X_{12}^{12}) + \left(\sum_{i=1}^{2} b_{i2}^{11(1)}\right)(F_2^{12} + X_{21}^{12} + X_{22}^{12})$ for *R2*, respectively. Feedback effects caused by trade of intermediate goods, i.e. X_{11}^{12}, X_{12}^{12}, X_{21}^{12}, X_{22}^{12}, X_{11}^{21}, X_{12}^{21}, X_{21}^{21} and X_{22}^{21}, which are treated exogenously the same as trade of final goods, can not be captured by the multiplier analysis.

The loop of interregional spillover effect and feedback effect manifested by MRIO, which is hardly handled by other two models, can better explain the interwoven network of globalized economy. When multi-region trade are considered as research boundary, MRIO is a more consistent and systematic approach to account embodied emissions than other two models.

The MRIO used in this work, including twenty-four sectors in ten regions for 2000, is developed by IDE-JETRO (IDE-JETRO, 2006). It is Chenery-Moses type of model (Miller & Blair, 1985; Chenery, 1953; Moses, 1955). To calculate embodied carbon, we use GTAP-e database, which provides data on CO_2 emissions from combustion of six types of fuels from sixty sectors (including households and government) in eighty-seven regions for 2001. By aggregating and matching sectors from 60 in GTAP-e to 24 in MRIO and using sectoral outputs from GTAP database, the sectoral intensity of CO_2 emissions are calculated for 24 sectors in 2001. This is then used for calculating embodied emissions. The equations are presented as follows:

$$X = (I - A)^{-1} F \tag{4}$$

$$CX = C(I - A)^{-1} F \tag{5}$$

where X: a vector of 240×1 representing output of 24 sectors in 10 regions; I: 240×240 identity matrix; A: 240×240 matrix representing inter-sectoral and interregional transaction coefficients; F: 240×10 matrix representing final demand of each of 24 sectors in each region provided by each of ten regions; C: 240×240 diagonal matrix with CO_2 intensity of 24 sectors in ten regions on the diagonal.

2.2. Two Responsibility Allocation Schemes

National CO_2 inventory are adjusted for trade based on two responsibility allocation schemes, viz. consumer responsibility (*Eq. 7*) and shared producer and consumer responsibility (*Eq. 8*) which is based on share of each agent in value added to the supply chain of a final goods (Lenzen et al., 2007).

$$E_{\text{producer}} = CX \tag{6}$$

$$E_{\text{consumer}} = C(I - A)^{-1} F \tag{7}$$

$$E_{\text{share}} = \underbrace{C(I - \alpha A)^{-1}(1 - \alpha)F}_{\text{consumer's responsibility}} + \underbrace{C(I - \alpha A)^{-1}\left[(I - \alpha)F + (I - \alpha)AX\right]}_{\text{producer's responsibility}} \tag{8}$$

where $E_{\text{production}}$: national CO_2 emissions based on producer responsibility; $E_{\text{consumption}}$: national CO_2 emissions based on consumer responsibility; E_{share}: national CO_2 emissions based on shared producer and consumer responsibility and α : 240×240 diagonal matrix with $\alpha_i^r = 1 - \frac{v_i^r}{X_i^r - X_{ii}^{rr}}$ on the diagonal; v_i^r : value added of sector i in region r; X_i^r : total output of sector i in region r; X_{ii}^{rr} : intra-sectoral transaction of sector i in region r.

3. Results

3.1. Trade Adjustment To National CO_2 Account

Table 2 and Table 3 present trade adjusted national CO_2 inventory for ten countries based on consumer responsibility (*Eq. 7*) and shared producer and consumer responsibility (*Eq. 8*), respectively. After adjustment account are then compared with current national CO_2 account calculated based on producer responsibility (*Eq. 6*).

<Insert Table 2>

<Insert Table 3>

In 2000, trade adjustment to national CO_2 inventory calculated based on consumer responsibility makes changes to current national emission account ranging from -262Mt-CO_2 for China to 212Mt-CO_2 for USA. By percentage, these changes range from -21.6% for Malaysia to 11.4% for Japan. Trade adjustment based on shared producer and consumer responsibility indicate changes from a reduction of -63Mt-CO_2 in China's current account to an increase of 56Mt-CO_2 in U.S. current account. Changes in national account in terms of percentage indicate from -10.7% for Malaysia to 4.4% for Singapore.

3.2. Multilateral Trade Balance For Embodied Carbon

Table 4 presents sources of embodied carbon in national account calculated based on consumer responsibility. Rows read carbon embodied in trade from a producing region and columns read data from a consuming region. Table 5 indicates net multilateral and bilateral trade balance of embodied carbon counted based on consumer responsibility. Rows read carbon balance embodied in bilateral trade between a specific region indicated by the row and other regions presented by each column.

