Production vs. Consumption and the Carbon content of Trade – A Worldwide Analysis for Agriculture

Carlos E. Ludena

Sustainable Energy and Climate Change Unit
Inter-American Development Bank
carlosl@iadb.org

Contributed Paper at the IATRC Public Trade Policy Research and Analysis Symposium

"Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security"

June 27 - 29, 2010
Universität Hohenheim, Stuttgart, Germany.

DRAFT- DON NOT QUOTE

Production vs. Consumption and the Carbon content of Trade – A Worldwide Analysis for Agriculture

by

Carlos E. Ludena

Sustainable Energy and Climate Change Unit

Inter-American Development Bank

carlosl@iadb.org

Paper prepared for presentation at the Public Trade Policy Research and Analysis Symposium "Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security", June 27 - 29, 2010, Stuttgart-Hohenheim, Germany

June 2010

Introduction

The carbon content of trade in international trade is an issue that has arisen in the last few years (Su et al., 2010; Aichele and Felbermayr, 2010; Peters and Hertwich, 2008b; Ackerman et al., 2007; Babiker, 2005). As commitments under the Kyoto protocol set production based emissions targets for developed countries, carbon leakage has risen as emissions migrate to countries without emissions targets. For example, Wang and Watson (2007) argue that the large increase in China's emissions is largely due to exports to Western consumers.

Under this context, the debate of consumer emissions (carbon footprint) versus producer (territorial) emissions of greenhouse gases takes relevance, as developing countries are increasingly becoming production centers of the carbon intensive goods that rich countries consume. This has important implications for the Copenhagen Accord, as developing countries have committed to voluntary reductions of greenhouse gases (GHG).

Atkinson et al. (2009) mentions that a complete picture of virtual carbon trade needs to include other GHG emissions and CO_2 emissions from agriculture, land-use change and other processes. All previous studies discussing the carbon content of trade have only focused in CO_2 emissions. However, non-CO2 emissions are responsible for one third of all GHG emissions. This is especially important for agriculture, as this sector accounts for more than 80 percent of N_2O emissions and more than 50 percent of CH_4 emissions.

Agriculture is a major source of GHG emissions, especially methane gas (CH_4) from livestock and rice production, and nitrous oxide (N_20) from fertilizer use. At the same time, for the majority of developing countries, agriculture is a major share of exports. Under the Copenhagen Accord, several major developing countries such as Brazil and China have committed to voluntary reductions in GHG. These reduction commitments will certainly have impacts on their agricultural sector and the way they produce their goods.

The purpose of this study is to analyze the emissions content of trade in agriculture, in the context of the current debate of the carbon content of production versus consumption. We extend previous research in two areas. First, the paper incorporates non-CO_2 emissions to the analysis of carbon content of trade in agriculture. This is important, as non- CO_2 emissions represent a large share of emissions in the agricultural sector. Second, we analyze agriculture to a greater detail than any other study to date, as we analyze a total of 12 agricultural sectors.

The remainder of the paper is structure as follows. We describe the methodology used in this paper, followed by a description of the construction of the GHG data base used in the analysis. Finally, we show the results and draw some conclusions and policy implications.

Methodology – Input-Output Model

To estimate GHG emissions embodied in international agricultural trade we use an Input-Output (I-O) analysis framework developed by Leontief (1970). We apply this I-O analysis using a multi-regional approach. For comparison purposes, we follow closely the definition in Atkinson et al. (2010), where they define a bilateral I-O model (BTIO) and a multi-regional I-O model (MRIO). This definition draws on Peters (2008).

We first introduce a single region or country *r*, where the standard I-O framework is given by the balance of monetary flows in an economy with *k* sectors

$$x^r = A^r x^r + y^r + e^r - m^r \quad (1)$$

where x^r is the vector of total output in each economic sector *k*, A^r is a matrix of intermediate consumption where each column represents the input in each industry k (both domestic and imports) to produce a unit of output in each domestic industry *k*, and $A^r x^r$ is the vector of total intermediate consumption, *y* is the vector of final consumption (households, government and capital accumulation) in each sector (domestic and imports); e^r is the vector of total exports, m^r is the vector of total imports. The vector of total exports e^r can be expressed as the sum of all bilateral trade flows from all other regions *s* to region *r*, as

