Global Integration and Carbon Flow in EU and Rest of the World: A 2-regional Input-Output Framework

Amarendra Sahoo, Arjan de Koning, Reinout Heijungs
Institute of Environmental Sciences (CML), Leiden University

Abstract: So far, carbon intensities have been used widely in modelling the effectiveness of emission policy instruments, e.g. emission taxes or cap-and-trade system. However, computation of fossil carbon flows would help develop an alternative carbon policy instrument. We compute carbon flows, for EU and rest of the world (ROW) with the help of a two-regional input-output analysis. The carbon flow is evaluated with the help of carbon contents based on mass-balance principle and the Leontief multipliers. A linear multiplier analysis with different scenario settings is used to evaluate the carbon flows due to inter-regional consumptions and productions interdependencies. The methodology helps in assessing the contribution of trade in generating carbon flows. Alternative scenario settings also appraises carbon flows due to (a) domestic production (producer's responsibility) (c) domestic consumptions (consumer's responsibility), (d) consumer's responsibility when consumption is internalized to generate induced effect.

Key words: Carbon flow, carbon content, multi-regional trade, input-output analysis, induced consumption, production and consumption responsibilities.

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1. Introduction

In the face of global integration, issues on trade linkages and environmental responsibility have carved important niches in the environmental research. A number of analyses have contributed to the literature that look into carbon embodiment and carbon content in the multiregional international trade (Williams, 2001; Shuhi and Harsiss, 2006; Kejun et al, 2008; Peters and Hertwich, 2008, Lenzen et al. 2004; Ackerman et al., 2007; McGregor et al. 2008; Andrew et al. 2009; Su and Ang 2010). An increasing dilemma over global agreement on policies to control greenhouse gas emissions has driven the researchers and policy makers to come up with different challenging policy proposals. So far, carbon intensities have been widely used in modelling emission policy instruments, e.g. emission taxes or cap-and-trade system. However, computation of carbon contents in carbon substance flow analysis between regions would help develop an alternative carbon policy instrument (Huppes, 2011). We compute and analyse carbon flow between EU and rest of the world (ROW) using fossil carbon contents in an input-output (IO) framework. A multiplier analysis with different scenario settings would evaluate fossil carbon flow due to inter-regional consumptions and productions interdependencies.

Embodied carbon refers to all stages of carbon emitted, inputs going into a product, starting from its extraction, through the distribution process to the final consumption of the product. Methodological assumptions and calculations vary depending on different scopes and assumptions. However, in our case we are interested in carbon content of all product groups, creating a fossil carbon dimension, which is based on a mass-balance approach (Heijungs, et al, 2012). We calculate fossil carbon flows for EU and ROW with the help of an inter-regional in the input-output framework. Several studies have argued about the production-based national emissions inventories and others about consumption-based national emissions inventories, but many researchers have proposed to analyse the shared responsibility between producers and consumers (Ferng, 2003; Gallego and Lenzen, 2005; Rodrgues et al, 2006; Lenzen et al, 2007; Peters, 2008).

We have two-regional input-output table and we modify it to have an accounting balances for consumption expenditures, income, investments and savings of the economy. In one of the alternative scenario settings, consumption demand is internalized in the IO transaction, which links the income-consumption gap in the economy and results in induced consumption multipliers. Alternative scenario settings also appraises carbon flows due to (a) domestic production (producer's responsibility) (b) domestic consumptions (consumer's responsibility), (c) consumer's responsibility when consumption is internalized to generate induced effect.

2. Methodology

Several researchers have addressed carbon emissions from fossil fuels (Francis, 2004; Mol et al 2005). We use fossil carbon contents of product groups based on mass balance concept taken from Heijungs et al (2012). In mass balance approach, what goes into the system is either accumulated in the system or leaves the system. An activity requires products as well as environmental extraction, e.g. crude oil, gas etc. for its use and may have emissions containing fossil carbons, e.g. CO_2, CO and CH_4. They have calculated carbon contents by combining monetary input-output transaction matrix along with physical satellite account containing emissions and resource uses, and carbon contents of the environmental extensions.

Following Heijungs et al (2012), carbon contents of product groups that likely contain the most important fossil carbon are considered. This is quite logical, if we consider all other product groups, we may encounter negative carbon contents due to either service sectors or product groups having negligible fraction of carbon content in total flow. We have now 14 products having fossil carbon contents for each region. In a global multiregional trade framework, fossil carbon products going into the domestic activities may also be imported from other countries, for example, in our two-regional IO framework, EU may import fossil carbons from rest of the world and also the other way around. The analysis is based on an industry-by-industry input-output transaction table. We accept the limitation of this transaction table as all products are identified as average product of the covering industry. We could also use product-by-product IO table for our analysis. Heijungs et al. (2012) have observed very marginal difference between calculated carbon contents based on industry-by-industry and product-by-product IO tables.After having fossil carbon contents for the product groups, we need to estimate the total carbon flows of EU and ROW with direct and indirect demands from activities. As the computation of carbon flows also depends on the IO multipliers, change in scenarios would influence the multipliers and hence, the carbon flows. The next part of our analysis is based on a linear multiplier model with alternative scenario options. A two-regional IO table for aggregate EU and rest of the world is used, which captures inter-linkages in the economies through the productions and demand flows within and between the two regions.