<Insert Table 4>

In the national CO_2 account of the Philippines and Taiwan, the USA is the largest source of embodied carbon and in other eight countries, China is the largest source. Embodied carbon contributes to national CO_2 emissions based on consumer responsibility accounted from 0.3% for China to 14.8% for Singapore.

<Insert Table 5>

Two extreme regions, China and USA represent net balance and deficit of carbon embodied in the bilateral trades with all other regions, respectively. From multilateral trade viewpoint, embodied carbon ranges from a net trade balance of 162.3Mt-CO_2 in China and -138Mt-CO_2in USA.

4. Conclusions And Policy Implications

Current national GHG accounting based on producer responsibility could cause issues such as (i) carbon leakage from Annex I to non-Annex I countries through trade of carbon-intensive goods; (ii) equity of allocating embodied carbon to exporting countries; and (iii) potential of shifting carbon-intensive production to developing countries. Among other measures such as border carbon adjustment to address these issues, this paper presents trade adjustment to national accounting for CO_2 emissions as an option. Adjustment for trade is calculated based on two responsibility allocation schemes, i.e. consumper responsibility and shared producer and consumer responsibility. MRIO is applied to calculation, which enables (i) to trace sources and destinations of embodied carbon in imports and exports; and (ii) to systematically integrate both spillover effect and feedback effect into multiplier analysis. As explained in methodology, MRIO is more appropriate to calculate embodied emissions in the context of multilateral. Rather than other articles focusing on developed countries, this paper gives special emphasis to Asian developing countries in the calculation of embodied emissions and trade adjustment to national emissions. It also points out the importance of embodied emissions in multilateral trade and balance of carbon embodiments in bilateral trade.

Several findings are summarized as follows:

(i) According to consumer responsibility, carbon embodied in multilateral trade among ten countries was 303 Mt-CO_2 in 2000, accounting for 3% of their total emissions (10,422 Mt-CO_2). Carbon embodiments were especially significant for Japan (82 Mt-CO_2) and USA (163 Mt-CO_2), accounting for 6.5% and 2.9% of their national CO_2 inventory, respectively.

(ii) Adjustment for trade based on different responsibility allocation schemes does not change the total emissions from ten countries but change their relative responsibilities. Trade adjustments indicate significant changes to current national inventories, ranging from (-262Mt, 212Mt) and (-63Mt, 56Mt) of CO_2 for China and USA, respectively, based on consumer responsibility and shared producer and consumer responsibility. For ten countries, the national emission account of six developing countries is adjusted lower than current national inventory while ROK, Japan, USA and Singapore are adjusted higher.

(iii) In terms of trade balance of embodied carbon, Japan, Singapore and especially USA had trade deficit while other developing nations (IDN, MYS, PHL, THA and especially CHN) had trade balance. From bilateral trade viewpoint, USA and Japan had trade deficit with all other eight countries in terms of embodied carbon. This research indicates significant carbon leakage from Japan and USA (195 Mt-CO_2) to non-Annex I countries. Not only being the largest source of embodied carbon in the national account of most countries, China also had trade balance of embodied carbon with all regions.

From climate policy point of view, carbon leakage through emissions embodied in trade between Annex I and non-Annex I countries are happening in an unnegligible way under current Kyoto regime, by which only Annex I countries committing to CO_2 reductions. This could offset the efforts made to achieving the mitigation target in the global context and should be properly considered by the UNFCCC. To address this issue, trade adjustment to current national accounting could be a policy option among others, such as extending the participation of non-Annex I countires in binding reduction and border carbon adjustment.

To conduct trade adjustment accounting, more data is required including bilateral trade and carbon intensity by sector/product and by country. The latter one is rarely transparent nor provided by countries or by authority international organizations. Information on geographical identity, energy intensity and carbon intensity of tradable goods are important to inform environmentally conducive purchasing decision and should be addressed by the collaboration between the global climate regime and the international trade regime.

Among different responsibility allocation schemes for trade adjustment, shared producer and consumer responsibility could be more appropriate. Both producers and consumers are making their decisions on operating production and purchasing everyday impacting our environment. Shared producer and consumer responsibility can work as direct incentive to both actors to change their environmental behaviour. To address all major actors who influence the carbon intensity of a supply chain effectively and fairly, sharing environmental responsibility between each pair of upstream producer and downstream consumer according to their share of value added to the product chain could work as an optional criterion.

As like goods embody different carbon intensity during their production, spending 1US$ on imports of like goods may contribute to global CO_2 emissions differently. Changing trading partners can make a change in a nation’s profile of embodied carbon. More open economies dependent on imports, e.g. Singapore, could reduce their induced CO_2 emissions through carefully selecting trading partners.

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References

Bastianoni, S., Pulselli, F. M. and Tiezzi, E. (2004) The problem of assigning responsibility for greenhouse gas emissions, *Ecological Economics*, 49, pp. 253-257.

