CO_2 emissions production-based accounting vs consumption: Insights from the WIOD databases

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Abstract

The Kyoto protocol has defined the accounting framework for industrial GHG emissions on production-based accounting. Since then, international negotiations of Climate Change did not make significant progress on new GHG emissions ceiling. For numerous non-Annex 1 countries, an accounting framework based on consumption would be advantageous and could help in international negotiations. Similarly, in the European Union, criticisms arise against European Climate Change policy arguing that they mainly lead to carbon leakage. Indeed, the de-industrialisation of the developed countries in favor of developing countries led to a displacement of the pollutant activities towards developing countries without a similar reduction of manufactured goods consumption in developed countries. This paper aims to quantify CO_2 emissions embodied in trade and displays the dynamics of CO_2 emissions counts with regard to production and consumption using WIOD databases: WIOD Input-Output Tables and WIOD Environmental Accounts.

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1 Introduction

Since the awareness and large scientific consensus on Global warming and its anthropogenic origins, it has become fundamental to identify and quantify the Greenhouse Gases (GHG) ensure as the sources of the Global warming. The GHG inventory is essential to ensure commitment and consequently facilittate the monitoring of emissions' changes. Thereby, from 1995, the Task Force on the National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change published a huge report on the Guidelines for National Greenhouse Gas Inventories (IPCC [1995]) which were completed and amended several times (IPCC [1997, 2000, 2007]). The methodology used for the National Inventory Report of the IPCC obviously uses, for practical reasons, the production-based GHG accounting framework. Indeed, "*national inventories include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction*" (IPCC [2007]).

This framework counts the GHG emissions as the national emissions coming from domestic production which can lead to a biased view of national GHG emissions. By definition, the international activities, such as international transportation, pose a problem of allocation. Its geographical definition hides the GHG emissions embodied in trade. In addition, the production-based GHG inventory can give misleading insights on the mitigation effort within a specific geographical area and raises the question of carbon leakage. Carbon leakage is defined as "*the increase in emissions outside a region as a direct result of the policy to cap emission in this region*" (Reinaud [2008]).

Numerous authors have already discussed these issues[1]. For instance, Peters and Hertwich [2008a] distinguish three approaches for GHG accounting. Two approaches use production-based accounting and differ by a geographical definition or an economic one whereas the last one uses consumption-based accounting. Even if the distinction between both production-based approaches could be useful for several accounting problems such as international transportation and Carbon Capture and Storage (CCS) (Peters and Hertwich [2008a]), the consumption based accounting fully counterbalances the unilateral responsibility of the producer for the pollution inherent to the production-based GHG inventory.

With the consumption-based accounting for GHG, the emissions are computed as follows:

$$GHG^{cons} = GHG^{dcons} - GHG^{exp} + GHG^{imp} \tag{1}$$

National GHG emissions (GHG^{cons}) come from GHG emissions from domestic final consumption (GHG^{dcons}) to which is added GHG emissions embodied in the importations (GHG^{imp}) and reduced by GHG embodied in the exports (GHG^{exp})[2].

[1] See *e.g.* Wyckoff and Roop [1994], Kondo et al. [1998], Lenzen [1998], Battjes et al. [1998], Munksgaard and Pedersen [2001], Ahmad and Wyckoff [2003], Ferng [2003], Peters and Hertwich [2006].

[2] We defined « embodied emissions » as the emissions resulting from the production of the goods exported or/and imported.

The beauty of this approach is that it avoids international trade distortion in the GHG emissions accounting and avoids the consideration of carbon leakage as a positive effect on emissions monitoring. Furthermore, GHG accounting options have an important impact in defining binding commitments across countries.

Numerous countries are reluctant to pledge binding commitments as it was the case with the Kyoto Protocol and, even more so, these commitments will be based on GHG emissions counted using production-based approach. Indeed, in the light of existing studies, the GHG emissions measured either with the production-based GHG inventory or the consumption-based, the results can differ substantially. Literature comparing production-based and consumptions based GHG inventories have shown non negligible gaps between both GHG emissions inventories. Generally, developed countries show higher GHG emissions than developing countries (Peters and Hertwich [2008b])[3] with an increasing gap such as the case for China (Xu et al. [2011]).

Norway is a good example of the problem of commitment when inventory is based on production-based GHG emissions; this example is already developed in (Peters and Hertwich [2008a]). An important share of the Norwegian economy is based on fossil fuels quarrying which is a pollution intensive activity. Nevertheless, Norway is only consuming a very small part of its fossil fuels, a large majority of which is exported. Thereby, the only mitigation policy for Norway to reduce its GHG emissions, when they are counted with the production-based method, is a reduction of fossil fuels exports. So, with the production-based GHG inventory, Norway must reduce its economic activity to reduce its emissions whereas with the consumption-based GHG inventory, Norway could continue to export fossil fuel[4].

The methodology used to count GHG with consumption-based approach, is based on Input-Output Analysis (IOA) applied to environmental issues (Leontief [1970]). The Multi-Regional Input-Output analysis (MRIO)[5], an extension of the IAO, is the main methodological tool used to implement consumption-based GHG inventory in several region or countries. And the quality of scope the MRIO analysis will strongly be dependent on the availability of the relevant data. This methodology is used in this study.

In this study, we use the WIOD databases[6] to count national GHG emissions with the consumption-based inventory for 41 countries from 1995 to 2009. In the first part, we develop the methodology used for the computation of the national

[3] See *e.g.* Pan et al. [2008] or Xu et al. [2011] for studies on China, Peters and Hertwich [2008b] for Annex B and non-Annex-B countries as well as Davis et al. [2011] for multinational study.

[4] Obviously, the demand for fossil fuels from foreigner countries could diminish and consequently reduce the Norway exports. But, in term of national binding commitment, Norway could pledge important effort without *directly* endanger a large part of its domestic economic activity.

[5] See Peters [2007] for details explanation of the MRIO analysis in the case of GHG emissions.

