Embodied emissions and the carbon trade balance between world regions

Alexandra Marques*, João Rodrigues, Tiago Domingos

IN+, Center for Innovation, Technology and Policy Research
Energy and Environment Scientific Area, Mechanical Engineering Department , Instituto Superior Técnico
Technical University of Lisbon
Av. Rovisco Pais nº1, 1049-001 Lisbon, Portugal

Abstract

Upstream embodied carbon emissions are the greenhouse gas (GHG) emissions required to generate a physical good or service and downstream embodied emissions are the GHG emissions required to generate the monetary payment for that good or service. The upstream emissions embodied in international trade have been extensively reported. In this paper we report the downstream emissions embodied in the international trade, for a set of aggregated world regions. We find that Developed Economies and Fossil Fuel Exporters are the regions whose payments to primary factors of production are most dependent on emissions generated elsewhere. Developed Economies receive downstream embodied emissions mainly via the payments for manufactured products and Fossil Fuel Exporters through the payments received for fossil fuels. Accounting for downstream emissions allows the determination of the extent to which an agent's wealth benefits from emissions generated elsewhere. The use of upstream and downstream emissions allows a fairer sharing of responsibility between consumers and producers that could solve the issue of 'common but differentiated responsibilities' in the context of climate change policy.

Keywords: international trade, greenhouse gas emissions, embodied emissions, upstream and downstream, carbon responsibility, multi-regional input-output model

1. Introduction

According to current global climate policy a country is responsible for the emissions that are generated within its geographical border (IPCC, 1997). In a globalized world where economic growth and international trade are strongly interrelated (Tamiotti et al., 2009) the adequacy of such a measure is questionable. For example, a country whose economy is mainly supported by exports will have, for a given amount of final consumption, more direct emissions than a non-exporting country.

As seen in 15th United Nations Climate Change Conference, held in Copenhagen in December 2009, this framework is unlikely to be accepted by rapidly developing countries, like

*To whom correspondence should be addressed.
Email address: alexandra.marques@ist.utl.pt (Alexandra Marques)

China or India, whose economies are highly dependent on exports and have the highest current CO_2 emissions growth rates (Raupach et al., 2007). In fact, this is one of the main sensitive aspects of climate policy, since it raises issues of competitiveness and fairness between countries (Peters and Hertwich, 2008b; Whalley and Walsh, 2009). Recognizing that the contribution of developed and developing nations to climate change are different, the Kyoto Protocol highlighted the importance of 'common but differentiated responsibilities', but it did not specify how these responsibilities should be shared.

Consumer responsibility, the upstream emissions embodied in a country's final consumption, is a measure that takes into account the implications of international trade, and it has been proposed as a better and fairer measure of a country's responsibility for climate change (Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008b; Davis and Caldeira, 2010). The idea behind consumer responsibility is that carbon emissions are generated to ultimately produce goods and services to satisfy final consumption. Consumption based GHG inventories are calculated by summing upstream embodied emissions, that is, by assigning to an agent the emissions associated with the production chains leading to the transactions in which he/she benefited as a final consumer.

However, the economic process does not occur only to satisfy consumers. In most transactions, consumers and producers embark on a voluntary exchange that makes them better off. At the aggregate level intermediate transactions cancel off and only two types of transaction remain: final consumption and primary inputs. At one end of every economic chain is the final consumer, who receives the good or service. At the other end is the primary producer, who receives wages, rents, interest and other factor payments.

In the context of climate policy, it is intuitive that if an agent benefits from an economic transaction, then it should be responsible for some of the emissions generated by that transaction (Caney, 2009). It is possible to define producer responsibility as the downstream emissions embodied in the payments for primary factors of production (or value added) (Rodrigues et al., 2006; Lenzen et al., 2007; Rodrigues and Domingos, 2008; Rodrigues et al., 2010; Lenzen and Murray, 2010). Whereas upstream emissions reflect the total (direct and indirect) emissions that an economic agent requires to fulfill its consumption patterns, downstream emissions reflect the total emissions that an economic agent requires to generate its income. A recent work by Lenzen and Murray (2010) presents a clarifying parallel between the terminology of upstream and downstream emissions.

In climate policy, the use of consumer or producer responsibility instead of direct emissions would alter the perception of a region's contribution to total emissions, especially for economies heavily dependent on international trade. The difference between a region's direct emissions and its consumer or producer responsibility are, respectively, that region's upstream or downstream carbon trade balance (CTB), the net difference between the embodied carbon it gains and it loses through its imports and exports (Rodrigues et al., 2010).

Several authors, for example, Peters and Hertwich (2008a, 2009); Davis and Caldeira (2010); Rodrigues et al. (2010); Serrano and Dietzenbacher (2010); Muñoz and Steininger (2010) have computed upstream CTBs and consumer responsibilities using multi-regional input-output models. Among other results, these studies found that the consumer responsibility of Developed Economies is higher than their direct emissions, and that this imbalance is a result of imports from Asia and Fossil Fuel Exporters.

