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The Drivers of GHG Emissions Intensity Improvements in Major Economies Analysis of Trends 1995-2009[1]

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Abstract

This paper analyzes the trends in GHG emissions intensity over the period 1995-2009, in a mix of developing and developed economies that account for constitute almost 2/3[rd] of global emissions. In doing so it distinguishes between the demand-based emissions (DBEs) and production-based emissions (PBEs). Several studies find that while PBEs in the developed economies during the period have been stabilized, the DBEs are on the rise. Understanding the relative influence of various factors that has shaped the differential patterns of emissions growth will provide us with important policy insights for controlling GHG emissions. It undertakes a decomposition exercise to understand the changes in both PBEs and DBEs intensities due to changes in technological change and structural shifts in production and final consumption. Main findings of the paper are that technology change has been the key driver of emissions intensity improvements in production and consumption. Intensity improvements in production activities has been more than those in consumption. Structural changes in composition of production and demand has relatively smaller contribution in overall intensity improvement. Structural shifts have somewhat negatively contributed to emissions intensity improvements in Canada and China. In India structural shift in both production and consumption activities have contributed significantly in emissions intensity improvements. Changes in regional composition of final consumptions have worked against emissions intensity improvements particularly in developed economies of Canada, EU 27 and United States.

Key Words: GHG emissions intensity, Demand-based emission, embodied emissions, convergence.

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1. Introduction

Successive IPCC assessment reports including the latest (5th report) one concluded that increasing CO2 emissions in the atmosphere has been the dominant driver of global warming over the industrial era. It stipulates that to keep the global warming below 2 degree centigrade by the turn of the century the cumulative sum of emissions (since the pre-industrial era) needs to be limited to about one trillion tonnes of carbon. About half of this amount has already been emitted. Thus all economies in the world to a varying degree are under increasing pressure to reduce greenhouse gas emissions. This paper makes an attempt to understand the drivers of emissions growth in the major world economies (developed and developing) in the last two decades in order to be able to better address policy issues around emissions reductions.

The greenhouse gas (GHG) emissions from developed economies have been somewhat stabilized since 1990, however, it has been increasing rapidly in large developing economies during the last two decades. This has been partly the result of economic transformation these economies are going through. As laid down in Polyani's (1994) *Great Transformation*, economies move up from an initially dominant agricultural sector into fledgling labour intensive manufacturing industries (such as textiles and apparel) and then moves up a technology ladder to more sophisticated but still labour intensive manufacturing (e.g., furniture), and onto heavy industry (such as steel, chemicals), and eventually higher technology products and services (Ghosh and Whalley 2007). The differential emissions growth across the developed and the developing economies observed are inherent in the structural shifts associated with this pattern of growth. The early development phase is characterized by dependence on low-tech emissions intensive sources of fossil fuels mostly coal, then gradually moving up in the technology ladder to high technology and less emission intensive production processes. Importantly, the industrial structure in developing countries is therefore, skewed towards low-tech manufacturing base, which is one of the key driver of emissions growth. The third important factor is the technological progress within an industrial sector. Associated with this is the energy mix - as economies progress and also partly changes in relative prices the energy mix also changes.

The objective of this paper is first to examine the trends in emissions growth in a mix of developing and developed economies, and then decompose the emissions intensity changes into structural and technology effect. The country/regions chosen for detailed analysis are Canada, United States, European Union, China and India. To disentangle the drivers of emissions growth the paper makes a distinction between production-based emissions (PBEs) and demand-based emissions (DBEs) (Ghosh and Agarwal 2013). A number of studies indicate that PBEs in many developed economies have been stabilized during the last two decades but the DBEs have been on the rise. It is also argued that rapid increases in PBEs in large developing economies such as China are caused by increasing demand for their products from developed economies. The decomposition of both PBEs and DBEs intensities will allow us to understand the underlying the sources of the growth in emissions.

It finds that a while both PBEs and DBEs intensity declined in all economies, the decline have been more rapid in developing than developed economies. The PBEs intensities declined relatively more than the DBEs through international trade. Decomposition of changes in intensities reveal that structural changes in composition of production and demand has relatively smaller contribution in overall intensity improvement. In some cases structural shifts has negatively contributed to emissions intensity improvements. For example although marginally production activities have moved towards energy/emission intensive sectors in Canada and China. In India structural shift in both production and consumption activities have contributed positively in emissions intensity improvements. Decomposition analysis also suggests that through international trade countries move towards more emissions intensive sources of demand particularly the developed economies. It is plausible that this compositional changes in sources of final demand is one reason for growth in DBEs in developed in Canada and the EU 27.

In what follows, a brief literature overview is presented in Section 2. Section 3 discusses the data and methodology used in decomposition of the emission intensity changes into technological and structural changes. Section 4 discusses the trends in PBEs and DBEs and the intensity changes. Section 5 provides main summary of findings and concludes.

2. Brief overview of Literature

Energy use and emissions are tightly linked – more than 80 percent of global GHG emissions are energy related. There are plenty of studies that analyze changes in energy intensity for various countries, while there are relatively less studies that analyze emission intensities. Bruneau and Renzetti (2009) analyze the trends in GHG emissions intensity in Canada and UK. To identify how much of the observed changes in emission intensity can be attributed to changes in techniques, they use the divisia index methodology described in Cole, Elliott, and Shimamoto (2005, 62-3). For Canada Bruneau and Renzetti (2009) find an improvement in sectoral energy intensity from 1990 to 1996 but a reversal to 2001 so that, by 2002, after accounting for sector mix effects, energy intensity was about 3 percent higher than in 1990.

Metcalf (2008) finds that rising per capita income and higher energy prices have played an important part in lowering energy intensity at the State level in the US. His results reveal that price and income predominantly influence intensity through changes in energy efficiency rather than through changes in economic activity. Metcalf (2008) also suggests that little policy intervention will be needed to achieve the Bush Administration goal of an 18 percent reduction in carbon intensity by the end of this decade. Other studies also show that efficiency gains are the primary driver in the energy intensity decrease between 1970s and 1990s (Rose & Chen (1991), Schipper et al. (1990)). Sue Wing (2008) finds that while the structural change has been the primary factor since 1958, accounting for 2/3 of the decrease in energy intensity, efficiency gains were more important from the 1970s onward until 2000. Sue Wing and Eckaus (2004) decomposed the trend in US energy-GDP ratio into the contributions of structural change and shifts in the intensity of energy use within individual sectors. Their econometric estimation results indicate that while the intra-sectoral reductions in intensity were driven by the substitution of variable inputs and the embodied energy-saving technology within accumulating stocks of capital, the overall influence of disembodied technological progress was small and energy-using in its overall character.

Most studies find that the most important factor is the technological change in China (see Ang & Zhang (2000), Ma and Stern (2008). Ma and Stern (2008) find that structural change at the industry and sector level has in fact increased the energy intensity during 1980-2003, although the structural change at the industry level was very different in the 1980s and in the post-1990 period. While structural change involving shifts of production between sub-sectors decreased overall energy intensity, the increase in energy intensity since 2000 is explained by negative technological progress and inter-fuel substitution is found to contribute little to the changes in energy intensity. As far as emissions intensity is concerned, Zhang (2009) finds that of the 76% energy related CO2 intensity improvement from 1992-2006, 70% was due to efficiency gains. This study also finds similar results for the period 1995-2009.

A study involving a mix of six developed and developing regions for the period 1971-1998, Schafer (2005) finds that for most developed areas, structural change reduced energy intensity, while for developing countries, the effect of structural change was mixed, putting a small upward pressure on energy intensity in Asia while reducing energy intensity by 5% in Latin America and 27% in eastern Europe. Cornillie and Fankhauser (2002) uses an arithmetic method to decompose the aggregate energy data in the transition economy over the period 1992 to 1998 into four parts. These include, energy intensities of industry, transport and the rest of the economy, and the effect of structural change, that is a shift in the relative importance of energy-intensive and less energy-intensive sectors within the economy. It uses panel data to identify the main factors driving improvements in energy intensity. It shows that energy prices and progress in enterprise restructuring are the two key important drivers for more efficient energy use in economies of central and Eastern Europe and the former Soviet Union. While there are numerous studies decomposing the aggregate energy intensities in production related economic activities in various economies to our knowledge there is hardly any study analyzing the trends in DBEs intensities and the role trade plays in this context. This paper aims to fill this gap. In doing so it analyzes both PBEs and DBEs intensities in terms of the contributions of the technology and structural shifts in overall emissions intensities.

3. Data and Methodology

Data

We use World Input-Output Database (WIOD) prepared on the basis of officially published input-output tables in conjunction with national accounts and international trade statistics (Timmer (ed.) 2012).[2] It consists of a series of databases and covers 27 EU countries and 13 other major countries in the world for the period from 1995 to 2009.[3] These include national input-output accounts, the Socio-economic accounts (which contain industry-level data on employment (number of workers and educational attainment), capital stocks, gross output and value added at current and constant prices. The environmental accounts contain data on energy use, CO2 emissions and emissions to air. The input-output table represents 35 industrial sectors for reach regions. For the purpose of the paper the 40 region input-put table is aggregated into a fourteen region input-output table by aggregating the 27 countries of the EU 27 into a single

[2] This project was funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities.
[3] Recently some of these databases have been updated until 2011.

region. To understand the patterns and the drivers of emissions intensity improvements five regions are chosen for detailed analysis. These include Canada, China, EU 27, India and the US. This provides a diverse representation of economies of the world economies; developed and developing and net imports of emissions and net exporters of emissions. The significance of Canada is that while being a developed economy it is also a major energy supplier and interestingly it has now transformed from an emissions exporter to emissions importing nation.

Production and demand-based emissions intensities

The paper distinguishes between two types of aggregate emissions intensities. First, analogous to emissions per unit of GDP is the aggregate production-based emissions intensity, and second, aggregate demand-based emission intensity. The former accounts for all emissions generated within a country in carrying out economic activities.[4] The latter is based on the notion of embodied emissions (or carbon) in final consumption or alternatively called final demand.[5] This therefore includes all direct and indirect emissions irrespective of territorial boundaries in the production of goods and services used in final consumption. The final demand includes final consumption by households, governments and firm's investments. The main difference between the DBEs and the PBEs accounting is the treatment of emissions embodied in trade flows. DBEs which is also called consumption-based emissions (CBEs) accounting excludes emissions embodied in exports, but includes emissions embodied in imports. Several studies including a recent one from the Brookings Institution (Grasso and Roberts, 2013) have argued that the allocation of the emissions reduction target should be based on the carbon footprint of own consumption (i.e., DBEs), not territorial emissions (i.e., PBEs).