[6] The World Input-Output Databases is a project funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities (www.wiod.org).

CO_2 emissions with the consumption-based inventory. The second part displays and analyzes the results. It also compares the results with the production-based GHG inventory. Finally the last section compares, summarizes and puts in perceptive the results with future potential developments.

2 Methodology

2.1 Databases

We use the World Input-Output Databases (WIOD) as unique sources of data. The WIOD databases provide detailed data on trade and GHG emissions for 41 countries and 35 economic sectors. The database on "*Environmental Accounts*" (Villanueva et al. [2009], Neuwahl et al. [2010]), gives GHG and CO_2 emissions for 37 sectors (36 production sectors and one representative household - see Tables 2 and 3 in Annex)[7]. Those emissions are counted using the production-based approach from 1995 to 2009 for 41 countries (see Table 4 in Annex). The second database is World Input-Output Tables (WIOTs, Erumban et al. [2010]) which cover the same 41 countries and the same economic sectors[8]. The WIOTs have been constructed for 14 years, from 1995 to 2009. Figure 1 displays the structure of the WIOTs.

Fig. 1: WIOTs structure

	$IND_{AUS,01}$	$IND_{AUS,02}$	.	.	.	$IND_{CD,SD}$	.	.	.	$IND_{RoW,35}$	$IND_{RoW,35}$	$CONS_{AUS}$	.	.	.	$CONS_{RoW}$	PROD
$IND_{AUS,01}$	$CI_{AUS,01,AUS,01}$	.		.	.	.		.	.	.	$CI_{AUS,01,RoW,35}$	$CONS_{AUS,01,AUS}$		.	.	$CONS_{AUS,01,RoW}$	$\sum$
$IND_{AUS,02}$	$CI_{AUS,02,AUS,01}$	.		.	.	.		.	.	.	$CI_{AUS,02,RoW,35}$	$CONS_{AUS,02,AUS}$		.	.	$CONS_{AUS,02,RoW}$	$\sum$
.	.		.			.			.		.	.	.			.	.
.	.			.		.	.				.	.		.		.	.
.	.				.	.					.	.			.	.	.
$IND_{CP,SP}$	$CI_{CP,SP,AUS,01}$	.		.	.	$CI_{CP,SP,CD,SD}$		.	.	.	$CI_{CP,SP,RoW,35}$	$CONS_{CP,SP,AUS}$		.	.	$CONS_{CP,SP,RoW}$	$\sum$
.	.		.			.			.		.	.	.			.	.
.	.			.		.		.			.	.		.		.	.
.	.				.	.	.				.	.			.	.	.
$IND_{RoW,34}$	$CI_{RoW,34,AUS,01}$	.		.	.	.		.	.	.	$CI_{RoW,34,RoW,35}$	$CONS_{RoW,34,AUS}$		.	.	$CONS_{RoW,34,RoW}$	$\sum$
$IND_{RoW,35}$	$CI_{RoW,35,AUS,01}$	.		.	.	.		.	.	.	$CI_{RoW,35,RoW,35}$	$CONS_{RoW,35,AUS}$		.	.	$CONS_{RoW,35,RoW}$	$\sum$
VA	$VA_{AUS,01}$	$VA_{AUS,02}$	.	.	.	$VA_{CD,SD}$	.	.	.		$VA_{RoW,35}$						
PROD	$\sum$	$\sum$	.	.	.	$\sum$	.	.	.	$\sum$	$\sum$						

Where:

- $IND_{CP,SP}$: the Industry SP in the country CP.
- VA is the value added, $PROD$: the production, CI: the intermediate consumptions and $CONS$: the final consumptions which are divided between:
  - final consumption expenditure by households (H),
  - final consumption expenditure by government (GOV),

[7] In this first version of the study, we only focus on CO_2 emissions, a similar analysis on GHG emission will be done later.

[8] The version of WIOTs used is the April 2012 ones.

  - gross fixed capital formation (INV),
  - and changes in inventories and valuables ($STOCK$).

- CP indicates the country where the good is produced and SP the sector
- CD indicates the country where the good is consumed and SD the sector.

In this study, as the WIOTs include bilateral trade between each country, it is possible to use them directly without transformation or completion. Nevertheless, as presented above, the WIOTs distinguish four different final demands which are not dispatched between industries[9] but only between countries. Therefore, we aggregated those final demands except for "*changes in inventories and valuables*" that are considered as null. Thus, it seems relatively difficult to allocate the "*changes in inventories and valuables*" insomuch as it results from past productions. To remain consistent, the total output has been computed assuming that "*changes in inventories and valuables*" are null.

2.2 The MRIO method

The MRIO method is the most popular tool used by scientists to assess the impact of trade on environmental issues such as GHG emissions. And it allows an analysis at a multi-regional level (intra- or inter-national)[10]. In this study, we have applied the MRIO method developed by Peters [2008] that allow the distinction between trade for final expenditures and intermediate consumptions. The MRIO model can be represented by:

$$x = Ax + f \tag{2}$$

Or in a detailed version,

$$\begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \vdots \\ x_N \end{pmatrix} = \begin{pmatrix} A_{11} & \cdots & A_{1v} & \cdots & A_{1N} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ A_{m1} & \cdots & A_{mv} & \cdots & A_{mN} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ A_{N1} & \cdots & A_{Nv} & \cdots & A_{NN} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \vdots \\ x_N \end{pmatrix} + \sum_{m=1}^{N} \begin{pmatrix} f_{1m} \\ \vdots \\ f_{vm} \\ \vdots \\ f_{Nm} \end{pmatrix} \tag{3}$$

Where, x_m is the vector of total output in country m with $m = v = 1, ..., N$, A_{mv}: the inter-industrial matrix between country m and country v, where the elements are measured per unit of output, and $f_{v,m}$ is a vector of the final demands in country m addressed to country v.