Until this date to our knowledge only two studies have quantified downstream embodied emissions (Rodrigues et al., 2010; Lenzen and Murray, 2010). Rodrigues et al. (2010) have showed the downstream CTB for six world regions; Developed Economies and Fossil Fuel Ex-

porters have positive downstream CTBs, Asia and Eastern Europe have negative downstream CTBs and Latin America exhibits balances close to zero. Lenzen and Murray (2010) used structural path analysis to analyze the producer responsibility associated with the provision of primary inputs to a number of Australian industries.

In this paper we contribute to this literature by reporting the contribution of different economic sectors to the carbon trade balance of aggregate world regions. Since more attention has been devoted to upstream emissions, we focus our attention on the downstream carbon trade balance. We discuss our results in the context of producer responsibility and its implications for climate change policy.

The remainder of the paper is organized as follows: in Section 2 methods and data sources are described, Section 3 presents and discusses the results obtained and Section 4 provides some conclusions.

2. Methodology

Let us consider that the world is divided into R regions, and each region into S internal and one external sector. Let indices a, b denote regions, indices i, j denote internal sector and 0 denote the external sector. Let t_{ij}^{ab} be an *economic transaction* from sector i in region a to sector j in region b, and for simplicity, let there be only domestic transactions with the external sector. t_{i0}^{aa} and t_{0i}^{aa} are, respectively, the final consumption and added value of sector i of region a. Let index $*$ denote sum over all regions or *internal* sectors and let l_i^a be the *direct* (or local or territorial) *carbon emissions* of sector i of region a. Using this notation, the *direct carbon responsibility* of region a is $L_a = l_*^a$, the sum of the direct emissions over all sectors, and L_* is the carbon responsibility of the world.

Following the approach of Rodrigues et al. (2006, 2010), carbon *embodied emissions* are quantities associated with economic flows that follow a conservation law at the sector level. The *upstream* embodied emissions, u_{ij}^{ab}, are direct emissions plus the emissions embodied in economic inputs, while *downstream* emissions, d_{ij}^{ab}, are direct emissions plus the emissions embodied in economic outputs:

$$\begin{aligned} u_{i0}^{aa} + u_{i*}^{a*} &= l_i^a + u_{*i}^{*a}; \\ d_{0i}^{aa} + d_{*i}^{*a} &= l_i^a + u_{i*}^{a*}. \end{aligned} \tag{1}$$

The fraction of upstream emissions distributed among different outputs (and downstream among inputs) is determined because the upstream and downstream carbon *intensities* of a sector are constant, u_i^a and d_i^a, such that $u_{ij}^{ab} = u_i^a t_{ij}^{ab}$ and $d_{ji}^{ba} = d_i^a t_{ji}^{ba}$. Upstream carbon intensity is determined using the Leontief price model and downstream carbon intensity using the Ghosh price model (Oosterhaven, 1996, 2006).

It is conventional to talk about *consumer* responsibility as the upstream embodied emissions in the final consumption of a region, $U_a = u_{*0}^{aa}$ (Munksgaard and Pedersen, 2001; Rodrigues et al., 2006; Lenzen et al., 2007), and it is less common but equally logical to talk about *producer* responsibility as the downstream emissions embodied in the added value of a region, $D_a = d_{0*}^{aa}$ (Rodrigues et al., 2006; Lenzen et al., 2007) Note that since embodied emissions are conserved the three types of responsibility add up to the total emissions of the world, $L_* = U_* = D_*$.

It is easy to see that the difference between the direct responsibility of a region and either its consumer or producer responsibility lies in the amount of embodied emissions carried in its international trade. Introducing the definitions of responsibility in Eq. 1 leads to:

$$U_a - L_a = u_{**}^{*a} - u_{**}^{a*};$$
$$D_a - L_a = d_{**}^{a*} - d_{**}^{*a};$$

Note that $u_{**}^{aa} = \sum_i \sum_j u_{ji}^{aa} = \sum_i \sum_j u_{ji}^{aa}$ and $d_{**}^{aa} = \sum_i \sum_j d_{ji}^{aa} = \sum_i \sum_j d_{ji}^{aa}$. The previous expression can be simplified to:

$$U_a - L_a = \sum_{b \neq a} u_{**}^{ba} - \sum_{b \neq a} u_{**}^{ab}; \tag{2}$$
$$D_a - L_a = \sum_{b \neq a} d_{**}^{ab} - \sum_{b \neq a} d_{**}^{ba}.$$

Note that in Eqs. 2 the difference between upstream/downstream embodied emissions of region (U_a and D_a) and its direct emissions (L_a) is respectively, the *upstream* and *downstream carbon trade balance* (UCTB and DCTB); or in other words, the sum of all emissions received minus the sum of all emissions sent by a region, embodied in that regions' international trade. If there is a carbon trade surplus, the CTB is positive. In UCTB, embodied carbon is gained through economic imports and lost through economic exports. In DCTB the situation is reversed, embodied carbon is gained through the monetary payment for economic exports and lost through the monetary payment for economic imports.

