How Does Trade Adjustment Influence National Inventory of Open Economies? Accounting for Embodied Carbon Emissions Based on Multi-Region Input-Output Model

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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, this paper presents an alternative approach by trade adjustment to national CO_2 accounting with application to ten economies (Indonesia, Malaysia, the Philippines, Singapore, Thailand, China, Taiwan, the Republic of Korea, Japan and USA) in the year 2000, based on two responsibility allocation schemes: i) consumer responsibility and ii) shared producer and consumer responsibility. A multi-region input-output model and a single-region input-output model are applied to calculate embodied emissions, and the results are compared. Based on consumer responsibility, embodied CO_2 accounted for 13% of total national responsible emissions of ten economies. Trade adjustments also indicate significant changes to current national inventories of ten economies, ranging from –525 Mt-CO_2 in China to 543 Mt-CO_2 in USA. In terms of trade balance of embodied CO_2, USA, Japan and Singapore have a deficit while other economies, in particular China, have a trade surplus.

Key Words: *embodied carbon emissions, national emission accounting, trade adjustment, carbon leakage, multi-region input-output model, producer vs. consumer responsibility*

1. INTRODUCTION

World merchandise trade grew at twice the rate of world GDP in the period 2000-2006[1]. Whilst contributing to economic growth by global specialization and efficient resource allocation, world trade also impacts on regional disparity and contributes to the degradation and depletion of natural resources because social and environmental externality costs are not properly internalized in the trade system. Moreover, emissions are embodied in goods which are shipped to the destination countries but leave their hidden impacts on the exporting countries or on the global environment. "Embodied emissions" 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 emissions has profound implications for the international climate regime; however it is an issue that has yet to receive proper consideration by the United Nations Framework Convention on Climate Change (UNFCCC). First, the Kyoto Protocol sets targets for industrialized countries to collectively reduce their 1990 GHG emissions by 5% for 2008-2012. With the mitigation commitments only bound to a subset of 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, the current national GHG inventory reported to the UNFCCC accounts for "all greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction"[2]. The equity of this territorial responsibility has been argued by some major exporting countries. They produce goods that are consumed by other countries, but carbon emissions are charged to their national GHG accounts. This is also argued as one of the barriers keeping developing nations from participating because many of them such as China, India and ASEAN countries, have experienced rapid economic development largely owing to the steady growth in exports, which contributes to the increase in their national GHG emissions.

Several articles indicate that a significant amount of CO_2 is embodied in international trade. CO_2 emitted inside Japan was estimated to be 304Mt-C in 1990, while carbon embodiments in imports to Japan was 68Mt-C, surpassing those embodied in Japan's exports (46.4Mt-C)[3]. For Denmark, CO_2 trade balance changed from a surplus of 0.5Mt in 1987 to a deficit of 7Mt in 1994[4]. Norwegian household consumption-induced CO_2 emitted in foreign countries represented 61% of its total indirect CO_2 emissions in 2000[5]. For the US, the overall CO_2 embodied in US imports grew from 0.5-0.8Gt-CO_2 in 1997 to 0.8-1.8Gt-CO_2 in 2004, representing 9-14% and 13-30% of US national emissions in 1997 and 2004, respectively[6]. At the multi-region level, about 13% of the total carbon emissions of six OECD countries (Canada, France, Germany, Japan, UK and USA) were embodied in their manufactured imports in mid 1980s[7]. More recent research[8] shows that around 5Gt-CO_2 of 42Gt-CO_2 equivalent of global GHG emissions in 2000[9] are embodied in international trade of goods and services, most of which flow from non-Annex I to Annex I countries.

To address the impacts of trade on climate policy, trade adjustment to the national GHG inventory is one policy option among others such as Border Tax Adjustment[10]. Several articles proposed alternative methods to allocate responsibility, including consumer responsibility and shared responsibility between exporting and importing countries[3, 11, 12] or among upstream and downstream agents in a supply chain[13, 14, 15].