Following Ghosh and Agarwal (2013) and Böhringer, Carbone, and Rutherford (2011), total embodied emissions in final product *j* produced in a region can be written as the sum of direct combustion and process emissions $\left(E_d^{js}\right)$ and indirect emissions to produce domestic $\left(I_D^{ijs}\right)$ and imported $\left(I_M^{ijrs}\right)$ intermediates from region *r*. Using the multi-regional input-output (MRIO) identity, the above can be written as:

$$y^{js}a^{js} = E_{dr}^{js} + \sum_i I_d^{ijs}a^{is} + \sum_r \sum_i I_m^{ijrs}a^{ir} \qquad (1)$$

Where a^{js} refers to emission intensity of sector *j* in country s to be determined endogenously by solving equation (1). Where y^{js} represent the activity level in sector *j*. Activities are classified into production and final consumption expenditures. Given the values of y^{js}, $\left(E_d^{js}\right)$, $\left(I_D^{ijs}\right)$ and $\left(I_M^{ijrs}\right)$ the emission intensity factor of activity j in country s can be determined as a solution to the system of j X s equations (Ghosh and Agarwal 2013).[6]

Total demand-based emissions (DBE_r) in country *r* can be written as

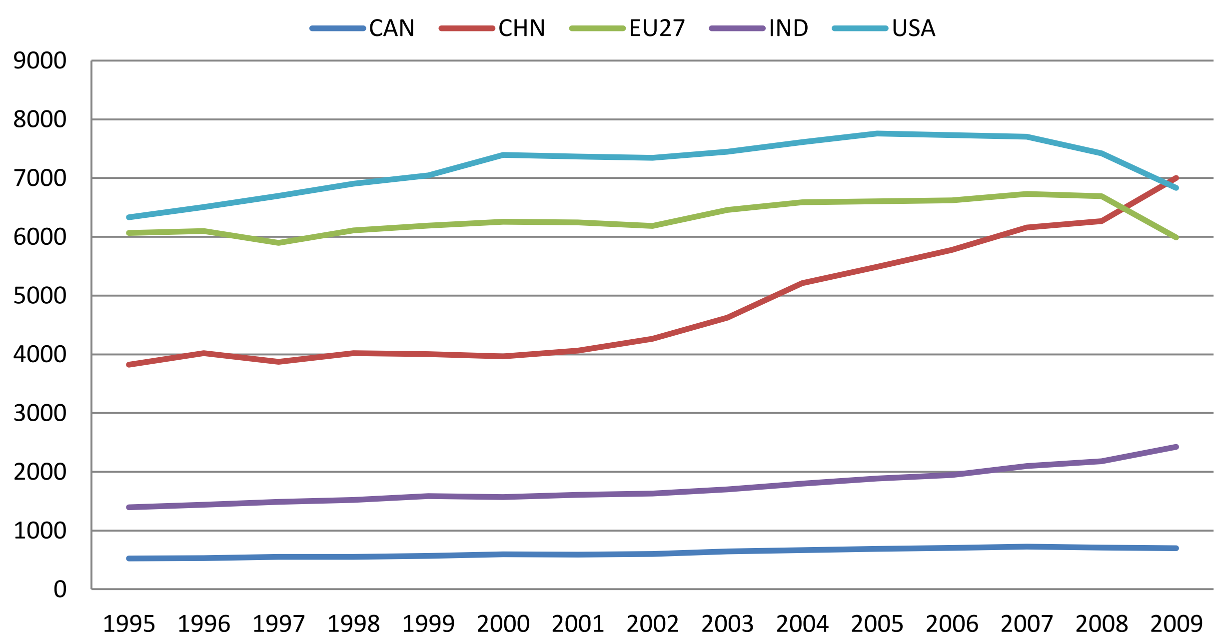
[4] IPCC(2007) defines it as, "national inventories include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction" (IPCC [2007])
[5] There is a wide body of literature on the demand-based emissions – please see Wiedmann (2009) for a review.
[6] Emissions data on the latter two are not directly available.

$$DBE_r = \sum_{f,s} a^{fs} y^{fs} \tag{2}$$

Where *f* represents, final consumption by households, government, and investment expenditures. Figures 1-2 present the PBEs and DBEs and Figure 3 presents the balance of embodied emissions (BEETs) in trade for the five regions namely Canada, China, EU 27, India and US. The BEETs or the net traded emissions are computed as the difference between PBEs and DBEs. While the US and EU 27 have been predominantly remained net importers of emissions with increasing net imports until recently, the magnitude declined in US since 2006 and since 2008 in the EU 27. Canada became net importer of emissions since 2006. Net imported emissions in Canada estimated to be 20MT in 2006 and 33MT in 2009.

Looking at Figures 1 and 2 it appears that both PBEs and DBEs in the US and the EU 27 declined in 2009 perhaps due to economic down turn, while in China and India both continue to increase but exports increase less than imports. We also show the composition of imported and exported emissions for each of the five regions by source and destination countries (Appendices 1-5). Results in general show that the share of emissions imports from developing regions in the economies of Canada, EU 27 and the US are on the rise mostly reflecting on increased trade. For example, share of Canadian imports from China has increased from 3.2 percent in 2000 to 8.7 and 10.9 percent in 2006 and 2009. The increase in net imported emissions by the developed economies is partly a reflection of increasing share of their imports from developing nations with relatively higher emissions intensities.

Figure 1: Demand-based Emissions (MT): 1995-2009



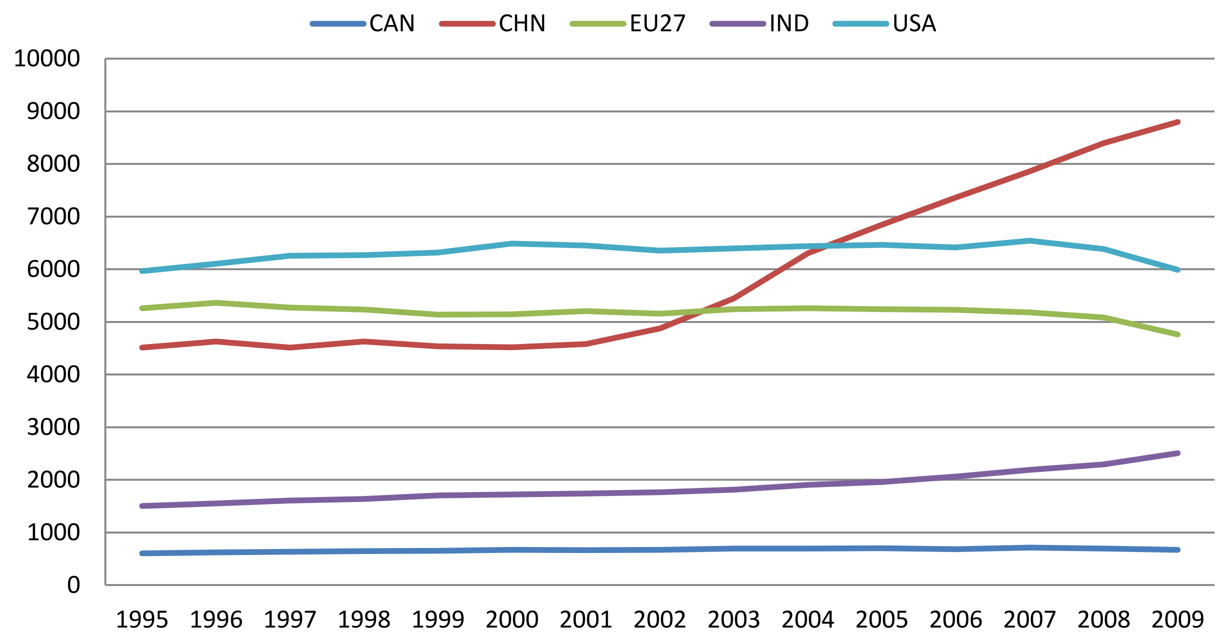


Figure 2: Production-based Emissions (MT): 1995-2009

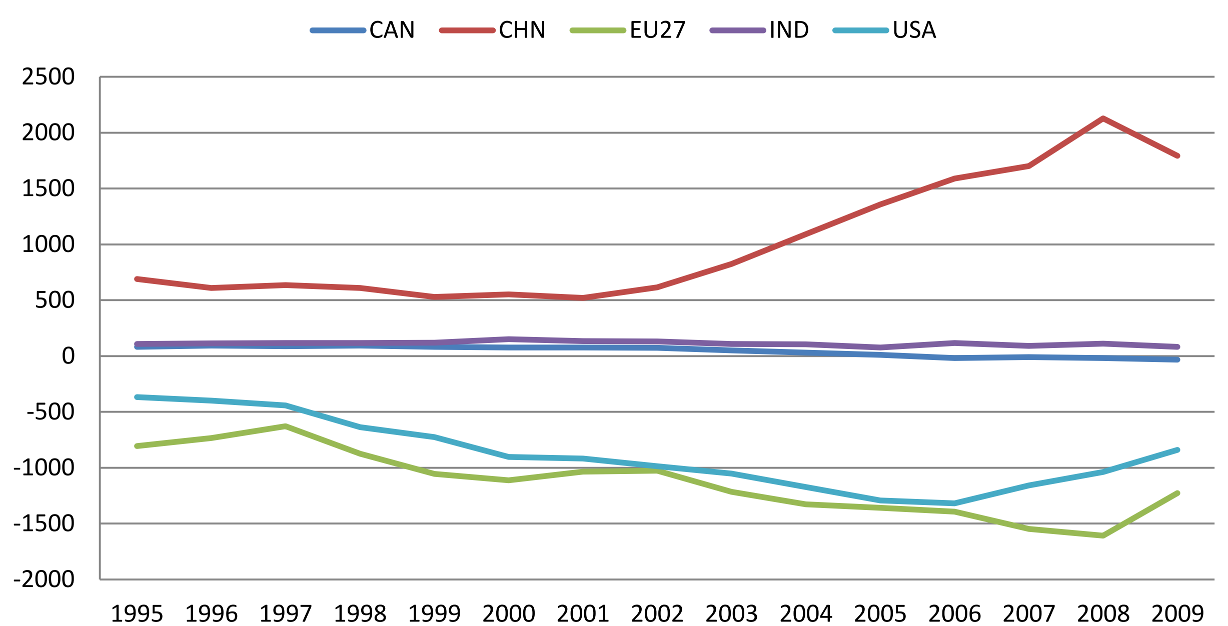


Figure 3: Balance of Embodied Emissions in Trade (MT): 1995-2009

Decomposition of emissions intensity: The Mean Divisia Index

Most studies use logarithmic mean Divisia index (LMDI) techniques to decompose changes in energy intensity into, technological change and structural change Ang, Mu and Zhou (2010), Ang and Choi (1997), Choi and Ang (2003) and Antweiler, Copeland and Taylor (2001). For an early survey of decomposition literature please see Ang and Zhang (2000). Boyd, McDonald, Ross and Hanson (1987) were the first to use index number theory to provide a theoretically based decomposition. They used a divisia index number methodology and like earlier methodologies (which were essentially based on a Laspeyres Index), these decompositions had residual terms which could account for a considerable degree of the variability in the underlying index of energy intensity change. Research using some sort of index decomposition methodology has increased sharply with Ang and Zhang noting that their 2000 survey found 124 studies, up from 51 in their 1995 survey. Following the literature this paper also applies the mean divisia index methodology to decompose the changes of emissions intensities of PBEs and DBEs.