In this paper we report carbon trade balances, and discuss their implication for carbon responsibilities. Since a large literature on upstream emissions and consumer responsibility is already available, our focus is on downstream emissions and producer responsibility. To perform the calculations, we developed an environmental multi-regional input-output (MRIO) model based on the version 6 of the Global Trade Analysis Project (GTAP) database, with 87 regions and 57 sectors covering the whole world (Dimaranan, 2006). We used the emissions data reported in Peters and Hertwich (2008b). For the purpose of presentation, the results were aggregated into 6 world regions and 11 sectors, whose aggregation is reported in the Appendix A. Further details on the calculations can be found in Rodrigues et al. (2010) or by contacting the authors.

In what follows, it is important to bear in mind that downstream emissions refer to the direct and indirect emissions generated in the payments of goods and services internationally traded. To avoid ambiguities, we use the terms *exporter* and *importer* as the source and destination of an economic transaction, and the terms *sender* and *receiver* as the source and destination of a transfer of embodied emissions. In the case of upstream emissions, sender = exporter and receiver = importer, but in the case of downstream emissions those roles are reversed: receiver = exporter and sender = importer.

3. Results and discussion

3.1. Downstream carbon trade balance

In 2001, the amount of downstream emissions embodied in international trade was 18% (4360 Mt CO_2) of total world emissions (24750 Mt CO_2). This value is slightly smaller than the

upstream emissions embodied in international trade (5054 Mt CO_2) (the total of downstream and upstream emissions embodied in each region's imports and exports is presented in Table B.3).

Manufactured products is the sector with the largest contribution to internationally traded carbon emissions (Fig.1). In Fig.2 we can see that there are two groups of sectors: those that have high direct carbon intensity (i.e., which use a lot of fossil fuels as an economic input), and those that have low direct carbon intensity. The first group contains the transport, minerals and metals, electricity and fossil fuels sectors. The second group contains all other sectors. Embodied emissions spill over from the carbon intensive sectors to the others. That is, the exports of carbon intensive sectors have a higher upstream intensity than their imports, which consist of a mix of exports from either high or low intensity sectors. The reverse is true for the other sectors (exports have lower upstream intensity than imports), due to the same averaging out of imports. If we look at the emissions embodied in the payments for exports we observe the same phenomenon (Fig.2). The payments for imports of carbon intensive sectors have higher downstream emissions than their exports and for the other sectors the reverse is true. The contrast between the carbon intensity of imports and exports (or payments thereof) of a sector is particularly strong in the electricity sector. This occurs because according to the GTAP 6 database this sector accounts for approximately half of the world total direct carbon emissions.

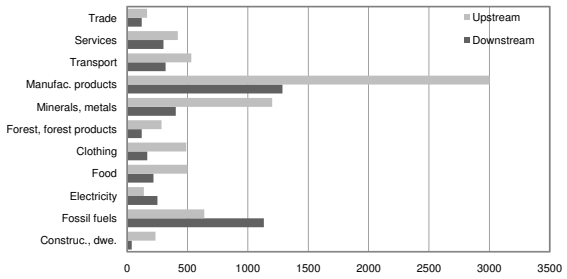

Figure 1: Average emissions embodied in international trade (in Mt CO_2) by sector.

In Fig.3 we see the DCTB for the six world regions, with sector discrimination. The transfer of downstream emissions through international trade occurs essentially (80%) between three world regions: Developed Economies, Fossil Fuel Exporters and Asia. Asia and Fossil Fuel Exporters have clear patterns regarding downstream emissions, the first is a net sender and the second a net receiver. For Asia this negative imbalance is a result of the outflow of downstream emissions mainly through payments for imported fossil fuels (209 Mt), electricity (139 Mt), minerals and metals (114 Mt), transport (70 Mt), manufactured products (60 Mt) and trade (42 Mt). For Fossil Fuel Exporters the positive imbalance is a result of the inflow of downstream emissions mainly through the payments for exported fossil fuels (684 Mt). Although it is clear that Developed Economies are net receivers of downstream emissions the pattern is not so clear since they are also the world's second largest senders. This region sends this type of emissions

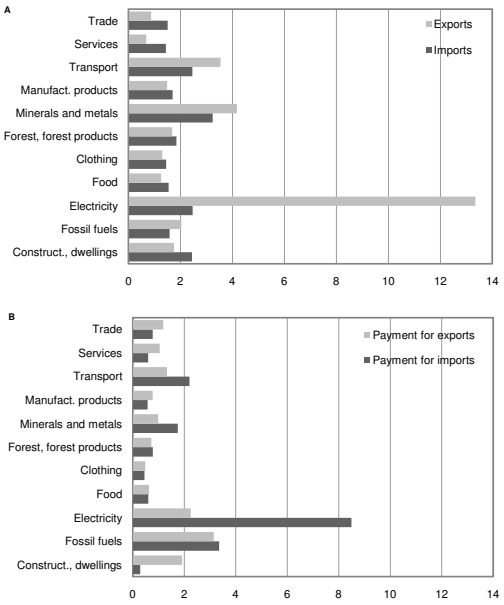

Figure 2: Upstream (A) and downstream (B) carbon intensity (in kg CO_2/USD 2001) of sectors.