Starting from 2, the output can be calculated in terms of final consumption:

[9] This remark is valid for gross fixed capital formation which could be allocated with intra-industrial exchange matrix.

[10] For a survey of MRIO method used for environmental impact assessments see *e.g.* Wiedmann et al. [2007], Wiedmann [2009]. And see *e.g.* Peters [2007], Weber [2008], Lenzen et al. [2010] for discussion on MRIO method.

$$
\begin{aligned}
x - Ax &= \sum_m f_m && (4)\\
x\,(I - A) &= \sum_m f_m && (5)\\
x &= \sum_m (I - A)^{-1} f_m && (6)\\
x &= \sum_m y_m && (7)
\end{aligned}
$$

Now, breaking down equation 6 into domestic output used for domestic final consumption of country m ($y_{m,m}$) and domestic output of country m used for foreign final consumption of country v ($y_{m,v}$):

$$
\begin{aligned}
y_{m,m} &= (1 - A_{m,m})^{-1} f_{m,m} && (8)\\
y_{m,v} &= (1 - A_{m,v})^{-1} f_{m,v} && (9)
\end{aligned}
$$

Thus, total output in country m is:

$$
x_m = \sum_{v=1}^{N} y_{m,v} \qquad (10)
$$

Thereafter, emissions of country m for domestic consumption ($E_{m,m}$) and emissions of country m export in country v ($E_{m,v}$) are determined using the environmental technology of country m (e_m: the emission factor *i.e.* emissions per unit of output):

$$
\begin{aligned}
E_{m,m} &= e_m y_{m,m} && (11)\\
E_{m,v} &= e_m y_{m,v} && (12)
\end{aligned}
$$

Thereby, the matrix of embodied emissions can be drawn as:

$$
\begin{pmatrix}
E_{11} & \cdots & E_{1v} & \cdots & E_{1N}\\
\vdots & \ddots & \vdots & \iddots & \vdots\\
E_{m1} & \cdots & E_{mv} & \cdots & E_{mN}\\
\vdots & \iddots & \vdots & \ddots & \vdots\\
E_{N1} & \cdots & E_{Nv} & \cdots & E_{NN}
\end{pmatrix} \qquad (13)
$$

Where the domestic emissions in country m are $E^d = E_{mm}$, emissions embodied in exports in country m are $E^{exp} = \sum_{v \neq m} E_{mv}$ and emissions embodied in importations of country m are $E^{imp} = \sum_{m \neq v} E_{mv}$.

Finally, national consumption-based CO_2 emissions are computed as: $E^{cons} = E^d + E^{imp} + E^H$, with E^H: national emissions coming from direct households' consumption, whereas national production-based CO_2 emissions are computed as: $E^{prod} = E^d + E^{exp} + E^H$.

We have applied this methodology to each country and each year and it results in 14 matrices of dimension 41x41.

3 Results

3.1 Analysis

Figure 1 displays the calculation of CO_2 emissions with the both methods from 1995 to 2009 for 6 aggregated areas[11] (see Table 4 in Annex for aggregation details).

Tab. 1: CO_2 production-based accounting vs consumption

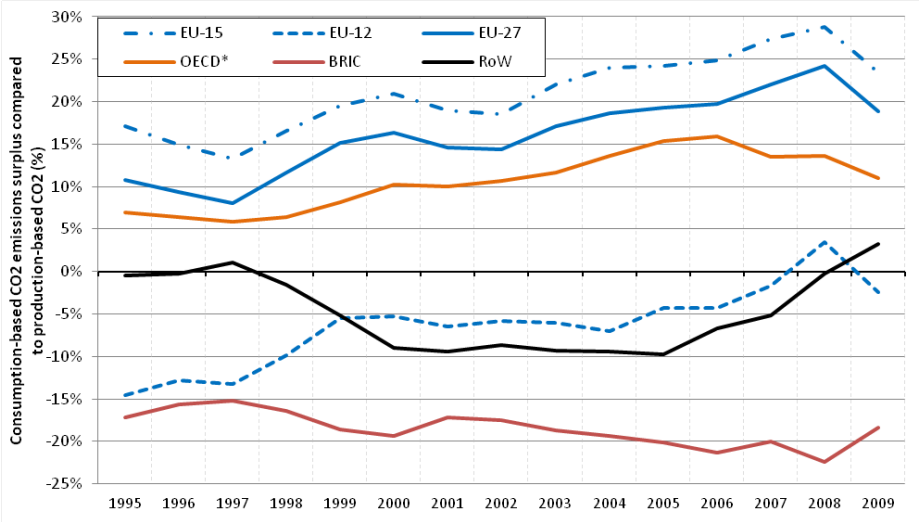
Mt CO_2		EU-15	EU-12	EU-27	OECD*	BRIC	RoW	Total
CO_2 emissions production-based	1995	3 421	851	4 273	7 756	5 719	4 295	22 042
	1996	3 506	872	4 378	7 967	5 817	4 442	22 604
	1997	3 459	844	4 303	8 236	5 728	4 544	22 811
	1998	3 519	789	4 307	8 235	5 863	4 494	22 899
	1999	3 497	744	4 241	8 404	5 866	4 631	23 143
	2000	3 525	743	4 268	8 699	5 947	4 859	23 773
	2001	3 596	755	4 351	8 642	6 028	4 868	23 889
	2002	3 582	741	4 323	8 618	6 283	5 066	24 290
	2003	3 654	769	4 423	8 731	6 876	5 270	25 299
	2004	3 668	777	4 446	8 811	7 709	5 591	26 557
	2005	3 672	773	4 446	8 887	8 226	5 851	27 410
	2006	3 655	792	4 447	8 853	8 829	6 113	28 242
	2007	3 606	800	4 406	9 109	9 405	6 298	29 217
	2008	3 543	776	4 320	8 853	9 952	6 503	29 628
	2009	3 339	720	4 059	8 369	10 254	6 195	28 877
CO_2 emissions consumption-based	1995	4 008	727	4 735	8 297	4 736	4 274	22 042
	1996	4 028	761	4 789	8 475	4 909	4 431	22 604
	1997	3 918	733	4 651	8 715	4 853	4 592	22 811
	1998	4 100	711	4 811	8 766	4 899	4 423	22 899
	1999	4 181	703	4 884	9 092	4 774	4 392	23 143
	2000	4 262	704	4 966	9 588	4 797	4 421	23 773
	2001	4 278	706	4 984	9 506	4 989	4 409	23 889
	2002	4 246	698	4 943	9 535	5 184	4 628	24 290
	2003	4 457	722	5 179	9 748	5 592	4 781	25 299
	2004	4 549	723	5 272	10 007	6 212	5 065	26 557
	2005	4 563	740	5 304	10 255	6 570	5 281	27 410
	2006	4 565	758	5 323	10 263	6 951	5 705	28 242
	2007	4 591	786	5 378	10 344	7 522	5 973	29 217
	2008	4 563	803	5 366	10 056	7 722	6 484	29 628
	2009	4 120	702	4 823	9 293	8 368	6 393	28 877

