Tracking Environmental Impacts of Consumption: an economic-ecological model linking OECD and developing countries

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Abstract

Production-consumption chains are getting global but environmental impacts induced by OECD in developing countries are still only loosely assessed. We present an analytical framework and a 12 regions inter-regional input-output model extended for CO2 to track emissions worldwide and to quantify the link between producers and consumers. It is shown that while emissions are largely occurring domestically for satisfying domestic consumption, some countries like China emit twice as much CO2 as required by domestic households. Emissions due to exports from China and India are mainly due their upstream position in production chains, i.e. to triangular trade. Adequate modeling requires therefore a true world model with a disaggregated Rest Of the World and considering full exchanges between trade partners.

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Background

Introduction

Globalization and the related growth in trade provoke socio-economic as well as environmental changes. There is currently a need to shed a new light on international responsibilities for the environmental impacts of current consumption and related trade patterns. This is particularly needed for covering the relations between consumers in developed countries and affected citizens in emerging countries. A challenge induced by (a) the development of global production-consumption chains and the growing share of developing countries in international trade, (b) the importance of atmospherical pollutants on daily life (c) the lack of models considering adequately these economic and environmental relations on a large scale.

The importance of trade for each nation has been growing during the last century, exports accounting for example for 33.7% of GDP in Germany, and for as much as 85% of GDP in New Industrialized Countries (HSBC 2004). While regional trade is still more frequent than international trade, the later is growing, accounting, for example, for 42% of exports in Europe. Some developing countries like China are now getting a major share (6% for China) of world exports (WTO 2006). The North-South pattern of trade is evolving: from mining and agricultural products to two-ways trade in manufactures (80 to 90% for China in 2003) (WTO 2006). The share of triangular trade flows is also increasing. Electronics exports of China are, for example, assemblies of components imported from Korea or Taiwan at 60% which are re-exported after assemblage to Asia (40%) or the rest of the world (HSBC Global Research 2004). The split of the production processes in different locations and the consumers' love for variety[2] result in longer, sometimes truly global production-consumption chains. As a result, emissions due the production of final goods are increasingly spread worldwide. While pollutants like CO_2 and global warming gases are slowly being considered by the international community, other environmental impacts related to atmospherical pollutants like sulfur dioxide, dioxin or heavy metals are however still largely unaccounted for in international negotiations. These pollutants are however particularly relevant since they directly influence the state of regional environments, e.g. the quality of lands, modifying regional capacities to sustain livelihoods and affecting people's daily life and health. The largest manifestation so far is probably the Asian brown cloud, which put hundreds of thousands of people at risk (UNEP and c4 2002). Locally deposited, these pollutants are however truly trans-boundary, and therefore international, since they are dispersed on long distances: for mercury, Keeler et al. have calculated that air transfers from China to USA are up to 25% of the US exposure (Keeler Gerald 2006).

Should these issues be considered at the bilateral or international level or even be considered at all? Part of the answer lies first in the identification and quantification of the portion of national environmental impacts related to economic exchanges (export activities and transport) and due to the trans-boundary transfers of pollutants between nations.

While there is a tradition of assessing environmental impacts of national consumption patterns by the consumption-environment community using input-output analysis, e.g. among others in Australia (Lenzen 1998), Denmark (Munksgaard, Pederson et al. 2000),

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[2] Dixit, A. K. and J. E. Stiglitz (1977). "Monopolistic competition and Optimum Product Diversity." American Economic Review **67**(3).

Sweden (Bergstedt , Eriksson et al. 1999), Switzerland (Kaenzig and Jolliet 2005) or in Europe (Tucker 2006), few of these studies consider however explicitly impacts in foreign countries. Due to time and data limitations, the overwhelming majority of studies assume identical technologies for a large number of countries (the rest of the world) and therefore do not account adequately for the wide differences in terms of emissions coefficients between countries, e.g. due to different energy sources and end-of-pipe technologies. As shown by Peters for Norway, a large part of emissions due to national consumption occurs however outside the national borders, especially for small open economies (Peters and Hertwich 2006). In this study and in others like in Ahmad (Ahmad and Wyckoff 2003) or Machado (Machado, Schaeffer et al. 2001), simplifications have been done using either trade models or multi-regional input-output models: they do not consider full exchanges between trade partners of the country under study. This practice is supported by (Lenzen, Pade et al. 2004), advocating that fully accounting for multilateral trade only slightly affect results. Such models are however not adequate to fully track environmental impacts due to the increasing share of triangular flows.

A proper understanding of the relationships, between consumers in developed countries and affected citizens in developing countries, due to these international production-consumption chains and related exchanges of goods and pollutants seems therefore to be explored with a joint worldwide economic and environmental model. .