$$e^r = \sum_s e^{rs} \quad (2)$$

as with exports, imports can also be expressed as bilateral flows, as

$$m^r = \sum_s e^{sr} \quad (3)$$

where m^r is the sum of exports from all regions (except r) to region r. As mentioned by Peter (2008), to perform analysis with these models, imports are usually removed from equation (1), thus,

$$x^r = A^{rr}x^r + y^{rr} + e^r \quad (4)$$

equation (4) expresses the same balance as equation (1), but only considering domestic activities. Final consumption can be decomposed as,

$$y^r = y^{rr} + \sum_s e^{sr} \quad (5)$$

and intermediate consumption can be decomposed as

$$A^r = A^{rr} + \sum_s A^{sr} \quad (6)$$

where A^{rr} represents the industry requirements of domestically produced products and A^{sr} represents the industry requirements of import products from region s to r. Then, domestic emissions can be estimated as

$$f^r = F^r x^r = F^r(I - A^{rr})^{-1}(y^{rr} + e^r) \quad (7)$$

where I is the identity matrix and F^r is a k-dimensional row vector where each element represents the emission intensity (or environmental impact) per unit of industry k output. The emissions f^r occur domestically to produce both the domestic component of final consumption and total exports.

As outlined by Peters (2008), there are two main approaches to determine the emissions of imported goods and services. The first considers emissions embodied in bilateral trade between regions (EEBT) and the second considers trade to final consumption and endogenously determined trade to intermediate consumption (MRIO). The main difference between these two approaches is the way they allocate imports to intermediate consumption (imports which are later used in the production of exports). EEBT only considers the emissions that occur in one region to produce exports to another region. However, this analysis does not incorporate emissions from imports necessary to produce exports.[1] MRIO incorporates these emissions into its analysis and distinguishes between trade that goes to intermediate and final consumption.[2]

EEBT determines the emissions in one region *r* to produce a bilateral trade flow e^{rs}, which are the emissions embodied in trade from region *r* to region *s*. Decomposing equation (7) into domestic demand on domestic production in region *r* and EEBT from region *r* to region *s*

$$f^{rr} = F^{r}(I - A^{rr})^{-1}y^{rr} \quad (8)$$

$$f^{rs} = F^{r}(I - A^{rr})^{-1}e^{rs} \quad (9)$$

By summing over the importing regions, we can estimate the total emissions embodied in bilateral trade for exports (EEBE) from region *r* to region *s*

$$f^{r*} = \sum_{s} f^{rs} \quad (10)$$

by reversing the summation over exporting regions r, we estimate the total emissions embodied in bilateral trade from imports (EEBI)

$$f^{*s} = \sum_{r} f^{rs} \quad (11)$$

The production based emissions are from residential institutions to produce domestic final demand and exports,

$$f_{p}^{r} = f^{rr} + f^{r*} \quad (12)$$

Consumption based emissions are emissions from total domestic consumption, including imports, but excludes exports

$$f_{c}^{r} = f^{rr} + f^{*r} \quad (13)$$

The BTIO does not account for imports from region *s* used by industry *j* in region *r* to produce export commodities to region *s*. The MRIO accounts for this import use, endogenizing imports. The main difference between the BTIO and the MRIO frameworks is that MRIO

[1] Hummels, Ishi and Yi, 1999 and 2001 discuss this concept as vertical integration in international trade. Vertical integration on trade looks at the import content of a country's exports.
[2] One key assumption used in I-O analysis is that the production technology is based on fixed proportions. That is, for a sector k, the production for domestic demand is the same as the production of exports.

distinguishes trade that goes to intermediate use by industry and final demand. MRIO separates bilateral trade data into intermediate use, *z*, and final demand, *y*,

$$e^{rs} = z^{rs} + y^{rs} \tag{14}$$

where exports by industry are

$$z^{rs} = A^{rs} x^{s} \tag{15}$$

where x^s represents the output of region *s*. By substituting (14) and (15) into equation (4) we have

$$x^{r} = A^{rr} x^{r} + y^{rr} + \sum_{s \neq r} A^{rs} x^{s} + \sum_{s \neq r} y^{rs} \tag{16}$$

Equation (16) is used to estimate both production and consumption based GHG emissions.

Data

We use both CO2 emissions (Lee, 2008) and non-CO2 emissions (Rose et al., 2010) derived for use with the Global Trade Analysis Project (GTAP) database, version 7.0. The GTAP Data Base version 7.0 is a snapshot of the world economy in the year 2004 with 113 regions/countries (94 individual countries) and 57 sectors, 12 of those being agricultural sectors. These sectors include rice, wheat, grains, oilseeds, fruits and vegetables, sugar cane, plant based fibers, other crops, cattle, other animals, milk production and wool production.