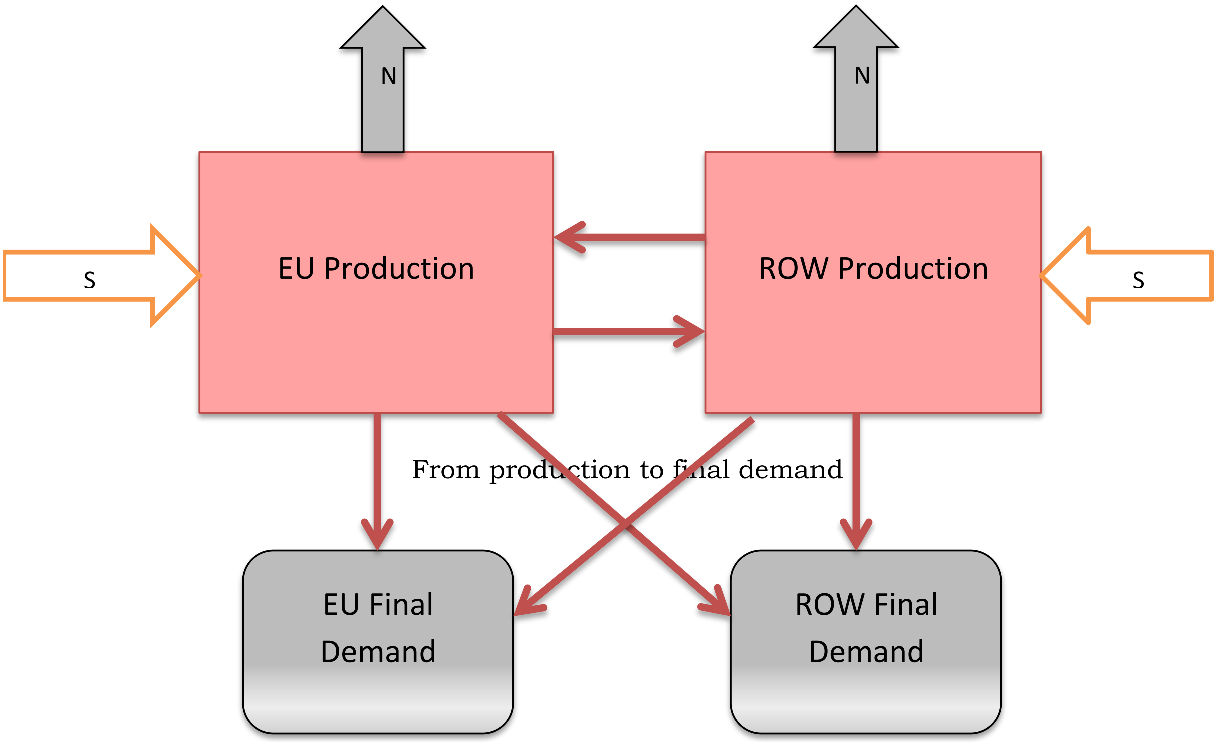

Figure 1 Carbon flow in 2-regional perspective

Figure highlights the carbon flow for EU and ROW due to the trade link. Production of each region caters to the intermediate demand of its own, final demand of its region and final demand for other region by way of exports. The arrow, *S*, indicates the carbon enters into the regional boundary through environmental extraction and the arrow, *N*, is the emissions going out of the region.

By adding an income flow account that links production, income and expenditures converts the IO table into a social accounting matrix (SAM). A SAM captures flows among different activities and circular transmissions within the economy and between the regions, as in our case. A multiplier analysis has become a useful tool to capture this transmission mechanism.

We do not distinguish between different types of consumption expenditures, e.g. households, non-government and government. Our aim is to incorporate the induced effect of consumption expenditures and income of the economy as a whole. Though our modified IO table does not represent a full-fledged SAM, due to its accounting balances, we call it a SAM in our paper. It includes standard Leontief inverse (IO multipliers) along with some additional accounting multipliers. In addition to the Leontief multiplier, SAM may contain induced effects based on various additional information on institutions/accounts, e.g. households, government and non-government and capital (investment demand, change in stock and valuables). By making one of these institutions endogenous, we can bring the activities of the institution and related leakages into the SAM multipliers. For example, if the consumption account is not internalized into the multiplier analysis, then the incomes generated from the endogenous account (production activities) are leakages into the exogenous account.