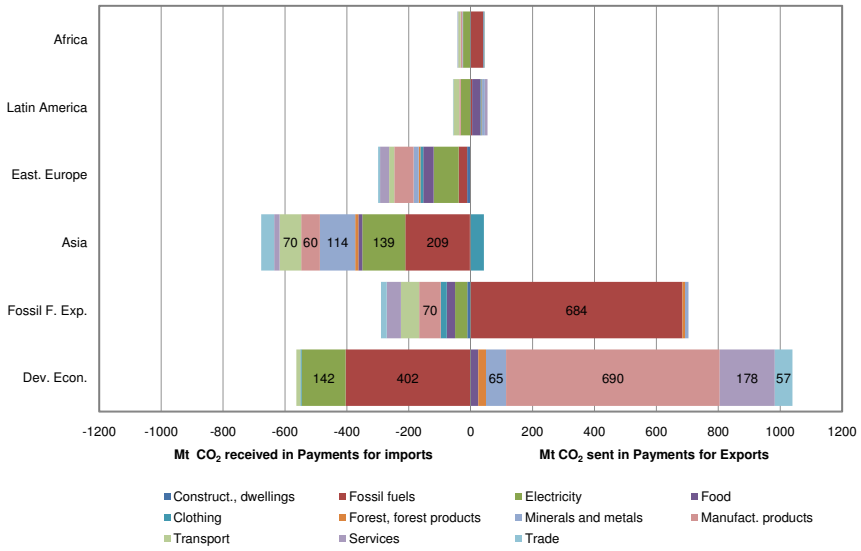

Figure 3: Balance of downstream emissions embodied in the payment for exports (negative number) and in the payment for imports (positive numbers) for six world regions (in Mt CO_2).

mainly through the payment for imported fossil fuels (402 Mt) and electricity (142 Mt) and receives mainly through the payment for exported manufactured products (690 Mt) and services (177 Mt).

The differences standing out between these results and the results obtained with upstream emissions (Peters and Hertwich, 2008a; Rodrigues et al., 2010; Davis and Caldeira, 2010)(Fig. B.6) are: the shift on Fossil fuels CTB (they hold a positive DCTB and a negative UCTB) and the predominance of the fossil fuel and manufactured products sectors in the DCTB's of Developed Economies and Fossil Fuel Exporters. Although these sectors are also important in their UCTB this is more heterogenous than the DCTB.

3.2. Downstream carbon intensity of trade

The downstream carbon intensity (in kg CO_2/USD 2001) of international trade (Fig. 4) shows that for Developed Economies, Fossil Fuel Exporters and Africa the intensity of the payments received for exports is higher than the intensity of the payments sent for imports. This difference indicates that these economies' production chains are less carbon intensive than their trading partners'.

This can occur either because production processes are more efficient or because their economies rely on less carbon intensive fuels. On the other hand the higher carbon intensity of the payment received for exports indicates that these economies' primary factors of production, or value

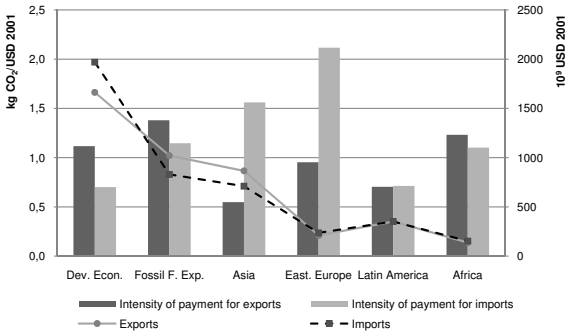

Figure 4: World regions' downstream carbon intensity (in kg CO_2/ USD 2001) of the payments for imports and payments for exports, and monetary value of exports and imports (in 10^9 USD 2001).

added, benefit from emissions occurred in other regions. In Asia, Eastern Europe and Central and Latin America the intensity of the payments for imports is higher than the intensity of the payments for exports. The higher upstream carbon intensity of exports (Rodrigues et al., 2010) indicates that these economies have less efficient production chains or use more carbon intensive fuels (for example, the importance of coal in Asia and Eastern Europe is well known). Under this rationale, the value added of these economies is *cleaner* than the value added of the other regions.

3.3. Transfer of downstream emissions between world regions

Fig. 5 presents main transfers of downstream emissions.