We build a consolidated GHG emissions database, combining both data bases. As explained before, by expanding the definition of carbon content to include non-CO_2 GHG such as CH_4, N_2O and F-gases provides a more complete analysis of the carbon content of trade, especially for agriculture, given that a large share of non-CO_2 emissions come from that sector. In the following paragraphs, we detail the process of building this consolidate GHG data base.

CO_2 emissions

The original CO_2 emissions data (Lee, 2008) is expressed as CO_2 emissions from fossil fuel combustion by sector *j* in region *r* (including emissions from households, government and capital goods)[3]. These CO_2 emissions are based on the GTAP energy volume database following the Tier 1 method of the revised 1996 IPCC Guideline. Emissions are estimated based on the six energy commodities in GTAP, namely coal, crude oil, natural gas, petroleum products, electricity and gas distribution. The use of the GTAP energy volume database assures consistency in terms of sector classification, as well as between values and volumes. We add the CO_2 emissions by energy source and express it by sector *j* in region *r*. This later allows us to distribute emissions across intermediate industry use and final demand (households, government, capital goods and exports).

Non-CO2 emissions (N2O, CH4 and F-gases)

Non-CO_2 emissions for GTAP version 7 were estimated by Rose et al. (2010) based on 2001 emissions data (Rose et al., 2007) used by Rose and Lee (2008, 2009) to produce a consistent non-CO_2 emissions for version 6 of the GTAP data base. These data consists of the four different data sets of non-CO_2 emissions:

a) Non-CO2 emissions associated with output by industries
b) Non-CO2 emissions associated with endowment by industries
c) Non-CO2 emissions associated with input use by industries
d) Non-CO2 emissions associated with input use by households

The allocation of non-CO_2 emissions across these four data sets follows the distribution detailed in Table 3 in Rose and Lee (2008). These authors allocate the various categories and sub-categories on non-CO_2 emissions to specific GTAP sectors. The description in Table 3 of Rose and Lee (2008) later serves us as a guide to distribute emissions across intermediate use and final demand, both domestic and imports.

It is worth noting that the non-CO_2 emissions in GTAP do not include: a) N_2O and CH_4 emissions from specific biomass burning not uniquely attributable to anthropogenic activity

[3] However, emissions from government consumption and capital goods are equal to zero.

(forest and grassland fires); b) N_2O, CH_4, and CO_2 emissions from biomass burning tropical forest fire deforestation associated with land-use change (GTAP land-use database does not provide land-use change data); c) N_2O, CH_4, and CO_2 emissions from biomass combustion (as GTAP energy database does not include biomass energy volumes); d) Methane from underground storage and geothermal energy; e) Other CO_2 emissions not attributable to fossil fuel combustion, including fugitive and combustion CO_2 emissions from the chemical industry and metal production, fugitive CO_2 emissions from oil production/transmission/handling, and CO_2 emissions associated with cement production.

Emissions distribution across intermediate use and final demand, domestic and imports

We distribute both CO2 and non-CO2 emissions into intermediate industry use and final demand (household and government consumption, transport and exports). For CO_2 emissions we allocate them across domestic and import use using the shares at market prices in the GTAP data base (see Appendix A). Emissions from commodity i were distributed across both domestic and import firm intermediate use. Emissions from households and government consumption (both vectors) were distributed across domestic and import use according to consumption shares between domestic and import commodities.

For non-CO2 emissions, we distribute the four data sets according to the following convention:

a) Emissions from output by industries: Domestic and import intermediate use, transport and exports
b) Emissions from endowment by industries: Domestic intermediate use, transport and exports
c) Emissions from input use by industries: Domestic and import intermediate use
d) Emissions from input use by households: Household domestic and import consumption

Output by industries is allocated across intermediate use and final demand as it corresponds to emissions processes that use both domestic and import commodities, and that later are exported. Emissions from endowment are allocated entirely into domestic emissions, as they correspond to emissions generated from land (i.e. savannah and shrub fires) and capital use (i.e. livestock enteric fermentation) by industry *j*. Emissions from input use by industries is assumed that is only use in intermediate use (firms). Finally, emissions from input use by households is allocated between domestic and imports, according to the shares of household consumption in GTAP.