The aggregate PBEs inventory emissions intensity (pe_t) at time *t* is defined as the ratio of direct emissions (PBE_t) and aggregate gross output (Y_t), while DBEs inventory intensity (de_t) is defined as the ratio of total DBEs (DBE_t) to the values of aggregate final demand (FD_t).

$$pe_t = \frac{PBE_t}{Y_t} \quad \text{and} \quad de_t = \frac{DBE_t}{FD_t} \tag{3}$$

The PBEs and DBEs intensities are reported in Figures 4 and 5 for the period 1995-2009. The GHGs emissions intensities are represented in tonnes per $1000 of gross output in current prices. The DBEs intensity in each region is higher than its PBEs intensity. This is because DBEs include both direct and indirect emissions. Starting with a large gap in emissions intensities between the developing and the developed regions, the gap decreased significantly over the period between 1995 and 2009 due to proportionally higher intensity improvements by the developing regions. For example, PBEs intensity in China improved from 1.7 tonne per $1000 (6 times of that in US) of output in 1995 to 0.5 tonne per $1000 (3 times of that in US) in 2009.

In the Copenhagen Accord of 2009 while the EU, the US and Canada have set their emissions reduction pledge in terms of terms of historical base line emissions, the economies of China and India have set their targets in terms of emissions intensity reduction. China pledged for to lower its carbon-dioxide emissions per dollar of economic output at least 40 percent by 2020 from 2005 levels, while India committed to cut its emissions per dollar at least by 20 percent in the same period. If the trends in intensity reductions continue it is likely that China and India do not have to put any additional efforts to reduce their GHG emissions to comply with the Copenhagen commitments. A number of energy emissions forecasts suggest that the targets set by China and India would be achieved by the natural growth process, the structural shifts and the technological improvements these economies are going through (references to be added).

Figure 4: PBEs intensity: 1995-2009

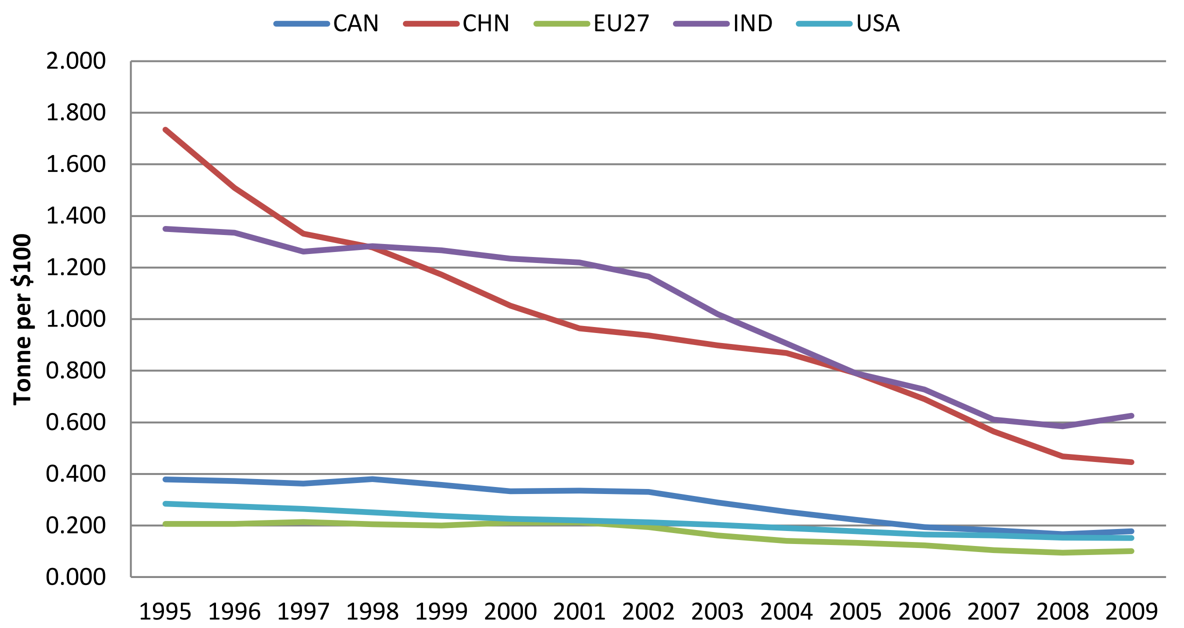
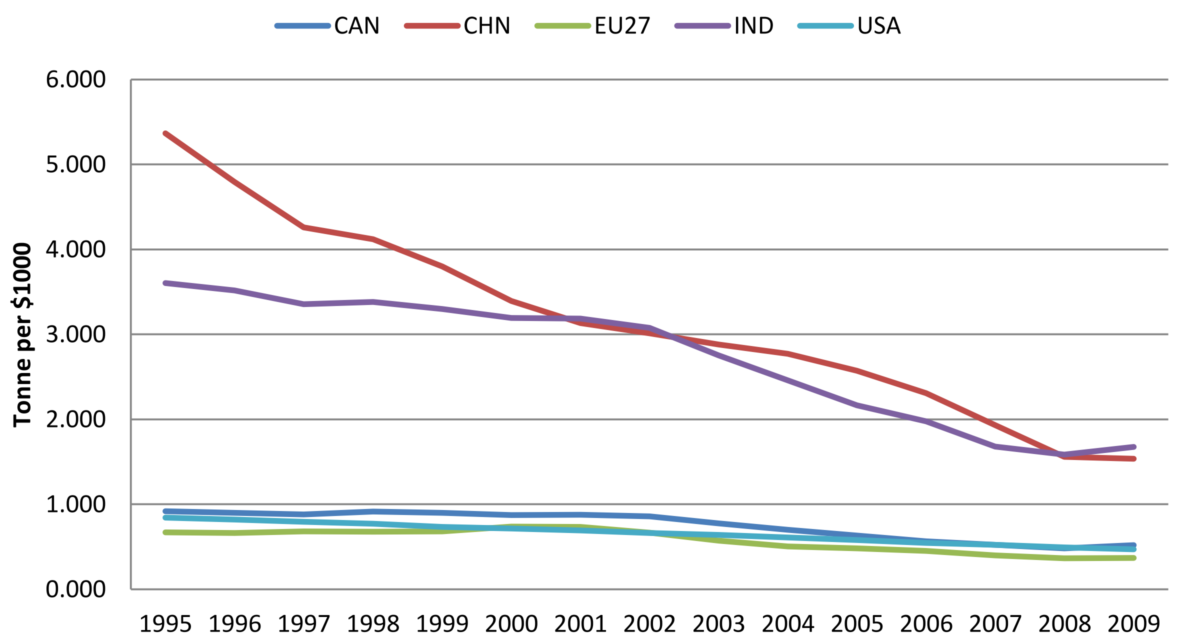


Figure 5: DBEs intensity: 1995-2009



The PBEs intensity defined in Equation (3) can be written in a slightly different way to form the basis for the decomposition as follows:

$$pe_t = \frac{PBE_t}{Y_t} = \sum_{s=1}^{n} \frac{PE_t^s}{Y_t^s}\frac{Y_t^s}{Y_t} = \sum_{s=1}^{n} I_t^s S_t^s \tag{4}$$

Where PE_t^s and Y_t^s are the emissions and output in sector *s* in a region at time *t*. Aggregate emission intensity can therefore be decomposed into sectoral emission intensity (I) and the sector shares (S) in the economy. The changes in aggregate emissions intensity can therefore be expressed into changes into the two components; changes in within sector emissions intensity which can also be termed as technological improvement and the changes in the weights of sectors or changes in sector composition. The technological change covers a broad range of elements including energy efficiency improvements and changes in energy mix resulting in declining emissions per unit of output. This therefore can further be decomposed into changes in energy mix and efficiency improvement. However, given that there is not much detail available in this database we do not undertake this exercise in this paper.

Following Bruneau and Renzetti (2009) and Cole, Elliott, and Shimamoto (2005, 62-3) changes in emissions intensity between two periods can be written as:

$$\frac{PBE_{t+1}}{PBE_t} - 1 = \frac{1}{pe_t}\sum_{s=1}^{n} \frac{L(I_{t+1}^s S_{t+1}^s, \mathrm{I}_t^s\, S_t^s)}{L(\mathrm{I}_{t+1}^s\, I_t^s)}(I_{t+1}^s - I_t^s) + \frac{1}{pe_t}\sum_{s=1}^{n} \frac{L(I_{t+1}^s S_{t+1}^s, \mathrm{I}_t^s\, S_t^s)}{L(\mathrm{S}_{t+1}^s\, S_t^s)}(\mathrm{S}_{t+1}^s - S_t^s) \tag{5}$$

where L is the log-mean function

The left hand side of Equation (5) gives the relative changes in production-based emission intensities between time t+1 and t, while the first term on the right hand side provides the estimates of technical changes in production processes in different sectors of the economy and the second term provides estimates the contribution of structural shifts across industrial sectors.