TREI-C project

The here presented input-output model is part of the “Tracking environmental impacts of consumption: Linking OECD and developing countries for risk analysis and related pressure's alleviation" project, supported by the RUIG-GIAN (Geneva International Academic Network). It aims at quantifying the role played by Germany and USA, through consumption, in the environmental impacts in India and China. It builds up on interdisciplinary bases to develop a multi-region, multi-pollutant exchanges model providing a world vision of the transfer of pollutants embodied in goods and through the atmosphere. The model will report on environmental impacts due to atmospherical pollutants like sulfur, particles and dioxin and identify the links between three different actors: the producers of the goods (emitters of pollution), the benefiters of the goods (consumers) and the ones who eventually cope with the pollution (either one of the trade partners or a third party).

We focus in this paper on the allocation of pollutants embodied in goods during the production process, not considering household direct emissions, and for CO2 only. We introduce an analytical framework based on an interregional industrial ecology perspective and a 12 regions (single or aggregated countries) and 15 (+1) sectors world input-output model to track emissions worldwide. Objectives are to (a) quantify and localize total output and emissions due to household demand of each region, providing a spatially explicit industrial ecology view (b) identify the underlying flows responsible of these emissions in India and China (c) compare national emissions with emissions induced worldwide by domestic final demand. Both a producer and a consumer perspective are applied

Methodology

Description of the model

The TREI-C model is a generalized input-output model describing inter-industrial relationships and emissions of pollutants on a world scale. The objectives of the model are to quantify multipliers effects and the magnitude of total emissions in each region of the world for the satisfaction of a location-specific vector of final demand. Based on the IRIO (Interregional Input-Output) philosophy to account for multi-directional trade flows, it provides full interregional feedbacks and is adapted to the international context. The TREIC-C model represents flows of goods between countries and between sectors. An aggregated version of the model with three regions (A, B, rest of the World) and one supranational trade sector (TR) is presented in table 1. Capital letters are matrices and small letters are vectors.

[Insert table 1]

Compared to a one-region input-output model, the TREI-C is characterized by the split of exports into two categories (intermediary inputs and final demand). Exports to foreign sectors (Z^{de}) (usually part of final demand) are integrated into the intermediate matrix. Note that Z^{de} can also be interpreted as imports by country e from country d. Final demand for goods of country d ($y^{d.}$) is split into local (y^{dd}) and foreign final demands (y^{de}). Each final demand vector is the sum of Households, Government and Investment demand.

A supranational trade sector has been specified as a separate entity to (a) specifically model international transport (b) comply with UNFCCC emissions repertories accounting separately for international marine bunkers and international civil aviation (c) match specificities of the data source. This supranational entity is composed of three sectors, namely land, water and air transport sectors. Each element of the column TR represents the sales of a sector to the supranational trade entity, while the row TR represents the international trade margins.

The TREI-C intermediary matrix combines therefore both domestic (main diagonal) matrices and import matrices (from a specific country or from the supranational trade sector) covering all intermediary exchanges. It is a square matrix.

The basic equation of the input-output model becomes, for country *A*:

$$x^{A} = (Z^{AA} + Z^{AB} + Z^{AW})i + z^{AT} + y^{AA} + y^{AB} + y^{AW}$$

The first and fifth elements are domestic sales, elements 2 and 3 (6 and 7) are exports to foreign sectors, respectively final demand, while element 4 is sales to the supranational trade sector.

The input coefficient matrix A is:

$$A = Z\hat{x}^{-1}$$

The matrix A is composed of four different types of coefficients. First, the domestic input coefficients (diagonals), i.e. like in classical Input-Output models:

$$a_{ij}^{dd} = \frac{z_{ij}^{dd}}{x_j^d} \qquad , d = A, B, W$$

, where subscripts i, j are sectors i and j. Second, the interregional trade coefficients:

$$a_{ij}^{de} = \frac{z_{ij}^{de}}{x_j^e} \quad , d = A, B, W \;\; \& \;\; e = A, B, W \;\; \& \, e \neq d$$

, where the denominator is output of the receiving country. Third, supra-national trade coefficients:

$$a_i^{dT} = \frac{z_i^{dT}}{x^T} \quad and \quad a_j^{Td} = \frac{z_j^{Td}}{x_d^T}$$

Decomposing flows (Z), the basic equation becomes:

$$x^A = A^{AA}x^A + A^{AB}x^B + A^{AW}x^W + a^{AT}x^T + y^{AA} + y^{AB} + y^{AW}$$

Similar equations can be written for x^B, x^W and x^T and therefore A satisfies the basic input-output relationship. This decomposition allows us to evaluate the direct and indirect production in each region or entity (A, B, W, TR) linked to any kind of final demand. Multipliers can be calculated with the Leontief inverse:

$$x = (I - A)^{-1}y \quad \text{, where } y = (y^A + y^B + y^W + y^T)$$

A more complete description of the IRIO model is available in (Miller and Blair 1985), page 54.

Emissions allocation scheme

The underlying allocation scheme for attributing emissions to sectors and countries is a classical consumption (industrial ecology) perspective which relates all direct and indirect emissions along the production chain of a good (upstream emissions for energy and materials, manufacturing, transport, disposal) to the final consumer. It is extended to be spatially explicit.