Chenery, H. B.(1953) Regional Analysis. In *The Structure and Growth of the Italian Economy*, edited by Chenery, H. B., Clark, P. G. and Pinna, V. C., U.S. Mutual Security Agency, Rome, pp. 97-129.

Ferng, J. J. (2003) Allocating the responsibility of CO_2 over-emissions from the perspectives of benefit principle and ecological deficit, *Ecological Economics*, 46, pp. 121-141.

Gallego, B. and Lenzen, M. (2005) A consistent input-output formulation of shared producer and consumer responsibility, *Economic Systems Research*, 17, pp. 365-391.

Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO) (2006) Asian International Input-Output Table 2000, Volume 1, Explanatory Notes.

Intergovernmental Panel on Climate Change (IPCC) (1996) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.2 Workbook, pp.Overview.5. [Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/guideline/ overwb.pdf.]

Kondo, Y. and Moriguchi, Y. (1998) CO_2 emissions in Japan: influences of imports and exports, *Applied Energy*, 59, No. 2-3, pp. 163-174.

Lenzen, M., Murray, J., Sack, F. and Wiedmann, T. (2007) Shared producer and consumer responsibility – Theory and practice, *Ecological Economics*, 61, pp. 27-42.

Miller, R. E. and Blair, P. D. (1985) *Input-output analysis: Foundations and Extensions*, Prentice-Hall, Inc., New Jersey, USA, pp. 45-9.

Moses, L. N. (1955) The stability of interregional trading patterns and input-output analysis, *American Economic Review*, 45, pp. 803-832.

Munksgaard, J. and Pedersen, K. A. (2001) CO_2 accounts for open economies: producer or consumer responsibility? *Energy Policy*, 29, pp. 327-334.

Peters, G. P. (2008) From production-based to consumption-based national emission inventories, *Ecological Economics*, 65, pp. 13-23.

Peters, G. P. and Hertwich, E. G. (2006) The importance of imports for household environmental impacts, *Journal of Industrial Ecology*, 10, pp. 89-109.

Peters, G. P. and Hertwich, E. G. (2008) CO_2 embodied in international trade with implications for global climate policy, *Environmental Science & Technology*, 42, pp. 1401-1407.

Stern, N.: The Economics of Climate Change: The Stern Review (2007) Cambridge University Press, New York, U.S.A.

Turner, K., Lenzen, M., Wiedmann, T. and Barrett, J. (2007) Examining the global environmental impact of regional consumption activities – Part 1: A technical note on combining input-output and ecological footprint analysis, *Ecological Economics*, 62, pp. 37-44.

Webber, C. and Mattews, H. S. (2007) Embodied environmental emissions in U.S. International Trade, 1997-2004, *Environmental Science & Technology*, 41, pp. 4875-4881.

Wiedmann, T., Lenzen, M., Turner, K. and Barrett, J. (2007) Examining the global environmental impact of regional consumption activities – Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade, *Ecological Economics*, 61, pp. 15-26.

World Trade Organization (WTO) (2008) International Trade Statistics 2008. [Available at http://www.wto.org/english/res_e/statis_e/its2008_e/its2008_e.pdf.]

Wyckoff, A. W. and Roop, J. M. (1994) The embodiment of carbon in imports of manufactured products, *Energy Policy*, 22, pp. 187-194.

Table 1. The structure of a two-sector and two-region MRIO

		Intermediate Demand				Final Demand		Total Output
		S1_R1	S2_R1	S1_R2	S2_R2	R1	R2	
Supply	S1_R1	X_{11}^{11}	X_{12}^{11}	X_{11}^{12}	X_{12}^{12}	F_1^{11}	F_1^{12}	X_1^1
	S2_R1	X_{21}^{11}	X_{22}^{11}	X_{21}^{12}	X_{22}^{12}	F_2^{11}	F_2^{12}	X_2^1
	S1_R2	X_{11}^{21}	X_{12}^{21}	X_{11}^{22}	X_{12}^{22}	F_1^{21}	F_1^{22}	X_1^2
	S2_R2	X_{21}^{21}	X_{22}^{21}	X_{21}^{22}	X_{22}^{22}	F_2^{21}	F_2^{22}	X_2^2
Value-added		V_1^1	V_2^1	V_1^2	V_2^2			
Total input		X_1^1	X_2^1	X_1^2	X_2^2			

Note: S1, S2, R1, R2: sector 1, sector 2, region 1 and region 2, respectively; X_{ij}^{rs} : trade flow of intermediate goods from sector *i* in region *r* to sector *j* in region *s*, for sectors *i*, *j* = 1, 2 and regions *r*, *s* = 1, 2; F_i^{rs} : trade flow of final goods *i* from region *r* to region *s*; X_i^r : total output of sector *i* in region *r*; V_j^s : value added of sector *j* in region *s*.