The most significant fluxes occur from Asia and Fossil Fuel Exporters to Developed Economies, with the transfer of 642 and 681 Mt CO_2, respectively, and from Developed Economies to Fossil Fuel Exporters, with a transfer of 747 Mt CO_2. Developed Economies and Fossil Fuel Exporters receive downstream CO_2 embodied emissions associated with the payment for their exports. The high inflow of downstream emissions to Developed Economies from Fossil Fuel Exporters and Asia is mainly a result of this region's export of manufactured products (55%) and to a lesser extent services (13%) (Table 1). The explanation for this lies in the high value of these exports and in the high intensity of the payments from Fossil Fuel Exporters (1.09) and Asia (1.29) (e.g., when compared to the less valuable imports and smaller intensity of Developed Economies' payments for imports; Table 2). Fossil Fuel Exporters inflow of downstream emissions from Developed Economies is mainly a result of this region's exports of fossil fuels (65.7%) (Table 1). Developed Economies' payments are the least carbon intensive (Table 2), however the amount imported from this region is very high.

3.4. Comparison with upstream emissions

We also calculated upstream embodied emissions and found that our results are broadly consistent with previous studies (Peters and Hertwich, 2008a; Rodrigues et al., 2010; Davis and

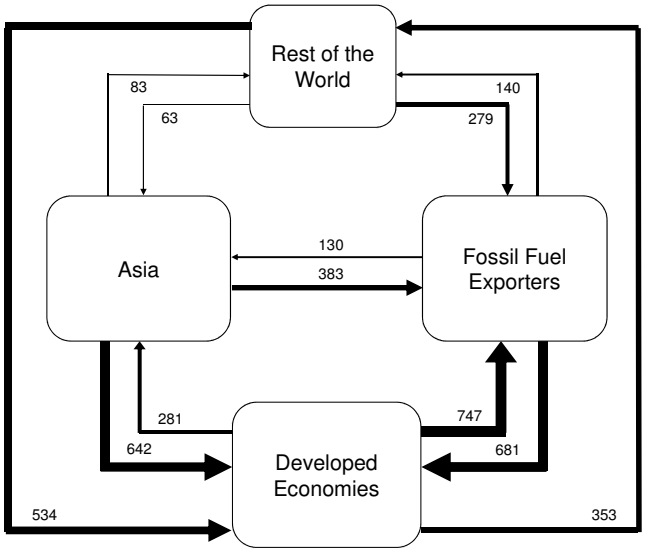

Figure 5: Downstream emissions embodied in trade between Developed Economies, Fossil Fuel Exporters, Asia and the Rest of the world (in Mt CO_2).

Caldeira, 2010). The comparison between results obtained for upstream and downstream emissions enables to see if a region is more dependent on emissions to fulfil its consumption or to generate its value added (Table B.3). The region with the largest discrepancy between the carbon embodied in final demand and in primary inputs is Fossil Fuel Exporters (Fig. B.6). The consumption of this region needs fewer emissions than the ones they generate or, in other words, they are net senders of upstream emissions. For downstream emissions the opposite is true, which means that the payments made to this region's primary factors of production need more emissions than the ones they generate or, in other words, they are net receivers of downstream emissions. The main contribution to the added value of this region is the sector of fossil fuels, which has a high downstream intensity, and therefore results in a large inflow of downstream emissions.

4. Conclusions

In this paper we have calculated the carbon emissions embodied in international trade and the carbon trade balance between world regions. We have found that the downstream emissions embodied in international trade represent 18% of world total emissions. Although this is a considerable amount, the number is higher if individual countries are considered, since in this work intra-regional trade (the trade between countries belonging to the same region) was not considered. Developed Economies, Asia and Fossil Fuel Exporters contribute to 80% of the downstream emissions embodied in international trade. In a previous work (Rodrigues et al., 2010) we determined that both Developed Economies and Fossil Fuel Exporters were net receivers of downstream emissions, whereas Asia was a net sender of downstream emissions. This means that the first two regions, in order to pay their primary factors of production needed more emissions than their direct emissions, whereas for the latter the opposite was true.

We have shown how these emissions are transferred. Developed Economies is the region that is most dependent on outside emissions to generate its payments for primary factors of production. The highest inputs of downstream emissions to this region are from Asia and Fossil Fuels Exporters, and result from payments to the sector of manufactured products. The next largest receiver of downstream emissions is the region of Fossil Fuel Exporters, whose inputs are mainly from Developed Economies, and (not surprisingly) result from payments to the sector of fossil fuels. This region exhibits a positive downstream carbon trade balance and a negative upstream carbon trade balance. Asia's payments for primary factors of productions requires less downstream emissions than its direct emissions. This means that the emissions occurring in this region originate the accumulation of wealth in other parts of the world, namely Developed Economies and Fossil Fuel Exporters.