*Except: EU and Chile, Iceland, Israel, Norway, New-Zealand and Switzerland

Results from WIOTs emphasize two types of regions and with two different dynamic during the period 1995-2009. Firstly, the World could be broadly split between two regions:

[11] More detailed country results are available in Annex for 1995, 2000, 2005 and 2009. See Figures 5, 6, 7 and 8. And full results are available: http://www.erasme-team.eu/modele-economique-econometrie-vpub1.html.

Fig. 2: Consumption-based vs production-based CO_2 emissions in 4 regions in the World (from 1995 to 2009)



- "*CO_2-consumers*": developed countries, including EU-27 (and especially EU-15) and OECD countries in which CO_2 emissions from production are lower than CO_2 emissions embodied.
- And "*CO_2-producers*": developing countries (BRIC) and at a lesser extent the Rest of the World in which CO_2 emissions embodied in exports are higher than CO_2 emissions embodied in imports.

In depth, from 1995 in EU-27, CO_2 emissions counted with consumption-based approach were 11% higher than CO_2 emissions with the production-based approach. This CO_2 consumption surplus reached up to 24% in 2008 before relapsing to 19% in 2009 following the economic crisis[12]. In the OECD countries, production-based CO_2 emissions are, an average, 11% higher than consumption-based CO_2 emissions. In contrast, even if the consumption-based CO_2 emissions have strongly increased in the BRIC passing from 4.7 $GtCO_2$ to 8.4 $GtCO_2$ between 1995 and 2009, BRIC remain largely "*CO_2-producers*". In 2009, production-based CO_2 emissions were 18% higher than consumption-based ones and a maximum of 22% was found in 2008. Similarly, the Rest of the World is also a "*CO_2-producer*" even if the difference between both accounting approaches was null at the beginning and it shows a slight surplus in consumption-based CO_2 emissions in 2009 (+3.2%).

[12] Obviously, the CO_2 emissions embodied in trade have strongly decreased in 2009 due to trade collapse caused by "sub prime mortgage" crisis. Thereby, looking at Figure 2, the ratio between consumption-based and production-based CO_2 emissions returns towards zero in all regions.