Table 2. Trade adjustment to national emission account based on consumer responsibility 2000

Region	E_{consumer} ($Mt\text{-}CO_2$)	E_{producer} ($Mt\text{-}CO_2$)	Difference of two accounts ($Mt\text{-}CO_2$)[1]	Difference by percentage (%)[2]
IDN	190	235	-45	-19.2
MYS	70	89	-19	-21.6
PHL	56	60	-4	-6.7
SGP	47	43	4	10.1
THA	119	125	-6	-4.9
CHN	2572	2834	-262	-9.2
TWN	165	174	-10	-5.7
KOR	366	365	1	0.3
JPN	1253	1125	128	11.4
USA	5586	5373	212	4.0
Total	10422	10422	0	

Note: IDN: Indonesia; MYS: Malaysia; PHL: the Philippines; SGP: Singapore; THA: Thailand; CHN: China; TWN: Taiwan; KOR: the Republic of Korea; JPN: Japan; USA: the United States of America.

1. Equals to $E_{\text{consumer}} - E_{\text{producer}}$;
2. Equals to $(E_{\text{consumer}} - E_{\text{producer}}) / E_{\text{producer}} \times 100\%$

Table 3. Trade adjustment to national emission account based on shared producer and consumer responsibility 2000

Region	E_{share} (Mt-CO_2)	$E_{producer}$ (Mt-CO_2)	Difference of two accounts (Mt-CO_2)[1]	Difference by percentage (%)[2]
IDN	226	235	-9	-4.0
MYS	79	89	-10	-10.7
PHL	59	60	-1	-2.1
SGP	45	43	2	4.4
THA	124	125	-1	-1.0
CHN	2770	2834	-63	-2.2
TWN	168	174	-6	-3.6
KOR	363	365	-2	-0.5
JPN	1160	1125	35	3.1
USA	5429	5373	56	1.0
Total	10422	10422	0	

Table 4. Sources of embodied carbon in national CO_2 account based on consumer responsibility 2000 (in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA
IDN	133.2	0.8	0.2	0.6	0.4	0.3	0.6	0.4	2.6	6.4
MYS	0.3	47.2	0.3	1.8	0.6	0.5	0.9	0.4	3.5	6.7
PHL	0.0	0.1	36.5	0.0	0.1	0.1	0.1	0.1	1.5	4.1
SGP	0.1	0.8	0.3	35.7	0.3	0.3	0.4	0.3	1.1	2.9
THA	0.3	0.5	0.2	0.5	91.8	0.3	0.4	0.2	3.1	5.3
CHN	1.3	2.0	0.4	1.9	2.0	2252.2	3.6	4.8	51.6	103.6
TWN	0.3	0.5	0.3	0.2	0.4	2.1	94.4	0.4	3.1	8.4
KOR	0.3	0.3	0.3	0.3	0.2	1.4	1.0	267.5	4.0	9.8
JPN	0.5	1.0	0.4	0.8	0.9	1.7	2.6	1.6	861.9	15.4
USA	0.4	1.0	0.5	0.9	0.8	2.3	4.1	2.6	11.3	4318.5
Households emissions	53	15	17	4	21	311	56	88	310	1105
National emissions	190	70	56	47	119	2572	165	366	1253	5586
Share of embodied carbon in national emissions (%)	1.9	10	4.8	14.8	4.9	0.3	8.3	2.9	6.5	2.9

Table 5. Bilateral trade balance of embodied carbon based on consumer responsibility 2000 (in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA
IDN	0.0	0.4	0.1	0.4	0.1	-1.0	0.3	0.1	2.1	6.0
MYS	-0.4	0.0	0.2	1.0	0.1	-1.5	0.4	0.0	2.5	5.8
PHL	-0.1	-0.2	0.0	-0.2	0.0	-0.3	-0.1	-0.1	1.1	3.6
SGP	-0.4	-1.0	0.2	0.0	-0.2	-1.6	0.2	0.0	0.3	2.0
THA	-0.1	-0.1	0.0	0.2	0.0	-1.7	0.4	-0.1	2.2	4.5
CHN	1.0	1.5	0.3	1.6	1.7	0.0	1.5	3.3	49.9	101.3
TWN	-0.3	-0.4	0.1	-0.2	-0.4	-1.5	0.0	-0.6	0.5	4.2
KOR	-0.1	0.0	0.1	0.0	0.1	-3.3	0.6	0.0	4.0	9.8
JPN	-2.1	-2.5	-1.1	-0.3	-2.2	-49.9	-0.5	-4.0	0.0	4.1
USA	-6.0	-5.8	-3.6	-2.0	-4.5	-101.3	-4.2	-9.8	-4.1	0.0
Trade balance	8.5	8	3.5	-0.5	4.9	162.3	1.9	6.9	-57	-138