As mentioned in Atkinson et al. (2009), the GTAP data base differentiates import use by intermediate industry demand and final demand (households and government). However, it does not specify the country of origin of these imports. For this reason, we estimate the share of country *s* in total imports of country *r* and distribute import use in intermediate and final demand according to that share. We use an input-output approach based on the concept of vertical integration in international trade (Hummels, Ishi and Yi, 1999 and 2001). Vertical integration on trade looks at the import content of a country's exports. We use the concept of vertical integration, as it provides an appropriate methodological framework for complete carbon footprint estimates at the national and supra-national level.

Finally, we standardize all GHG emissions into Million Tonnes of CO_2 equivalent. We transform the CO_2 emissions from Gigagrams to Tonnes (dividing it by 1,000) and the non-CO_2 emissions from MMTCe (Million Metric Tonnes of Carbon Equivalent units, C-eq) into MMTCO_2-eq (CO_2 equivalent) multiplying it by 44/12.

Results

We present some preliminary results for the carbon content of trade in agriculture, with focus on the 14 agricultural sectors from the GTAP data base (see Table A2). This analysis is preliminary, and a more detailed analysis will come in future versions of this paper.

Figure 1 shows the estimates of GHG emissions data for agriculture. It shows that most emissions come from methane gas and nitrous oxide, with less prevalence of CO_2 emissions. Most emissions come from livestock production, especially methane. For crops production, most emissions come from N_2O, probably from emissions from fertilizer use.

Figure 1. GHG emissions from agriculture, 2004

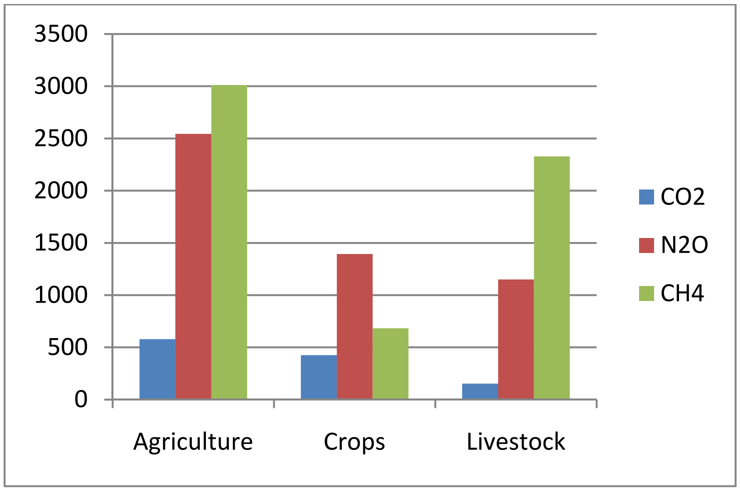

Table 1 shows the estimates of production and consumption based GHG emissions for the agricultural sector. The results show that the carbon content of agricultural trade is relative low to overall production or consumption, especially for developing countries such as Brazil, China, India or Mexico.

Table 1. Production and Consumption based GHG emissions (MMT CO_2-eq) for Agriculture

Country	Production	Consumption	GHG Exports	GHG Imports
Brazil	492	482	3	13
Canada	76	74	10	11
China	1,253	1,278	35	8
EU15	478	493	54	40
Economies in Transition	276	279	12	12
India	433	429	1	4
Japan	61	67	6	1
Low Income countries	739	732	14	17
Mexico	80	75	2	7
Russia	135	143	8	2
USA	543	530	27	41
High-Income Economies	97	102	13	6
Middle Income countries	1,249	1,229	27	43
Other Annex 1 countries	261	255	9	13
South Africa	46	42	1	4

Table 2 shows the comparison of production based and consumption based GHG emissions for selected countries for all 14 agricultural sectors. The results show that for most commodities, consumption is equal to consumption. This is mainly because emissions in agriculture, specially those associated with endowment use (land and capital) are domestic emissions. However, as we analyze country by country, we observe that there are certain commodities where production base emissions are different from consumption based.