The answer to the question “What is the magnitude of the emissions induced nationally and in foreign countries by the consumption of households from country A?” can be answered by post-multiplying the Leontief inverse by the diagonalized vector of household consumption from country A and pre-multiplying the result by the vector of emissions factors. Emissions factors are:

$$\hat{f} = \hat{e}\hat{x}^{-1}$$

For country A, total emissions (TE) due to its consumption are:

$$TE = \hat{f}(I - A)^{-1}\hat{y}^{\cdot A}$$

TE is a matrix where TE^{de} are emissions in country d induced by the demand from country A for final goods of country e.

Analytical framework: an interregional industrial ecology perspective

Adopting such a consumption perspective and taking advantage of the interregional framework, we can allocate emissions and output produced in each country according to their underlying flows. In addition to show the direct and indirect emissions for domestic and foreign consumption, we quantify the amount of emissions due to international feedbacks and triangular trade flows.

Underlying flows are separated into 6 categories and 2 sub-categories shown in figure 1, for country A. The first row represents households. The second row, the production of final goods, i.e. sold to households only. The third row is production of intermediary goods, i.e. not sold to households. Note that the same good can be either final or intermediary, according to its buyer. Numbers in brackets indicates flows induced by the flows having the same number without brackets, and which are not contributing to the emissions of country A.

[Insert figure 1]

Underlying flows are:

1. The production of final goods, locally consumed (direct emissions for domestic households): y^{dd}
2. The upstream production chain (intermediary goods) of these final goods (indirect emissions for domestic households):
   a) Domestic upstream chain: not accounting for intermediary imports linkages

   $$[(I - A^{dd})^{-1} - I]y^{dd}$$

   b) International upstream chain: production of intermediary goods due to intermediary imports linkages

   $$[H^{dd} - (I - A^{dd})^{-1}]y^{dd} \qquad , H^{dd} = [(I - A)^{-1}]^{dd}$$
3. The production of final goods, exported (direct emissions for foreign households):

$$y^{de}$$

4. The upstream production chain (intermediary goods) of these exported final goods (indirect emissions for foreign households):
   a) Domestic production chain: not accounting for intermediary imports linkages

   $$[(I - A^{dd})^{-1} - I]y^{de}$$

   b) International production chain: production of intermediary goods due to intermediary imports linkages

   $$[H^{dd} - (I - A^{dd})^{-1}]y^{de}$$

5. The production of intermediary goods, exported for the production of imports of final goods (indirect emissions for domestic households)

   $$H^{de}y^{ed} \qquad , H^{de} = [(I - A)^{-1}]^{de}$$

6. The production of intermediary goods, exported for the production of imports by a third country, i.e. triangular trade (indirect emissions for foreign households)

   $$H^{de}y^{eg} \quad , g \neq d$$

   Adding 1, 2 and 5 provides emissions for domestic consumption, and adding 3, 4 and 6 show the emissions for foreign consumption, which can be computed for each country separately.

Scenarios

We will investigate 12 scenarios, one for each region, to:

a) Quantify and localize the economic production and CO2 emissions induced by the households' demand of each of the 12 regions for products of the whole world.

b) Allocate emissions and output induced in China and India to these 12 households' demands, according to their underlying flows.

Scenarios are only run with households' demands; therefore the y vector includes only household's demand in the rest of the document.

Data Sources and Preparation

Economic data

TREI-C is based on the GTAP database v.6. GTAP is a global database representing the world economy as flows of 57 goods and services between 87 regions, in millions U.S. dollars for 2001 (Dimaranan 2006). Both input-output flows within each region and bilateral international trade flows are included, measured both at tax-free and tax-paid prices. The dataset is coherent on a world level and calibrated on macro-economic and trade data from the World Bank. Input-Output tables are adapted to conform to the GTAP format: cleaning, aggregation to 57 sectors and disaggregation when required (mainly primary goods and food sectors) using a "representative table". "Composite tables" are created for regions without original tables. Input-output tables are then updated to conform to the macro and trade data and re-exports are re-allocated to the destination country. International transport margins are based on US data and international trade in services is modeled according to the balance of payment database from the IMF.

The main interest of using the GTAP database is coherence: international trade data is already harmonized on a world scale. Thanks to world coverage, the Rest Of the World region is a detailed aggregated region which can be split as required by the different scenarios. This malleability seems essential when working at world scale to fully capture the elements of interests without being lost in an overwhelmingly large residual category. Since our focus is on the geographic distribution of emissions we have preferred to have a less monolithic bloc than a unique “rest of the world” region and have added 7 geographically homogeneous regions to our 4 countries of interest (China, Germany, India, and USA). The compromise, for the time being, has been to reduce the number of sectors, resulting in a flow matrix of 181x181 sectors (15 sectors x 12 regions + 1 supranational transport sector). Sectors include energetic sectors (1), transport sectors (4), extractive industries and agricultural sectors (5), manufacturing sectors (4) and services (2). The model used here has been designed for a study of the textile industry, hence the resulting sectoral and country classification. A list of regions and of sectors in provided in table 2.

