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Counting CO_2 Emissions in a Globalised World

Producer versus consumer-oriented methods for CO_2 accounting

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Martin Bruckner is a researcher at the Sustainable Europe Research Institute (SERI), Vienna
E-mail: martin.bruckner@seri.at

Christine Polzin is a researcher at the Sustainable Europe Research Institute, Vienna
E-mail: christine.polzin@seri.at

Stefan Giljum is head of the research group "Sustainable Resource Use" at the Sustainable Europe Research Institute, Vienna
E-mail: stefan.giljum@seri.at

Tulpenfeld 6, 53113 Bonn
☏ +49 (0)228 94927-0
🖷 +49 (0)228 94927-130
E-Mail: die@die-gdi.de
http://www.die-gdi.de

Foreword

This paper has been produced under the umbrella of the DIE research project „Development Policy: Questions for the Future," funded by the German Ministry for Economic Cooperation and Development (BMZ). A main objective of this research project is to stimulate thinking about how the context that development policy responds to could change in the long-term. In the short-term, policymakers face numerous decisions with far-reaching implications of their own. Among them are decisions concerning how to respond to the global climate challenge by crafting a successor to the Kyoto climate regime set to expire in 2012. This paper by Martin Bruckner, Christine Polzin, and Stefan Giljum from the Sustainable Europe Research Institute, Vienna, offers a contribution to the debate about what considerations should be incorporated into deliberations on the governance of the global climate in the future by identifying how consumption-focused methods of accounting for carbon dioxide emissions can provide a more complete picture of national responsibilities to take action against climate change than production-focused accounting methods alone might allow. The paper highlights the environmental dimensions of interstate economic relations and encourages policymakers to acknowledge the implications of economic interdependence for global climate policy to a greater extent. The research presented here provides a complement to several ongoing strands of research at the Deutsches Institut für Entwicklungspolitik/German Development Institute (DIE), touching on issues such as the compatibility between the global trade and climate regimes, the place of climate adaptation measures within the framework of global climate governance, and pathways toward a global low-carbon economy. A common concern within this body of work is the need to accommodate the interests of developing countries within global environmental governance processes while putting the world as a whole on a more sustainable development path in the future.

Erik Lundsgaarde Bonn, July 2010

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Abbreviations

BEET	Balance of Emissions Embodied in Trade
BTD	Bilateral Trade Data
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CSS	Carbon Capture and Storage
EIT	Economies in transition
GHG emissions	Greenhouse gas emissions
GRAM	Global Resource Accounting Model
GTAP	Global Trade Analysis Project
GWS	Gesellschaft für wirtschaftliche Strukturforschung
IEA	International Energy Agency
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land-use, land-use change and forestry
MRIO model	Multi-regional input-output model
Mt	Million tonnes
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
RoW	Rest of the World
SERI	Sustainable Europe Research Institute
SRIO	Single-region Input-Output analysis
UNFCCC	UN Framework Convention on Climate Change
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)

Summary

This paper compares the Kyoto Protocol's production-based accounting method to calculate a country's carbon emissions with a consumption-based accounting method that measures the carbon embodied in goods in the country where they are consumed. The choice between the two accounting principles implies an inherent judgment on whether the producer or the consumer is responsible for the CO_2 emissions. The comparison raises questions on international environmental justice as well as political implications regarding the responsibility for carbon emissions and climate change. This paper argues that consumption-based accounts are a useful complement to production-based accounts because they provide a basis for sharing environmental responsibilities between producer and consumer countries.

Using a multi-regional input output (MRIO) model we find that CO_2 emissions embodied in internationally traded goods accounted for 27% of the total energy-related CO_2 emissions in 2005, up from 22% in 1995. The G77 countries consume 23% less CO_2 emissions than they produce while the countries Organisation for Economic Co-operation and Development (OECD) consume almost 30% more CO_2 emissions than they produce. The G77 have a combined CO_2 trade deficit of more than 3 billion tonnes and thus deliver almost all the net imports of the OECD countries. The largest net importers of embodied carbon emissions in 2005 were the US (1255 Mt), Japan (380 Mt) and the biggest European economies (France 275 Mt, Germany 257 Mt, and the UK 232 Mt). The largest net exporters were China with 990 Mt (an increase of 63% compared to 1995), the Russian Federation (330 Mt) and India (136 Mt). The highest carbon leakage occurred in the United States (1,250 Mt CO_2 from consumption originated from non-Annex I countries). The European Union imported 1,450 Mt CO_2 from non-Annex I countries.

The paper also raises some pertinent policy implications. Consumption-based carbon accounting puts the credibility of the reduction achievements under Kyoto into a different perspective because it would not allow the reduction of national carbon budgets by substituting domestic production for imports. A consumption-based accounting system might be perceived as fairer than production-based accounting, especially by net-exporting countries. Measuring the CO_2 emissions and other environmental outputs of world trade may be useful in revising and finding fair emission targets and may encourage technology transfers and mitigation activities. A consumption-based approach to carbon accounting combined with appropriate policy instruments such as quotas or taxes may help shift comparative advantage away from pure economic measures to a logic that also considers environmental aspects. Finally, the debate on global environmental responsibility should not only focus on CO_2 emissions but also consider the effects of other greenhouse gases and the unsustainable use of other resources such as raw materials, land and water.

1 Introduction[1]

The attention of both national and international climate change policy negotiations has increasingly focused on reducing the growth of anthropogenic greenhouse gas (GHG) emissions – most importantly of carbon dioxide (CO_2), one of the main drivers of global warming. The Kyoto Protocol of the UN Framework Convention on Climate Change (UNFCCC 1998), the most prominent example of global policy efforts, sets targets for the main industrialised countries to reduce the greenhouse gases they produce.[2]

The measurement of emissions in the Kyoto Protocol follows the UNFCCC convention of territorial accounting, a method that attributes all emissions generated from production activities within a country's territory to that country's total emissions. It does not take into account emissions which occur along international value chains (embodied emissions of traded goods and services). Some argue that the method is inadequate for open economies engaged in trade because the amount of GHG emissions they produce hardly ever corresponds to the amount of emissions released to enable their consumption of domestic and imported products (see for example Li / Hewitt 2008; Peters / Hertwich 2008a; Wilting / Vringer 2009; Davis / Caldeira 2010). Indeed, as this paper will show, there is a large difference between countries' emissions related to production and consumption.

The selection of different ways to measure CO_2 emissions is not only an academic issue but also raises questions of international environmental justice and carries political implications regarding responsibility. Production-related emissions in many export-oriented developing and emerging economies are to a considerable extent driven by the consumption patterns in industrialised countries. So who should be responsible for the emissions embodied in trade, the developing countries in their role as producers or the industrialised countries as consumers? In order to devise fair and equitable climate policies it is worth analysing where and for what purpose greenhouse gases are emitted.[3]

Doubts about the usefulness of territorial accounting as a basis for the assignment of responsibility between different countries may also arise because national action plans aimed at reducing domestic CO_2 emissions can increase the emissions of other countries and thus counter the global efforts to tackle climate change. This effect, which is known as carbon leakage (Ahmad / Wyckoff 2003; Barker et al. 2007), can be measured in terms of CO_2 emissions that are not consumed in the same country where they are produced. Such carbon shifts from one country to another may occur as a result of two different processes. First, some pollution intensive industries in the country with stricter national environmental regulations may migrate

1 The authors would like to thank Kirsten Wiebe and Christian Lutz from the Institute of Economic Structures Research (GWS) in Osnabrück for their support in building up and running the model on which the analysis in this paper is based.

2 The Kyoto Protocol, an international agreement to reduce greenhouse gas emissions worldwide, entered into force on 16 February 2005. Parties to the UNFCCC are classified as Annex I parties (industrialised countries that are members of the OECD and economies in transition (EIT)), Annex II parties (OECD members of Annex I but not EITs who are required to provide financial resources to developing countries for adaptation to climate change), and Non-Annex I parties (mostly developing countries who are not required to reduce emission levels unless developed countries supply enough funding and technology).

3 Climate justice and responsibility are commonly raised ethical concerns in the literature on climate policies (Ringius / Torvanger / Underdal 2002; Bastianoni / Pulselli / Tiezzi 2004; Vanderheiden 2008; Hoekstra / Janssen 2006; Ikeme 2003; Rose 1990; Bulkeley / Newell 2010; Roberts / Parks 2009).

to countries with less stringent environmental regulations. Helm / Smale / Phillips (2007), for example, argue that developed countries have ‘pushed’ dirty production into developing countries, helped by policies of deindustrialisation. In the literature, the jury is still out on this so-called strong pollution haven hypothesis (see for example Cole / Elliott / Shimamoto 2005; Xing / Kolstad 2002; Brunnermeier / Levinson 2004). Carbon leakage may also occur when production increases in less environmentally regulated countries (e.g. non-Annex I countries) for reasons that are not connected to climate change mitigation in countries with stronger environmental regulation (e.g. Annex I countries) (Rothman 1998). There is strong evidence for the occurrence of weak carbon leakage, as this paper will show.