Table 2. Production and Consumption based GHG emissions (MMT CO_2-eq) for agricutural sectors

	USA		EU 15		China		Brazil		India		Russia	
Sector	**Prod**	**Cons**	**Prod**	**Cons**	**Prod**	**Cons**	**Prod**	**Cons**	**Prod**	**Cons**	**Prod**	**Cons**
pdr	12	12	2	2	270	270	9	9	98	98	2	2
wht	24	20	17	17	34	39	1	2	15	15	5	5
gro	86	84	21	21	26	26	11	10	3	3	8	8
v_f	59	68	49	53	320	321	8	8	17	16	21	28
osd	41	34	9	14	11	20	46	40	12	11	1	1
c_b	3	3	6	6	4	4	8	8	4	4	0	0
pfb	43	33	3	3	27	37	3	2	3	3	0	0
ocr	15	16	58	65	5	4	27	24	11	10	0	1
ctl	141	141	146	146	302	302	319	319	211	210	33	33
oap	58	58	64	64	200	201	25	25	21	21	9	10
rmk	55	55	91	91	13	13	35	35	33	33	50	50
wol	0	0	0	0	1	2	0	0	1	1	0	0
frs	3	2	3	2	9	9	0	0	2	2	6	5
fsh	3	4	9	9	31	30	0	0	2	2	0	0

For the United States we observe difference in wheat, oilseeds, plant based fibers, and fruits and vegetables. For the first three commodities, production based emissions are larger than consumption. This is probably mainly due to that the USA is a major exporter for those commodities. For fruits and vegetables, the USA consumes both fruits (i.e. bananas, mangoes, etc.) and vegetables (i.e. tomatoes, avocadoes, etc.) from imports. For the EU15 we observe differences for fruits and vegetables (same as the USA) and other crops, a trend that is repeated with Russia for fruits and vegetables.

For China, we observe that consumption based emissions are larger than production based for wheat, oilseeds and plant based fibers. This reflects the fact that China is a major importer of cereals grains and raw materials (i.e cotton). For Brazil, oilseeds stand up, as production based emissions are larger than those based on consumption. For India, there is not much difference between the two indices. Finally, for Russia, we observe, as with USA and EU15, that

Conclusions

In this study we have analyzed the carbon content of trade in agriculture. This paper expands previous research as it incorporates non-CO_2 emissions into the analysis of virtual carbon trade. This is specially important for agriculture, as this sectors account for most N_2O and CH_4 emissions worldwide.

The paper contrasts the differences between developed and developing countries and the importance of consumption-based targets versus production-based targets. We observe that for agriculture, production based GHG emissions for major exporters of grains and raw materials such as the USA (wheat, oilseeds and cotton) and Brazil (oilseeds) are larger than consumption based. The opposite is true for China, as a major consumer of cereal grains and raw materials. For fruits and vegetables, consumption based GHG are larger in northern hemisphere countries such USA, EU15 and Russia.

In future versions of the paper we intend to extend this research to analyze the implications to border taxation in agriculture, and extend the work of Atkinson et al. (2009).

References

Ackerman, F., M. Ishikawa, and M. Suga. 2007. The Carbon Content of Japan-US Trade. *Energy Policy*, 35, 4455-4462.

Ahmad, N. and A. Wycko. 2003. Carbon Dioxide Emissions Embodied in International Trade of Goods. OECD, Directorate for Science, Technology and Industry Working Papers, November 2003, No. 2003/15.

Aichele, R. and G. Felbermayr. 2010. Kyoto and the Carbon Content of Trade. FZID Discussion Paper 10-2010, Universitat Hohemheim.

Andrew R., G. Peters, J. Lennox. 2008. New Zealand's Carbon Balance: MRIO Applied to a Small Developed Country, Paper presented at the International Input Output Meeting on Managing the Environment, Seville (Spain) July 9-11, 2008.

Atkinson, G., K. Hamilton, G. Ruta and D. Van Der Mensbrugghe. 2010. Trade in 'Virtual Carbon': Empirical Results and Implications for Policy. Policy Research Working Paper No. 5194. The World Bank, Washington D.C.

Babiker, M.H. 2005. Climate Change Policy, Market Structure, and Carbon Leakage. *Journal of International Economics*, 65, 421-445.

Bednar-Friedl, B., P. Muñoz Jaramillo, T. Schinko and K. Steininger. 2010. The Carbon Content of Austrian Trade Flows in the European and International Trade Context. Research Centre International Economics (FIW) Research Reports 2009/10 No. 05. Vienna, Austria.

Hertwich, E.G. and G.P. Peters. 2009. Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environmental Science and Technology*, 43 (16), 6414–6420. DOI: 10.1021/es803496a

Hummels, D. J. Ishii and K-M. Yi. 1999. The Nature and Growth of Vertical Specialisation in World Trade," Manuscript. New York: Federal Reserve Bank of New York, August.