The accounting multiplier matrix, M, is calculated by

$$Y= (I-A)^{-1}X = MX \qquad \text{(Eq. 1)}$$

X and Y represent exogenous and endogenous accounts respectively and A is the coefficient matrix. Different alternative scenarios in exogenous accounts would set the closures for the multipliers. In a single country framework, Leontief multiplier matrix has the $n \times n$ dimension of M_{ij} reflecting the required flows of inputs offered by sector i to produce one unit worth of the value of sector j's output to final demand, X_i. Once we close the Leontief inverse with the consumption demand of the economy, the additional row of the IO matrix represents as $n+1,j$ payments by j^{th} sector to the factors to produce additional unit of j output to final demand. In case of two regional IO, e.g. EU and rest of the world (ROW), final demands (consumption as well as investment) may be considered as exogenous and be included in X. In a multiregional IO or SAM framework, the intermediate transaction coefficient matrix constitutes A^{EE}, A^{RE}, A^{RR} and A^{ER}, indicating intermediate flows within EU, from ROW to EU, within ROW and from EU to ROW respectively (see Table 1).

Table 1: Schematic 2- regional SAM and possible closures

		Ind1 EU	Ind2 EU	Ind1 ROW	Ind2 ROW	Consump-tions EU	Consump-tions ROW	Investment EU	Investment ROW	TOTAL
Production Account (EU)	**Ind1**	A_{11}^{E}	A_{12}^{E}	A_{13}^{ER}	A_{14}^{ER}	C_{EE1}	C_{ER1}	N_{EE1}	N_{ER1}	Y1
	Ind2	A_{21}^{E}	A_{22}^{E}	A_{23}^{ER}	A_{24}^{ER}	C_{EE2}	C_{ER2}	N_{EE2}	N_{ER2}	Y2
Production Account (ROW)	**Ind1**	A_{31}^{RE}	A_{32}^{RE}	A_{33}^{R}	A_{34}^{R}	C_{RE2}	C_{RR1}	N_{RE1}	N_{RR1}	Y3
	Ind2	A_{41}^{RE}	A_{42}^{RE}	A_{43}^{R}	A_{44}^{R}	C_{RE2}	C_{RR2}	N_{RE2}	N_{RR2}	Y4
Income (EU)		V_{E1}	V_{E2}							Y5
Income (ROW)				V_{R1}	V_{R2}					Y6
Net Savings EU						S_E				Y7
Net Savings ROW							S_R	S_{RE}		Y8
TOTAL		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	

In Table 1, value added paid to the factors of production from the activities goes as income to the economy that is spent on consumption of domestic products as well imported products. An induced circular flow would be established if we internalize consumption demand account and include the value added income to close the leakage. The net savings account containing output residuals balances the investment demand account. In one of our scenarios analysis, we endogenize consumption demand of the economy, both for EU and ROW, in the IO transaction matrix. However, if we internalize only EU's consumption demand, we would include value added income of EU only, leaving out value added of ROW.

***Scenario 1**: Production based fossil carbon flow*

Production based carbon flow calculation is the base case scenario where carbon flow is associated with the productions in the concerned region, irrespective of destinations of the produced goods (Papathanasopoulou, 2005). In this case, fossil carbon flow is due to the direct industry use in the IO transaction matrix and also because of direct final demand. It should be kept in mind that the production base effect does not consider the interaction, indirect effects due to exogenous final demand. The calculation is very straight forward. We just need to assume that fossil carbon contents by product groups are linearly related to industry sector output, $y_{i,j}$, and also to final demand, x_j. Vector of total carbon flows due to the production activities of all sectors in EU is represented as:

$$F_{prd}^{E} = \propto'.Y \qquad \text{(Eq. 2)}$$

$\propto$ is the vector containing product group-wise fossil carbon contents. Fossil carbon associated with direct final demand in EU is computed by multiplying vector of carbon contents by the final demand vector:

$$F_{fd}^{E} = \propto'.X \quad \text{(Eq. 3)}$$

Adding equation 4 and 5, we arrive at production based carbon flow for EU.

$$F_{tot=}^{E} F_{prd}^{E} + F_{fd}^{E} \quad \text{(Eq. 4)}$$

Similarly, we get production based carbon flow for ROW:

$$F_{tot=}^{R} F_{prd}^{R} + F_{fd}^{R} \quad \text{(Eq. 5)}$$

It is to be noted that vector of fossil carbon flow associated with final demand can be split into three parts: carbon flow associated with final domestic consumption demand, exports of final consumption goods and intermediate goods to other region.

***Scenario 2**: Consumption based fossil carbon flow: without induced consumption-income effect*

In case of consumption based carbon flow, we consider fossil carbons associated with the consumption activities in the concerned region, irrespective of where the goods are produced, domestically or abroad. This scenario explains the carbon flow of a region due to the activities of industries and carbon embodied in intermediate and final imported products in order to meet demand in that region.

With the help of our accounting multiplier, we have our matrix of total carbon flows:

$$C = \propto' \ (I - A)^{-1} \quad \text{(Eq. 6)}$$

C is the *1 x n* row vector whose i^{th} element shows the fossil carbon contents directly or indirectly embodied in one unit of final production i^{th} sector.