This paper will provide an overall account of the emissions embedded in global trade flows to and from different countries and regions. While knowledge about the size of embodied CO_2 emissions in imports and exports has long been limited, new models are now enabling the calculation and analysis of these embodied emissions. This paper uses a multi-regional input-output (MRIO) model to compare energy-related CO_2 emissions from production and consumption by calculating the emission balances of consumption (= production – exports + imports) in 54 countries and comparing them to the production-based emission balances.

The paper will thus provide answers to three main questions. First, which countries and regions are the biggest net importers and net exporters of embodied CO_2 emissions from international trade? Second, what amount of CO_2 emissions has been shifted between different regions through international trade? Third, what is the influence of considering consumer responsibility on the goals of international climate agreements?

The main conclusions from this paper are:

- Comprehensive carbon trade balances with embedded emissions show that emissions related to domestic consumption of products are significantly higher than those related to domestic production in many industrialised countries. The opposite is revealed for trade-engaged developing and emerging economies.
- Consumption-based carbon trade balances should be established in addition to production-based balances because they can help in finding solutions to issues such as carbon leakage and emission targets for developing countries.

The next section explains how to measure embodied carbon emissions in traded goods and provides a brief review of the literature on consumption-based accounting. It will also explain the method and data used to calculate the embedded carbon emissions in the paper. Section 3 presents the results generated with the MRIO model. Section 4 considers implications for global climate policies. Section 5 concludes.

2 Background and methodology

2.1 Approaches to carbon accounting

The most commonly used method for CO_2 accounting – *production-based* or *territorial accounting* – measures the CO_2 emitted within a country. While it can be used to evaluate the global environmental impacts of the production and consumption activities of a specific country, it cannot identify shifts of environmental pressures as a result of changing global production, trade and consumption patterns. Moreover, it is not possible to use this approach to analyse carbon leakage or equity concerns related to the structure of trade relations between developing and industrialised countries (Schaeffer / Leal de Sá 1996).

By contrast, consumption-based emissions are calculated by adding the emissions arising from domestic production and emissions embodied in imports and subtracting the emissions embodied in exports (Nakano et al. 2009). Allocating emissions on a national production basis is easier than calculating them on a consumption basis because the latter requires the detailed specification of inter-industry and international trade structures. The calculation of emissions from the production of exports furthermore requires large quantities of country-specific, up-to-date data (in the form of so-called input-output tables and international trade data). Territorial accounting, by contrast, has clear system boundaries and good data availability.

The choice between the production and consumption accounting principle implies an inherent judgment on whether the producer or the consumer is responsible for the CO_2 emissions.

2.2 Models for economy-wide carbon accounting

The most commonly used methodology to estimate embodied emissions in international trade and identify all direct and indirect effects of production is based on the analysis of input-output (IO) tables. Input-output tables express the structure of an economy in terms of the inputs to its various sectors and the nature of the outputs from those sectors. They can be used to investigate what an economy extracts from and introduces into the natural environment as well as the environmental implications of resource use of final consumption (Leontief / Ford 1970; Miller / Blair 1985; Walter 1973). Environmentally extended input-output analysis can be used to analyse the environmental effects of structural changes in the economy, such as technology, trade, investment and consumption.

Box 1: A short description of input-output analysis

Input-output analysis helps to understand the interactions between economic sectors, producers and consumers. The method tracks all financial transactions between industrial sectors and consumers within an economy. It is possible to assign an environmental impact to these financial transactions by adding environmental information, such as greenhouse gas emissions, to each sector. An environmentally extended input-output model tracks the flow of environmental impacts along supply and production chains. As each production step adds an environmental burden, the result is a life-cycle inventory of impacts of production and consumption, e.g. carbon or water footprints of product groups, industries, regions or countries. Data is largely obtained from input-output tables, which show the flows of goods and services from every sector to every other sector in the economy over a given year. Table 1 represents a simplified example of an input-output table of a three sector economy.

Table 1: Transactions in a three sector economy

Economic Activities	**Inputs to Agriculture** (x_{i1})	**Inputs to Manufacturing** (x_{i2})	**Inputs to Services** (x_{i3})	**Final Demand** (y)	**Total Output** (X)
Agriculture (x_{1j})	5	15	2	68	90
Manufacturing (x_{2j})	10	20	10	40	80
Services (x_{3j})	5	15	10	0	30
CO_2 emissions (p_i)	15	50	10		

Note: Data in input-output tables are usually given in monetary units. The exception here is the row which shows the environmental impacts (here the use of biomass from eco systems).

The columns in the table explain what inputs a sector uses to produce its output. They refer to the production side, while the rows show the distribution of the produced goods and services. In order to produce 68 units of agricultural products for final demand in this representative three sector economy, 5 units of inputs are needed from the agricultural sector, 10 units from the manufacturing sector and 5 units from the services sector. The agricultural sector also produces 15 units of CO_2 emissions.

There are two kinds of input-output-based approaches – Single-Region Input-Output (SRIO) models and Multi-Regional Input-Output (MRIO) models.[4] As supply chains have become increasingly global over the past decades, MRIO models have gained in importance in measuring emissions embodied in trade. A multi-regional input-output model includes all trade linkages between regions and shows how many domestic and imported products are required from each sector in each region. The main advantages of the MRIO approach are:

— MRIO models enable an accurate and comprehensive evaluation of the environmental impacts embedded in trade because they link (monetary) trade flows and environmental databases, taking variations in production structures and technologies between different countries and world regions into account (Wiedmann et al. 2007a).

4 On single-region input-output models, see for example Machado / Schaeffer / Worrell (2001) for Brazil, Munksgaard / Pedersen (2001) for Denmark, Mongelli / Tassielli / Notarnicola (2006) for Italy. For an excellent comparisons of the different approaches, please see Lenzen / Pade / Munksgaard (2004), Haukland (2004), Peters / Hertwich (2006).

- MRIO models can be used to conduct different analyses at the international level, such as structural path analysis, production layer composition, quantification of shared environmental responsibilities between producers and consumers of goods (Wiedmann et al. 2007a; Wiedmann et al. 2007b).
- MRIO models can help to capture direct, indirect and induced effects of international trade (Wiedmann et al. 2007a).

In recent years, complex multi-regional multi-sectoral input-output models have been used to identify the environmental pressures that occur along the international supply chains of products (Ahmad / Wyckoff 2003; Peters / Hertwich 2004).[5] The latest studies to calculate embodied CO_2 emissions which distinguish a large number of countries and regions, based on the Global Trade Analysis Project (GTAP) database, include Peters and Hertwich (2008b) and Minx et al. (2008).

The results presented in this paper were also derived using a MRIO model, the Global Resource Accounting Model (GRAM).[6] The GRAM model is a so-called multi-directional model, which includes all trade relations between the different countries and regions in the model.[7] Following the OECD definition (Nakano et al. 2009; 10), this paper defines imported CO_2 as the emissions embodied in the imports used for immediate and final consumption. In contrast to the UNFCCC model, that does not include emissions from aviation and shipping in national carbon accounts, the model used in this paper to calculate production-based CO_2 balances includes these emissions. The GRAM model may therefore produce higher emissions than those used in the Kyoto protocol.

For the calculation of carbon leakage this paper follows the methodology used by Peters and Hertwich (2008b; 1402) for "weak" carbon leakage - the total aggregated CO_2 emissions embodied in imports from non-Annex I countries to Annex I countries.[8] In a "strong" definition (generally used by the Intergovernmental Panel on Climate Change IPCC), in contrast, carbon leakage is defined as the *"increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries"* (IPCC 2007; 12). In theory this definition can be used to determine production shifts in response to GHG mitigation policies. Empirically, however, there is little evidence of such shifts on a significant scale (Peters / Hertwich 2008a). For the global climate, it is less relevant if a policy change in an Annex I country caused production to increase in a non-Annex I country. What matters for global climate policy goals is the total amount of carbon consumption in industrialised countries that is produced in countries without binding GHG emission targets and policies in place.

5 Extensive reviews of environmentally extended MRIO studies have been published by Wiedmann et al. (2007a; 2007b) and Wiedmann (2009).

6 For more information on the GRAM model, see www.seri.at/GRAM.

7 There are also uni-directional MRIO models. These are more appropriate for the analysis of single countries (Lenzen / Pade / Munksgaard 2004; Munksgaard et al. 2009).