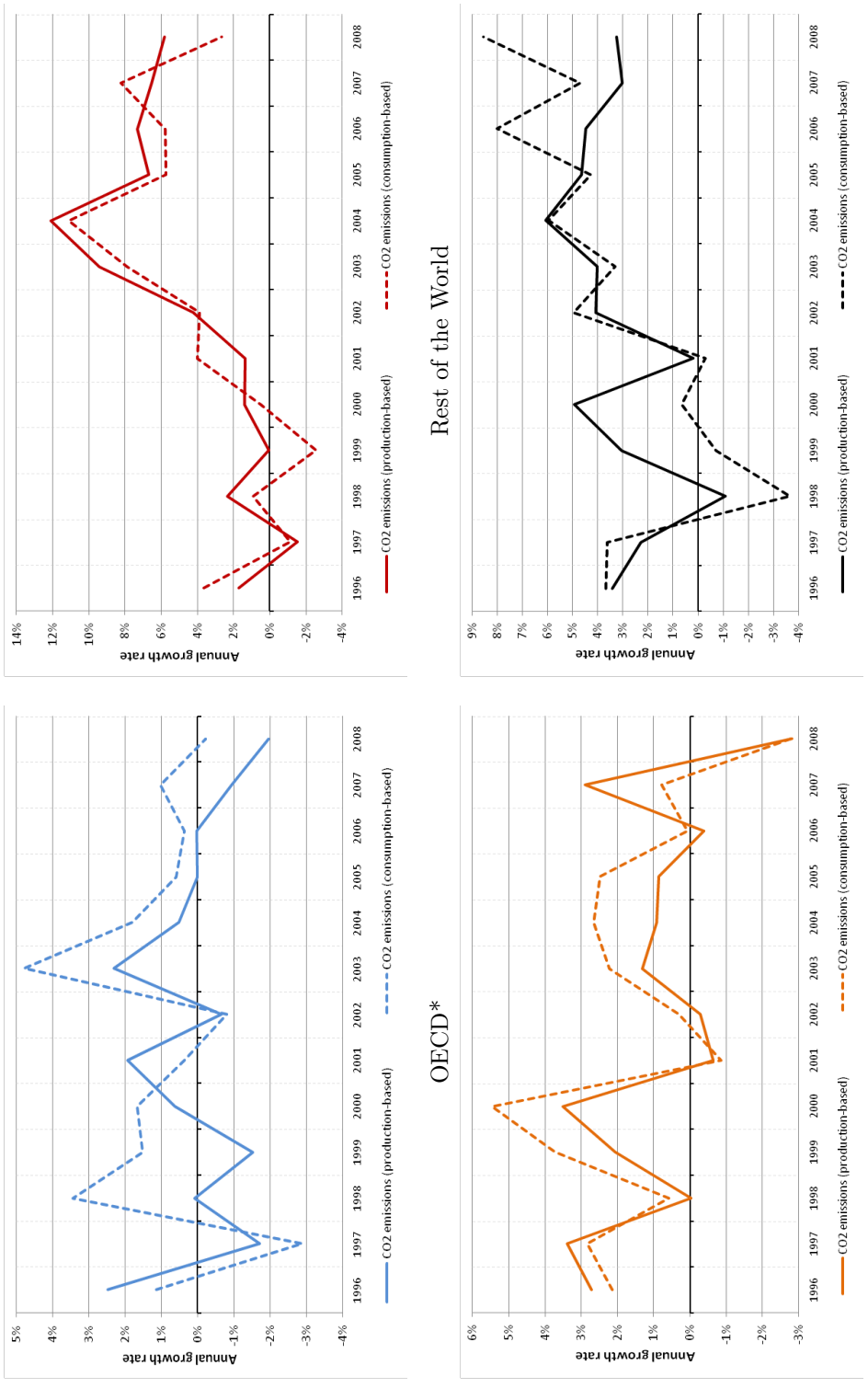


Fig. 3: CO_2 emissions evolution with both inventory methods (from 1996 to 2008)

In addition to usual static analysis in the MRIO studies, the work achieved in this study allows a dynamic analysis of consumption-based CO_2 emissions. Figure 3[13] displays the evolution for each of the four regions of production-based CO_2 emissions and consumption-based CO_2 emissions. In European Union, there is a real divergence between consumption-based and production-based CO_2 emissions. Despite there are three years (1996, 1995 and 2001) where the surplus of consumption-based CO_2 emissions is reduced, their evolutions diverge. There is a permanently higher growth rate of CO_2 emissions embodied in consumption than CO_2 emissions coming from domestic production. Thereby, as observed in Figure 2, the surplus in consumption-based CO_2 emissions is increasing, reaching 24% in 2008. This phenomenon is more profound between 2002 and 2008 leading to a surplus in consumption-based CO_2 emissions of about $1\,GtCO_2$ in 2008. Similarly, in the ten years in the OECD countries, between 1998 and 2008, this surplus has grown to about 125% passing from $531\,MtCO_2$ in 1998 to more than $1\,200\,MtCO_2$ in 2008. Obviously, the rise of the surplus of consumption-based CO_2 emissions have been made possiblely by an increasing deficit in the developing countries. In the BRIC, there is a rapid growth of CO_2 emissions embodied in exports that CO_2 emissions embodied in imports. Consequently, the deficit in consumption-based emissions in BRIC has surpassed from $980\,MtCO_2$ in 1995 to $2\,230\,MtCO_2$ in 2008.

3.2 Discussions

The results presented above are relatively comparable with the literature. For instance, Peters and Hertwich [2008b] compute CO_2 emissions embodied in trade with the GAP 6 database (Dimaranan [2006]) which supposedly reflects the World in 2001. By aggregating their results and trying to fit our regional aggregation, EU and OECD countries are "*CO_2-consumer*" with a surplus of consumption-based CO_2 emissions of about 14% and 3% respectively. In BRIC, the deficit of consumption-based CO_2 emissions is about 16% whereas it is about 6% in the rest the World. Thus, the division in two groups of countries is a robust result: *(i)* "*CO_2-consumers*" in developed countries and *(ii)* "*CO_2-producers*" in developing countries.

Nevertheless, our study has also emphasized the temporally robustness of this analysis. Indeed, there is a strong tendency for the divergence of both groups. From 1995, the gap between CO_2 consumed and CO_2 produced have continuously increased in EU, OECD and BRIC countries.

This raises the question of the definition of binding commitment across countries for CO_2 mitigation policy. Even without considering the internal dynamic of developing economies, it seems relatively difficult for developed countries to ask developing countries to commit to mitigation policy insomuch as a huge and increasing amount[14] of their CO_2 emissions are consumed by developed coun-

[13] The year 2009 have been drop from the Figure 3 in order to keep a good readability and to ease the analysis.

[14] CO_2 embodied in trade in BRIC in 1995 represented 31% of the CO_2 emissions domestically consumed whereas it represented 44% in 2009 (see Figures 5 and 8).

tries. Therefore, a double accounting for GHG emissions should be implemented at international level in order to have a relevant monitoring of mitigation policy. Even if they are, at a global level, similar, two following issues should be considered for a Worldwide successful mitigation policy: *(i)* reduction of CO_2 emissions by restricting pollutant activities or by improving and developing cleaner technologies and *(ii)* reduction of CO_2 embodied in goods. Regarding international negotiations on climate change, a consideration of both GHG inventory approaches could facilitate the national/regional binding commitments.

Besides monitoring issues, CO_2 embodied in final consumption could be directly useful for mitigation policy instruments. Even if it is not possible to directly relate the growth of the European surplus in consumption-based CO_2 emissions to the mitigation policies within EU, it, at least, invokes the issues of the carbon leakage in the EU. A deeper analysis should be carried out to provide a definitive conclusion on the effect of the design of European mitigation policies. But looking at those figures, it becomes pertinent to question the EU mitigation policies and to emphasize the European CO_2 border tax[15]. Indeed, a carbon border tax could be a much more efficient instrument to reduce European CO_2 emissions balance and to reach the final objective of combating global warming through the avoidance of carbon leakage.

4 Conclusion

The development of the World Input-Output Tables achieved by the WIOD European project allows a large scale application of the MRIO method for environmental issues. In this study, the MRIO method has been used to quantify CO_2 emissions embodied in trade from 1995 to 2009. In addition, a comparison between production-based and consumption-based accounting has been attained for four large regions (EU-27, OECD, BRIC and the Rest of the World). This analysis confirms the results observed in previous studies on the divergence in two regions: *(i)* "*CO_2-consumers*" in developed countries with an important surplus in CO_2embodied in imports compared to exports and *(ii)* "*CO_2-producers*" in developing countries in the opposite situation.