In this scenario, interregional trade between EU and ROW is accounted for as described above, with rest of the accounts set as exogenous final demand. The first block in the Table 1 gives the production accounts of EU and ROW. It describes the inter-industry demand for domestic industry and also intermediate industry products from abroad. Hence, the inter-industry flow in the inter-regional trade account has four transaction blocks. By arranging the monetary transaction matrix with respect to exogenous demand and Leontief inverse matrix:

$$\begin{pmatrix} (I - A^{E}) & -A^{ER} \\ -A^{RE} & (I - A^{R}) \end{pmatrix}^{-1} \begin{pmatrix} X^{EU} \\ X^{ROW} \end{pmatrix} = \begin{pmatrix} Y^{EU} \\ Y^{ROW} \end{pmatrix} \qquad \text{(Eq. 7)}$$

The demand vector for EU and ROW ($X^{EU}$and X^{ROW}) can be split and written as

$$\begin{pmatrix} X^{EU} \\ X^{ROW} \end{pmatrix} = \begin{pmatrix} X^{E} & X^{ER} \\ X^{RE} & X^{R} \end{pmatrix} \qquad \text{(Eq.7.1)}$$

A^{E}, A^{R}, A^{RE} and A^{ER} represent IO transaction coefficient matrices for EU, rest of the world, intermediate trade transaction coefficient matrices from ROW to EU and from EU to ROW respectively. X and Y are final demand and final output with superscripts, E, R, RE and ER indicating demand of EU from EU, from ROW to ROW, imports from ROW to EU and from EU to ROW respectively. Following Proops et al (1993) and Papathanasopoulou (2005), we break down the multiplier and final demand blocks in order to account for the production and consumption carbon flow between the regions.

For the sake of convenience, we write the elements of inverse multiplier matrix as

$$\begin{pmatrix} (I - A^{E}) & -A^{ER} \\ -A^{RE} & (I - A^{R}) \end{pmatrix}^{-1} = \begin{pmatrix} M^{E} & M^{ER} \\ M^{RE} & M^{R} \end{pmatrix} \qquad \text{(Eq. 7.2)}$$

Using monetary flow equation 5 along with region-wise disaggregated diagonal vector of carbon contents, we account for the carbon flows between two regions.

$$\begin{pmatrix} \propto^{E} & 0 \\ 0 & \propto^{R} \end{pmatrix} \begin{pmatrix} M^{E} & M^{ER} \\ M^{RE} & M^{R} \end{pmatrix} \begin{pmatrix} X^{E} & X^{ER} \\ X^{RE} & X^{R} \end{pmatrix} = \begin{pmatrix} \propto^{E} & 0 \\ 0 & \propto^{R} \end{pmatrix} \begin{pmatrix} Y^{EU} & 0 \\ 0 & Y^{ROW} \end{pmatrix} \qquad \text{(Eq. 8)}$$

$\propto^{E}$ and $\propto^{R}$ are the vectors of carbon contents of industry products for EU and ROW respectively. We can split the equation 8 to derive the carbon flows of industries from the consumption perspective for EU and ROW separately, based on Y^{E} and Y^{R}. If we calculate consumption based fossil carbon flow for EU, we should use the first column of final demand X matrix.

$$S^{E} = \propto^{E} M^{E} X^{E} + \propto^{E} M^{ER} X^{RE} + \propto^{R} M^{RE} X^{E} + \propto^{R} M^{R} X^{RE} \qquad \text{(Eq. 9)}$$

In order to calculate consumption based fossil carbon flow for ROW, we should consider the second column of final demand X matrix in equation 10. The consumption based fossil carbon flow for ROW is written as:

$$S^R = \propto^R M^R X^R + \propto^R M^{RE} X^{ER} + \propto^E M^{ER} X^R + \propto^E M^E X^{ER} \quad \text{(Eq. 10)}$$

We define each component of equations 9 and 10 according to their functions. We have:

$CP^E = \propto^E M^E X^E$,$CT^E = \propto^E M^{ER} X^{RE}$, $CR^E = \propto^R M^{RE} X^E$ and $CQ^E = \propto^R M^R X^{RE}$.

$CP^R = \propto^R M^R X^R$,$CT^R = \propto^R M^{RE} X^{ER}$, $CR^R = \propto^E M^{ER} X^R$ and $CQ^R = \propto^E M^E X^{ER}$.

CP^E, CP^R : Fossil carbon flow with production of goods in EU (ROW) to meet demand in EU (ROW).

CT^E, CT^R: Fossil carbon associated with production of exports goods in EU (ROW) to meet final demand for imported goods from ROW (EU).

CR^E, CR^R: Fossil carbon flow associated with industries in ROW (EU) that are imported to meet intermediate demand in EU (ROW) destined for final demand.

CQ^E, CQ^R: Fossil carbon flow associated with industries in ROW (EU) to produce final goods that are imported by EU (ROW) to meet imported final demand.