Hummels, D., J. Ishii and K.-M. Yi. 2001. The nature and growth of vertical specialization in world trade. *Journal of International Economics*, *54*, 75–96.

Ismer, R. and K. Neuhoff. 2007. Border tax adjustment: a feasible way to support stringent emission trading. Eur J Law Econ (2007) 24:137–164

Lee, H., Roland-Holst, D., 2000. Trade-induced pollution transfers and implications for Japan's investment and assistance. *Asian Economic Journal* 14 (2): 123–146.

Lee, H-L. 2008. The Combustion-based CO2 emissions data for GTAP version 7 Data base. Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA.

Leontief, W. 1970. Environmental repercussions and the economic structure: an input–output approach. *The Review of Economics and Statistics* 52 (3), 262–271.

Liu, X. M. Ishikawa, C. Wang, Y. Dong and W. Liu. 2010. Analyses ofCO2 emissions embodied in Japan–China trade. *Energy Policy*, 38, 1510–1518.

Mattoo, A. A. Subramanian, D. van der Mensbrugghe, and J. He. 2009a. *Can Global De-Carbonization Inhibit Developing-Country Industrialization?* Working Paper No. 188. Center for Global Development, Washington D.C.

Mattoo, A. A. Subramanian, D. van der Mensbrugghe, and J. He. 2009b. *Reconciling Climate Change and Trade Policy*. Policy Research Working Paper No. 5123. The World Bank, Washington D.C.

Muradian, R., O'Connor, M., Martinez-Alier, J., 2002. Embodied pollution in trade: estimating the 'environment load displacement' of industrialized countries. *Ecological Economics* 41 (1): 51–67.

Nakano, S., A. Okamura, N. Sakurai, M. Suzuki, Y. Tojo, and N. Yamano. 2009. The Measurement of CO_2 Embodiments in International Trade: Evidence from the Harmonised Input-Output and Bilateral Trade Database. OECD Science, Technology and Industry Working Papers, 2009, No. 2009/3.

Pan, J., J. Phillips and Y. Chen. 2008. China's Balance of Emissions Embodied in Trade: Approaches to Measurement and International Responsibility", *Oxford Review of Economic Policy*, 24(2): 354-376.

Peters, G.P. 2008. From Production-Based to Consumption-Based National Emissions Inventories, *Ecological Economics*, 65(1):13-23.

Peters, G.P. and E.G. Hertwich. 2008a. CO_2 Embodied in International Trade with Implications for Global Climate Policy, *Environmental Science & Technology*, 42 (5), 1401-1407.

Peters, G.P. and E.G. Hertwich, 2008b. Post-Kyoto greenhouse gas inventories: production versus consumption. *Climate Change*, 86, 51-66.

Rose, S.K., M. Avetisyan and T.W. Hertel. 2010. Development of the Preliminary Version 7 Non-CO_2 GHG Emissions Dataset. GTAP Research Memorandum No. 17. Center of Global Trade Analysis, Purdue University.

Rose, S., S. Finn, E. Scheele, J. Mangino, K. Delhotal, J. Siedenburg, H. Perez. 2007. Detailed greenhouse gas emissions data for global economic modeling, United States Environmental Protection Agency (EPA), Washington, DC.

Rose, S.K. and H-L Lee. 2008. Non-CO_2 Greenhouse Gas Emissions Data for Climate Change Economic Analysis. GTAP Working Paper No. 43. Center of Global Trade Analysis, Purdue University.

Rose, S.K. and H-L Lee. 2009. Non-CO_2 Greenhouse Gas Emissions Data for Climate Change Economic Analysis. In: T.W. Hertel, S.K. Rose, R. Tol (eds.), *Economic Analysis of Land Use in Global Climate Change Policy,* Routledge Publishing.

Su, B., H.C. Huang, B.W. Ang and P. Zhou. 2010. Input-output analysis of CO2 emissions embodied in trade: The effects of sector aggregation. *Energy Economics*, 32, 166-175.

Wang, T. and J. Watson. 2007. Who Owns China's Carbon Emissions? Tyndall Centre Briefing Note, 2007, No. 23.

Veel, P-E. 2009. Carbon tariffs and the WTO: An evaluation of feasible policies. *Journal of International Economic Law*, 12(3), 749–800

Wheeler, D. and K. Ummel. 2007. Another Inconvenient Truth: A Carbon-Intensive South Faces Environmental Disaster, No Matter What the North Does. Working Paper Number 134. Center for Global Development, Washington D.C.