[Insert table 2]

Due to its characteristics, the GTAP database seems especially useful for modeling and understanding production chains in a globalised economy. It is however, in its original form, less adapted to specific country studies, due to the varying quality of the input-output tables (various years and proprietary scaling procedures). Benefitting from GTAP advantages and reducing uncertainties requires therefore an automated data preparation and model building process as well as extensive GTAP readings since definitions of prices, sectors and the way to consider tourism (among others), are somewhat different from national accounting rules.

Input-Output analysis with the GTAP database requires some initial preparation steps. Due to the coherent nature of the database there was neither a need to re-classify goods, nor to apply any currency conversion schemes but to deal with the estimation of aggregated regions domestic matrices, trade flow matrices, supranational trade sector and valuation.

Estimation of domestic matrices for aggregated regions

International trade (exports and imports) between countries of the same aggregated region has to be re-integrated into the regional matrices. We distributed exports within the domestic intermediary and final demand matrices proportionally to existing row elements. Import matrices are also corrected by subtracting exports in the same way. Each aggregated region has therefore domestic, export and import matrices different from the original GTAP matrices.

Valuation

Intermediary imports and exports are integrated within the intermediary matrix. For equilibrium reasons, and because they are represented with the same sub-set of coefficients, exports from country A to B are to be exactly equivalent to imports from country B from A. This is possible with the use of basic prices in the whole intermediary matrix. Since exports and imports prices are, by definition, different: FOB and CIF respectively, we have split each import price into its various components, provided in GTAP. The price of imports coming from A in B (P_m^B) is equal to the price in A plus export taxes, international trade margins and import taxes.

$$P_m^B = P_{dom}^A + T^{xA} + z^{TA} + T^{mB}$$

The decomposition is provided in GTAP. This step results in the addition of three rows to the flow matrix: taxes and international transport, the last one being integrated, as an additional sector, into the intermediary matrix. We do not however integrate export and import taxes into the intermediary matrix.

Estimation of the supranational trade sector

While it is possible to get data on the supply of international trade services by each country, there is a lack of information on the nationality of the provider of international trade service for each of the imported goods. The GTAP approach consider that each country provides international trade transport to an international pool, which then supply transport services to each country. We extend this approach by explicitly modeling the supranational trade sector. The intermediary flow matrix is extended by splitting the inputs of the transport sector into domestic and international, based on the share of each kind of transport into the total output of the transport sector. The assumption is that the structure required to deliver both types of transport are the same, which seems adequate providing that we model separately air, water and land transport. This additional column match the additional row added by including international trade margins.

Estimation of trade flow matrices

GTAP provides a unique import matrix for each country specifying the quantity of each imported commodity used by domestic sectors.

Based on the assumption that each imported good is a weighted average of imports from all regions of origin, country-specific imports matrix are generated. The structure of imports regarding origins is therefore specific to each imported good, whatever is the importing sector. For example, for imports of country A, 2/3 of good i is imported from region B and 1/3 from region W and this for all sectors.

Environmental data

Emissions of CO2 presented here are emissions available from GTAP, calculated with physical data from the GTAP energy database and IPCC emissions factors. A regional comparison with IEA publications (International Energy Agency 2006) reveals differences ranging from 2 to 5% on average, which is in the usual uncertainty range for CO2 emissions

Results & discussion

The localization of output and CO_2 emissions generated to satisfy the various households' final demands is presented in table 3. Column 1 (2) shows, for example, total output (CO_2 emissions) generated by the US households in the various countries (in rows).

[Insert table 3]

The largest shares of outputs and emissions are on the diagonal for all regions: domestic output and emissions are dominant. Proportions of output are however largely different across regions, ranging from 88% for USA, while for East Europe and Oceania, output generated in foreign countries accounts for more than 20% of total output. It accounts for even more than 25% of total output for Germany, Africa and the Rest of the world, and even more than 35% for South-East Asia. Regarding CO_2, a large part (more than 40%) of emissions induced by OECD Europe and German consumers is emitted in foreign countries. The variation observed in proportions can be due both to energy resources and the energy base of electricity production but equally to the size, openness of the economies and the type of traded goods.

Comparing CO_2 and output shares, regions can be classified in two categories: regions with a domestic output proportion larger or smaller than the domestic CO_2 proportion. In the first case, output generated domestically is less CO_2 intensive than output generated in foreign countries. This is the case for USA, Germany, OECD EU, East Asia and Latin America. The gap between output and emissions shares can be large (22% for OECD Europe). Results therefore show that a large part of emissions due to consumption can occur in other regions and that emissions can have a much larger foreign share than output measured in dollars, especially for open developed countries. A multi-country model with a detailed rest of the world seems therefore more adapted than single-country models or models which are too aggregated from a spatial perspective.