It should be noted that carbon flow associated with consumption-based perspective may not equal with production perspective carbon flow for one region. This is because consumption responsibility in a region may include imported intermediate and final demand consumption from the other region and total productions in the region also includes production to satisfy intermediate and final demands from abroad. Production and consumption based carbon flows for one region will be equal if we adjust and rearrange the components in the consumption-based accounting. Total production-based carbon flow in EU is equal to carbon associated with productions in EU to meet domestic final (CP^E) as well as imported consumption demand (CT^E), and carbon associated with flow good produced in EU to meet final (CR^R) as well as intermediate demand (CQ^R) in ROW. We can express the carbon flow associated with EU on the basis of production as:

$$F^{E}_{tot=}CP^{E} + CT^{E} + CR^{R} + CQ^{R} \quad \text{(Eq. 11)}$$

Similarly, the production based carbon flow for ROW as:

$$F^{R}_{tot=}CP^{R} + CT^{R} + CR^{E} + CQ^{E} \quad \text{(Eq. 12)}$$

Scenario 3*: Consumption based fossil carbon flow: with induced consumption-income effect.*

In this scenario we conduct the same exercise as in scenario 2, but with an extension of the IO coefficient matrix. We internalize the economy’s consumption vector for both EU and ROW by closing the leakages of value added income. This gives us the direct, indirect and induced effect of final demand on the carbon flows. The *A* matrix in equation 1 has now additional column vectors of final consumptions of EU and ROW as shown in the second block in Table 1. We also add the row vectors of value added income for both EU and ROW. Now, investment demand vectors for both EU and ROW become the exogenous final demand in *X*. Internalizing consumptions and establishing a circular flow between production-consumption-income captures the induced effect of increase in income due to exogenous increase final demand and hence, leading to more production due to increase in consumptions induced by income.

The multiplier matrix in equation 7 now consists of 12 additional block matrices due to additional two more columns and rows in the flow matrix *A*. Equation 7 is re-written as;

$$\begin{pmatrix} M^{E} & M^{ER} & M^{E}_{C} & M^{ER}_{C} \\ M^{RE} & M^{R} & M^{RE}_{C} & M^{R}_{C} \\ M^{E}_{I} & M^{ER}_{I} & M^{E}_{X} & M^{ER}_{X} \\ M^{RE}_{I} & M^{R}_{I} & M^{RE}_{X} & M^{R}_{X} \end{pmatrix} \begin{pmatrix} X^{EU} \\ X^{ROW} \\ X^{EU}_{C} \\ X^{ROW}_{C} \end{pmatrix} = \begin{pmatrix} Y^{EU} \\ Y^{ROW} \\ Y^{EU}_{I} \\ Y^{ROW}_{I} \end{pmatrix} \quad \text{(Eq. 13)}$$

X^{EU} and X^{ROW} are final demands (investment demands) for EU and ROW respectively. Additional final demand elements corresponding to factor income of EU and ROW are X^{EU}_{C} and X^{ROW}_{C}. Additional two column vectors and two row vectors in the multiplier matrix are related to consumption and income of EU and ROW. As in Scenario 2 (EQ. 7.1), we can split the final demand vector into two column vectors according to the destination of the demand.

$$\begin{pmatrix} X^{EU} \\ X^{ROW} \\ X_C^{EU} \\ X_C^{ROW} \end{pmatrix} = \begin{pmatrix} X^{E} & X^{ER} \\ X^{RE} & X^{R} \\ X_C^{E} & X_C^{ER} \\ X_C^{RE} & X_C^{R} \end{pmatrix} \qquad \text{(Eq. 13.1)}$$

From consumption perspective, the first column indicates final demand of EU for its domestic as well as imported products. Similarly, the second column is for the ROW. Our intention is to calculate and account for the carbon flow of product groups due to the activities in the economy. It is also important to mention that in our SAM, there is no value in investment demand vector corresponding to the factor income. Hence, we can put zeros in the last two rows of final demand vectors. This leads us to consider only first two row vectors of multiplier equation 13. Now, inserting equation 13.1 into equation 13, ignoring the last two rows and pre-multiplying the equation with the diagonal matrix of fossil carbon contents for EU and ROW, we get an equation similar to equation 9. Total induced consumption-based carbon flows for EU and ROW are expressed as

$$S_C^E = \propto^E M_C^E X_C^E + \propto^E X_C^{ER} X_C^{RE} + \propto^R M_C^{RE} X_C^E + \propto^R M_C^R X_C^{RE} \qquad \text{(Eq. 14)}$$

$$S_C^R = \propto^R M_C^R X_C^R + \propto^R X_C^{RE} X_C^{ER} + \propto^E M_C^{ER} X_C^R + \propto^E M_C^E X_C^{ER} \qquad \text{(Eq. 15)}$$

3. Data

EXIOBASE provides the multi-regional supply-use (SU) database for the year 2000 for 43 countries and one rest of world. Based on this data base, we construct a multi-regional IO table for EU and all other countries in the world (ROW) with a size of 258 x 258 industry sectors. The EXIOBASE supply-use tables have also quite detailed environmental and material extensions, from we have resource extraction of coal, peat, crude oil and the environmental emissions of CO_2, CH_4 and CO. For details about data on calculating carbon contents, one may refer to Heijungs et al (2012). Carbon contents for 14 fossil carbon products based on industry-by-industry IO matrix are calculated for EU and rest of the world.