Our results provide information about the producer responsibility of each region, the embodied emissions required to generate its added value or income. The use of this indicator in climate change policy is potentially useful since it shows how a region benefits from carbon emissions in terms of generating income. If consumer and producer responsibility are combined, a fairer indicator of carbon responsibility is obtained (Rodrigues et al., 2006, 2010). Such indicator, by considering the benefit taken by an agent both as a producer and a consumer could solve the issue of 'common but differentiated responsibilities', potentiating the adoption of a globally accepted climate policy. Moreover we believe that this indicator would trigger carbon efficiency measures at all levels since, in order to reduce its carbon responsibility, an environmentally minded agent could not only to reduce the carbon intensity of its production chains but could also to choose the most carbon efficient trading partners.

Acknowledgements

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Appendix A. Region and Sector Aggregation

The composition of aggregate regions is provided below:

Developed Economies United States, Japan, Germany, United Kingdom, France, Italy, Spain, The Netherlands, Belgium, Greece, Finland, Denmark, rest of Europe, Portugal, Austria, Sweden, Hong Kong, Switzerland, Singapore, Ireland, New Zealand, Luxembourg, Cyprus, rest of Oceania, Malta and rest of North America.

Fossil Fuel Exporters Rest of EFTA, Russian Federation, rest of Middle East, Canada, Australia, South Africa, Indonesia, rest of North Africa, Venezuela, Malaysia, Colombia.

Asia China, India, Korea, Taiwan, Thailand, rest of South Asia, rest of East Asia, Philippines, Vietnam, Bangladesh, rest of South-east Asia, Sri Lanka.

Eastern Europe Rest of Former Soviet Union, Poland, Czech Republic, Romania, Hungary, Bulgaria, Slovakia, Croatia, Slovenia, Estonia, Lithuania, Latvia, Albania.

Central and Latin America Mexico, Brazil, Argentina, rest of FTAA, Chile, rest of the Caribbean, Central America, rest of Andean Pact, Peru, rest of South America, Uruguay.

Africa Turkey, rest of Sub-Saharan Africa, Morocco, Tunisia, rest of SADC, Zimbabwe, Tanzania, Rest of South African CU, Uganda, Botswana, Madagascar, Zambia, Mozambique, Malawi.

The composition of aggregated sectors is provided below (nec stands for 'not elsewhere considered'):

Construction and dwellings Construction, dwellings.

Fossil fuels Coal, oil, gas, petroleum/coal products, gas manufacture/distribution.

Electricity Electricity.

Food Paddy rice, wheat, cereal grains nec, vegetables/fruits/nuts, oil seeds, sugar cane/sugar beet, plant-based fibers, crops nec, cattle (sheep, goats, horses), animal products nec, raw milk, fishing, meat (cattle: sheep, goats, horse), meat products nec, vegetable oils and fats, dairy products, processed rice, sugar, food products nec, beverages and tobacco products, water.

Clothing Wool, silk-worm cocoons. textiles, wearing apparel, leather products.

Forest and forest products Forestry, wood products, paper products/publishing.

Minerals and metals Minerals nec, mineral products nec, ferrous metals, metals nec, metal products.

Manufactured products Motor vehicles and parts, transport equipment nec, electronic equipment, machinery and equipment, manufactures nec.

Transport Transport nec, sea transport, air transport.

Services Communication, financial services nec, insurance, business services nec, recreation and other services, public administration/defence/health/education.

Trade Trade.

Appendix B. Upstream Carbon Trade Balance

In Table B.3 we present the total of upstream and downstream emissions embodied in each region exports and imports.

In Fig.B.6 we see the UCTB for the six world regions, with sector discrimination. Developed Economies are the major net receivers of upstream emissions Fossil Fuel Exporters and Asia the major net senders of upstream emissions.

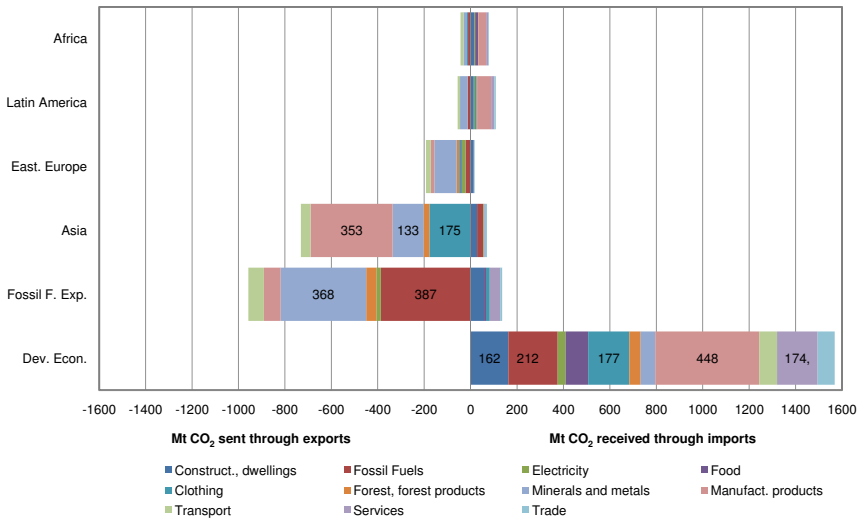

Figure B.6: Balance of upstream emissions embodied in the payment for exports (negative number) and in the payment for imports (positive numbers) for six world regions (in Mt CO_2).