A sectoral view of the world emissions for satisfying the German households demand is proposed in figure 2. Sectors are presented aggregated: primary sectors (sectors 1-5), secondary sectors (sectors 6-9), electricity generation (sector 10), transport (11-13 + international transport), and services (14, 15). Half of the emissions are due to electricity generation, mainly in Germany. A bit less than a third is due to transport of which 43% in Germany. The majority of emissions from the primary and secondary sectors are occurring outside Germany. The distribution between local and foreign emissions is therefore different for each sector.

[Insert figure 2]

Comparing now emissions induced by household consumption[3] worldwide with the total of national CO2 emissions, it can be inferred from results that allocating emissions from a territorial or a consumption perspective provide different results, especially for countries with a weak domestic consumption and high exports. Results are presented in figure 3 for the 12 regions. Assuming a large (10%) error margin, it can be saide that two regions (Germany and OECD Europe) induce more emissions worldwide for their consumption than what they emit. The majority of regions emits more than what they need for their consumption. This is especially striking for China which emits twice as much. Interestingly, there is a similarity of both measures for the USA.

[Insert figure 3]

The 4 countries of interest (USA, Germany, China and India) have a large share (47.3%) of world expenses for consumption and jointly induce 44.5% of emissions generated for household consumption, which is equivalent to 28.9% of total world national emissions (without accounting for international trade). These countries are in majority relying on domestic output and domestic emissions (table 2) for satisfying their consumption, even when accounting for multilateral and triangular trade flows. As a result, while they cover almost half of the emissions induced by consumption, their direct cross-impacts are quite low in percentage terms: only 3.2% (4%) of emissions for American (German) demand are emitted in China and 0.4 % (0.7%) in India. Emissions generated in China and India for the German and American demand are however equivalent to 10% of the emissions induced

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[3] Including in this case direct emissions by Households

by the Chinese and Indian consumption and to 30% of the emissions generated for the German consumption worldwide.

On the basis of these first results, it seems justified to aim at tracking environmental impacts, especially from rich and open countries into poor, exported oriented ones. Concentrating on China, Germany, India and USA seems also adequate due to their aggregate share of world emissions. However, the rest of the world cannot be ignored since the direct links are quite weak. This result is confirmed by the application of the proposed analytical framework for CO2 emissions in China and India. Results of the decomposition proposed here consider only emissions due to the production of goods for household consumption and therefore accounts only for 67.5% of total emissions (32.5% is due to investment and government spending) in India, and 48% in China. Direct emissions by households, e.g. fuel burning at home or while driving, are also not part of this total.

While the pictures for China and India are different regarding the proportion of emissions due to exports (30% for China and 11.5% for India) the structural pattern is quite similar regarding the type of underlying flows (figure 4). First, emissions for exports are in majority due to the role of both countries in triangular trade, i.e. as upstream trade partner. Both for Germany and USA, around 60% of their induced emissions in China and India are linked to triangular trade flows. Second, the international feedback loops are low.

[Insert figure 4]

The bulk of Indian emissions are to satisfy domestic household demand (88.5%) and therefore only 11.5% are due to exports. A third of the former are direct emissions for the production of final goods (1) and two-thirds (2a) are linked to the domestic upstream chain (figure 5). Both emissions due to the production of intermediary goods for the international production chain linked to Indian household consumption (2b and 5) are almost insignificant. International feedback loops in India for domestic consumption are therefore very low. Such results meet expectations since India abandoned only recently import-substitutions strategies and linkages with the rest of the world are still limited. Emissions related to Indian exports in its role of exporter of final goods (3, 4a, 4b) are lower than emissions related to its role of provider of intermediary goods to the rest of the world (6). In other terms India emits more CO_2 as upstream trade partner in triangular trade than as provider of final products to foreign consumers.

[Insert figure 5]

China is much more oriented towards exportations and this is clearly reflected in the patterns of CO_2 emissions: 30% are for exports (10% for exports to USA and Germany only). These emissions are six times higher than emissions for exports generated in India and slightly larger than emissions induced by the German demand worldwide. Similarly to India, more than half of these emissions are for exports of intermediary products linked to the upstream position of China in triangular trade and international feedback loops are low.

Since tracking environmental impacts requires accounting for triangular trade flows, a model with full trade seems required.

Are these numbers somehow representative of real life? According to the number of Computable General Equilibrium simulations run with the GTAP database, and the WTO discussion papers (Nordas 2004), they seem to be reliable. However, as expressed earlier in this paper, a closer look at Input-Output tables and their updating procedure show that homogeneity at world level is achieved at the expense of the quality of individual tables: outdated table are sometimes used which is particularly detrimental for rapidly changing economies like India and China. With newer tables, international feedback loops would probably be higher[4]. In addition, since China and India are experiencing a rapid increase in exports (55% (75%) for India (China) between 2003 and 2005) (WTO 2006) and since the energy bases will apparently remain carbon based (International Energy Agency 2006), total emissions for exports in the current and future years are already much higher than the proposed numbers. The here presented results are therefore probably in the lower range. It should also be noted that the similarity of patterns between China and India could be partly explained by the publication dates of these tables (India: 1993, China: 1997) and by the fact that they do not capture adequately the different structural changes having occurred in both countries since this date.