Table 2: Carbon contents (Kg C/Million Euro)

	EU	ROW
	Industry x Industry	Industry x Industry
Coal and lignite, peat	18257038	19284233
Crude petroleum	4099526	508621
Natural gas	3970953	7123296
Other petroleum, gaseous materials	1488240	1484728
Coke oven products	6079870	2552079
Motor spirit (gasoline)	2901028	3047804
Kerosene, kerosene type jet fuel	25530933	1484756
Gas oils	2668794	2557002
Fuel oils n.e.c.	2003605	2465284
Petroleum gases, other gaseous	2529451	2533838
Other petroleum products	842318	1925405
Chemicals, chemical products	100731	144853
Manufacture of gas; distribution of gaseous fuels	1490456	2015885
Retail sale of automotive fuel	23702	9964

Source: Heijungs et al. (2012)

4. Results

We have described fossil carbon flow accountings from production as well consumption perspective. Production based carbon flow (**Scenario 1**) as in Table 2 indicates that EU is responsible for 1047.3 million tonnes while rest of the world is for 9481.4 million tonnes, over 6 times more than EU's carbon flow. It is not surprising that the production based carbon flow is mainly from the industry demand for the production activities. On the other hand carbon flow due to direct EU consumption from ROW (both intermediate as well as final consumption) is 679.7 million tonnes, while for ROW it is only 93 million tonnes. 'Coal, lignite and peat' is the most responsible fossil product group followed by 'gas oil' and 'motor spirit' from EU point of view. 'Crude petroleum' and 'Coal, lignite and peat' contribute the most to the carbon flow in ROW.

Table 2: Production-based fossil carbon flows for EU and ROW

	EU				ROW			
	Ind. demand	Final dom. Cons.	Exports	Total	Ind. demand	Final dom. Cons.	Exports	Total
Coal and lignite, peat	272.63	35.87	3.12	311.62	2183.43	251.08	33.59	2468.10
Crude petroleum	118.83	1.69	18.64	139.16	2209.41	118.66	472.60	2800.67
Natural gas	110.14	17.89	5.46	133.49	876.51	196.21	102.96	1175.67
Other Petroleum	7.44	1.04	0.15	8.63	131.06	34.43	4.37	169.86
Coke oven products	19.97	2.79	0.37	23.12	167.99	51.16	5.12	224.27
Motor spirit (gasoline)	75.84	152.65	17.66	246.16	520.72	318.92	15.88	855.52
Kerosene, jet fuel	15.70	2.42	3.72	21.84	113.11	76.98	2.92	193.01
Gas oils	244.23	28.79	20.60	293.62	419.09	16.90	15.18	451.17
Fuel oils n.e.c.	13.59	1.03	7.84	22.46	159.94	48.13	8.22	216.28
Petroleum gases, other gaseous	20.85	4.87	2.66	28.39	104.47	18.99	6.55	130.01
Other petroleum products	6.06	0.26	0.88	7.20	214.37	78.70	2.22	295.29
Chemicals, chemical products	29.68	11.49	11.76	52.93	151.19	49.52	6.41	207.12
Manufacture of gas; distribution of gaseous fuels	91.07	26.11	0.41	117.60	179.66	109.63	3.71	293.00
Retail sale of automotive fuel	0.52	0.53	0.03	1.08	0.50	0.96	0.00	1.46
TOTAL	1026.56	287.44	93.29	1407.29	7431.43	1370.27	679.72	9481.42

Methodology based on consumption perspective (**Scenario 2**) gives an account of direct and indirect fossil carbon flow of product groups in EU and rest of the world. Unlike the production-based flow, the overall consumption responsibility of ROW is found to be 4.3 times that of EU (see Table 2). Carbon flow associated with overall EU consumption is 2049.5 million tonnes, which is higher than in case of production perspective, and carbon flow due to ROW consumption is 8801.6 million tonnes, lower than in case of production perspective. Difference in consumption-based and production-based carbon flow is on account of inclusion of embodied trade flows. One can clearly see that the carbon flow associated with the production to support domestic consumption for ROW is almost 96 percent of the total accounted consumption-based carbon flow and only around 4 percent is due to import demand from EU. Carbon flows attributable to direct and indirect EU consumptions produced in ROW is 906.7 million tonnes $(CR^E + CQ^E)$ and ROW consumption produced in EU is 247.8 million tonnes ($CR^R + CQ^R$). Here it should be noted that the carbon flows attributed to the direct and indirect demand are higher than the carbon associated with the direct consumptions as in Table 2. Carbon flow to ROW from EU's consumption is mainly due to the significant of use of 'crude petroleum', 499.4 million tonnes and attribution of carbon flow to EU from ROW is due to use of 'gas oil' (60.17 million tonnes), 'coal, lignite, peat' (40.7 million tonnes) and 'crude oil' (38.9 million tonnes).