Share of downstream emissions embodied in payments for exports (%)

	Construc. and dwe.	Fossil fuels	Electricity	Food	Clothing	Forest and forest prod.	Min. and metals	Manufac. prod.	Transport	Services	Trade	
Payments received by Developed Economies from:												
Fossil Fuel Exporters	0.3	3.4	0.4	4.9	1.8	3.8	7.8	51.3	6.1	16.6	3.7	100
Asia	0.4	2.6	0.1	3.3	3.2	2.5	8.9	57.1	4.8	9.3	7.9	100
Eastern Europe	5.0	2.1	0.7	4.6	5.1	4.0	10.1	48.7	4.3	13.6	1.7	100
Latin America	0.2	16.1	0.6	3.3	2.8	2.8	6.0	47.1	9.2	9.6	2.4	100
Africa	0.1	10.3	0.6	7.6	3.5	2.7	10.0	45.5	4.5	12.1	2.9	100
Payments received by Fossil Fuel Exporters from:												
Developed Economies	0.1	65.7	0.3	2.4	1.2	2.9	5.6	13.4	4.3	3.5	0.7	100
Asia	0.1	63.6	0.0	3.0	0.9	3.2	10.4	14.5	1.5	2.2	0.7	100
Eastern Europe	0.5	58.8	1.1	4.7	1.7	2.0	9.9	16.9	1.3	2.7	0.3	100
Latin America	0.1	65.4	0.8	2.2	0.9	1.6	4.5	13.2	6.0	4.5	0.9	100
Africa	0.0	64.1	0.9	4.3	1.5	1.9	8.1	14.0	1.6	3.0	0.7	100
Payments received by Asia from:												
Developed Economies	0.2	7.9	0.1	3.9	15.7	2.7	6.9	48.3	6.9	5.3	2.1	100
Fossil Fuel Exporters	0.1	5.9	0.1	7.7	16.4	2.6	9.5	45.2	3.9	6.4	2.1	100
Eastern Europe	3.0	3.5	0.1	7.3	14.1	1.0	7.0	46.2	5.4	10.0	2.4	100
Latin America	0.1	11.4	0.2	1.7	11.8	1.2	5.3	51.5	8.5	5.7	2.4	100
Africa	0.1	7.4	0.1	7.0	14.6	0.9	10.3	48.6	3.0	5.2	2.8	100
Payments received by Eastern Europe from:												
Developed Economies	0.3	20.1	3.8	3.8	7.2	5.7	12.7	30.0	8.7	6.1	1.4	100
Fossil Fuel Exporters	0.2	24.5	3.0	9.4	2.8	4.3	17.5	29.2	3.4	4.5	1.2	100
Asia	0.9	5.4	1.4	3.9	1.2	1.7	33.6	26.8	9.5	11.6	3.9	100
Latin America	0.4	27.6	7.5	2.0	0.9	0.6	9.4	18.8	19.1	10.7	3.0	100
Africa	0.1	13.9	15.5	6.0	1.3	2.3	29.2	22.7	3.2	4.6	1.3	100
Payments received by Latin America from:												
Developed Economies	0.1	25.7	0.8	10.5	5.3	2.7	10.6	29.3	8.6	5.6	0.8	100
Fossil Fuel Exporters	0.2	2.8	0.7	28.6	2.7	3.1	12.1	23.8	10.9	13.0	2.0	100
Asia	0.2	18.9	0.3	21.1	1.1	4.4	27.1	11.5	6.5	7.4	1.4	100
Eastern Europe	3.9	1.6	1.4	34.1	1.2	0.8	10.7	14.8	11.8	17.9	1.7	100
Africa	0.1	26.0	1.1	18.1	0.8	2.2	11.0	17.8	9.0	11.9	1.9	100
Payments received by Africa from:												
Developed Economies	0.2	54.8	0.1	6.8	7.6	1.1	6.6	8.3	9.3	4.1	1.2	100
Fossil Fuel Exporters	0.3	23.7	4.6	10.2	5.3	3.5	16.1	17.4	8.9	7.9	2.2	100
Asia	0.4	60.1	0.0	5.3	0.8	4.3	8.7	8.6	5.6	4.2	2.2	100
Eastern Europe	3.9	1.4	0.7	17.8	8.6	3.9	15.1	35.1	5.8	6.5	1.2	100
Latin America	0.2	73.0	0.3	1.6	0.9	0.2	3.5	4.2	11.1	3.8	1.3	100

Table 1: Emissions embodied in the payment received for exports by the six world regions from other world regions (in percentage per region).