To calculate embodied emissions, a large body of literature in the stream of input-output analysis applies either single-region model (SRIO) or multiple single-region models (MSRIO). By SRIO[3, 4], domestic production recipes and emission intensity are applied to imports even though technologies and emission intensities vary from one country to another in producing similar products. As an improvement to SRIO, MSRIO[5, 6, 7, 9] emphasizes emissions embodied in bilateral trade and uses production recipes and emission intensity of each of the trading parties for imports, including both final goods and intermediate products. Assuming that imports of intermediate commodities are exogenouse variables fails to account for feedback impacts associated with the use of intermediate commodities by downstream production. The multi-region input-output model (MRIO) applies technical input coefficients with identification of source countries. Intermediate commodities both produced domestically and imported are endogenously accounted for in multiplier analysis. Compared with the other two models, MRIO is more appropriate to calculate consumption-based emissions at a multi-region level[16, 17]. In addition, previous works focused mainly on developed economies and few of them measured the impacts on the national GHG inventory of developing nations. They also hardly identified the source and destination countries of embodied emissions.

As such, the purpose of this work is twofold. One is to calculate national responsible emissions based on two responsibility allocation schemes: (i) consumer responsibility; and (ii) shared producer and consumer responsibility. The other is to test the difference in results calculated by SRIO and MRIO. Ten economies are selected, including three OECD countries (Japan, ROK and USA), five ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand), China and Taiwan. The rest of world (ROW) apart from the ten selected economies is also considered. This paper could be used to inform negotiators to the UNFCCC the importance of embodied emissions associated with multilateral trade. It also indicates how different accounting methods could influence national emission inventory. From a specific country standpoint, it also provides breakdowns of sources and destinations of embodied emissions and trade balance of CO_2.

The rest of the paper is organized as follows. Section 2 explains methodology emphasizing the differences of MRIO and SRIO. Two responsibility allocation schemes are explained. Section 3 presents the results on regional responsible emissions and trade balance of CO_2. Section 4 provides policy implications and concludes the paper.

2. METHODOLOGY

(1) Multi-region input-output model

This work applies Asian International Input-Output Table 2000 (AIO 2000), developed by IDE-JETRO[18], to calculate CO_2 embodied in multilateral trade. AIO 2000 includes 24 sectors and ten regions in Asia and the Pacific. It is Chenery-Moses type of MRIO[19, 20, 21]. To calculate embodied CO_2, we use GTAP-E database, which provides data on CO_2 emissions from combustion of six types of fuels from 60 sectors (including capital goods, households and government) in 87 regions for 2001. By aggregating and matching sectors from 60 in GTAP-E[22] to 24 in MRIO (see Appendix) and using sectoral outputs from GTAP database, intensity of CO_2 emissions are calculated for 24 sectors in 2001. These are used for calculating embodied emissions.

The framework of AIO 2000 is illustrated by the simplified two-sector and two-region case (**Table 1**), in which intra-regional and interregional trade of both intermediate and final goods among two regions are made explicit by bivariates indicating the source and destination sectors and regions.

Table 1 Simplified framework of AIO 2000 in a two-sector and two-region case

		Intermediate Demand				Final Demand		Export to *ROW*	Total Output
		$s1r1$	$s2r1$	$s1r2$	$s2r2$	$r1$	$r2$		
Supply	$s1r1$	x_{11}^{11}	x_{12}^{11}	x_{11}^{12}	x_{12}^{12}	f_1^{11}	f_1^{12}	e_1^{1ROW}	x_1^1
	$s2r1$	x_{21}^{11}	x_{22}^{11}	x_{21}^{12}	x_{22}^{12}	f_2^{11}	f_2^{12}	e_2^{1ROW}	x_2^1
	$s1r2$	x_{11}^{21}	x_{12}^{21}	x_{11}^{22}	x_{12}^{22}	f_1^{21}	f_1^{22}	e_1^{2ROW}	x_1^2
	$s2r2$	x_{21}^{21}	x_{22}^{21}	x_{21}^{22}	x_{22}^{22}	f_2^{21}	f_2^{22}	e_2^{2ROW}	x_2^2
Import from *ROW*		m_1^{ROW1}	m_2^{ROW1}	m_1^{ROW2}	m_2^{ROW2}				
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} : transaction of intermediate goods from sector i in r to sector j in s, where $i, j = 1, 2$ representing two sectors and $r, s = 1, 2$ representing two regions; f_i^{rs} : final demands of i in s supplied from r; e_i^{rROW} : exports of i from r to *ROW*; m_j^{ROWs} : imports of j from *ROW* to s; x_i^r : total output of sector i in r; v_j^s : value added of sector j in s.