Furthermore, this quantification of CO_2 embodied in trade from 1995 to 2009 has shown an increasing gap between developed countries and developing, from $1\,GtCO_2$ in 1995 to $2.25\,GtCO_2$ in 2008. The European and OECD countries export their polluting activity towards the BRIC. This increasing surplus in consumption-based CO_2 raises several important questions regarding climate change policies. Among others, how to carry out international negotiation on climate change without considering those aspects? And to what extent do economic instruments used by European Union mitigation policy (such as EU-ETS market) are relevant in tackling its objective: to fight global warming? Therefore, a deeper analysis of the results achieved in this study should be carried out to provide the necessary elements for an understanding of these questions; espe-

[15] See *e.g.* Biermann and Brohm [2004], Manders and Veenendaal [2008], Gros [2009], Gros and Egenhofer [2011], Elliott et al. [2012] for discussion of carbon tax border.

cially by detailing results, comparing the evolutions in emissions with economic evolutions and developing tools to deal with emissions embodied in trade, such as large applied economic model.

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Annex

Tab. 2: WIOD economic sectors (1/2)

Number	Code	Name
01	secAtB	Agriculture, Hunting, Forestry and Fishing
02	secC	Mining and Quarrying
03	sec15t16	Food, Beverages and Tobacco
04	sec17t18	Textiles and Textile Products
05	sec19	Leather, Leather and Footwear
06	sec20	Wood and Products of Wood and Cork
07	sec21t22	Pulp, Paper, Paper, Print. and Pub.
08	sec23	Coke, Refined Petroleum and Nuclear Fuel
09	sec24	Chemicals and Chemical Products
10	sec25	Rubber and Plastics
11	sec26	Other Non-Metallic Mineral
12	sec27t28	Basic Metals and Fabricated Metal
13	sec29	Machinery, Nec
14	sec30t33	Electrical and Optical Equipment
15	sec34t35	Transport Equipment
16	sec36t37	Manufacturing, Nec; Recycling
17	secE	Electricity, Gas and Water Supply
18	secF	Construction

Tab. 3: WIOD economic sectors (2/2)

Number	**Code**	**Name**
19	sec50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20	sec51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21	sec52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22	secH	Hotels and Restaurants
23	sec60	Inland Transport
24	sec61	Water Transport
25	sec62	Air Transport
26	sec63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27	sec64	Post and Telecommunications
28	secJ	Financial Intermediation
29	sec70	Real Estate Activities
30	sec71t74	Renting of M&Eq and Other Business Activities
31	secL	Public Admin and Defence; Compulsory Social Security
32	secM	Education
33	secN	Health and Social Work
34	secO	Other Community, Social and Personal Services
35	secP	Private Households with Employed Persons
36	secQ	Extra-territorial organizations and bodies

Tab. 4: WIOD geographical coverage

Code	**Name**	**Code**	**Name**
AUS°	Australia	*ITA**	Italy
*AUT**	Austria	*JPN°*	Japan
*BEL**	Belgium	*KOR°*	South Korea
*BGR**	Bulgaria	*LTU**	Lithuania
BRA˜	Brazil	*LUX**	Luxembourg
CAN°	Canada	*LVA**	Latvia
CHN˜	China	*MEX°*	Mexico
*CYP**	Cyprus	*MLT**	Malta
*CZE**	Czech Republic	*NLD**	Netherlands
*DEU**	Germany	*POL**	Poland
*DNK**	Denmark	*PRT**	Portugal
*ESP**	Spain	*ROM**	Romania
*EST**	Estonia	*RUS˜*	Russian Federation
*FIN**	Finland	*SVK**	Slovakia
*FRA**	France	*SVN**	Slovenia
*GBR**	United-Kingdom	*SWE**	Sweden
*GRC**	Greece	*TUR°*	Turkey
*HUN**	Hungary	*TWN²*	Taiwan
IDN²	Indonesia	*USA°*	United States of America
IND˜	India	*RoW²*	Rest of the World
*IRL**	Ireland		