8 The model used for the carbon calculations in this paper includes 35 out of 40 Annex I countries (excluding Liechtenstein, Monaco, Croatia, Belarus, and Ukraine). Annex I countries are industrialised countries with greenhouse gas emissions limitations or a reduction commitment as well as countries currently making a transition to a market economy.

2.3 Data sources

The two key data sources for the Global Resource Accounting Model (GRAM) model adapted to the purpose of this paper are the International Energy Agency (IEA) and the OECD. Data on CO_2 emissions for all countries are obtained from the IEA. The energy balances of the IEA (2008a; 2008b) contain physical data on the use of energy carriers in kilo tonnes oil equivalents (ktoe) for 68 economic sectors. One assumption of the model is that energy-related CO_2 emissions per unit of energy carrier do not vary between different economic sectors.

To conduct a detailed multi-regional input-output analysis highly harmonised economic data sets are essential (Peters 2008), including input-output data for every country and reliable data on bilateral trade. This data is generally available for most OECD countries, but only for a few non-OECD countries. The model uses the international input-output (IO) tables published by the OECD (Yamano / Ahmad 2006). This dataset covers 30 out of 31 OECD countries and 11 non-OECD countries (Argentina, Brazil, China, Estonia, India, Indonesia, Israel, Russia, Slovenia, South Africa, and Taiwan) with a resolution of 48 economic sectors. Input-output tables for 13 additional countries or regions were estimated under the assumption that they used the same technology as neighbouring countries or countries with a similar economic structure (see Table 2). In total, the model distinguishes 54 countries and world regions and 48 economic sectors. For most countries the OECD input-output tables are available for the years 1995, 2000 and 2005 (see OECD 2009). For some countries, however, data are only available for one or two of these three years or for different years.

The trade data for the multi-regional input-output models also comes from the OECD. Linking national input-output tables for cross-country analyses requires a consistent set of harmonised international bilateral trade data. Therefore, the Bilateral Trade Data (BTD, see OECD 2006) were harmonised with the IO tables of the OECD. They contain data on imports and exports for all OECD countries, broken down by 61 trading partners and 25 product groups as well as one aggregated service sector. Re-exports were fully integrated in the final demand data used in this analysis. Bilateral trade data are directly available for almost all countries in the model. In addition to most of the trade relations between OECD member states, the current OECD trade data set also comprises the trade flows between the most important trading partners such as China, India, Brazil, Russia, etc. Estimations based on international statistics were necessary only for the trade between six small Eastern EU member states as well as for the OPEC and the country group "Rest of the World". For more information on the technical implementation of the model, see Bruckner et al. (2009).

Some of the trade data on which the modelling is based should be treated with caution as inconsistencies may distort the results. Such inconsistencies are known to exist with regard to re-exports and input-output tables. As re-exports are inconsistently reported to the OECD, this may create a bias in the results, especially for countries with high re-exports (such as Singapore, Luxembourg, or the Netherlands). Comprehensive documentation is available for the trade data used. In future research, this could be used to adapt the data and exclude all re-exports in order to achieve greater consistency.

Care should also be taken with regard to the data estimations of the countries and country groups with incomplete data (trade data and/or input-output tables), and whose input-output structures were assumed to be the same as those of neighbouring countries or countries with similar economic characteristics (see Table 2).[9] In this group of countries and regions, the results for the OPEC group, Mexico, and South Africa should be treated with caution because of their high share in global production-based CO_2 emissions (6.6%).

Table 2: Assumed input-output structure for countries without available input-output data

Country	Assumed structure of
Bulgaria	Poland
Cyprus	Greece
Latvia	Poland
Lithuania	Poland
Luxembourg	Belgium
Malaysia	Korea
Malta	Greece
OPEC	Indonesia
Philippines	Korea
Singapore	Korea
Switzerland	Germany
Thailand	Korea
Rest of the World	Argentina

In GRAM the structure of the Argentinean economy is used for the group of "Rest of the World" (RoW) as Argentina is the country among the countries included in the OECD input-output dataset whose economic structure likely coincides best with the region RoW (Giljum et al. 2008). This assumption has led to a considerable overestimation of the production-based emissions of the G77 in the modelling results and therefore also in analysing embodied emissions in exports. Sensitivity analysis, i.e. testing different economic structures for RoW and their impacts could further clarify the dimension of this error.

3 Comparing consumption-based and production-based emissions

In this section we present selected results from the model calculations.[10] Table 3 provides an overview of production-based and consumption-based carbon emissions, carbon trade balances and the difference between consumption and production-based carbon emissions for the

9 Such estimations are needed to complete a multi-regional input-output model at the global level and are therefore common practice in MRIO modelling.

10 All data used for the calculations in this paper are available from the authors upon request.

Table 3: Production and consumption-based emissions, carbon trade balances and shares in global shifts of selected countries, 1995 and 2005

Country	Production-based emissions (Mt CO_2)		Consumption-based emissions (Mt CO_2)		Carbon trade balance (Mt CO_2)		Share in global carbon shifts (%)	
	1995	2005	1995	2005	1995	2005	1995	2005
Australia	265	359	300	469	35	109	1.5%	2.6%
Canada	389	497	415	547	26	50	1.1%	1.2%
France	340	366	496	641	157	275	6.5%	6.6%
Germany	861	805	1,023	1,061	162	257	6.7%	6.1%
Italy	379	430	532	610	153	180	6.3%	4.3%
Japan	1,099	1,193	1,530	1,573	431	380	17.8%	9.1%
Korea	304	460	360	496	56	36	2.3%	0.9%
Mexico	286	367	280	433	-6	66	-0.2%	1.6%
Netherlands	173	214	217	310	44	96	1.8%	2.3%
Spain	229	325	253	443	24	119	1.0%	2.8%
United Kingdom	514	596	737	827	222	232	9.2%	5.5%
United States	4,841	5,447	5,181	6,702	340	1,255	14.1%	29.9%
Rest of OECD	1,282	1,403	1,627	1,903	345	500	14.3%	11.9%
OECD	**10,962**	**12,461**	**12,951**	**16,014**	**1,989**	**3,553**	**82.2%**	**84.6%**
Argentina	104	158	126	132	22	-27	0.9%	-0.6%
Brazil	208	283	252	298	44	15	1.8%	0.4%
Chile	44	69	40	55	-4	-14	-0.2%	-0.3%
China	3,079	4,748	2,473	3,757	-607	-990	-25.1%	-23.6%
India	795	1,256	707	1,121	-88	-136	-3.6%	-3.2%
Indonesia	180	308	241	342	61	33	2.5%	0.8%
Malaysia	104	226	75	124	-28	-102	-1.2%	-2.4%
Philippines	53	76	60	68	7	-8	0.3%	-0.2%
South Africa	239	323	212	293	-26	-30	-1.1%	-0.7%
Thailand	136	283	145	190	10	-93	0.4%	-2.2%
OPEC	863	1,171	1,074	1,703	210	532	8.7%	12.7%
Rest of G77	3,557	4,799	2,102	2,475	-1,454	-2,324	-58.9%	-54.1%
G77	**9,414**	**13,779**	**7,588**	**10,635**	**-1,826**	**-3,144**	**-75.5%**	**-74.9%**
Russian Federation	1,071	1,274	885	945	-186	-330	-7.7%	-7.9%
Rest of the world	400	600	422	521	23	-79	0.9%	-1.9%
World Total	**21,847**	**28,115**	**21,847**	**28,115**	**0**	**0**	**0.0%**	**0.0%**

years 1995 and 2005.[11] Twelve members of the OECD and the G77 (a group of 130 developing states), two of the major negotiation blocks in climate change talks, are shown in detail as well as the average figures for two regions, the Russian Federation and the Rest of the World. The table also shows the development of the emissions of the world as a whole.

Some general patterns can be observed. Global carbon emissions have increased by 29% between 1995 and 2005, from 21,800 Mt to 28,100 Mt. During this period, the global gap between production-based and consumption-based CO_2 emissions has also grown. CO_2 emissions embodied in internationally traded goods accounted for 27% of all energy-related CO_2 emissions in 2005, up from 22% in 1995.