Conclusion

Tracking Environmental Emissions of Consumption worldwide seems feasible within the TREI-C analytical framework. Results for CO2 emissions with a 12 regions and 15(+1) sectors show that up to 47% of emissions linked to household demand, for Germany, is generated outside domestic boundaries, and that the picture for emissions is widely different between countries and follows only loosely the pattern of output. Regarding the allocation of CO2 emissions in one country according to underlying flows, emissions

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[4] Assuming everything else being constant

generated in India and China are very linked to production for domestic consumption. 30% of emissions in China are however generated for exports. A worldwide model seems therefore required to assess adequately the size and spatial distribution of emissions linked to consumption, particularly for open economies like Germany. This requirement is strengthened by the fact that the major part of emissions in China and India are induced by triangular trade, where both countries are producers of intermediate goods in the upstream production chain of final goods sold by and to third countries. Open questions regarding the update procedure of older tables to adequately reflect structural changes remain open for rapidly growing economies like India and China.

In the next steps of the TREI-C project, non-global pollutants e.g. sulfur and particulates will be included and the link between this input-output world model and a world diffusion model, for tracking the transfer of local pollutants trough the air, will be established. Further research could be orientated to the modeling of rapidly changing economies, like China and India, to increase accuracy of model results.

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Figures and tables

Table 1 TREI-C interregional Input-Output matrix, extended with CO2 emissions

		Intermediate demand				Final demand			Total output	CO$_2$
		A	B	W	TR	A	B	W		
Intermediate demand	A	Z^{AA}	Z^{AB}	Z^{AW}	z^{AT}	y^{AA}	y^{AB}	y^{AW}	x^{A}	e^{A}
	B	Z^{BA}	Z^{BB}	Z^{BW}	z^{BT}	y^{BA}	y^{BB}	y^{BW}	x^{B}	e^{B}
	W	Z^{WA}	Z^{WB}	Z^{WW}	z^{WT}	y^{CA}	y^{CB}	y^{CC}	x^{W}	e^{W}
	TR	z^{TA}	z^{TB}	z^{TW}	z^{TT}	y^{TA}	y^{TB}	y^{TW}	x^{T}	e^{T}
EX tax		T^{xA}	T^{xB}	T^{xW}						
IM tax		T^{mA}	T^{mW}	T^{mW}						
Primary inputs		P^{A}	P^{B}	P^{W}	P^{T}					
Total input		x^{A}	x^{B}	x^{W}	x^{T}					

A, B, W: 3 countries
TR: Supranational trade sector
Z^{dd}: Domestic table, d = A, B, W
Z^{de}: Export table from region d to region e, e = A, B, W
z^{Td}: International trade services sold to country d
z^{dT}: Intermediate inputs sold by country d to the international trade sector
$Z_{(3n+1),(3n+1)}$: Inter-industry, Inter-regional flows of goods.
T^{xe}: Export taxes for imported inputs of country e
T^{me}: Import taxes for imported inputs of country e
P^{d}: Primary inputs in country d
x^{d}: Total output
e^{d}: Emissions from region d
y^{de}: Final demand in region e for the goods of region d

Table 2 Regions and sectors of the TREI-C model for textile

Regions (12)	Sectors (15 +1)
Germany	Cotton production
USA	Other primary sectors
China	Extraction: coal
India	Extraction: gaz
OECD Europe	Extraction: oil
East Europe & ex-USSR	Textiles manufacturing
East Asia	Wearing manufacturing
South-East Asia	Chemicals
Oceania	Manufactures: others
Latin America	Electricity
Africa	Land tranport
Rest of the World	Sea transport
	Air transport
	Trade
	Services others
International transport	

Table 3 Distribution of total output and CO2 emissions to satisfy the column household final demand (% in columns)

	From:											
	USA		Germany		China		India		OECD Europe		EE & ex-USSR	
In:	USD	CO2	USD	CO2	USD	CO2	USD	CO2	USD	CO2	USD	CO2
USA	88.3	81.6	3.2	4.2	1.9	0.8	1.4	0.5	3.3	5.3	1.9	0.7
Germany	0.7	0.5	70.8	53.9	1.0	0.2	0.7	0.1	4.6	3.5	4.4	0.7
China	1.2	3.2	1.4	4.0	83.3	92.7	0.7	0.7	1.2	3.9	1.1	0.8
India	0.1	0.4	0.3	0.7	0.1	0.2	88.1	93.7	0.3	0.9	0.2	0.2
OECD EU	2.4	1.8	13.1	9.5	2.3	0.5	2.8	0.7	81.4	59.4	8.4	1.7
East EU & ex-USSR	0.4	1.4	4.3	12.5	1.0	1.0	0.6	0.6	2.4	8.7	79.6	92.1
East Asia	2.2	1.2	2.4	1.5	7.0	1.3	1.4	0.3	2.2	1.7	1.4	0.3
SE Asia	0.7	1.2	1.0	2.0	1.3	0.8	1.1	0.6	0.9	2.2	0.6	0.3
Oceania	0.1	0.3	0.2	0.5	0.4	0.2	0.3	0.2	0.3	0.7	0.1	0.1
Latin America	1.5	1.6	0.7	1.1	0.4	0.2	0.8	0.5	0.8	1.4	0.6	0.2
Africa	0.3	0.6	0.6	1.4	0.2	0.2	0.7	0.5	0.9	2.4	0.3	0.2
ROW	1.9	4.0	1.3	2.6	0.8	0.6	1.2	0.8	1.2	3.0	0.8	0.5
Intl transport	0.2	2.4	0.5	6.0	0.3	1.2	0.3	1.0	0.5	6.7	0.6	2.1