Table 3: Consumption-based carbon flows for EU and ROW

	EU					ROW				
	CP	CT	CR	CQ	Total	CP	CT	CR	CQ	Total
Coal and lignite, peat	269.64	0.58	91.23	30.43	391.88	2331.78	9.58	24.72	16.02	2382.11
Crude petroleum	98.57	0.56	463.32	36.10	598.55	2254.56	39.22	30.54	8.36	2332.68
Natural gas	112.16	0.28	119.11	14.84	246.39	1029.27	9.12	14.06	6.37	1058.83
Other petroleum, gaseous materials	6.85	0.02	8.32	1.38	16.58	159.31	0.79	1.19	0.55	161.84
Coke oven products	18.61	0.06	9.00	3.06	30.73	210.91	1.03	2.64	1.54	216.12
Motor spirit (gasoline)	214.11	0.32	19.02	14.74	248.19	818.16	1.93	16.01	10.08	846.18
Kerosene, kerosene type jet fuel	14.56	0.08	3.82	3.06	21.52	185.40	0.46	3.99	2.88	192.73
Gas oils	226.87	0.87	23.45	7.35	258.55	416.02	3.14	41.50	18.67	479.33
Fuel oils n.e.c.	12.44	0.12	11.11	2.75	26.41	200.81	1.10	6.21	3.19	211.32
Petroleum gases, other gaseous	20.94	0.09	7.54	2.98	31.55	118.40	0.84	4.13	2.70	126.08
Other petroleum products	4.47	0.04	7.47	3.10	15.09	283.34	0.99	1.73	0.76	286.82
Chemicals, chemical products	34.60	0.25	8.09	4.41	47.35	193.07	0.98	10.99	6.53	211.57
Manufacture of gas; distribution of gaseous fuels	104.56	0.17	8.01	3.01	115.75	280.91	0.75	7.03	5.23	293.92
Retail sale of automotive fuel	0.97	0.00	0.01	0.01	1.00	1.43	0.00	0.06	0.05	1.54
TOTAL	1139.35	3.46	779.51	127.22	2049.54	8483.37	69.93	164.81	82.95	8801.06

When we internalize consumption demands of EU and ROW into the input-output transaction matrix as in **Scenario 3**, we notice that there is only marginal difference between the aggregated carbon flows for EU and ROW as compared to Scenario 2, where induced effects are not taken into account. However, we observe the changes in functionalities of consumptions. There has been noticeable decline in carbon flows from goods produced in EU to meet final demand in EU (column CP) compared to Scenario 2; it has also declined for ROW. On the other hand, carbon flow associated with production in ROW going for consumptions in EU has gone up from 907 million tonnes (total of CR and CQ for EU) in

Scenario 2 to 1218 million tonnes in Scenario 3 and it has also gone up for ROW from 248 million to 570 million (total of CR and CQ for ROW). Unlike the extreme case of production-based carbon flow as in Scenario 1, where EU carries huge responsibility of carbon flow through importing carbon products, in case of induced consumption effect, both the regions share the responsibility. In any case, EU is more responsible for fossil carbon in ROW. Carbon flows due to imports by EU is almost 3.66 times higher in Scenario 2 and 2.13 times higher in Scenario 3.

Table 4: Induced consumption-based carbon flows for EU and ROW

	EU					ROW				
	CP	CT	CR	CQ	Total	CP	CT	CR	CQ	Total
Coal and lignite, peat	190.95	2.04	205.36	33.42	431.76	2203.55	20.70	99.75	18.22	2342.23
Crude petroleum	70.78	1.11	467.89	35.13	574.91	2247.31	42.86	59.57	6.58	2356.32
Natural gas	81.46	0.87	148.31	13.28	243.92	996.41	14.34	43.57	6.98	1061.30
Other petroleum, gaseous materials	5.27	0.06	12.18	1.57	19.08	154.88	1.17	2.91	0.38	159.34
Coke oven products	13.65	0.16	16.81	2.78	33.39	202.70	1.71	7.79	1.25	213.46
Motor spirit (gasoline)	144.15	1.64	74.81	11.98	232.58	759.68	7.39	82.09	12.65	861.80
Kerosene, kerosene type jet fuel	10.75	0.18	17.01	2.88	30.82	171.17	1.69	9.61	0.96	183.43
Gas oils	166.41	2.04	42.71	6.19	217.35	396.91	4.15	105.45	14.01	520.53
Fuel oils n.e.c.	9.41	0.21	21.14	3.06	33.82	189.50	2.07	11.55	0.79	203.91
Petroleum gases, other gaseous	15.03	0.22	14.01	2.02	31.28	112.36	1.38	10.96	1.66	126.35
Other petroleum products	3.34	0.07	25.24	4.53	33.17	262.61	2.53	3.32	0.27	268.73
Chemicals, chemical products	25.53	0.48	21.19	3.46	50.66	179.79	2.10	23.98	2.40	208.27
Manufacture of gas; distribution of gaseous fuels	73.41	0.74	25.76	4.72	104.63	259.60	2.60	36.20	6.64	305.04
Retail sale of automotive fuel	0.69	0.01	0.11	0.02	0.83	1.32	0.01	0.33	0.06	1.71
TOTAL	810.83	9.82	1092.52	125.03	2038.20	8137.77	104.70	497.07	72.85	8812.40

By comparing the carbon flows based on production perspective with the consumption perspective in our accounting framework as in equations 11 and 12 for the EU and ROW, we may encounter differences due to traded goods in consumption based analysis. Total production-based carbon flow in EU on the right hand side of the equation 11 is 1407.29 million tonnes and the left hand side of the equation presenting consumption based flow occurring in EU is 1377.54 million tonnes, leaving a difference of 29.74 million tonnes. Similarly ROW in equation 12, the difference has been 21.38 million tonnes.