Overall, the OECD countries had a positive carbon trade balance, with net imports of 3,600 Mt CO_2 in 2005, compared to 2,000 Mt in 1995. In all OECD countries, consumption-based CO_2 emissions are higher than production-based emissions. The OECD countries thus consume almost 30% more CO_2 emissions than they produce. The growth of production-based emissions was smaller than that of consumption-based emissions (14% vs. 24%). Many OECD countries produce low carbon goods and services while importing and consuming carbon-intensive goods (such as steel, iron, aluminium, and glass). In France, for example, consumption-based emissions exceeded production-based emissions by 75% in 2005. In Korea, this difference was only 8%. Especially smaller OECD countries which are highly dependent on trade have significantly larger emissions from consumption than from production. These trends are also reflected in global carbon shifts which describe the relocation of embodied carbon emissions worldwide. Thus, the share in global carbon shifts is the proportion of all global embodied emissions in trade imported or exported by a country or region. In 2005, the OECD imported 85% of all emissions embodied in trade. The largest share of traded emissions within the OECD (30% of all global embodied emissions in trade) was destined for the US.

The large majority of developing countries are net exporters of emissions. Using the production-based accounting approach, the G77 produced 11% more emissions than the OECD in 2005 (13,800 Mt CO_2 vs. 12,500 Mt CO_2). With a consumption-based approach, the G77 has about 60% fewer emissions than the OECD (10,600 Mt CO_2 vs. 16,000 Mt CO_2). The growth of emissions between 1995 and 2005 was larger when measured on a production basis than on a consumption basis (46% vs. 40%) but in both terms still significantly larger than in the OECD countries. This is also reflected in the carbon trade balance deficit, which increased significantly during this time. In 2005, the G77 had a combined CO_2 trade deficit of 3,100 Mt and thus delivered almost all the net imports of the OECD countries. In 1995, this deficit was only 1,800 Mt CO_2. In contrast to the OECD countries, the G77 countries consume 23% less CO_2 emissions than they produce. In some G77 countries such as Argentina, the Philippines and Thailand, the carbon trade balance has turned from surplus into deficit between 1995 and 2005. National CO_2 targets may be more difficult to achieve when a growing part of territorial emissions is caused by foreign demand. Measuring Thailand's CO_2 emissions on a consumption rather than production basis reduces the growth rate of emissions from 108% to 31% between 1995 and 2005. In Argentina, consumption only caused an increase of 4.3% of CO_2

11 Munksgaard and Pedersen (2001) developed the concept of 'CO_2 trade balances'. The carbon trade balance of a country is the difference between embedded CO_2 emissions from imports and exports. A positive carbon trade balance means that more emissions were imported than exported. In contrast, when the ordinary trade balance is positive, the monetary value of exports exceeds that of imports.

emissions, while overall production emissions (including for exports) increased by more than 50%. The consumption-based emissions of the OPEC countries have grown faster than those from production between 1995 and 2005 (59% vs. 36%). In the G77, China is the largest net exporter of emissions, accounting for the export of almost one quarter of all global emissions embodied in trade.

Table 4 shows the production and consumption-based CO_2 emissions per capita, net imports or exports per capita as well as the share of net trade flows in carbon consumption. The global average per capita CO_2 emissions were 4.3 t in 2005, an increase of 0.5 t from the year 1995. The table again confirms that all OECD countries have higher consumption-based than production based CO_2 emissions, also on a per capita basis. The largest per capita emissions in 2005 were produced by the US (18 t CO_2/person), Australia (18 t CO_2/person), and Canada (15 t CO_2/person). The majority of G77 countries, in contrast, have lower emissions on a consumption basis than on a production basis per person. Between 1995 and 2005, the OECD's net imports of CO_2 per capita increased by 67% (from 1.8 to 3.0 t CO_2/person). On average, the Netherlands import 5.9 t per person of embodied CO_2 emissions, Australia 5.4 t, and France 4.5 t.

Most G77 countries have net exports per capita, but the values vary significantly. For example, China's net exports of embodied CO_2 emissions per capita are eight times higher than those of India (0.8 vs. 0.1 t CO_2/person). Please note, however, that the data uncertainties for the G77 are comparatively high.

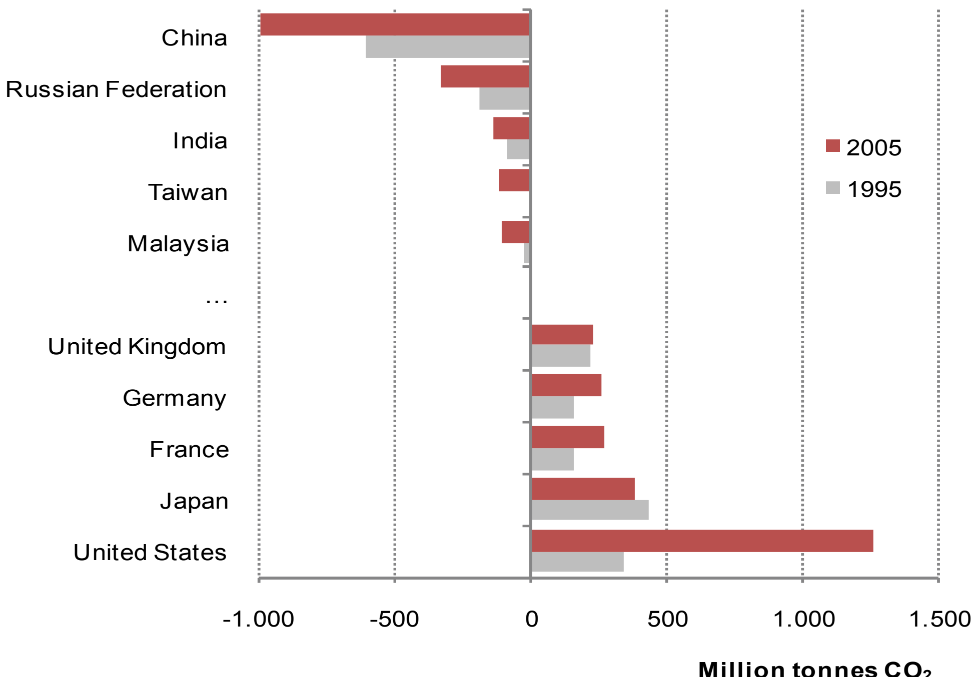
The top five net importers and exporters of embodied CO_2 emissions are shown in Figure 1. Together they accounted for 2,400 Mt of net imported CO_2 in 2005 (up from 1,300 Mt in 1995). The largest net importer, the US, accounted for 1,255 Mt CO_2 (about 30% of global net imports), followed by Japan (380 Mt) and the biggest European economies (France 275 Mt, Germany 257 Mt, and the UK 232 Mt). Most OECD countries increased net-imports from 1995 to 2005, most significantly the US, where the negative carbon trade balance increased by almost a factor of four. This can be explained by the rapidly growing imports of the US, in particular from China. In Japan, on the contrary, net-imports of CO_2 emissions were slightly lower in 2005 compared to 1995 when it was still the largest net importer (431 Mt CO_2).

Net CO_2 exports were shared among a larger number of countries. While the top 5 net importers of CO_2 accounted for 2,400 Mt of net imported CO_2 (8.5% of global CO_2 emissions, or 57% of global net imports), the top five net exporters accounted for 1,670 Mt of net exported CO_2 in 2005 (up from 900 Mt in 1995). These net exports represented 6% of global CO_2 emissions, or 40% of global net exports. The largest net exporters were China with 990 Mt CO_2 (an increase of 63% compared to 1995), the Russian Federation (330 Mt) and India (136 Mt). Thus, net imports of CO_2 emissions are relatively concentrated in a few highly industrialised countries while about half of all net exports are supplied by the large emerging economies of China, the Russian Federation and India, and the other half is supplied by a larger number of countries from the G77.