The supply-demand relations based on AIO 2000 could be generalized as follows:

$$X = AX + F + E$$

Or at the regional level,

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & \cdots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{pmatrix} \begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} + \begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \quad (1)$$

with X^r : total output of region r; $A^{rs} = X^{rs} / X^s$: transaction coefficient matrix representing ratios of trade from r to s to the total input of s; F^{rs} : final demand of s supplied by r; E^{rROW} : exports from r to *ROW*.

Eq.2 and Eq.3 are derived to indicate final demand-induced production, based on MRIO and SRIO, respectively. B^{rs} is the Leontief multiplier derived from MRIO, representing production in r induced by per unit final output in s.

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} B^{11} & B^{12} & \cdots & B^{1n} \\ B^{21} & B^{22} & \cdots & B^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B^{n1} & B^{n2} & \cdots & B^{nn} \end{pmatrix} \left[\begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \right] \quad (2)$$

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} (I - A^{11})^{-1} & 0 & \cdots & 0 \\ 0 & (I - A^{22})^{-1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & (I - A^{nn})^{-1} \end{pmatrix} \times \left[\begin{pmatrix} \sum_{s \neq 1} A^{1s} X^s \\ \sum_{s \neq 2} A^{2s} X^s \\ \vdots \\ \sum_{s \neq n} A^{ns} X^s \end{pmatrix} + \begin{pmatrix} F^{11} + \sum_{s \neq 1} F^{1s} \\ F^{22} + \sum_{s \neq 2} F^{2s} \\ \vdots \\ F^{nn} + \sum_{s \neq n} F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \right] \quad (3)$$

The system boundary for calculating the multipliers using MRIO and SRIO is different. By MRIO, intermediate inputs from ten regions are internalized in the multiplier calculation, while by SRIO only domestic intermediate inputs are internalized while the imports of intermediate goods from other nine regions are treated exogenously similarly to the final demands.

(2) Two responsibility allocation schemes

Taking international trade into account, national responsible emissions are calculated based on two responsibility allocation schemes, viz. (i) consumer responsibility (Scheme I); and (ii) shared producer and consumer responsibility[14), 23)] (Scheme II). For Scheme I, both MRIO and SRIO are applied.

Given c^r (row vector with each element representing CO_2 emissions per unit industrial output in r), national territorial emissions, C_{prod}^r, is estimated as follows, in which producers are taking full responsibility:

$$C_{prod}^r = c^r X^r + C_{hh}^r \quad (4)$$

C_{hh}^r represents direct emissions from regional households. According to this accounting method, the amount of national emissions is influenced by factors such as sectoral carbon intensity, national production output, and the share of carbon intensive sector in national economy. In this case, emissions embodied in trade are not taken into account.

a) Scheme I: consumer responsibility

Under Scheme I, national responsible emissions are calculated using both MRIO and SRIO. By MRIO (SchI-MRIO) in Eq. 5, this includes four parts: (i) emissions embodied in the final demands supplied domestically ($P1_M$); (ii) emissions embodied in the final demands provided by imports from other nine regions ($P2_M$); (iii) emissions embodied in imports (miscellaneous of intermediate and final goods) from ROW (regions other than ten regions) ($P3_M$); and (iv) direct emissions from regional households ($P4$).

$$C^s_{con\_M} = \underbrace{\left(\sum_r c^r B^{rs}\right)F^{ss}}_{P1_M} + \underbrace{\sum_{n\neq s}\left[\left(\sum_r c^r B^{rn}\right)F^{ns}\right]}_{P2_M} + \underbrace{C^s_{im}}_{P3_M} + \underbrace{C^s_{hh}}_{P4} \quad (5)$$

C^s_{im} (Eq. 6) are emissions embodied in imports from ROW to s calculated using emission coefficients and multipliers of ROW.

$$C^s_{im} = c^w B^w M^{ROWs} \quad (6)$$

with c^w : row vector indicating sectoral carbon intensity of ROW ; B^w: Leontief multiplier for ROW derived from GTAP database; M^{ROWs} : imports from ROW to s.