To understand the influences of changes in commodity composition and the sourcing goods and services for final consumption from different regions two different decomposition procedures are undertaken for changes in DBEs intensity. The first analogous to above is emissions intensity changes resulting from technological improvements embodied in composite goods and the structure of commodity composition. The second decomposes the contribution of technological changes originating from different sources of consumption and its composition. In the preceding, overall DBEs intensity (de_t) can be represented as summation of individual commodity emissions intensity and its share in commodity in the consumption basket.

$$de_t = \frac{DBE_t}{Y_t} = \sum_{c=1}^{n} \frac{DE_t^c}{FD_t^c}\frac{FD_t^c}{FD_t} = \sum_{r=1}^{n} DI_t^c DS_t^c \quad \text{where c = consumption goods (n=1…35)} \tag{6}$$

In the second, overall DBEs intensity (de_t) can be represented as summation of individual commodity emissions intensity originating from different sources (r) and its share in commodity in the consumption basket.[7]

$$de_t = \frac{DE_t}{Y_t} = \sum_{r=1}^{n} \frac{DE_t^r}{FD_t^r} \frac{FD_t^r}{FD_t} = \sum_{r=1}^{n} DI_t^r DS_t^r \qquad \text{where r = originating regions (n=1…14)} \tag{6}$$

Following the log mean divisia index methodology as in equation (5) DBEs intensity in Equations 5 and (6) can be decomposed as follows:

$$\frac{DBE_{t+1}}{DBE_t} - 1 = \frac{1}{de_t} \sum_{r=1}^{n} \frac{L(\mathrm{DI}_{t+1}^c DS_{t+1}^c, \mathrm{DI}_t^c DS_t^c)}{L(\mathrm{DI}_{t+1}^r DI_t^r)} (\mathrm{DI}_{t+1}^c - DI_t^r) + \frac{1}{de_t} \sum_{r=1}^{n} \frac{L(\mathrm{DI}_{t+1}^c DS_{t+1}^c, \mathrm{DI}_t^c DS_t^c)}{L(\mathrm{DS}_{t+1}^c DS_t^c)} (\mathrm{DS}_{t+1}^c - DS_t^c) \tag{7}$$

The first term on the right hand side captures the changes resulting from technical change and the second from the changes in commodity structure of the consumption basket effect

$$\frac{DBE_{t+1}}{DBE_t} - 1 = \frac{1}{de_t} \sum_{r=1}^{n} \frac{L(\mathrm{DI}_{t+1}^r DS_{t+1}^r, \mathrm{DI}_t^r DS_t^r)}{L(\mathrm{DI}_{t+1}^r DI_t^r)} (\mathrm{DI}_{t+1}^r - DI_t^r) + \frac{1}{de_t} \sum_{r=1}^{n} \frac{L(\mathrm{DI}_{t+1}^r DS_{t+1}^r, \mathrm{DI}_t^r DS_t^r)}{L(\mathrm{DS}_{t+1}^r DS_t^r)} (\mathrm{DS}_{t+1}^r - DS_t^r) \tag{8}$$

The first term on the right hand side captures the changes resulting from technical change taking place in various regions and the second from the changes in the sources of consumption.

4. Analysis of decomposition results

PBEs intensity has been declining in all economies although at a faster rate in China and India (Figure 6a and b). Appendix 6 provides detailed decompositions of both PBEs and DBEs intensities for the five country/regions. Between 1995 and 2009 emissions intensity in Canada, United States and the EU 27 has declined by 45 to 55%, while those in China and India it declined by 55% and 75% respectively. DBEs intensity has also declined in all economies but at a slower rate particularly in Canada and the EU 27 by about 45% during the same period (Figure 7). Interestingly, both DBEs and PBEs intensities in India have declined by 54% between1995-2009 (see Appendix 6 for further details). In case of China and the US the decline in DBEs intensity has been less by a couple of percentage points compared to that of its PBEs intensity.

[7] There are 40 global regions in the database however, since the 27 regions of the EU were aggregated into one single region the number of regions in the model becomes 14.

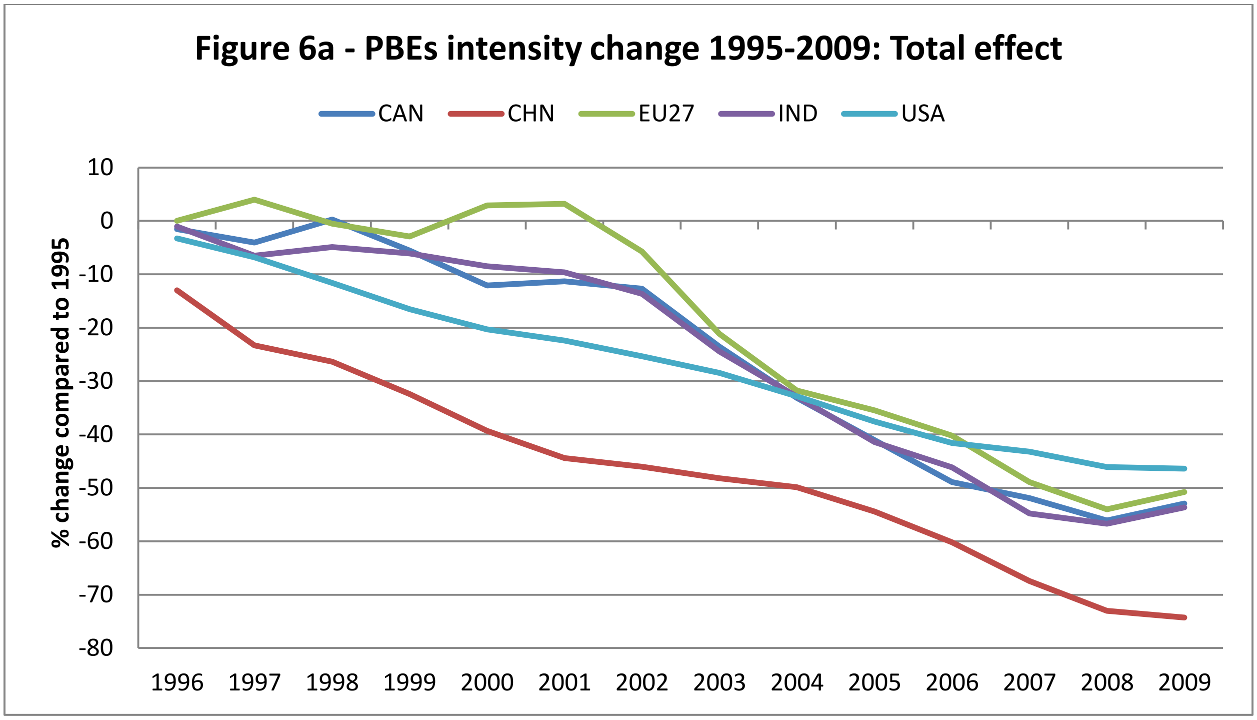


Figure 6a - PBEs intensity change 1995-2009: Total effect
CAN
CHN
EU27
IND
USA
10
0
-10
-20
-30
-40
-50
-60
-70
-80
% change compared to 1995
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009

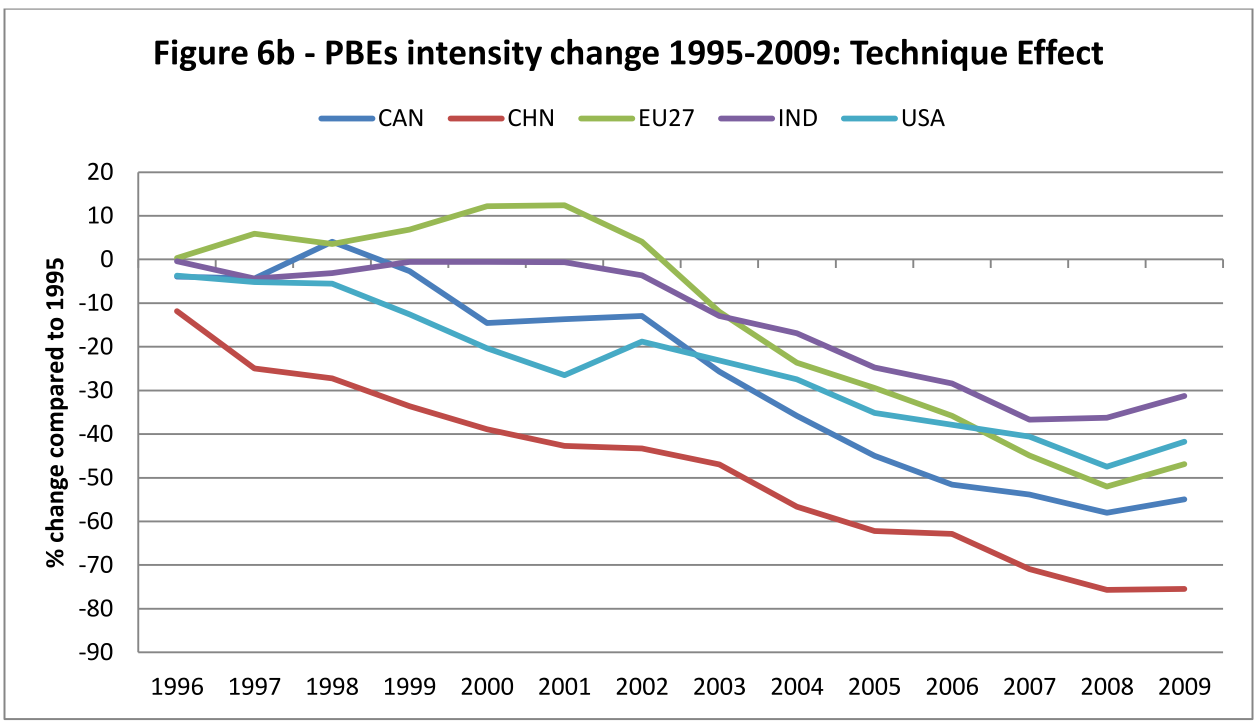


Figure 6b - PBEs intensity change 1995-2009: Technique Effect
CAN
CHN
EU27
IND
USA
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
% change compared to 1995
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009

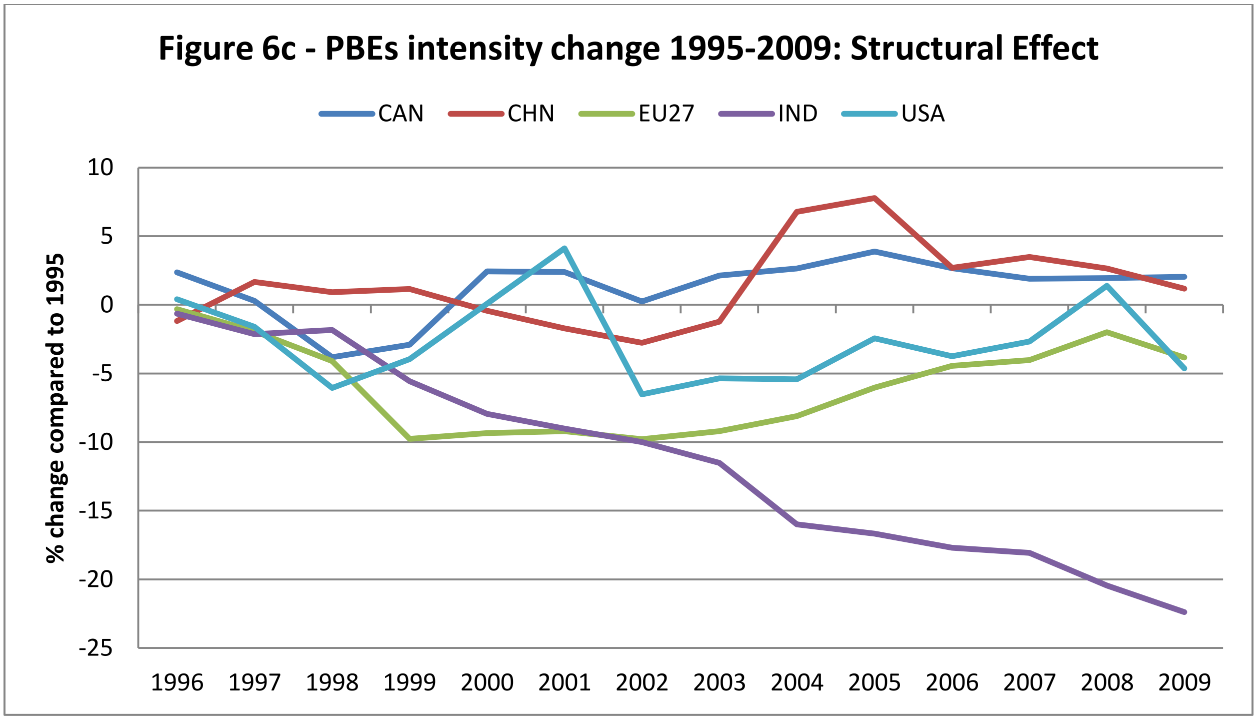


Figure 6c - PBEs intensity change 1995-2009: Structural Effect
CAN
CHN
EU27
IND
USA
% change compared to 1995
10
5
0
-5
-10
-15
-20
-25
1996
1997
1998
1999
2000
2001
2002
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2005
2006
2007
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2009