*: EU-27; ˜: BRIC; °: OECD and ²: Rest of the World

Tab. 5: CO_2 embodied in trade in 1995

Mt CO_2	1995 Production-based	Consumption-based	Embodied in exports	Embodied imports	Net embodied (%)
Austria	61.6	96.5	16.3	51.2	57%
Belgium	131.9	134.8	60.3	63.2	2%
Denmark	74.0	75.5	29.3	30.8	2%
Finland	60.5	63.7	22.1	25.3	5%
France	405.9	510.0	94.6	198.7	26%
Germany	949.5	1 173.1	175.6	399.2	24%
Greece	86.5	104.3	6.9	24.6	21%
Ireland	35.2	37.9	10.9	13.6	8%
Italy	454.3	530.3	101.6	177.6	17%
Luxembourg	7.8	7.6	5.0	4.8	-3%
Netherlands	193.2	198.2	85.0	89.9	3%
Portugal	54.1	61.7	12.2	19.8	14%
Spain	253.8	290.4	46.9	83.5	14%
Sweden	63.4	82.8	21.2	40.6	31%
United-Kingdom	589.7	640.9	133.1	184.2	9%
EU-15	3 421.4	4 007.7	820.8	1 407.1	17%
Bulgaria	62.1	40.1	29.2	7.1	-35%
Cyprus	5.4	8.4	0.7	3.8	56%
Czech Republic	118.6	101.6	40.0	23.0	-14%
Estonia	18.2	14.1	6.6	2.5	-22%
Hungary	60.9	62.8	16.4	18.3	3%
Latvia	9.9	10.7	2.9	3.7	8%
Lithuania	16.5	16.7	5.6	5.8	1%
Malta	2.2	3.2	0.5	1.5	47%
Poland	367.7	308.0	85.1	25.4	-16%
Romania	130.1	110.1	33.2	13.2	-15%
Slovakia	44.7	34.6	20.9	10.8	-22%
Slovenia	15.0	16.9	4.2	6.0	13%
EU-12	851.4	727.3	245.2	121.2	-15%
Euro Zone	2 779.8	3 285.7	670.0	1 176.0	18%
EU-27	4 272.8	4 735.0	1 066.1	1 528.2	11%
Australia	304.7	302.5	64.7	62.5	-1%
Canada	465.3	413.8	159.6	108.2	-11%
Japan	1 141.2	1 432.8	148.0	439.5	26%
Mexico	306.1	286.6	60.8	41.3	-6%
South Korea	409.1	405.4	108.9	105.2	-1%
Turkey	179.1	199.5	20.5	40.9	11%
United States	4 950.5	5 256.1	437.0	742.7	6%
OECD*	7 756.0	8 296.7	999.6	1 540.3	7%
Brazil	229.4	261.1	21.2	52.9	14%
China	3 074.7	2 524.3	646.4	96.0	-18%
India	806.5	736.0	119.4	48.9	-9%
Russia	1 608.2	1 214.6	450.1	56.5	-24%
BRIC	5 718.9	4 736.0	1 237.2	254.3	-17%
Indonesia	214.7	204.3	52.1	41.7	-5%
Taiwan	194.0	186.8	74.7	67.5	-4%
Rest of the World	4 294.5	4 274.5	847.8	827.8	0%
Total	22 042.2	22 042.2	4 150.7	4 150.7	0%

**Except: EU and Chile, Iceland, Israel, Norway, New-Zealand and Switzerland*

Tab. 6: CO_2 embodied in trade in 2000

Mt CO_2	2000 Production-based	Consumption-based	Embodied in exports	Embodied imports	Net embodied
Austria	62.9	96.2	20.4	53.7	53%
Belgium	132.5	134.9	65.7	68.2	2%
Denmark	75.0	66.6	37.4	29.0	-11%
Finland	60.8	67.0	23.9	30.1	10%
France	421.5	539.0	105.3	222.8	28%
Germany	914.8	1 127.0	218.0	430.1	23%
Greece	103.0	130.1	10.1	37.2	26%
Ireland	44.6	51.8	13.6	20.7	16%
Italy	474.0	590.7	106.6	223.3	25%
Luxembourg	4.0	7.6	1.5	5.2	93%
Netherlands	198.4	205.5	89.9	96.9	4%
Portugal	65.2	78.2	14.1	27.1	20%
Spain	305.5	359.1	66.9	120.5	18%
Sweden	60.4	87.3	22.7	49.6	44%
United-Kingdom	602.4	721.1	137.6	256.2	20%
EU-15	3 525.1	4 262.1	933.6	1 670.6	21%
Bulgaria	47.6	31.7	24.7	8.8	-33%
Cyprus	7.7	10.9	1.6	4.7	41%
Czech Republic	116.2	106.6	39.8	30.3	-8%
Estonia	15.4	14.5	5.3	4.4	-6%
Hungary	57.7	66.2	17.1	25.6	15%
Latvia	7.5	9.8	2.3	4.6	30%
Lithuania	13.3	17.9	4.4	9.0	34%
Malta	2.3	3.6	0.6	1.9	57%
Poland	323.2	305.2	76.1	58.1	-6%
Romania	95.8	84.2	27.6	16.1	-12%
Slovakia	41.0	34.5	20.1	13.6	-16%
Slovenia	15.2	18.4	4.2	7.4	21%
EU-12	743.0	703.7	223.6	184.3	-5%
Euro Zone	2 868.9	3 469.1	767.6	1 367.7	21%
EU-27	4 268.1	4 965.8	1 157.1	1 854.8	16%
Australia	357.6	343.8	90.7	76.9	-4%
Canada	527.5	474.3	194.9	141.7	-10%
Japan	1 204.3	1 444.5	183.7	423.9	20%
Mexico	374.3	406.0	68.0	99.6	8%
South Korea	495.2	452.1	157.7	114.7	-9%
Turkey	225.4	259.5	32.6	66.8	15%
United States	5 514.3	6 208.2	449.6	1 143.5	13%
OECD*	8 698.5	9 588.4	1 177.2	2 067.1	10%
Brazil	287.0	313.0	35.9	61.9	9%
China	3 100.8	2 688.1	598.8	186.2	-13%
India	990.3	893.8	169.2	72.7	-10%
Russia	1 569.2	902.4	703.3	36.5	-42%
BRIC	5 947.2	4 797.3	1 507.2	357.3	-19%
Indonesia	280.7	238.6	81.5	39.4	-15%
Taiwan	260.9	238.3	105.6	82.9	-9%
Rest of the World	4 859.0	4 421.3	1 295.4	857.8	-9%
Total	23 772.8	23 772.8	5 137.0	5 137.0	0%