Giving a cursory look at the activities that are responsible for more carbon flow and by arranging the activities in descending orders, we notice some interesting development in scenarios with indirect, indirect and induced effects over the base case scenario with direct coefficients. Table 5 gives region-wise and scenario-wise top 10 activities with respect to carbon flows. ‘Coke oven products’, ‘electricity by coal’, ‘motor spirit’ and ‘gas oil’ seem to play important role in contributing to the carbon flow. The ‘coke oven product’ sector, in particular, has been major the major contributor to carbon flow in EU irrespective of scenarios. The most interesting observation is that the ‘coal, lignite and peat’ activity is not figured in top ten contributors to carbon flow in the Scenario 1, where we only consider the direct transactions in the IO matrix. However, once the direct and indirect as in Scenario 2 and the induced consumption effects as in Scenario 3 are considered, the ‘coal, lignite and peat’ activity assumes the top responsibility in carbon flows both in EU and ROW. Besides, the ‘natural gas’ activity also assumes importance in these scenarios particularly in ROW.

Table 5: Top ten activities with respect to carbon flows

	Scenario1		Scenario2		Scenario3	
	EU	ROW	EU	ROW	EU	ROW
1	Coke oven products	Electricity by coal	**Coal, lignite, peat**	**Coal, lignite,peat**	**Coal, lignite, peat**	**Coal, lignite, peat**
2	Electricity by coal	Motor spirit (gasoline)	Coke oven products	**Natural gas**	Coke oven products	**Natural gas**
3	Motor spirit (gasoline)	Fuel oils n.e.c.	Motor spirit (gasoline)	Motor spirit (gasoline)	Motor spirit (gasoline)	Motor spirit (gasoline)
4	Fuel oils n.e.c.	Coke oven products	Gas oils	Electricity by coal	Gas oils	Electricity by coal
5	Gas oils	Gas oils	Electricity by coal	Other petroleum	Electricity by coal	Other petroleum
6	Kerosene, jet fuel	Electricity by gas	Kerosene including kerosene type jet fuel	Coke oven products	Petroleum gases	Coke oven products
7	Petroleum gases and otherS	Petroleum gases	Petroleum gases,other	Fuel oils n.e.c.	Kerosene, jet fuel	Fuel oils n.e.c.
8	Other petroleum	Other petroleum	Fuel oils n.e.c.	Gas oils	Fuel oils n.e.c.	Gas oils
9	Electricity by gas	Manufactured gas	Crude petroleum	Petroleum gases	Crude petroleum	Petroleum gases
10	Manufactured gas	Nuclear fuel	**Natural gas**	Crude petroleum	**Natural gas**	Crude petroleum

Conclusion

The paper presents an accounting of flows of fossil carbon contents in multi-regional trade with the help of an input-output framework. The analysis has generated interests in two aspects. One is the use of fossil carbon content based on mass balance approach by Heijungs et al (2012), instead of carbon emissions, is of particular interest for policy point of view. Extending the methodology to account for the fossil carbon flows for international trade, in our case between EU and rest of the world, assigns the responsibilities of carbon flows either to region's production or to consumption.

Rest of the world carries more fossil carbon than the EU both in production and consumption perspective. The analysis shows that both EU and ROW contribute a major part of their carbon flow by way of supporting their own industry demand for production activities. Though consumption based carbon flow is significantly more for rest of the world than the EU, EU contributes significantly more to carbon flow through the purchases from rest of the world than the other way round. If we consider induced consumption-income effects for EU and ROW, EU seems to carry even more responsibility for carbon flow by importing carbon products from rest of the world. Considering carbon flow from production perspective attributes the carbon flow more to ROW for its domestic production to meet its domestic intermediate as well as final demands, and EU takes more responsibility with respect to carbon flow through its significant imports from ROW. However, the consumption-based analyses assign more share responsibility between these two regions. However, once we consider from consumption perspective, carbon flows due to domestic production in order to meet domestic demand, relatively decline and consumptions assume increasing responsibility. This is because of the consumption demands from abroad, particularly EU importing fossil carbon products from rest of the world. EU's contribution of carbon flow in trade is the maximum due to its import consumption of crude petroleum, followed by natural gas and 'coal, lignite, peats'.

'Coke oven products', 'electricity by coal', 'motor spirit' and 'gas oil' activities carry responsibilities in carbon flows, both in EU and ROW. However, when we include direct, indirect and induced effects in the flows, the 'coal, lignite and peat' has been the top activity attributing to the carbon flow and the 'natural gas' sector assumes higher responsibility particularly in ROW.

The analysis may be extended to incorporate more scenario analysis by setting more alternative closures. We have not analysed the activity-wise carbon flows. We may consider that in extending our analysis.

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