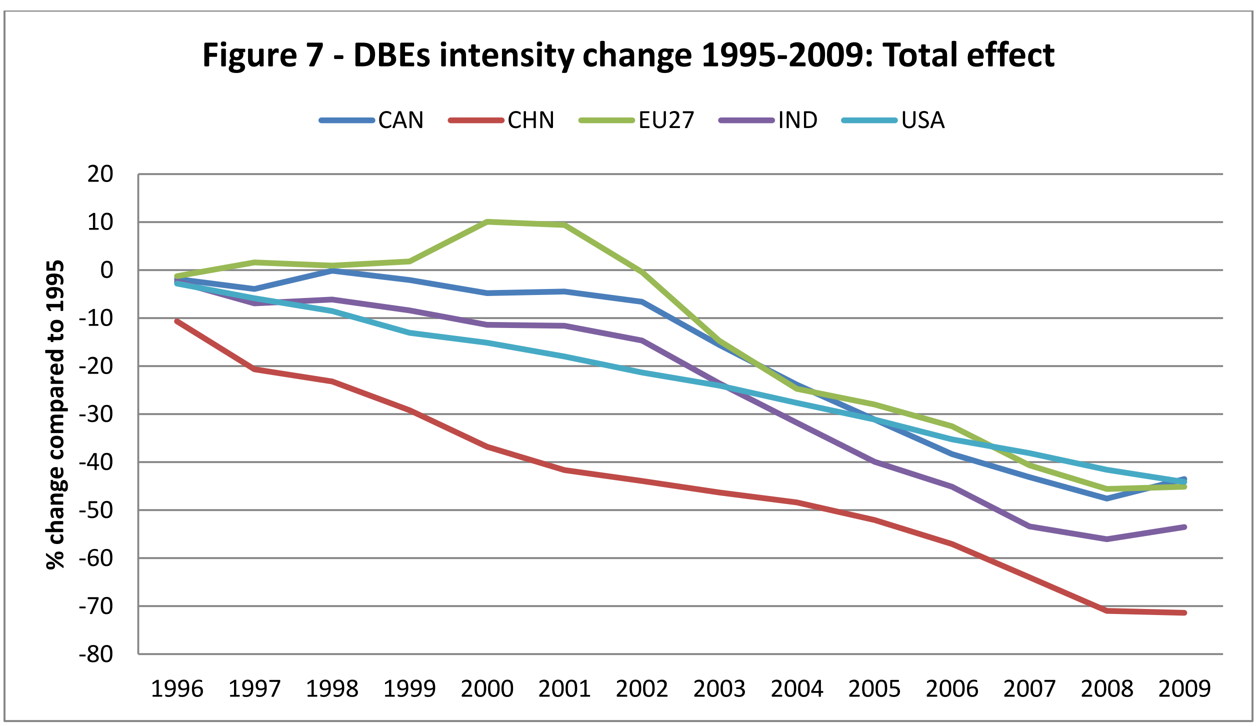

Figure 7 - DBEs intensity change 1995-2009: Total effect
CAN
CHN
EU27
IND
USA
% change compared to 1995
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
1996
1997
1998
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Figure 7a - DBEs intensity change 1995-2009: Technique effect (Decomposition by commodity composition)

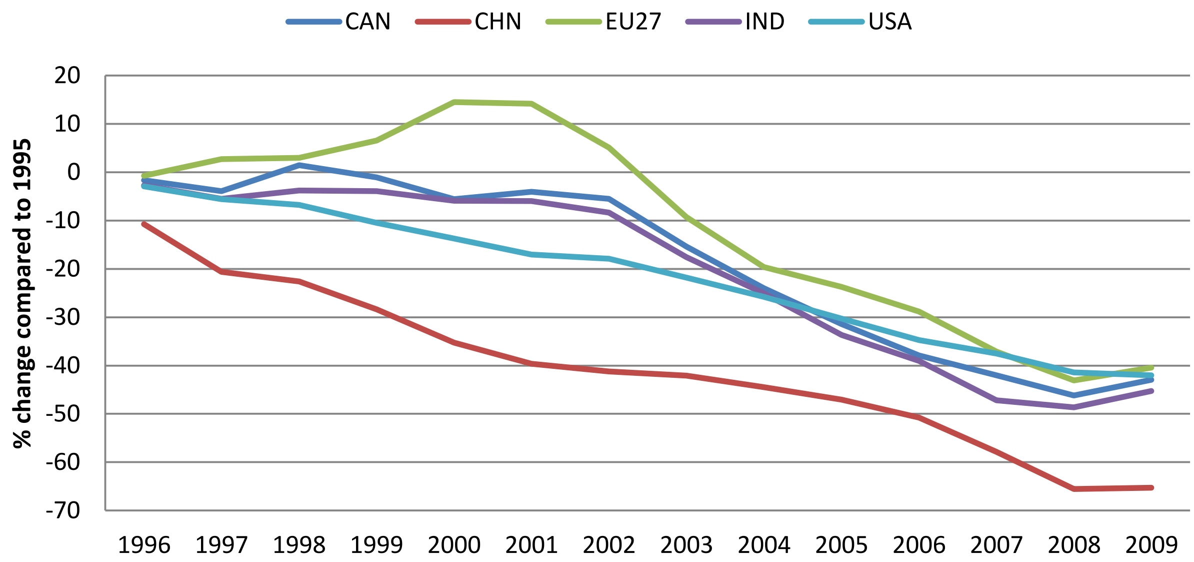
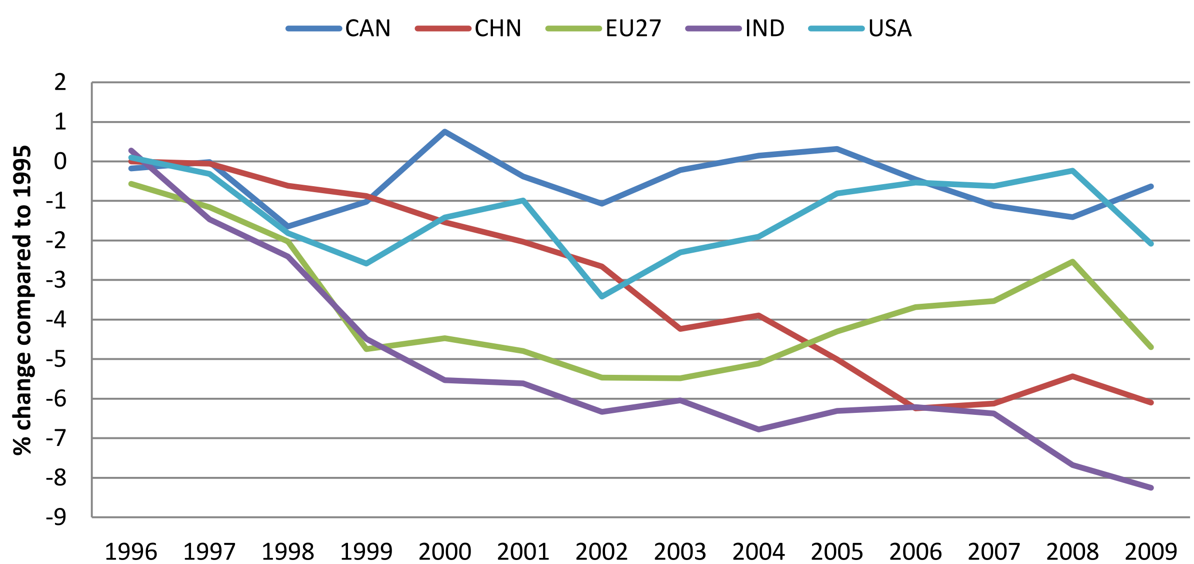


Figure 7b - DBEs intensity change 1995-2009: Structure effect (Decomposition by commodity composition)