*Except: EU and Chile, Iceland, Israel, Norway, New-Zealand and Switzerland

Tab. 7: CO_2 embodied in trade in 2005

Mt CO_2	2005 Production-based	Consumption-based	Embodied in exports	Embodied imports	Net embodied
Austria	74.7	107.5	29.5	62.3	44%
Belgium	131.4	152.2	67.4	88.2	16%
Denmark	85.5	71.7	51.7	38.0	-16%
Finland	62.3	72.8	24.2	34.8	17%
France	427.4	597.4	98.9	269.0	40%
Germany	898.6	1 075.0	258.5	435.0	20%
Greece	113.2	144.7	12.4	43.9	28%
Ireland	47.5	63.9	13.0	29.4	34%
Italy	499.4	632.1	111.0	243.8	27%
Luxembourg	5.4	9.5	2.0	6.1	77%
Netherlands	206.4	217.1	93.0	103.7	5%
Portugal	71.8	84.4	17.3	29.9	18%
Spain	364.9	455.9	78.3	169.3	25%
Sweden	62.7	92.1	26.4	55.8	47%
United-Kingdom	621.6	787.1	152.2	317.7	27%
EU-15	3 672.5	4 563.4	1 035.8	1 926.7	24%
Bulgaria	52.1	39.6	20.7	8.2	-24%
Cyprus	8.0	11.1	1.1	4.2	39%
Czech Republic	118.3	107.3	44.7	33.6	-9%
Estonia	16.7	16.4	5.1	4.8	-1%
Hungary	61.8	77.1	17.1	32.4	25%
Latvia	8.6	11.9	2.6	6.0	39%
Lithuania	16.1	20.0	6.1	10.0	24%
Malta	2.6	3.7	0.8	1.8	40%
Poland	324.0	292.6	88.5	57.1	-10%
Romania	106.3	104.1	28.9	26.6	-2%
Slovakia	41.3	36.5	21.9	17.0	-12%
Slovenia	17.4	19.8	6.3	8.8	14%
EU-12	773.3	740.1	243.6	210.5	-4%
Euro Zone	2 988.7	3 700.0	840.6	1 551.8	24%
EU-27	4 445.7	5 303.5	1 279.4	2 137.2	19%
Australia	402.3	444.6	86.8	129.1	11%
Canada	552.3	550.8	182.0	180.4	0%
Japan	1 206.9	1 449.6	223.1	465.8	20%
Mexico	413.7	453.8	73.1	113.2	10%
South Korea	533.9	521.6	171.4	159.1	-2%
Turkey	248.9	300.1	39.2	90.3	21%
United States	5 529.3	6 534.9	405.5	1 411.2	18%
OECD*	8 887.3	10 255.4	1 181.0	2 549.1	15%
Brazil	310.1	319.0	55.4	64.2	3%
China	5 082.3	3 981.6	1 426.3	325.6	-22%
India	1 197.9	1 160.0	213.2	175.3	-3%
Russia	1 635.4	1 109.2	604.2	78.0	-32%
BRIC	8 225.7	6 569.8	2 299.1	643.2	-20%
Indonesia	350.1	314.0	95.0	59.0	-10%
Taiwan	315.9	245.6	148.4	78.1	-22%
Rest of the World	5 851.4	5 281.5	1 778.8	1 208.9	-10%
Total	27 410.1	27 410.1	6 538.4	6 538.4	0%

*Except: EU and Chile, Iceland, Israel, Norway, New-Zealand and Switzerland

Tab. 8: CO_2 embodied in trade in 2009

Mt CO_2	2009 Production-based	Consumption-based	Embodied in exports	Embodied imports	Net embodied
Austria	64.0	94.9	25.6	56.4	48%
Belgium	120.6	144.6	55.9	79.9	20%
Denmark	86.6	65.4	55.5	34.3	-24%
Finland	61.8	70.3	22.1	30.7	14%
France	385.7	556.5	82.7	253.6	44%
Germany	855.7	1 008.4	249.2	401.9	18%
Greece	110.0	140.0	14.9	44.9	27%
Ireland	42.6	60.5	11.4	29.3	42%
Italy	424.8	550.0	90.2	215.4	29%
Luxembourg	4.8	8.6	1.8	5.5	78%
Netherlands	204.8	214.6	95.0	104.7	5%
Portugal	61.3	72.1	16.1	26.8	18%
Spain	300.0	378.9	67.8	146.7	26%
Sweden	57.9	83.4	25.0	50.6	44%
United-Kingdom	558.7	672.2	132.5	246.1	20%
EU-15	3 339.2	4 120.4	945.5	1 726.8	23%
Bulgaria	46.5	37.7	20.0	11.2	-19%
Cyprus	8.3	11.5	1.0	4.2	38%
Czech Republic	108.6	99.6	42.8	33.8	-8%
Estonia	15.6	12.7	6.6	3.7	-19%
Hungary	53.0	59.2	18.9	25.1	12%
Latvia	8.3	10.9	2.8	5.3	30%
Lithuania	14.8	19.3	5.6	10.1	30%
Malta	2.8	3.7	1.0	1.8	31%
Poland	316.9	292.9	86.5	62.6	-8%
Romania	91.4	96.8	20.5	25.8	6%
Slovakia	36.0	37.2	18.3	19.5	3%
Slovenia	17.7	20.8	6.1	9.2	17%
EU-12	720.0	702.2	230.1	212.2	-2%
Euro Zone	2 716.5	3 385.2	765.5	1 434.1	25%
EU-27	4 059.2	4 822.6	1 175.6	1 939.0	19%
Australia	405.5	453.2	86.0	133.7	12%
Canada	528.9	559.0	149.9	180.0	6%
Japan	1 101.9	1 291.4	196.2	385.7	17%
Mexico	426.4	447.6	75.1	96.3	5%
South Korea	583.7	517.0	210.8	144.2	-11%
Turkey	296.4	325.6	52.5	81.7	10%
United States	5 026.5	5 699.6	422.1	1 095.3	13%
OECD*	8 369.2	9 293.4	1 192.7	2 116.8	11%
Brazil	322.5	376.2	43.0	96.6	17%
China	6 691.3	5 187.8	2 000.5	497.0	-22%
India	1 641.6	1 563.7	261.3	183.3	-5%
Russia	1 598.3	1 240.6	468.6	110.9	-22%
BRIC	10 253.7	8 368.2	2 773.3	887.9	-18%
Indonesia	392.6	386.5	83.1	77.0	-2%
Taiwan	313.5	212.3	158.5	57.3	-32%
Rest of the World	6 195.3	6 393.2	1 447.9	1 645.8	3%
Total	28 877.5	28 877.5	6 589.6	6 589.6	0%

**Except: EU and Chile, Iceland, Israel, Norway, New-Zealand and Switzerland*