Emissions embodied in the total exports of region s calculated using multi-regional multipliers includes two parts: (i) emissions embodied in exports to other nine regions ($P5_M$); and (ii) emissions embodied in exports to ROW ($P6_M$)

$$P5_M = \sum_{n\neq s}\left[\left(\sum_r c^r B^{rs}\right)F^{sn}\right] \quad (7)$$

$$P6_M = \left(\sum_r c^r B^{rs}\right)E^{sROW} \quad (8)$$

with E^{sROW} : exports from region s to ROW .

National trade balance of CO_2 is shown in Eq. 9.

$$C^s_{tb\_M} = (P5_M + P6_M) - (P2_M + P3_M) \quad (9)$$

Using SRIO under Scheme I (SchI-SRIO), national responsible emissions, $C^s_{con\_S}$ (Eq. 10), includes also four parts, $P1_S$, $P2_S$, $P3_S$ and $P4$. World average sectoral CO_2 intensity $c^{\overline{w}}$ and world input-output multiplier $B^{\overline{w}}$ are applied to estimate imports from another nine regions and also ROW (regions other than the ten regions).

$$C^s_{con\_S} = \underbrace{\left[c^s\left(I - A^{ss}\right)^{-1}\right]F^{ss}}_{P1_S} + \underbrace{\sum_{n\neq s}\left[\left(c^{\overline{w}}B^{\overline{w}}\right)\left(A^{ns}X^s + F^{ns}\right)\right]}_{P2_S} + \underbrace{c^{\overline{w}}B^{\overline{w}}M^{ROWs}}_{P3_S} + \underbrace{C^s_{hh}}_{P4} \quad (10)$$

Similarly, emissions embodied in total exports calculated using single-region multipliers also includes two parts $P5_S$ and $P6_S$.

$$P5_S = \sum_{n\neq s}\left[C^s\left(I - A^{ss}\right)^{-1}\left(A^{sn}X^n + F^{sn}\right)\right] \quad (11)$$

$$P6_S = \left[C^s\left(I - A^{ss}\right)^{-1}\right]E^{sROW} \quad (12)$$

National trade balance of CO_2 calculated by SRIO is shown in Eq. 13.

$$C^s_{tb\_S} = (P5_S + P6_S) - (P2_S + P3_S) \quad (13)$$

According to the consumer responsibility method, factors influencing total national emissions may include a mixture of levels of sectoral carbon intensity, multiplier, level of consumption, share of carbon intensive consumption in total consumption, and trade, etc.

b) Scheme II: shared producer and consumer responsibility

Under Scheme II, emissions emitted from one sector are shared at a defined ratio between this sector ($C1$) and its downstream demands, including both intermediate demands of downstream producers ($C2$), and final consumers and exports ($C3$)[15), 23)]. These are calculated using MRIO (see Eq. 14).

$$\begin{aligned} cX &= c(AX + F + E) \\ &= \underbrace{c\left[(I - \alpha)(AX + F + E)\right]}_{C1\text{: upstream producer}} + \underbrace{c(\alpha AX)}_{C2\text{ downstream producer}} + \underbrace{c\left[\alpha(F + E)\right]}_{C3\text{ final consumers and exports}} \end{aligned} \quad (14)$$

α is a diagonal matrix with each element α^r_i on the diagonal representing the ratio of non-factor external inputs in sector i in region r to i's total external inputs. $\left(1 - \alpha^r_i\right)$ is therefore the factor inputs as a ratio to the total external inputs, defined as follows (Eq. 15):

$$1-\alpha_i^r = v_i^r / \left(x_i^r - a_{ii}^{rr} x_i^r\right) \quad (15)$$

with v_i^r: value added of sector i in r, representing factor inputs; $\left(x_i^r - a_{ii}^{rr} x_i^r\right)$ being the total external inputs in sector i in r.