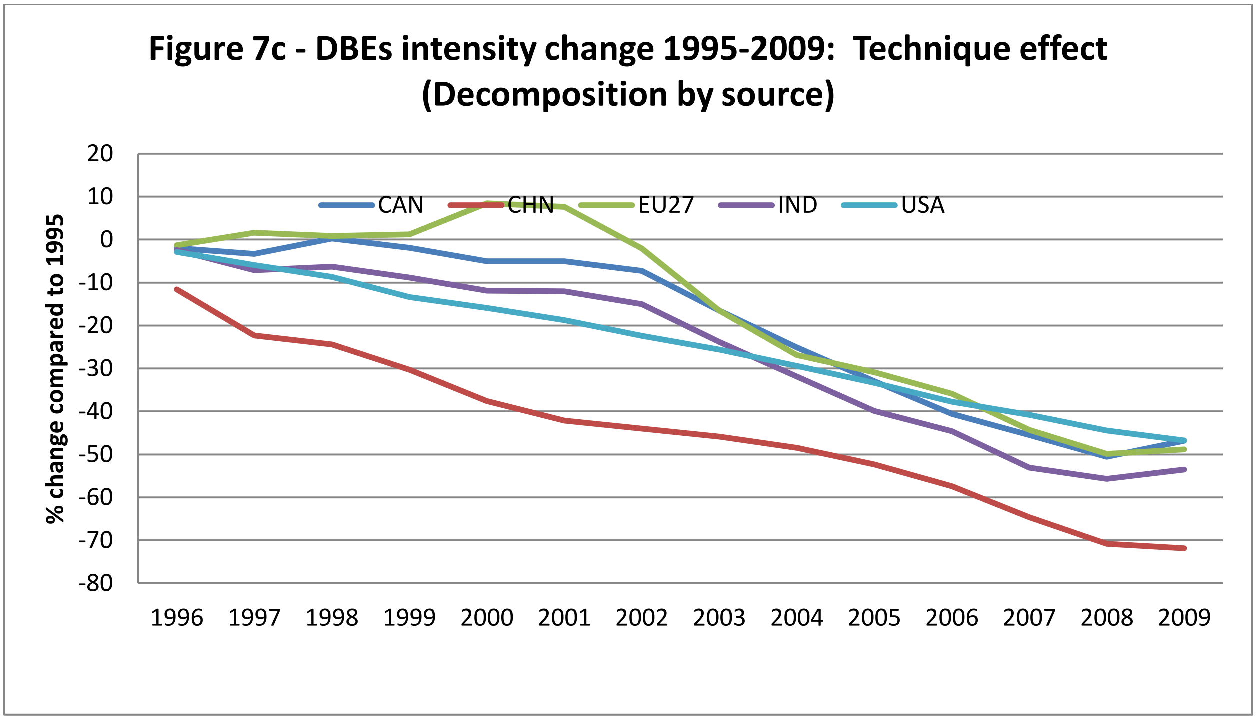


Figure 7c - DBEs intensity change 1995-2009: Technique effect
(Decomposition by source)
% change compared to 1995
CAN
CHN
EU27
IND
USA
20
10
0
-10
-20
-30
-40
-50
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-80
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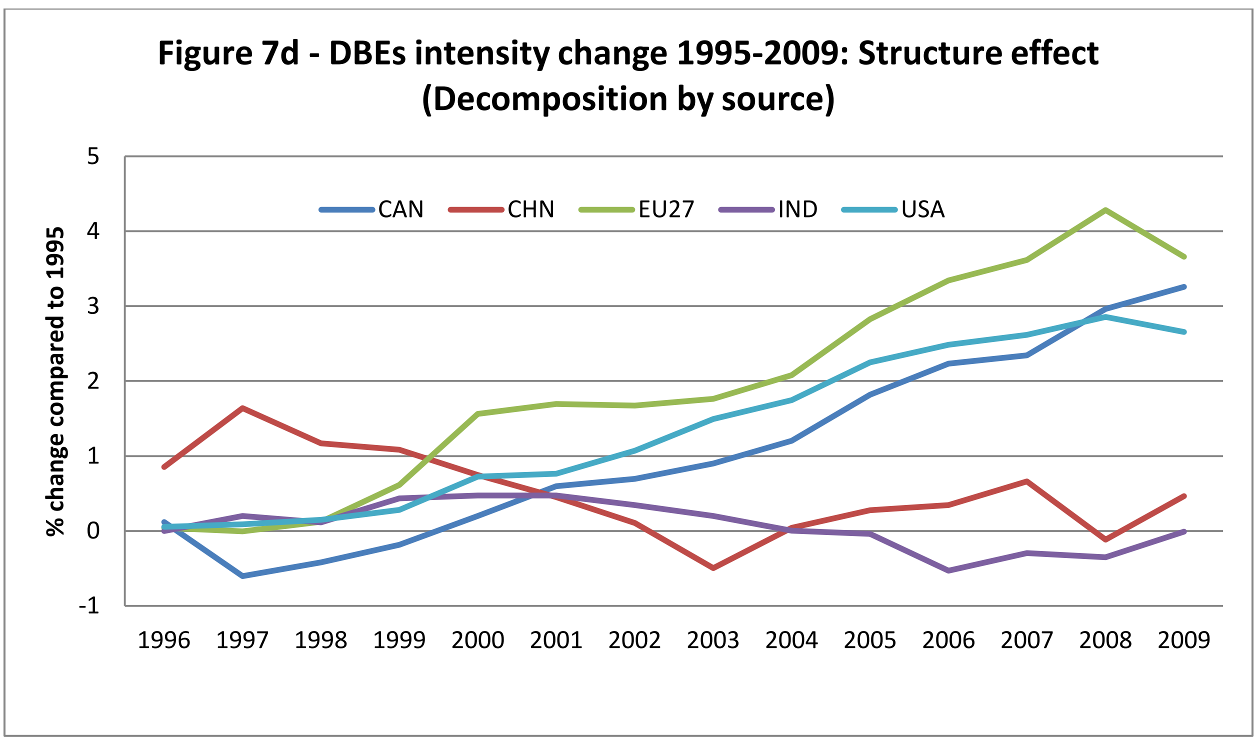


Figure 7d - DBEs intensity change 1995-2009: Structure effect
(Decomposition by source)
% change compared to 1995
CAN
CHN
EU27
IND
USA
5
4
3
2
1
0
-1
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

Decomposition of the GHG emissions intensity change suggests that the contribution of relevant structural changes such as the economic structure of production, and the commodity composition and the sources of consumption by regions have contributed little in overall intensity reduction except that in India in case of PBEs (Figures 7a and 7d). In India the contribution of structural change in overall PBEs intensity reduction between 1995 and 2009 has been over 40% (Appendix 6). In the EU 27 and US the contributions of changes in industrial structure have been one fourth of that of India (8% and 10% of overall PBEs intensity reduction). Interestingly, the economies of Canada (since 2000) and China (since 2004) have marginally moved towards more emissions intensive sectors compared to 1995 and thus contributing negatively towards intensity improvements. In the US, and EU 27 since 2002 a slightly upward movement towards emissions intensive sectors can be observed although its contribution to total intensity change still remains negative.

The results of intensity change decomposition based on the sources of final consumption or demand-based emissions show a clear trend that the developed regions, namely, the EU 27, Canada and the US are substituting towards more emissions intensive sources (Figure 7d). The technique effect, when the sources of demand for final consumption are kept unchanged, show declining emissions intensity (Figure 7c). This reflects the general decline in production-based emissions intensities across the globe. However, countries vary widely in terms of aggregate/average emissions intensities as described earlier. For example, in 2009 PBEs intensity per $ of output in China was three times of that of the US (Figure 4). Thus, although technological innovation across the countries are positively contributing to overall of emissions intensity improvements both in production and consumption activities, substitution of consumption from less emissions intensive source countries by more emissions intensive countries contributes negatively to overall intensity improvements. This phenomena, often termed as emissions leakage has widely been discussed in the literature (e.g., Ghosh et al (2012, Elliot et al. 2012 and OECD 2008). Results in this paper clearly show that EU 27, Canada and the US all moving towards relatively emissions intensive source for meeting their final demand. Between 1995 and 2009 this has contributed to increased emissions intensity by 2 to 4 percent in these economies (Appendix 6). Further, analysis suggest that the share Canadian imports from China has increased in recent years, while for the EU its share from relatively emissions intensive developing economies have increased. Share of Canadian imports from China has increased from 3.2 percent in 2000 to 8.7 and 10.9 percent in 2006 and 2009.[8] Similar observation can also be made for the United States.

In summary, detailed decomposition results suggests that technological change is the key driver of emissions intensity improvements both in production and consumption activities. The contribution of technological change is estimated to be large and it has been higher in the developing countries (although, with high base level emissions intensity). The impacts from structural change are small (except that in India) and vary across countries. It appears that

[8] Author's calculation from from Industry Canada trade data online.

although developed economies have stabilized their PBEs in recent years their DBEs continue to increase partly due to switching towards relatively more emissions intensive sources of supply.

One caveat in this study is that the emissions intensity is estimated in per current dollar terms and therefore possibly overestimated. We are looking for appropriate price indices to be used for converting the detailed multiregional input-output tables in real terms. Results from this version of the paper are for discussions only.

DBEs: Between 1997 and 2002 DBEs intensity in EU 27 increased mostly resulting from technique effect – why?

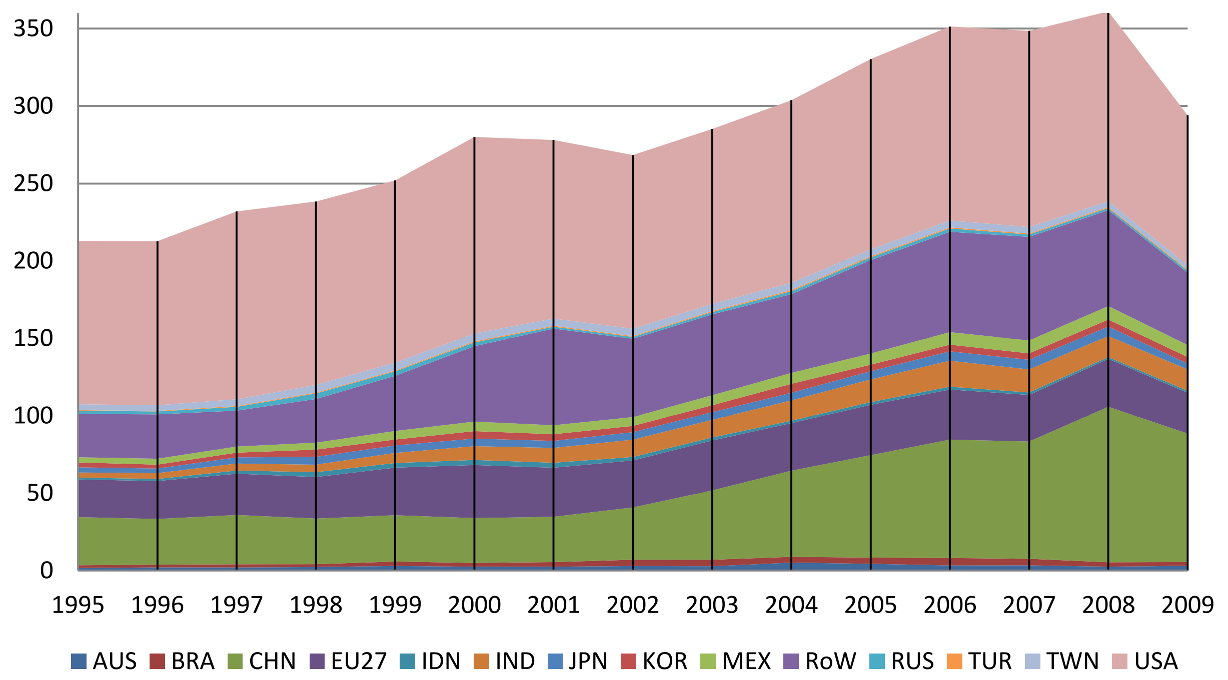
5. Summary and conclusions

This paper used the WIOD database (Timmer (ed.) 2012) to analyze the changes in emissions intensities in five regions, namely, Canada, China, EU 27, India and the United States which account for almost 2/3rd of global GHG emissions in recent years. Both production-based and demand-based emissions intensities are analyzed. To understand the sources of intensity improvements it uses the log mean divisia index methods to decompose the overall intensities into technique effect and structure effects. The main findings of the paper can be summarized as follows. Starting with much higher levels of emissions intensities, the developing economies particularly China has improved its intensities at more than those by the developed economies namely, Canada, EU 27 and the US. The improvements in production-based emissions intensities have been faster than the demand-based emissions intensities.