Table 4: Production- and consumption-based emissions per capita, net-imports/exports per capita and shares of net-trade flows in carbon consumption of selected countries, 1995 and 2005

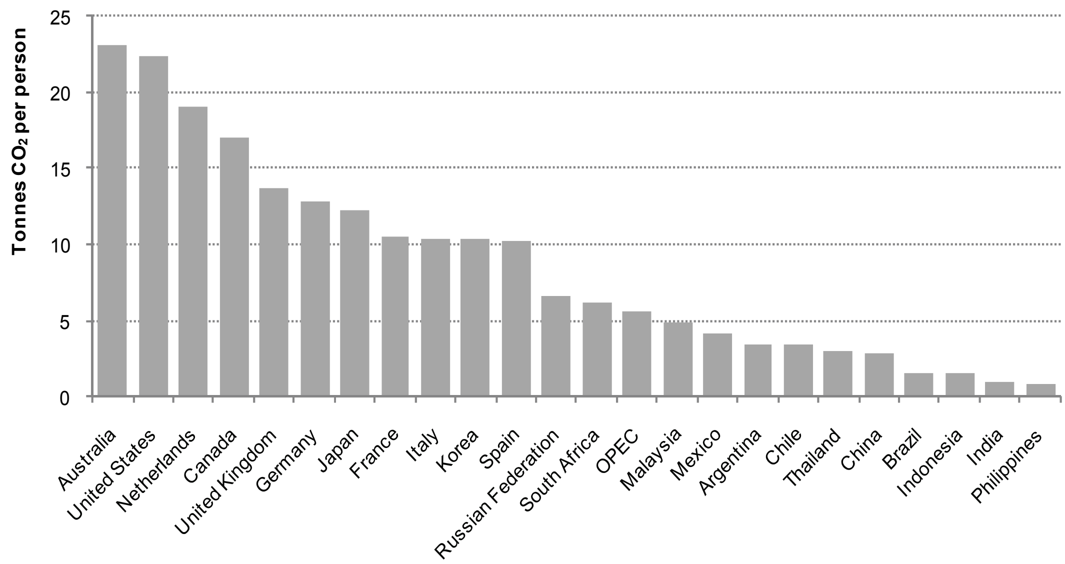
Country	Production-based emissions per capita (t CO_2/person)		Consumption-based emissions per capita (t CO_2/person)		Net-imports/exports per capita (t CO_2/person)		Share of net-trade flows in carbon consumption	
	1995	2005	1995	2005	1995	2005	1995	2005
Australia	14.6	17.7	16.6	23.1	2.0	5.4	11.8%	23.3%
Canada	13.3	15.4	14.2	17.0	0.9	1.5	6.2%	9.1%
Germany	10.5	9.7	12.5	12.8	2.0	3.1	15.9%	24.2%
Spain	5.8	7.5	6.4	10.2	0.6	2.7	9.5%	26.8%
France	5.8	6.0	8.5	10.5	2.7	4.5	31.6%	42.9%
United Kingdom	8.8	9.9	12.7	13.7	3.8	3.8	30.2%	28.0%
Italy	6.6	7.3	9.3	10.4	2.7	3.1	28.7%	29.5%
Japan	8.8	9.3	12.2	12.3	3.4	3.0	28.2%	24.2%
Korea	6.8	9.6	8.0	10.4	1.2	0.7	15.5%	7.2%
Mexico	3.1	3.5	3.1	4.2	-0.1	0.6	-2.0%	15.2%
Netherlands	11.2	13.1	14.0	19.0	2.8	5.9	20.1%	30.9%
United States	17.9	18.2	19.2	22.4	1.3	4.2	6.6%	18.7%
Rest of OECD	6.3	6.4	7.9	8.7	1.7	2.3	21.2%	26.3%
OECD	**10.0**	**10.6**	**11.8**	**13.7**	**1.8**	**3.0**	**15.4%**	**22.2%**
Argentina	3.0	4.1	3.6	3.4	0.6	-0.7	17.8%	-20.3%
Brazil	1.3	1.5	1.6	1.6	0.3	0.1	17.5%	5.0%
Chile	3.1	4.2	2.8	3.4	-0.3	-0.9	-10.3%	-25.2%
China	2.6	3.7	2.1	2.9	-0.5	-0.8	-24.5%	-26.4%
Indonesia	0.9	1.4	1.2	1.5	0.3	0.1	25.2%	9.7%
India	0.8	1.1	0.7	1.0	-0.1	-0.1	-12.5%	-12.1%
Malaysia	5.0	8.8	3.7	4.8	-1.4	-4.0	-37.8%	-82.0%
Philippines	0.8	0.9	0.9	0.8	0.1	-0.1	12.1%	-11.2%
Thailand	2.4	4.5	2.5	3.0	0.2	-1.5	6.6%	-48.8%
South Africa	5.8	6.7	5.1	6.1	-0.6	-0.6	-12.4%	-10.3%
OPEC	3.6	3.9	4.4	5.6	0.9	1.8	19.6%	31.2%
Rest of G77	2.5	2.7	1.4	1.4	-1.0	-1.3	-69.3%	-93.9%
G77	**2.1**	**2.7**	**1.7**	**2.1**	**-0.4**	**-0.6**	**-24.1%**	**-29.6%**
Russian Federation	7.2	8.9	5.9	6.6	-1.2	-2.3	-21.0%	-34.9%
Rest of the world	5.8	8.7	6.2	7.5	0.3	-1.1	5.3%	-15.2%
World Total	**3.8**	**4.3**	**3.8**	**4.3**	**0.0**	**0.0**	**0.0%**	**0.0%**

Figure 1: Ranking of top five net importers and exporters in 1995, 2005



The country rankings of embodied emissions can also be evaluated in per capita figures (Figure 2).

Figure 2: Consumption-based CO_2 emissions per capita, 2005



In terms of consumption-based emissions per capita, Australia leads the ranking (23 t CO_2), followed by the US (22 t CO_2) and the Netherlands (19 t CO_2). Mexico consumed the fewest emissions per capita in the OECD (4.2 t CO_2) in 2005.

With an average of 2.1 tonnes per capita, consumption-based emissions are by a factor of 6 lower in the G77 region than in the OECD countries. With 2.9 tonnes per capita, China is still well below the world average of 4.3 tonnes per capita. India's per capita consumption-based emissions were as low as 1 tonne.

Figure 3 shows the developments of the carbon trade balance of selected countries from 1995 to 2005. This balance is also called 'Balance of Emissions Embodied in Trade' (BEET). Comparing the developments in the industrialised countries it is noticeable that the growth of the carbon trade surplus was lower in the EU-27 than in the non-EU OECD countries between 2000 and 2005. In the EU-27 the carbon trade surplus grew from 903 Mt CO_2 in 1995 to 1,455 Mt in 2005 (61%). In the other OECD countries the surplus grew from 1,071 Mt CO_2 in 1995 to 2,114 Mt in 2005 (97%).

These emissions were largely produced by the G77 whose carbon trade deficit increased accordingly from 1,826 Mt in 1995 to 3,144 Mt CO_2 emissions in 2005 (72%). A small but considerably growing share of embodied emissions in trade came from the rest of the world. Thus, the gap between net importers (EU27 and non-EU OECD) and net exporters (G77 and the Rest of the World) has clearly grown between 1995 and 2005.

Please note that these balances should not be interpreted as a value judgement (e.g. a country should export more emissions than it imports). For the global environment it may be more beneficial to produce goods where it is most resource efficient and where the embedded GHG emissions are lowest (Peters / Hertwich 2008c), and then trade these products internationally as long as efficiency advantages of production are not cancelled out by resource requirements and carbon dioxide emissions of transport. The environmental comparative advantage would then determine which countries have positive or negative carbon trade balances.

Figure 3: Carbon trade balances of selected regions, 1995–2005

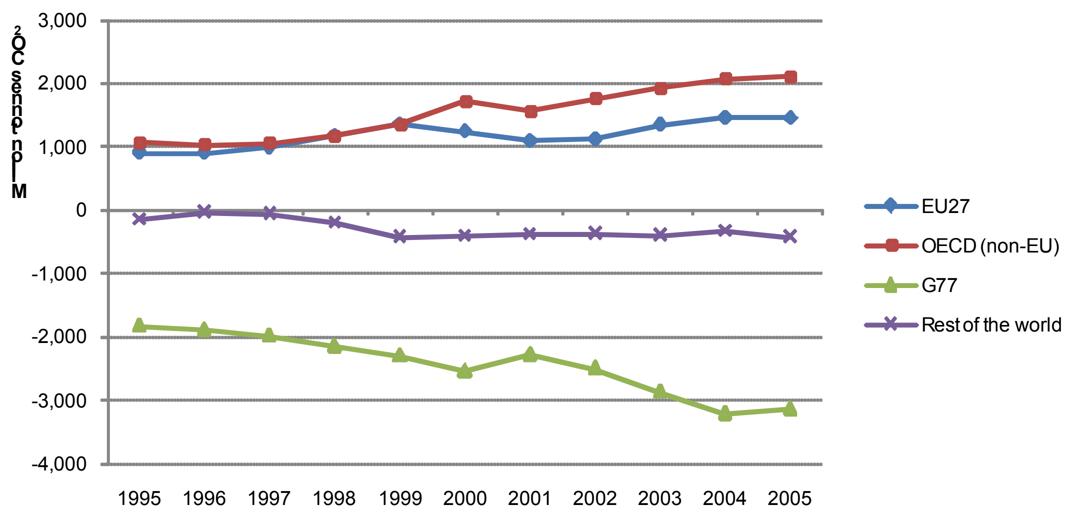


Figure 4 illustrates the shares of net imports or exports in carbon consumption in 1995 and 2005 for the 15 countries or regions with the highest net imports plus China and India in 2005. In France, the country with the highest proportion of carbon imports, 43% of all carbon emissions related to consumption were embodied in imports. France, the OPEC, the Netherlands, Italy, Spain, Germany, Australia, the US and Canada increased their shares of net imports in consumption-based carbon emissions between 1995 and 2005. While Mexico was still a net exporter of consumption-based carbon emissions the country turned into the 11th biggest net importer in 2005. The UK, Japan, Indonesia, Korea and Brazil on the other hand decreased their shares of net imports between 1995 and 2005. Both China and India are clear net exporters of CO_2 emissions. In 2005, India's share of net exports in carbon consumption was -12% (up from -13% in 1995), and China's share was -26% (down from -25% in 1995).