Downstream carbon intensity of world trade (in kg CO_2)/USD 2001)

	Developed Economies	Fossil Fuel Exporters	Asia	Eastern Europe	Latin America	Africa	
Developed Economies		1.09	1.29	1.59	0.61	0.98	1.56
Fossil Fuel Exporters	0.99		2.35	4.33	1.49	1.66	1.10
Asia	0.41	1.10		1.95	0.57	0.83	0.70
Eastern Europe	0.64	2.36	1.58		0.97	1.13	2.12
Latin America	0.55	1.04	1.49	2.11		1.15	1.15
Africa	0.95	1.64	2.60	2.41	1.77		0.71
	0.55	1.23	1.12	0.95	1.38	0.70	

Table 2: World regions downstream carbon intensity (in kg CO_2/USD 2001) of the payments for imports (columns) and payments for exports (rows).

Upstream and downstream emissions embodied in each region international trade

	Direct emissions	Exports	Imports	UCTB	Payment for imports	Payment for exports	DCTB
Developed Economies	11228	1175	2744	1569	1381	1858	477
Fossil Fuel Exporters	4872	1618	797	-821	951	1409	458
Asia	5549	1378	719	-659	1109	475	-634
Eastern Europe	1474	429	266	-163	499	200	-299
Latin America	1146	281	333	52	250	248	-2
Africa	481	166	201	35	169	170	1
Total	24750	5047	5060		4359	4360	

Table B.3: Direct emissions, upstream (export, imports) and downstream (payments for imports, payments for exports) CO_2 emissions embodied in economic imports and exports and carbon trade balance (CTB) (Mt CO_2). UCTB and DCTB stand for, respectively, upstream and downstream carbon trade balance.

References

Caney, S., 2009. Justice and the distribution of greenhouse gas emissions. Journal of Global Ethics 2, 125–146.

Davis, S., Caldeira, K., 2010. Consumption-based accounting of CO_2 emissions. Proceedings of the National Academy of Sciences 12, 5687–5692.

Dimaranan, B.V., 2006. Global trade, assistance and production: the GTAP 6 data base. Technical Report. Center for Global Trade Analysis - Purdue University. West Lafayette, IN.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Technical Report. Intergovernmental Panel on Climate Change. London.

Lenzen, M., Murray, J., 2010. Conceptualising environmental responsibility. Ecological Economics 70, 261–270.

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

Munksgaard, J., Pedersen, K., 2001. CO_2 accounts for open economies: producer or consumer responsibility. Energy Policy 3, 327–334.

Muñoz, P., Steininger, K.W., 2010. Austria's CO_2 responsibility and the carbon content of its international trade. Ecological Economics 69, 2003–2019.

Oosterhaven, J., 1996. Leontief versus Ghoshian price and quantity models. Southern Economic Journal 3, 750–759.

Oosterhaven, J., 2006. On the plausibility of the supply-driven input-output model. Journal of Regional Science 2, 203–217.

Peters, G., Hertwich, E., 2008a. CO_2 embodied in international trade with implications for global climate policy. Environmental Science and Technology 5, 1401–1407.

Peters, G., Hertwich, E., 2008b. Post-Kyoto greenhouse gas inventories: production versus consumption. Climate Change 1-2, 51–66.

Peters, G., Hertwich, E., 2009. Carbon footprint of nations: a global, trade-linked analysis. Environmental Science and Technology 16, 6414–6420.

Raupach, M.R., Marland, G., Ciais, P., Quéré, C.L., Canadell, J.G., Klepper, G., Field, C.B., 2007. Global and regional drivers of accelerating CO_2 emissions. Proceedings of the National Academy of Sciences 24, 10288–10293.

Rodrigues, J., Domingos, T., 2008. Consumer and producer environmental responsibility: Comparing two approaches. Ecological Economics 66, 533–546.

Rodrigues, J., Domingos, T., Giljum, S., Schneider, F., 2006. Designing an indicator of environmental responsibility. Ecological Economics 59, 256–266.

Rodrigues, J., Marques, A., Domingos, T., 2010. Carbon Responsibility and Embodied Emissions: Theory and Measurement. Routledge, U.K.

Serrano, M., Dietzenbacher, E., 2010. Responsibility and trade emissions balaces: An evaluation of approaches. Ecological Economics 69, 2224–2232.

Tamiotti, L., The, R., Kulaçoglu, V., Olhoff, A., Simmons, B., Abaza, H., 2009. Trade and Climate Change. Technical Report. World Trade Organization-United Nations Environment Programme. Geneva, Switzerland.

Whalley, J., Walsh, S., 2009. Bringing the Copenhagen global climate change negotiations to conclusion. CESifo Economic Studies 55, 255–285.