	East Asia		SE Asia		Oceania		Latin America		Africa		ROW	
In:	USD	CO2	USD	CO2	USD	CO2	USD	CO2	USD	CO2	USD	CO2
USA	2.8	4.4	6.1	3.5	3.7	3.1	7.0	6.4	3.3	1.9	9.0	5.0
Germany	0.8	0.7	1.9	0.7	1.3	0.5	1.1	0.7	2.1	0.7	1.8	0.6
China	3.2	10.3	3.3	4.8	2.2	3.2	0.9	2.1	1.6	2.0	1.8	2.3
India	0.1	0.5	0.5	0.9	0.2	0.4	0.1	0.4	0.6	0.8	0.6	0.8
OECD EU	2.6	2.7	6.6	2.7	4.7	2.3	3.6	2.5	8.9	2.8	6.3	2.2
East EU & ex-USSR	0.5	2.1	1.2	2.0	0.6	1.2	0.7	2.0	1.4	2.1	1.5	2.4
East Asia	85.9	65.1	10.6	3.1	3.9	1.3	2.2	1.1	2.5	0.7	3.3	1.0
SE Asia	1.5	3.3	64.2	72.6	1.7	1.8	0.6	0.9	1.0	0.9	1.2	1.1
Oceania	0.5	1.2	1.1	1.1	79.6	81.2	0.2	0.3	0.4	0.4	0.4	0.4
Latin America	0.4	0.7	0.8	0.6	0.5	0.4	82.1	77.7	0.8	0.5	1.0	0.7
Africa	0.2	0.7	0.5	0.6	0.3	0.5	0.3	0.6	75.2	82.2	0.5	0.5
ROW	1.1	3.2	2.3	2.7	1.0	1.3	0.8	1.6	1.5	1.5	71.9	79.9
Intl transport	0.4	5.1	0.8	4.8	0.4	2.7	0.4	3.6	0.7	3.6	0.6	3.2

Figure 1 TREI-C analytical framework with 2 countries and 2 goods

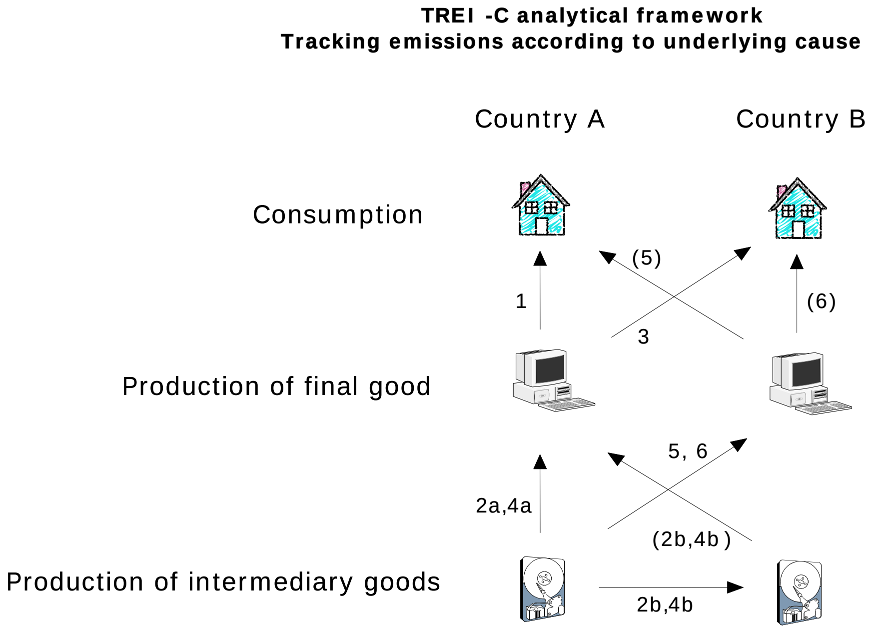

Figure 2 Total CO2 emissions induced worldwide, per sector, by the German household demand