Figure 4: Share of net imports/exports in consumption-based carbon emissions

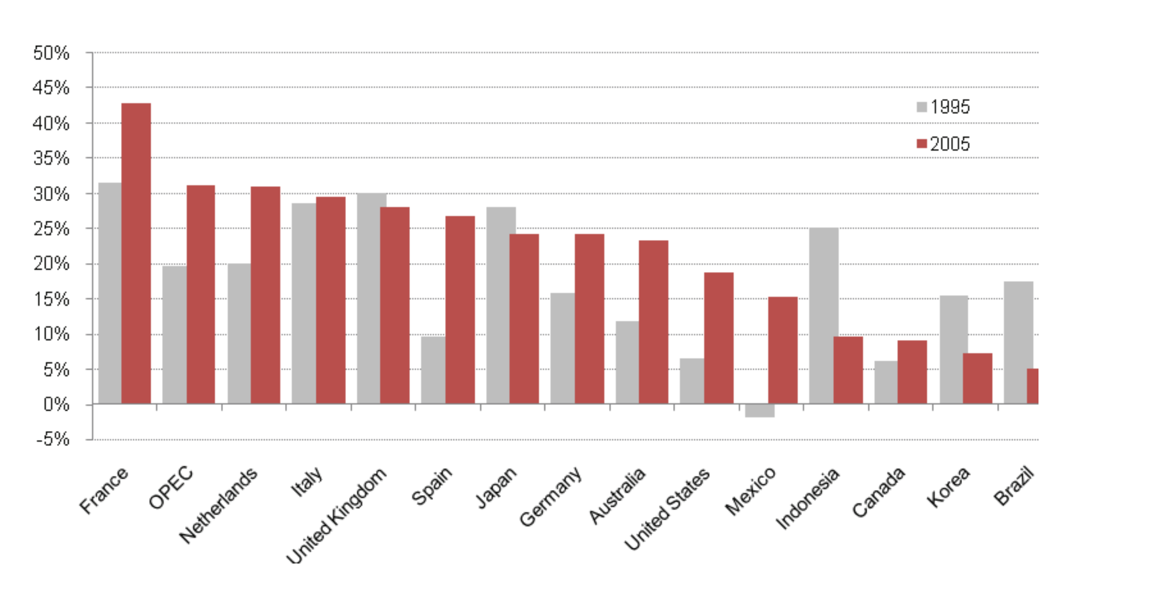
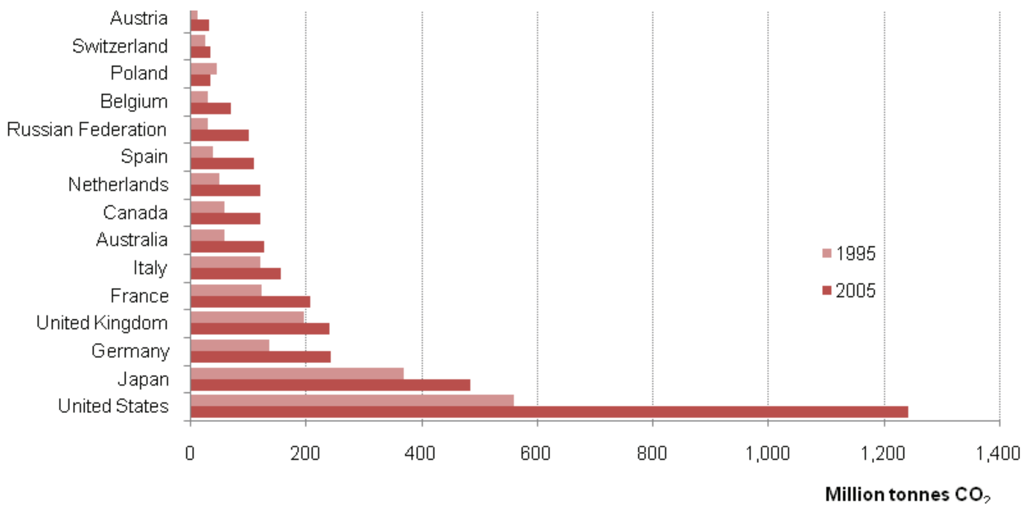


Figure 5 shows the weak carbon leakage from selected Annex I countries in 1995 and 2005, i.e. the imports of embodied CO_2 emissions from non-Annex I to Annex I countries. There are notable differences in the total amounts of carbon leakage, especially among the large countries leading the ranking. The highest carbon leakage occurred in the United States where 1,250 Mt CO_2 (4.1 t CO_2/person) from consumption originated from non-Annex I countries in 2005, an increase of 680 Mt compared to 1995. In Japan, second after the US, 485 Mt CO_2 (3.8 t CO_2/person) from consumption originated from non-Annex I countries in 2005 (an increase of 31% compared to 1995), in Germany carbon leakage amounted to 244 Mt CO_2 (2.9 t CO_2/person) (77% more than in 1995). In total, the European Union imported 1,450 Mt CO_2 (3.0 t CO_2/person) from non-Annex I countries. The growth rates of leakage from 1995 to 2005 also varied considerably between different countries: among the Annex I countries they ranged from -61% in Slovakia to 351% in Greece.

The results also confirm the global shift of CO_2 emissions that is enabled by international trade (see Table 5). In 1995 the imports of embodied CO_2 emissions in Annex I countries was about 2,100 Mt (10% of the global energy related CO_2 emissions). By 2005 these emissions had increased to 3,600 Mt CO_2 (12.8% of all global CO_2 emissions). This means that around a

Figure 5: Weak carbon leakage of selected countries, 1995–2005



quarter of the emissions increase in non-Annex I countries between 1995 and 2005 was caused by the consumption in Annex I countries.

Table 5: Share of weak carbon leakage in production, 1995 and 2005

	1995	2005	Difference
Total weak carbon leakage (in Mt)	2,096	3,603	1,507
Share in CO_2 production	9.6%	12.8%	24.0%

Figure 6 shows the production, consumption, imports and exports of CO_2 in China in 1995 and 2005. All of these emissions have increased during this time. Production-based emissions have risen steeply in China since 2001, not only because of growing exports but also due to higher domestic consumption. Total embodied emissions have constantly been larger in exports than in imports, and the gap between the two has widened. According to the OECD (2009), industry accounted for 65% of China's economic output in 2005. Energy-intensive industries such as steel, cement, and chemicals, provide inputs to China's large export and construction sectors, which are still flourishing.

The increased production in China has also turned the country into a net oil importer. While China was still a net oil exporter during the 1980s, the country became a net oil importer in 1993 and has become increasingly dependent on foreign oil. According to the IEA World Energy Outlook (IEA 2009), China will overtake the US around 2025 to become the world's biggest spender on oil and gas imports.

Figure 6 Production, consumption, imports and exports of CO_2 in China, 1995–2005