The supply and demand relations derived from Eq. 14 using MRIO is shown in Eq. 16:

$$cX = \left[c(I-\alpha A)^{-1}\right] \times \left\{\left[(I-\alpha)(AX+F+E)\right] + \alpha F + \alpha E\right\} \quad (16)$$

$c(I-\alpha A)^{-1}\left[(I-\alpha)(AX+F+E)\right]$ is the portion shared by upstream producers (*S1*) while $c(I-\alpha A)^{-1}\alpha F$ and $c(I-\alpha A)^{-1}\alpha E$ are the portions shared by final consumers (*S2*) in ten regions and exports to *ROW* (*S3*), respectively.

3. RESULTS

(1) National responsible emissions adjusted by trade

National responsible CO_2 emissions are calculated with trade adjustment based on SchI-MRIO (Eq. 5), SchI-SRIO (Eq. 10) and Scheme II. These accounts are then compared with the current national account estimated based on producer responsibility (Eq. 4).The focus is put on emissions embodied in multilateral trade among ten economies. Trade between each region and *ROW* is also calculated, but with less priority.

In **Table 2** (SchI-MRIO), national responsible CO_2 emissions indicate that changes to current national emissions vary from -525Mt-CO_2 (China) to 543Mt-CO_2 (USA). By percentage, these changes range from -25% (Malaysia) to 42% (Singapore).

In **Table 3** (SchI-SRIO), national responsible emissions adjusted by trade show changes to current national emissions ranging from -518Mt-CO_2 (China) to 322Mt-CO_2 (USA) or from -23% (Indonesia) to 42% (Singapore) in terms of percentage change.

Comparing two calculation results, $(\sum_s C^s_{con\_M} - \sum_s C^s_{con\_S})$ for ten regions indicates 2.6% of total consumption based emissions, $\sum_r C^r_{prod}$. However, $(C^s_{con\_M} - C^s_{con\_S})/C^r_{prod}$ at national level, is considerable, e.g. up to -12% for Malaysia. These are caused mainly by different emission multipliers (multi-region multipliers, single-region multipliers or multipliers of *ROW*) applied to imports and exports, and the way treating intermediate demands and the impacts of feedback effects.

Table 2 National responsible CO_2 emissions (SchI-MRIO, 2000)

Region	$P1_M$	$P2_M$	$P3_M$	$P4$	$C^s_{con\_M}$ (Mt-CO_2)	C^r_{prod} (Mt-CO_2)	Difference (Mt-CO_2)[1]	Difference (%)[2]
IDN	133	4	25	53	215	273	-58	-21%
MYS	47	7	19	15	88	118	-30	-25%
PHL	36	3	11	17	67	69	-2	-3%
SGP	36	7	38	4	85	60	25	42%
THA	92	6	25	21	144	155	-11	-7%
CHN	2,252	9	79	311	2,651	3,176	-525	-17%
TWN	94	14	46	56	210	217	-7	-3%
ROK	267	11	76	88	442	435	7	2%
JPN	862	82	189	310	1,443	1,179	264	22%
USA	4,318	163	659	1,105	6,245	5,702	543	10%
Total	8,137	306	1,167	1,980	11,590	11,384	206	2%

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

1. Equals to $C^s_{con\_M} - C^r_{prod}$;
2. Equals to $(C^s_{con\_M} - C^r_{prod})/C^r_{prod} \times 100\%$.

Table 3 National responsible CO_2 emissions (SchI-SRIO, 2000)

Region	$P1_S$	$P2_S$	$P3_S$	$P4$	$C^s_{con\_S}$ (Mt-CO_2)	C^r_{prod} (Mt-CO_2)	Difference (Mt-CO_2)	Difference (%)
IDN	128	11	19	53	211	273	-62	-23%
MYS	42	30	15	15	102	118	-16	-14%
PHL	33	11	9	17	70	69	1	1%
SGP	29	24	28	4	85	60	25	42%
THA	84	21	20	21	146	155	-9	-6%
CHN	2,214	68	65	311	2658	3,176	-518	-16%
TWN	82	47	38	56	223	217	6	3%
ROK	240	47	63	88	438	435	3	1%
JPN	769	107	155	310	1341	1,179	162	14%
USA	4,205	163	551	1,105	6,024	5,702	322	6%
Total	7,826	529	963	1,980	11,298	11,384	-86	-1%

Under Scheme II (Eq. 16), the focus is placed on responsibility shared among ten economies (**Table 4**).