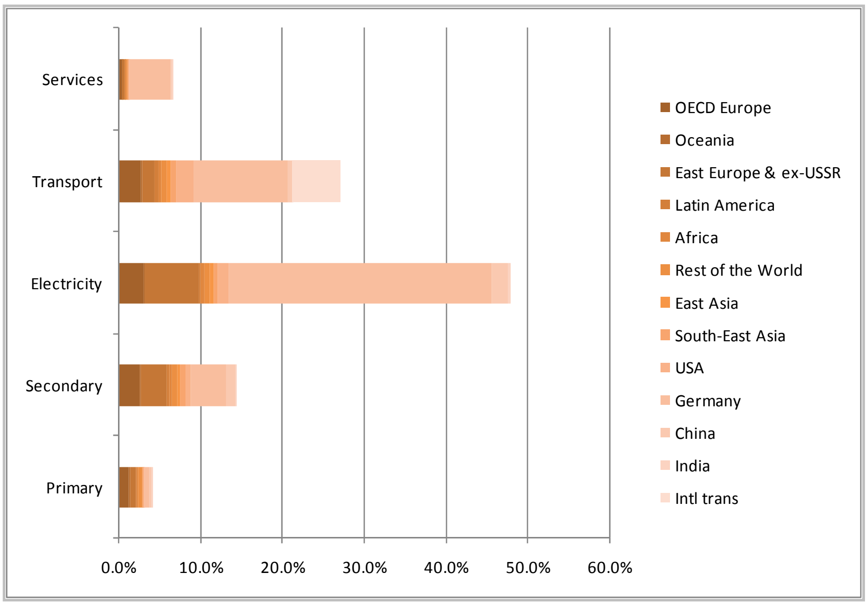

Figure 3 Ratio of CO2 emissions induced by households' consumption worldwide to national emissions. An error band of 10% around unity is shown in red.

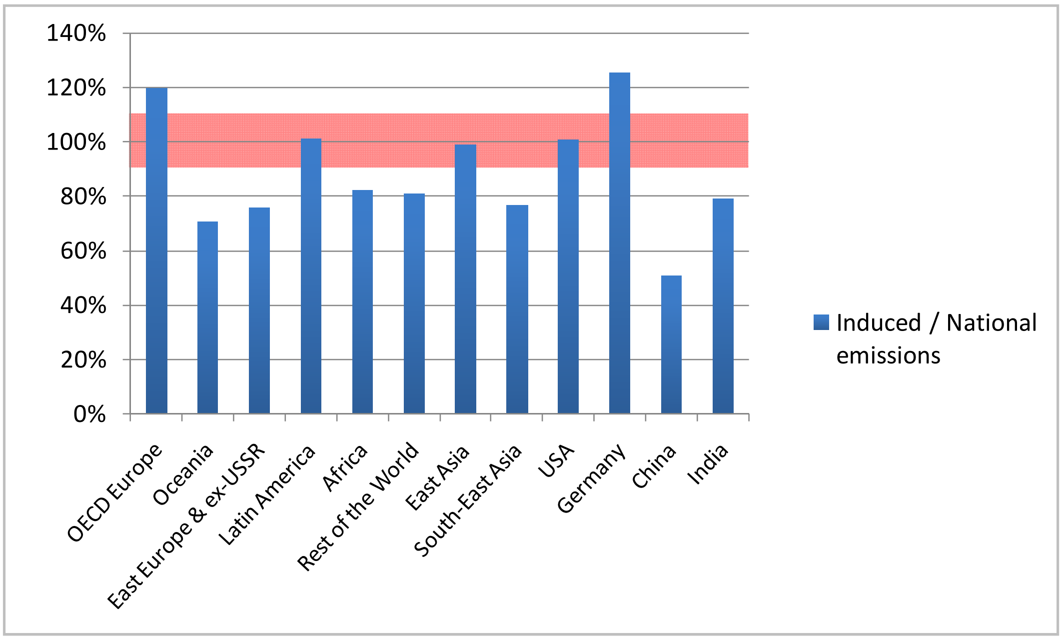

Figure 4 Proportion of CO2 emissions for exported final goods

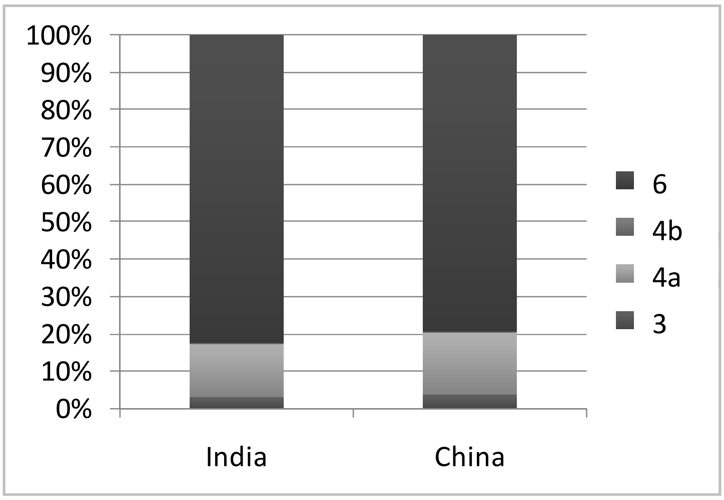

Figure 5 Proportion of CO2 emissions for locally consumed goods by households