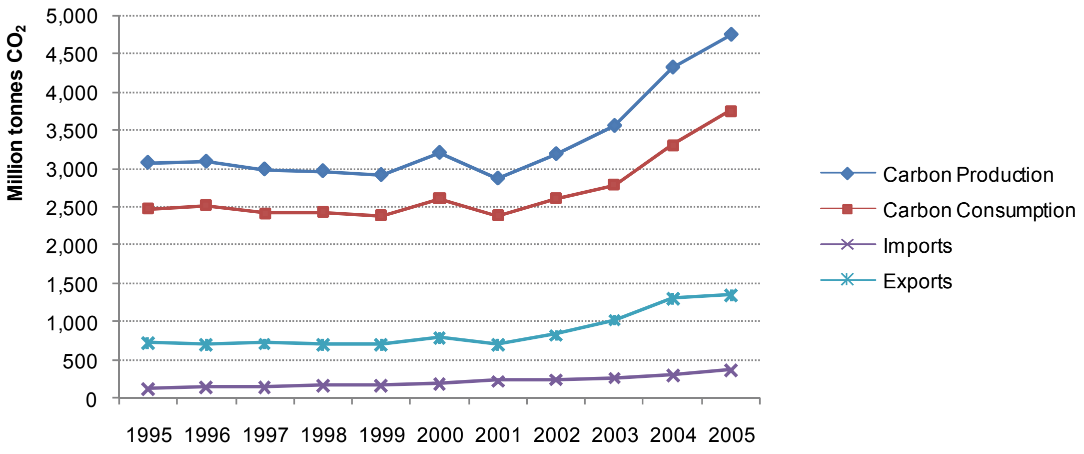
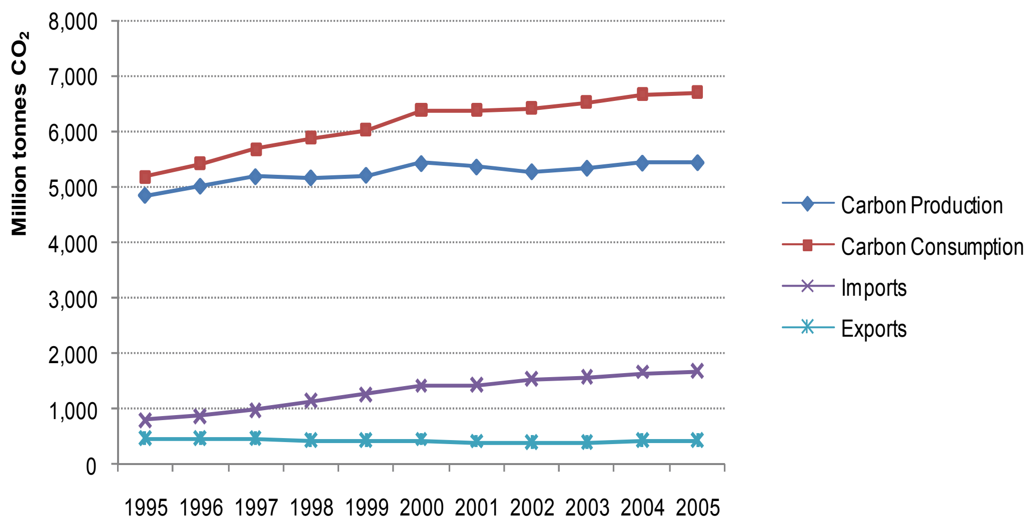


Figure 7 shows that the opposite of China is happening in the US. The differences between carbon production and consumption as well as between imports and exports have grown significantly between 1995 and 2005. In 2005, consumption-based emissions exceeded production-based emissions by 1,250 Mt (net imports).

Shui and Harriss (2006) find that 357 Mt CO_2 were avoided in the US in 2003 by importing Chinese goods. At the same time, China produced 497 Mt CO_2 as a result of the production of goods for export to the US. Carbon leakage as a result of industry relocation to production sites with higher carbon intensities may rapidly cancel out any reductions achieved in developed countries.

Figure 7: Production, consumption, imports and exports of CO_2 in the US, 1995–2005



4 Implications for global climate and trade policies

As the previous analysis has shown, considering a consumption-based approach to carbon accounting in future climate change negotiations may significantly alter the environmental responsibilities of individual countries. What would be the policy implications of changing the current accounting system? Some of the most striking implications for climate change, economic and trade policy negotiations will be discussed in this section.

4.1 Implications of a complete shift from producer to consumer responsibility

Switching completely from production-based to consumption-based carbon accounting would put the credibility of the reduction achievements under Kyoto into a different perspective. As Kyoto only limited the production-based emissions in Annex I countries, it was possible to substitute domestic production for imports from non-Annex I countries and thus improve the national carbon trade balance (carbon leakage). For example, Helm et al. (2007) show that the UK's achievement in meeting its Kyoto targets and sustaining high levels of consumption have been possible due to the relocation of production of pollution-intensive goods to developing countries such as China.

A consumption-based accounting system might be perceived as a fairer system than production-based accounting, especially by net-exporting countries (see for example Kondo / Moriguchi / Shimizu 1998; Ferng 2003). It implies that final users will pay the GHG "bill" (Bastianoni / Pulselli / Tiezzi 2004). For example, as this paper has illustrated, China produces around 30% of its emissions on behalf of consumers in other countries. Therefore, China has repeatedly argued that consumers should pay for the relevant emission reductions (Pan / Phillips / Chen 2008).[12] Moreover, production-based carbon accounting punishes countries with carbon-intensive production bases such as the basic metal industries, which are often located in developing and emerging countries. This may be regarded as problematic, as the costs for the resulting pollution are not internalised. The costs that arise from environmental policy agreements such as the Kyoto protocol have to be borne by those countries where production relocates. If these countries do not have emission reduction targets, no costs arise. This may distort environmental policy and establish the wrong incentives, for example to relocate production.

However, a production-based accounting system also emphasises the responsibilities of producer countries with respect to increasing energy and resource efficiency and the use of low-carbon technologies should not be disregarded. Implementing policies to increase the resource efficiency of industries and reduce their carbon emissions can have mutual benefits and can help reduce global emissions embedded in trade, as producers need fewer resources and consumers can reduce their carbon footprints.

In practice, switching to consumption-based carbon accounting would also have implications for existing climate policy instruments, such as emissions trading schemes. Current emission trading systems based on producer responsibility imply that emission allowances only have to be purchased if the domestic emissions of production exceed the given limit. With a consump-

12 Please note, however, that the share of net exported emissions embodied in trade is only 21%, as China also imports emissions embodied in trade from other countries.

tion-based accounting system, the responsibility for CO_2 emissions would shift from producers to consumers, and the latter would have to bear the costs regardless of where their products are produced. Thus, high-consuming countries would have to pay more in order to account for the emissions that are caused by their consumption abroad, and net CO_2 exporting countries would need fewer allowances. If limited CO_2 budgets were allocated to consumers they would have an incentive to demand low-carbon products.

Such CO_2 budgets can be calculated in different ways. Adopting a consumption-based carbon accounting method would have implications for proposals to establish equal carbon allocations per capita worldwide. In the WBGU budget approach (WBGU 2009), for example, the national emissions budget is the total amount of CO_2 a country is allowed to emit in a specified period of time (territorial accounting). Table 6 provides an example which illustrates the changes to the required emission reductions that would be required if carbon was accounted on a consumption basis. The example assumes that countries A and B have the same population, the same national emissions budget (1,000 Mt CO_2) for a specific period of time, and that country A imports 200 Mt of embedded emissions from country B. Measured on a production basis, country A produces 2,000 Mt in T_1, and B produces 500 Mt. In order to respect their given emission budget of 1000 Mt in T_2 country A would need to reduce its production emissions by 1,000 Mt, while country B may still increase its emission by 500 Mt. Using a consumption-based approach, country A would be responsible for its own carbon production of 2,000 Mt plus 200 Mt of embodied CO_2 emissions in imports from country B (i.e. a total of 2,200 Mt). Country B, by contrast, would only be responsible for the 300 Mt CO_2 it consumes, and not for the ones it produced for its exports. Therefore, to respect their given emission budget of 1,000 Mt in T_2 with a consumption-based approach, country A would need to reduce its production emissions by 1,200 Mt, while country B may still increase its emissions by 700 Mt. Thus, calculating the emissions on a consumption basis would increase the per capita reduction requirements of the net carbon importing countries (mainly Annex I countries) and decrease those of the net exporting countries (mostly non-Annex I countries).

Table 6: Example of emission reduction requirements in a budget approach (in Mt CO_2)

		Country A	Country B
	National emission budget in T_2	1000	1000
Production-based carbon accounting	Emissions in T_1	2000	500
	Required emission reduction / allowance to increase until T_2	-1000	+500
Consumption-based carbon accounting	Emissions in T_1	2200	300
	Required emission reduction / allowance to increase until T_2	-1200	+ 700

Consumption-based accounting may encourage technology transfers from Annex I to non-Annex I countries. As many of the environmental impacts caused by the consumption in Annex I countries occur in regions with lower abatement costs, it may encourage industry and policy actors to achieve emission reductions abroad. Quantifying the amount of carbon emissions and other environmental aspects linked to world trade may reveal opportunities and priorities for setting emission targets and implementing mitigation activities such as Clean Development Mechanism (CDM) projects. Moreover, the export of clean technologies for industrial production, from the US to China, for example, would decrease the current trade imbalance, reduce overall pollution and related negative environmental impacts in China, provide pollution 'credits' to the US, and reduce net global emissions (Shui / Harriss 2006). Consumption-based CO_2 inventories thus *"explicitly encourage emission abatement in foreign regions due to the reallocation of imports"* (Peters / Hertwich 2008c, 59).