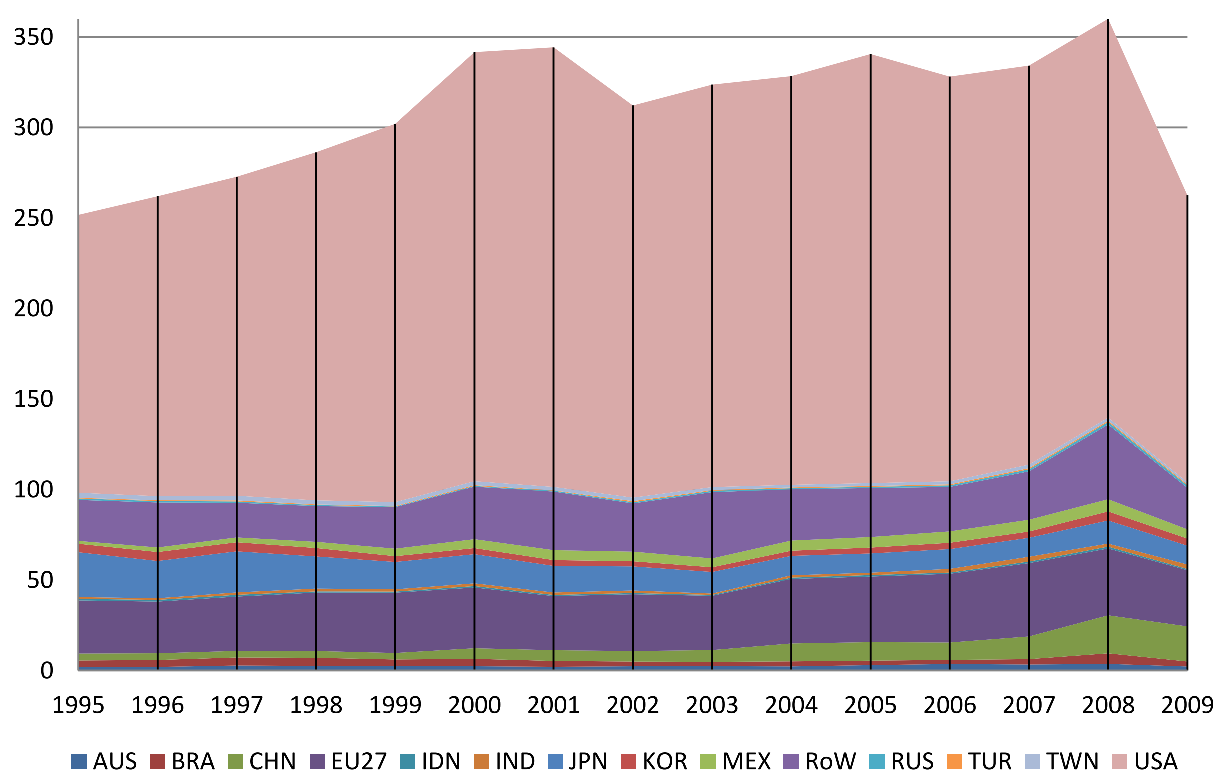
Technological change is the key driver of reduction in both PBEs and DBEs intensities. Structural changes in composition of production and demand has relatively smaller contribution in overall intensity improvement. In some countries structural shifts has negatively contributed to emissions intensity improvements. Although marginally production activities in Canada and China have moved towards energy/emission intensive sectors. In India structural shift in both production and consumption activities have contributed significantly in emissions intensity improvements. It appears that through international trade countries have move towards more emissions intensive sources of demand particularly the developed economies. It is plausible that this compositional changes in sources of final demand is one reason for growth in DBEs in developed in Canada and the EU 27.

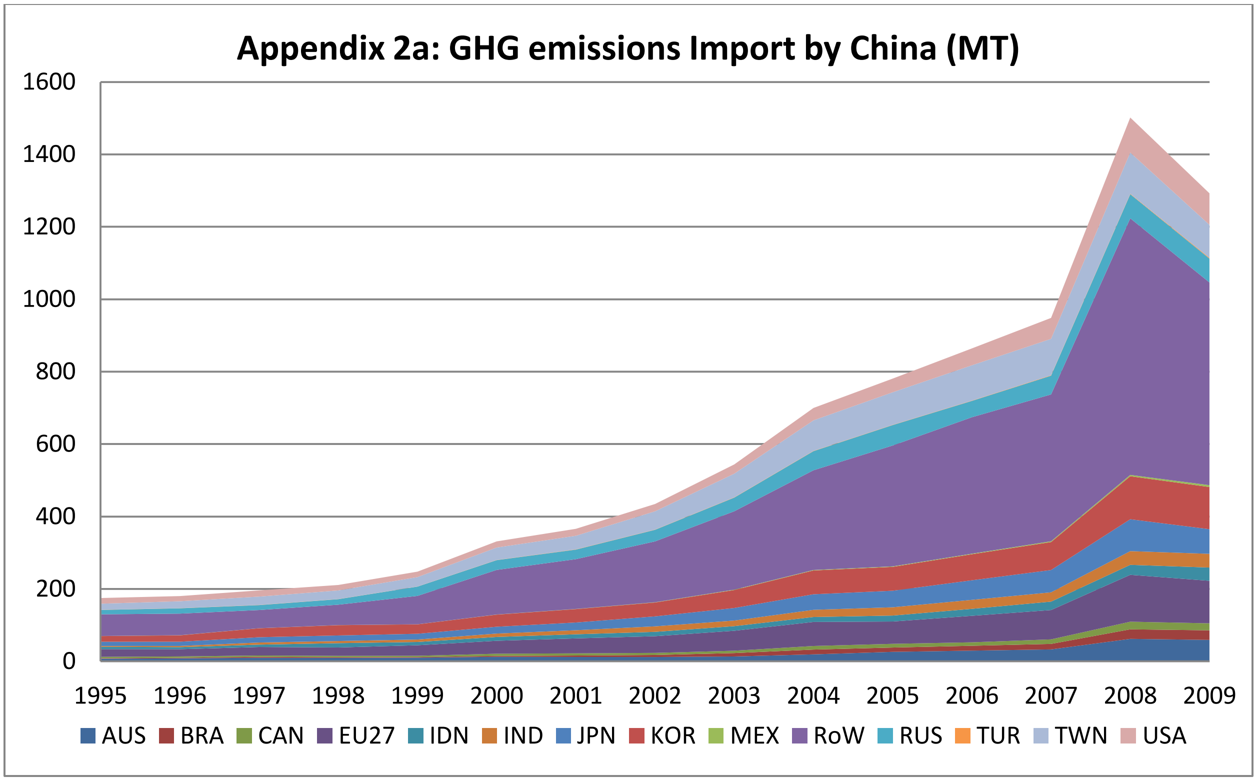
The emissions intensities calculated in this paper are from data at current prices, which may have resulted in overestimation of intensity improvements. The next step is therefore revising the estimates based on real input-output data. Future work will also explore the drivers of the changes in technical progress and structural shifts explaining energy emissions intensity improvements. This will involve econometric estimation using panel time-series cross-section data most of which are available in the database.

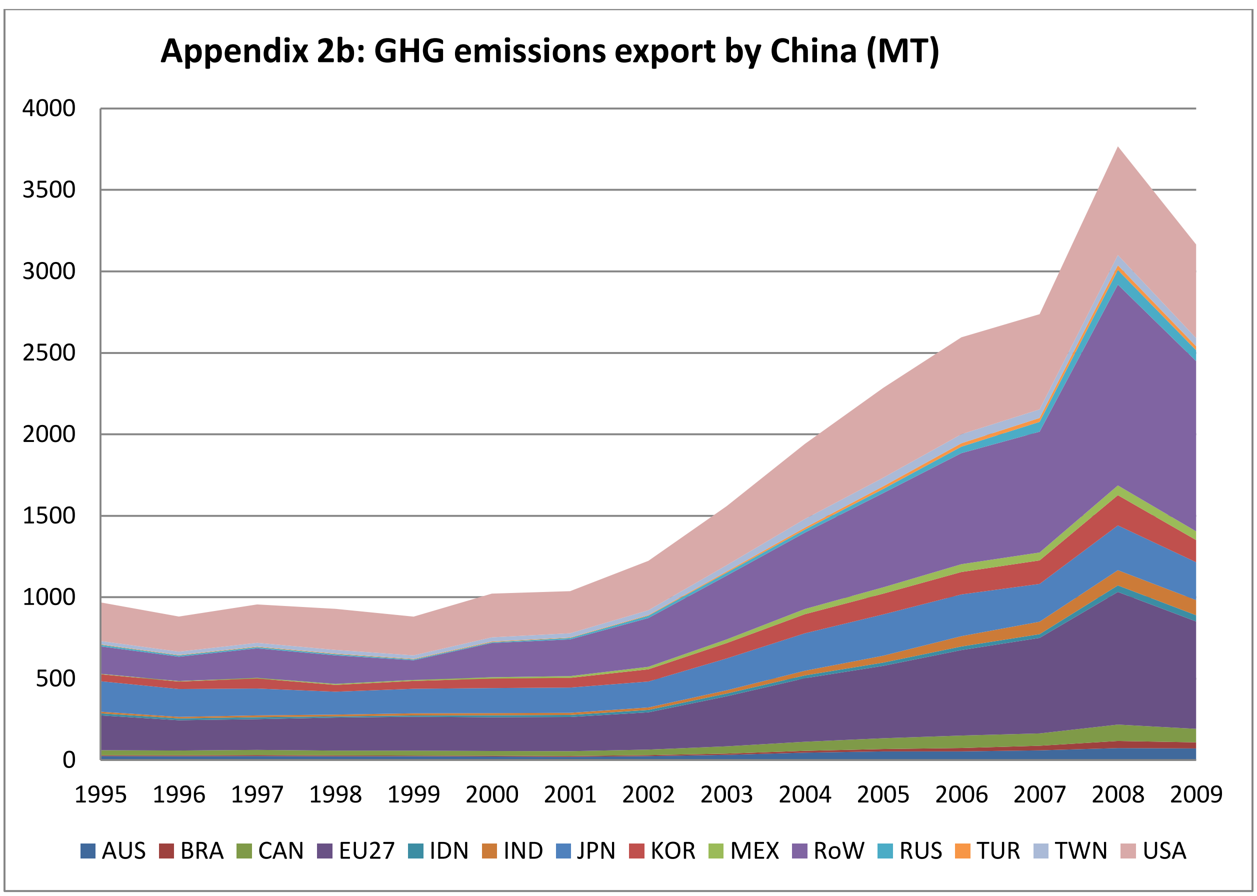
Appendix 1a: Imoprt of GHG emissions by Canada (MT)