Changes range from a decrease of -327Mt-CO_2 (China) to an increase of 386Mt-CO_2 (USA). Changes in terms of percentage exhibit -18% (Malaysia) to 38% (Singapore).

Table 4 National responsible CO_2 emissions (Scheme II, 2000)

Region	*S1*	*S2*	$P3_M$	*P4*	National responsible CO_2 (Mt-CO_2)	C^r_{prod} (Mt-CO_2)	Difference (Mt-CO_2)	Difference (%)
IDN	131	41	25	53	250	273	-23	-8%
MYS	45	18	19	15	97	118	-21	-18%
PHL	30	12	11	17	70	69	1	1%
SGP	29	12	38	4	83	60	23	38%
THA	79	24	25	21	149	155	-6	-4%
CHN	1,891	568	79	311	2,849	3,176	-327	-10%
TWN	86	26	46	56	214	217	-3	-1%
ROK	197	78	76	88	439	435	4	1%
JPN	658	193	189	310	1350	1,179	171	15%
USA	3,097	1,227	659	1,105	6,088	5,702	386	7%
Total	6,243	2,199	1,167	1,980	11,589	11,384	205	2%

Note: *S1*: emissions shared by the region as a producer; *S2*: emissions shared by the region as a final consumers (Eq. 16); national responsible emissions equal to ($S1+S2+P3_M+P4$).

(2) Multilateral trade balance of embodied CO_2

Table 5 presents sources and destinations of embodied CO_2 in multilateral trade (SchI-MRIO). Rows read CO_2 embodied in exports and columns read CO_2 embodied in imports. As a reference, the last three rows show CO_2 embodied in imports and exports and trade balance of CO_2 using SchI-SRIO. Singapore, Japan and USA have trade deficit, while other countries have trade surplus in terms embodied CO_2. Among ten economies, USA has the largest trade deficit (-464Mt-CO_2) followed by Japan (-191Mt-CO_2), while China has the largest trade surplus (452Mt-CO_2). In case of SchI-SRIO, USA, Japan, Singapore, Taiwan, ROK and the Philippines have trade deficit and other economies have trade surplus of CO_2.

Table 6 indicates the responsibility of emissions shared by an economy as a upstream producer (*S1* in **Table 4**) and the destinations of trade, for which the responsibility is shared between two trade partners. **Table 7** presents the source countries from which embodied emissions are shared by an economy as a consumer (*S2* in **Table 4**).

Table 8 indicates a bilateral trade balance of embodied CO_2 (SchI-MRIO). USA and Japan have a trade deficit of CO_2 in the bilateral relations with all other eight economies and *ROW*, while China has a trade surplus of CO_2 in relation with all other nine economies and *ROW*. In particular, the Sino-USA trade surplus of CO_2 is considerable large (101Mt-CO_2).