World Bank. 2008. World Development Report 2008: Agriculture for Development. Washington, D.C.: The World Bank.

World Bank. 2010. World Development Report 2010: Development and Climate Change. Washington, D.C.: The World Bank.

Appendix A. GHG emission Split

To estimate the shares used to distribute the GHG emissions across intermediate industry use and final demand, we only use variables valued at domestic markets prices. These data include shares for both domestic and import use: a) output disposition into domestic use (firm (*VDFM*), household (*VDPM*) and government (*VDGM*)), *VDM*, transport (*VST*) and exports (*VXMD*). b) for imports, we allocate emissions across firm (*VIFM*), household (*VIPM*) and government (*VIGM*) import use. For imports, this removes possible distortions from taxes and international margins. We use the derived data sets from the file GTAPView.har (Table 1).

Table A1. GTAP data used to distribute GHG emissions

GTAP Data	Data Description	Components
OUTDISP	Disposition of output	Domestic production, transport, exports
DOMSALESDISP	Disposition of domestic goods	Intermediate use, household consumption, government consumption
IMPSALESDISP	Disposition of imported goods	Intermediate use, household consumption, government consumption

Another advantage of this study is that is based on version 7 of the GTAP data base. Version 7 expands country coverage from version 6 from 87 regions/countries to 113 countries/regions, including countries from the former Soviet Union, Latin America, Africa and Asia (Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Ukraine, Norway, Bolivia, Costa Rica, Ecuador, Paraguay, Panama, Nicaragua, Guatemala, Egypt, Ethiopia, Mauritius, Nigeria, Senegal, Iran, Pakistan, Burma, Cambodia, and Laos PDR). This gives a complete coverage for Annex 1 countries, as it includes Norway, Belarus and Ukraine, removing the need for any additional estimation as in Peters and Hertwich (2008).

However, the GHG emissions data differs from other data sources (Peters and Hertwich, 2008), mainly due to three things: a) the system boundary for the energy statistics differs from the economic data in the GTAP data base; b) the GTAP energy data suffers various levels of modifications to make it consistent with other data sets; c) there is an error in the petroleum refineries sector (p_c) causing an overestimation.

Table A2. Agricultural sectors in the GTAP data base

GTAP Sector	Description	Products
pdr	Paddy rice	Paddy rice
wht	Wheat	Wheat
gro	Cereal grains nec.	Corn, oats, sorghum, etc.
v_f	Vegetables, fruits, nuts	Vegetables, fruits, roots and tubers, pulses, nuts
osd	Oil seeds	Oilseeds (soybeans, sunflower, canola, palm, etc)
c_b	Sugar cane, sugar beet	Sugar cane, sugar beet
pfb	Plant-based fibers	Cotton, yute, etc.
ocr	Crops nec	Beverage crops, tobacco leaves, flowers, etc.
ctl	Cattle, sheep, goats, horse	Cattle, sheep, goats, horses
oap	Animal products nec	Pigs, poultry, etc.
rmk	Raw milk	Raw milk
wol	Wool, silk-worm cocoons	Wool, silk-worm cocoons
frs	Forestry	Forestry
fsh	Fishing	Fishing

Table A3. Regional aggregation

Country	Description	Products
BRA	Brazil	Brazil
CAN	Canada	Canada
CHN	China	China
E15	EU15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK
EIT	Economies in Transition	Czech Rep., Estonia, Hungary, Latvia, Lithuania, Poland, Albania, Bulgaria, Belarus, Croatia, Romania, Ukraine, Rest of Eastern Europe, Rest of Europe, Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Georgia, Cambodia, Laos
IND	India	India
JPN	Japan	Japan
LIY	Low Income countries	Vietnam, Bangladesh, Sub-Saharan Africa
MEX	Mexico	Mexico
RUS	Russia	Russia
USA	USA	USA
XHY	High-Income Economies	South Korea, Taiwan, Singapore, Cyprus, Malta, Rest of Western Asia
XMY	Middle Income countries	Australia, New Zealand, Slovakia, Slovenia, Switzerland, Norway, Rest of EFTA, Turkey
XXL	Other Annex 1 countries	Latin America and the Caribbean, North Africa, Nigeria, Mauritius, South and South East Asia
ZAF	South Africa	South Africa