Even without emission targets for developing countries, consumption-based carbon accounting has the advantage of providing incentives for them to produce low carbon products for exports to Annex I countries. This may be achieved through clean and energy efficient production processes. Carbon competitive goods would have an advantage because Annex I countries with carbon restrictions will demand low carbon imports. Such a shift towards a consumption-based would have implications for emissions trading schemes. The responsibility would shift from producers to consumers at the national level. Consumers would demand low-carbon products if they had individual CO_2 budgets.

A consumption-based approach to carbon accounting combined with appropriate policy instruments such as quotas or taxes may help shift comparative advantage away from pure economic measures to a logic that also takes environmental aspects into consideration. Such a shift towards *"environmental comparative advantage"* (Peters / Hertwich 2006) may reduce competition on labour and capital costs. Depending on the relative price of carbon (e.g. based on emission commitments or carbon taxes), consumption-based inventories can thus "protect clean domestic industries and encourage environmental performance" (Peters / Hertwich 2008c, 59). Consumption-based accounting may also allay the concern of carbon leakage because any participant country would also be responsible for the emissions produced in countries from which it imports.

Consumption-based carbon accounting would provide support for complementary policies which strengthen individual consumer responsibility. Product labelling, for example, can show consumers the carbon content of a product, encouraging them to select low carbon products and induce suppliers to opt for energy efficient clean technologies.

4.2 Options for sharing responsibilities between producers and consumers

However, there are also doubts as to the usefulness of allocating responsibility purely on the basis of consumption-based accounting. From an economic point of view it may be argued that the responsibility for embedded emissions in trade should be shared between producers and consumers. Ekins (2009) questions whether a consumption-based approach to carbon accounting is actually more valid than the territorial approach. The relocation of production processes, for example, brings economic benefits for the recipient countries in terms of export revenues, employment and faster economic growth. China's rapid growth rates, for example, could not have been sustained on such a high level if the economy solely depended on domestic demand. As Pan / Phillips / Chen (2008) point out, the relocation of US production to China may have improved the efficiency and reduced the emissions intensity of the Chinese industry with potential spillovers to other sectors. Consumption-based accounting should not provide producers with an excuse for increasing emissions and not investing in clean production technologies. Moreover, from a methodological perspective, allocating emissions on a territorial basis is still simpler than on a consumption basis. However, Peters and Hertwich (2008c) are optimistic that *"many of the data issues [involved in MRIO models] will be resolved in the coming years"* (Peters / Hertwich 2008c, 60).

As both production (and net exports) and consumption bring economic benefits, importing and exporting countries could share the allocations of emissions from trade. Yet, *"it is not at all obvious what the share of the allocations should be"* (Ekins 2009, 314). Some propose indicators of environmental responsibility as the average of consumer and producer responsibility (Rodrigues / Domingos / Marques 2010; Kondo / Moriguchi / Shimizu 1998). Ferng (2003, 124) suggests that shares of the responsibility for CO_2 emissions should be decided through international negotiations taking into account that participant countries have different economic structures, consumption patterns and levels and that they have the same basic needs per capita. Others suggested that the responsibility should be shared in proportion to the value added along international production chains (Lenzen et al. 2007).

Moreover, as the Copenhagen Climate conference (COP-15) has shown, there is also reluctance from some developing countries to accept binding reduction targets for their own economies in the future. Pan / Phillips / Chen (2008, 370) argue that developing countries may be unable to follow the same strategy of outsourcing emissions when binding targets are required: *"locked into their emissions-intensive comparative advantage, abatement may be disproportionately costly."* The current system has created an advantage for industrialised countries that have largely outsourced their emission-intensive industries to developing countries. The necessary abatement investments into dirty industries will place a much larger burden on the economies of developing countries.

4.3 Implications for international trade policy

The results have clear implications for trade policy. World trade has largely been assessed in terms of its economic and social aspects. As CO_2 emissions are a major driver of climate change it is important to illustrate their importance in international trade. Multi-regional input-output analyses are an important instrument to take environmental aspects into account in comprehensive and sustainability-oriented policy assessments of trade.

Measuring the environmental dimensions of trade can help to reshape the global trading system in a way that minimises environmental implications. This should be done in accordance with a few key principles (see Dittrich 2007). First, trade should contribute to the minimisation of global resource use through exploiting transport and physical or geological potential in a way that minimises negative environmental impacts. For example, agricultural, forestry or fishery products should be produced in countries with the most favourable climate and geographic conditions and not in countries where production is most heavily subsidised. Second, trade should be organised in a way that reduces current inequalities in per capita resource use and CO_2 emissions rather than reinforcing inequalities. As the results in this paper have illustrated, the current international trade system generally re-allocates products and related CO_2 emissions from countries with low per capita income and low emissions to countries with high per capita income and emissions. Finally, as environmental impacts such as embodied carbon emissions are hidden in production-based carbon accounting, their costs (or sometimes benefits) to the environment should be accounted for. Shifts of environmental burdens and related environmental and social costs through international trade must be compensated through appropriate product prices or other price instruments.

4.4 Broadening the scope to other environmental issues

In order to address the responsibility of consumption in a more comprehensive way, it would be necessary to look beyond this paper's focus on energy-related CO_2 emissions. An extension of this approach may be done in three steps. First, analysing non-energy-related CO_2 emissions, such as those from land use, land use change and forestry (LULUCF), into carbon accounting would be a useful supplement to the present analysis as it would among other things allow for conclusions on the roles of agriculture and deforestation. Including such emissions into carbon accounting is currently being discussed at international negotiations and at the UNFCCC.

Second, future research on global environmental problems and responsibilities should not focus exclusively on CO_2 emissions. The focus on CO_2 reductions in most international climate policy negotiations, including the Copenhagen Climate Conference, is too narrow. As the case of biofuels has shown, it is also important to consider other greenhouse gases, such as nitrous oxide emissions that accompany increases in fertiliser use (Howarth / Bringezu 2009; Melillo et al. 2009), and land use changes from growing crops for biofuels. Otherwise, expensive policy instruments aimed at climate change mitigation by cutting CO_2 emissions, such as biofuel targets, Carbon Capture and Storage (CSS) and nuclear energy, may in fact increase overall levels of resource use and indirectly aggravate climate change.

Third, as most emissions of greenhouse gases are directly linked to extraction, processing and use of natural resources, such as raw materials (including for example metals and fossil fuels), land and water, it is crucial to address one of the most important contributors to climate change – the unsustainable use of resources (SERI / GLOBAL 2000 / Friends of the Earth Europe 2009). This is not only a root cause of climate change but also a serious environmental threat in a finite world and one which ultimately impacts people's livelihoods.

5 Conclusions

Climate change policies to reduce greenhouse gas emissions have so far focused on the reduction of direct emissions from national production. Existing climate agreements, such as the Kyoto Protocol, have not adequately acknowledged the economic interdependence among states, which is most visible in the globalisation of production processes and in the rapid expansion of international trade. As international trade reduces the informative value of national emission inventories, an alternative but currently less debated approach is the reduction of consumption-based emissions which includes emissions embodied in imports.

Both production and consumption-based emissions data is needed in order to discuss questions on global distribution and justice. Monitoring the reduction in consumption-related emissions requires a carbon accounting principle that is based on consumption instead of production. The choice of accounting principle to estimate the amount of CO_2 emissions that individual countries are responsible for influences the fairness of how the burden in the fight against climate change is distributed globally. Under the Kyoto Protocol countries with net exports of CO_2 emissions are disadvantaged while net importers face reduction targets that encourage carbon leakage.

This paper has shown that the biggest net exports of CO_2 emissions originate from the Group of 77 (most importantly China and India) and the Russian Federation, while the largest CO_2 importers are located in the OECD (led by the US, Japan and France). Carbon emissions embodied in trade have increased significantly between 1995 and 2005 and may be expected to increase further as the volume of traded goods will expand in the future, unless there are significant improvements in energy efficiency.

If future policies for carbon reductions adopted a consumption-based approach to carbon accounting, the environmental responsibilities of industrialised countries would increase while developing countries would be given larger allowances for emissions increases. For example, implementing a budget approach in this way would help ensure that goods are produced in countries with the highest carbon efficiency.

An agreement on the distribution of costs to reduce GHG emissions between the producers and consumers of products in the world economy is a possible step towards the realisation of an effective post-Kyoto regime. Alternatively, a global carbon tax could be a solution in sharing the common responsibility of all countries. A carbon tax in China, for example, would decrease their embodied emissions and, by raising their prices to consuming countries, reduce exports.

Even if not directly used as a basis for emissions reduction commitments, calculating CO_2 emissions embodied in global trade is useful in revealing the complex picture of globalisation and offers strong arguments for developing countries with regard to their historic and future responsibilities for carbon dioxide emissions.

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