Table 5 Sources and destinations of embodied emissions based on SchI-MRIO for 2000 (in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	ROW
IDN	133.2	0.8	0.2	0.6	0.4	0.2	0.6	0.4	2.6	6.4	32.4
MYS	0.3	47.2	0.3	1.8	0.6	0.5	0.9	0.4	3.5	6.7	27.8
PHL	0.0	0.1	36.5	0.0	0.1	0.1	0.1	0.1	1.5	4.1	9.3
SGP	0.1	0.8	0.3	35.7	0.3	0.3	0.4	0.3	1.1	2.9	25.6
THA	0.3	0.5	0.2	0.5	91.8	0.3	0.4	0.2	3.1	5.3	31.3
CHN	1.3	2.0	0.4	1.9	2.0	2,252.2	3.6	4.8	51.6	103.6	369.1
TWN	0.3	0.5	0.3	0.2	0.4	2.1	94.4	0.4	3.1	8.3	50.2
ROK	0.3	0.3	0.3	0.3	0.2	1.4	1.0	267.5	4.0	9.8	77.1
JPN	0.5	1.0	0.4	0.8	0.9	1.7	2.6	1.6	861.9	15.4	55.2
USA	0.4	1.0	0.5	0.9	0.8	2.3	4.1	2.6	11.3	4,318.5	333.8
ROW	25	19	11	38	25	79	46	76	189	659	
$P2_M+P3_M$	29	26	14	45	31	88	60	87	271	822	
$P5_M+P6_M$	45	43	15	32	42	540	66	95	80	358	
$C^s_{th\_M}$	16	17	1	-13	11	452	6	8	-191	-464	
$P2_S+P3_S$	30	45	20	52	41	133	85	110	262	714	
$P5_S+P6_S$	93	60	19	27	49	699	81	109	100	391	
$C^s_{th\_S}$	63	15	-1	-25	8	566	-4	-1	-162	-323	

Table 6 Destinations with which embodied CO_2 is shared by an economy as an upstream producer (Scheme II, 2000)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	Total
IDN	103.7	0.7	0.4	0.3	0.6	2.2	1.4	4.4	13.5	4.2	131
MYS	0.2	37.5	0.3	1.3	0.4	0.7	0.5	0.4	1.8	2.2	45
PHL	0.0	0.2	25.5	0.0	0.1	0.2	0.3	0.2	1.2	2.6	30
SGP	0.1	0.3	0.1	26.9	0.1	0.2	0.1	0.1	0.2	0.5	29
THA	0.2	0.4	0.1	0.2	73.9	0.4	0.3	0.2	1.3	1.9	79
CHN	0.9	0.8	0.3	0.8	1.0	1,844	1.8	3.4	15.1	23.5	1,891
TWN	0.2	0.4	0.2	0.2	0.3	3.3	74.5	0.3	1.7	4.3	86
ROK	0.2	0.3	0.2	0.2	0.2	2.4	0.6	187.1	2.4	3.6	197
JPN	0.3	0.7	0.2	0.6	0.7	2.1	1.5	1.4	644.0	6.0	658
USA	0.4	0.8	0.4	0.7	0.6	2.1	2.1	2.5	8.6	3,079	3,097

Table 7 Source countries with which embodied CO_2 is shared by an economy as a consumer (Scheme II, 2000)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA
IDN	40.2	0.2	0.0	0.2	0.1	0.1	0.2	0.1	0.8	2.0
MYS	0.1	16.8	0.1	0.5	0.3	0.2	0.5	0.1	1.1	2.0
PHL	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3
SGP	0.0	0.2	0.1	10.0	0.1	0.1	0.1	0.1	0.3	0.7
THA	0.1	0.1	0.0	0.1	22.2	0.1	0.1	0.0	0.8	1.3
CHN	0.3	0.5	0.1	0.4	0.5	565.9	0.9	1.1	11.3	25.4
TWN	0.1	0.2	0.1	0.0	0.1	0.7	22.6	0.1	0.9	2.6
ROK	0.1	0.1	0.1	0.1	0.1	0.4	0.3	75.3	1.3	2.9
JPN	0.1	0.2	0.1	0.1	0.2	0.3	0.5	0.3	173.3	2.6
USA	0.1	0.2	0.1	0.2	0.2	0.5	0.9	0.6	2.6	1,186.5
Total	41	18	12	12	24	568	26	78	193	1,227

Table 8 Bilateral trade balance of embodied CO_2 based on SchI-MRIO for 2000 (in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	ROW
IDN	0.0	0.5	0.2	0.5	0.1	-1.1	0.3	0.1	2.1	6.0	7.4
MYS	-0.5	0.0	0.2	1.0	0.1	-1.5	0.4	0.1	2.5	5.7	8.8
PHL	-0.2	-0.2	0.0	-0.3	-0.1	-0.3	-0.2	-0.2	1.1	3.6	-1.7
SGP	-0.5	-1.0	0.3	0.0	-0.2	-1.6	0.2	0.0	0.3	2.0	-12.4
THA	-0.1	-0.1	0.1	0.2	0.0	-1.7	0.0	0.0	2.2	4.5	6.3
CHN	1.1	1.5	0.3	1.6	1.7	0.0	1.5	3.4	49.9	101.3	290.1
TWN	-0.3	-0.4	0.2	-0.2	0.0	-1.5	0.0	-0.6	0.5	4.2	4.2
ROK	-0.1	-0.1	0.2	0.0	0.0	-3.4	0.6	0.0	2.4	7.2	1.1
JPN	-2.1	-2.5	-1.1	-0.3	-2.2	-49.9	-0.5	-2.4	0.0	4.1	-133.8
USA	-6.0	-5.7	-3.6	-2.0	-4.5	-101.3	-4.2	-7.2	-4.1	0.0	-325.2
ROW	-7.4	-8.8	1.7	12.4	-6.3	-290.1	-4.2	-1.1	133.8	325.2	0.0

4. CONCLUSIONS AND POLICY IMPLICATIONS

Current national GHG accounting based on producer responsibility causes the issue of carbon leakage because embodied carbon and associated global social costs are not taken into account. This paper presents trade adjustment accounting of national responsible emissions to help address this issue.

CO_2 embodied in multilateral trade is significant, and it accounts for about 1,473 Mt-CO_2 or 13% of the total national responsible emissions of ten economies (11,590 Mt-CO_2, SchI-MRIO). At a national level, it could reach as high as 53% (Singapore).

The results of this paper indicate that national emission accounting is very sensitive to different allocation methods. For example, responsibility allocated by two extreme methods, i.e. full producer responsibility vs. full consumer responsibility, could cause a change in national emissions from –525 to 543 Mt-CO_2 (SchI-MRIO).

Carbon leakage occurs in a non-negligible way from developed economies to developing economies. This could impact on the efforts made in achieving the mitigation target 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 countries in binding reduction and Border Tax Adjustment, etc. The comparison of advantages and disadvantages of different policy options to address the issue of embodied carbon could be included in the future research agenda.

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 is it provided by countries or by authoritative international organizations. Information on geographical identity, energy intensity and carbon intensity of tradable goods are important to inform environmentally-conducive purchasing decisions and should be addressed through the collaboration between global climate regime and international trade regime.

In allocating emission responsibility associated with international trade, full producer responsibility and full consumer responsibility are two extremes. Shared producer and consumer responsibility lie between them and can work as direct incentives to help change the environmental behaviors of both actors. In this paper, the ratio of added value in total external inputs is used to define shares. However, this is only one of the alternative ratios, such as the proportion of imports to exports. Further study is necessary to help select a fair, effective and robust ratio for sharing responsibilities between upstream producers and downstream consumers.

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APPENDIX SECTOR CLASSIFICATION

	Sector definition in AIO 2000	Sector code in GTAP Data Base 6
1	Paddy	pdr
2	Other agricultural products	wht, gro, v_f, osd, c_b, pfb, ocr
3	Livestock and poultry	ctl, oap, rmk, wol
4	Forestry	frs
5	Fishery	fsh
6	Crude petroleum and natural	oil, gas
7	Other mining	coa, omn
8	Food, beverage and tobacco	cmt, omt, vol, mil, pcr, sgr, ofd, b_t
9	Textile, leather and related products	tex, wap, lea
10	Timber and wooden products	lum
11	Pulp, paper and printing	ppp
12	Chemical products	crp
13	Petroleum and petro products	p_c
14	Rubber products	crp
15	Non-metallic mineral prod-	nmm
16	Metal products	i_s, nfm, fmp
17	Machinery	ele, ome
18	Transport equipment	mvh, otn
19	Other manufacturing products	omf
20	Electricity, gas, and water supply	ely, gdt, wtr
21	Construction	cns
22	Trade and transport	trd, otp, wtp, atp
23	Services	cmn, ofi, isr, obs, ros, dwe
2	Public administration	osg

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