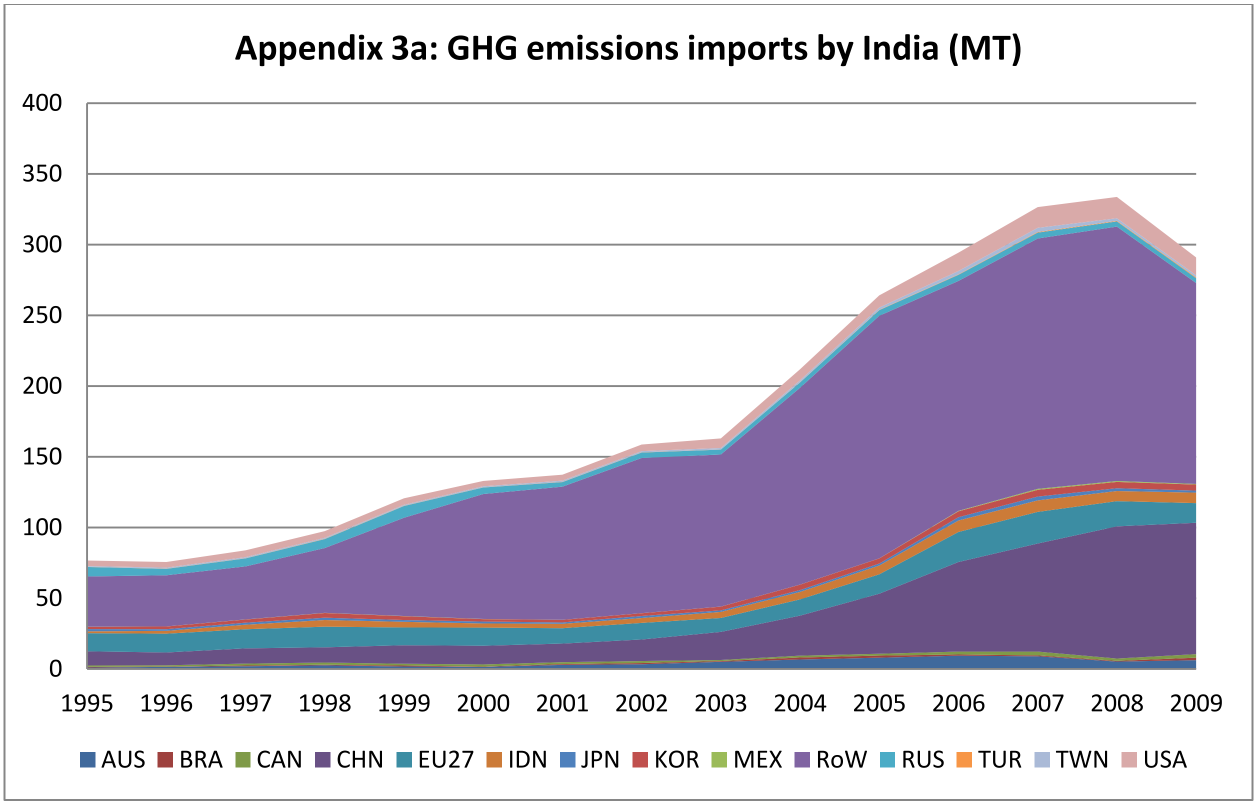


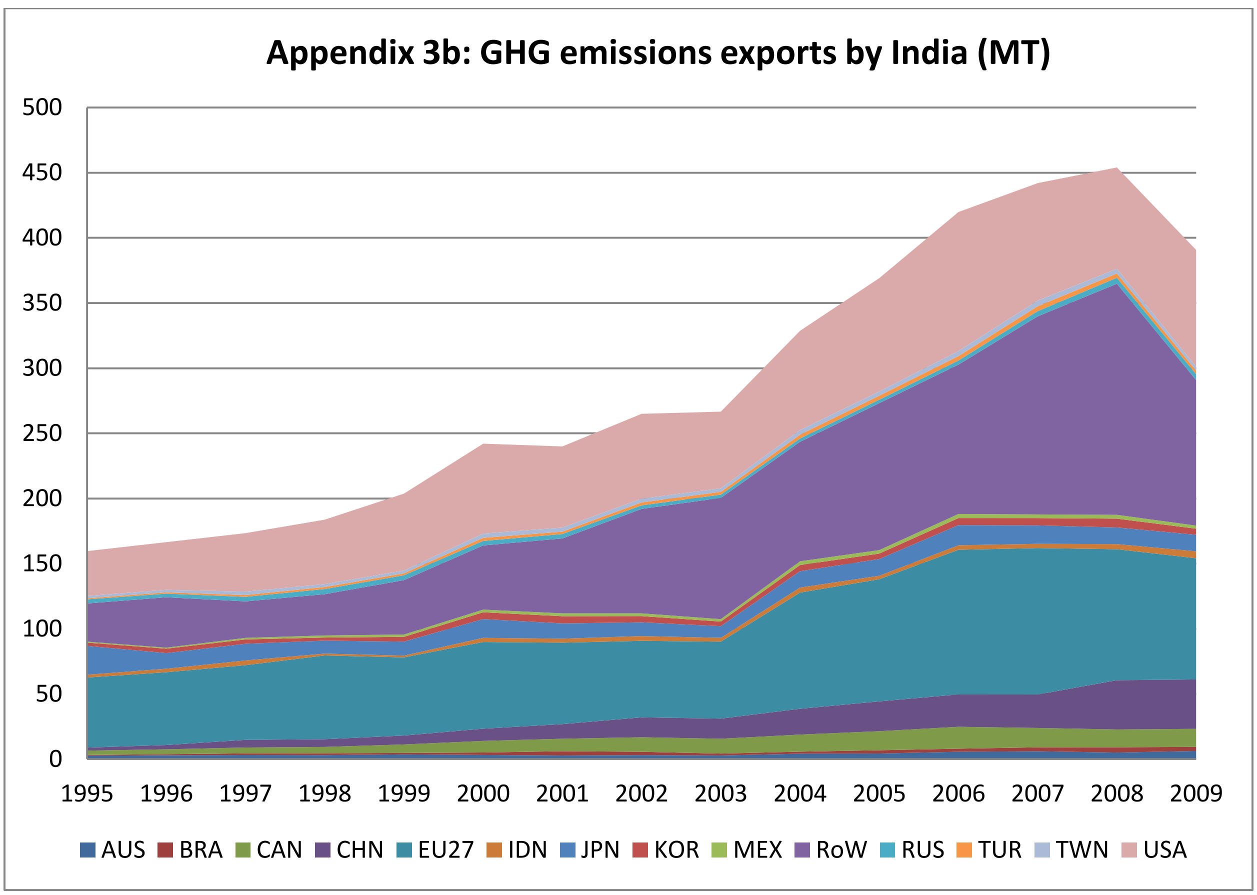
Appendix 1b: GHG Emissions Export by Canada (MT)

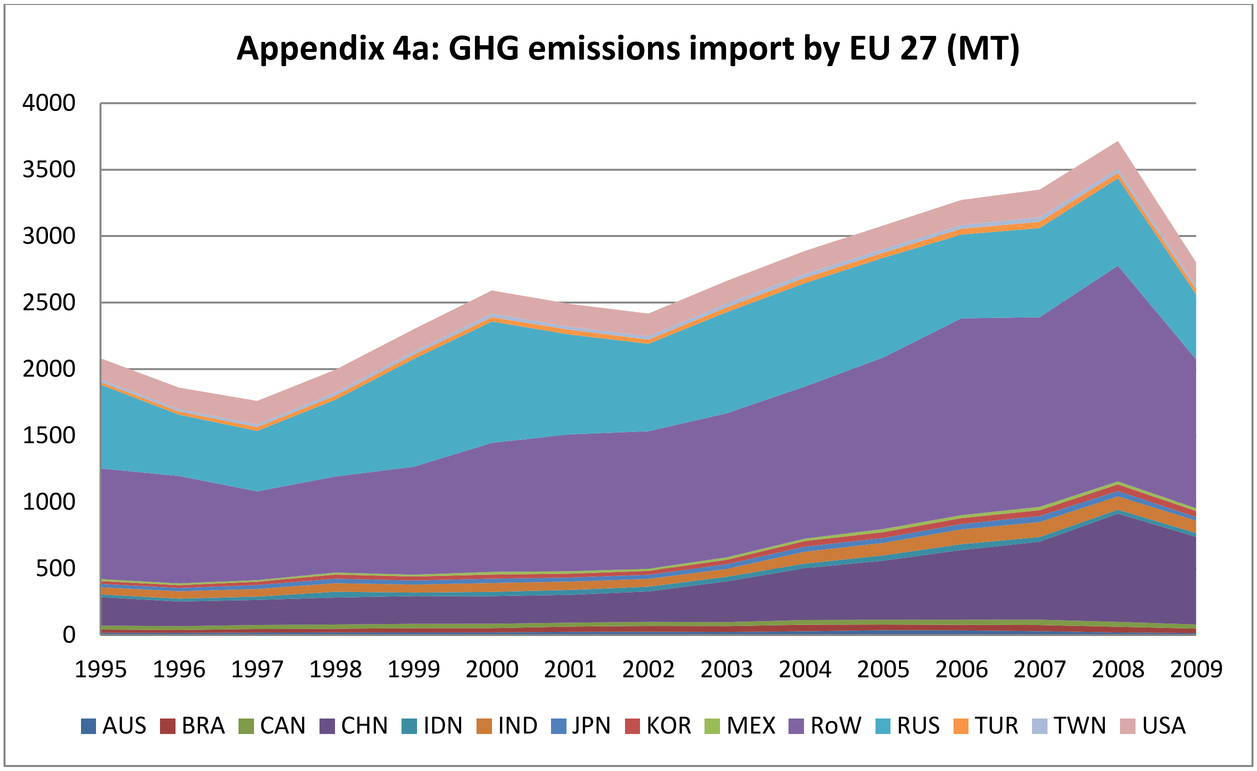


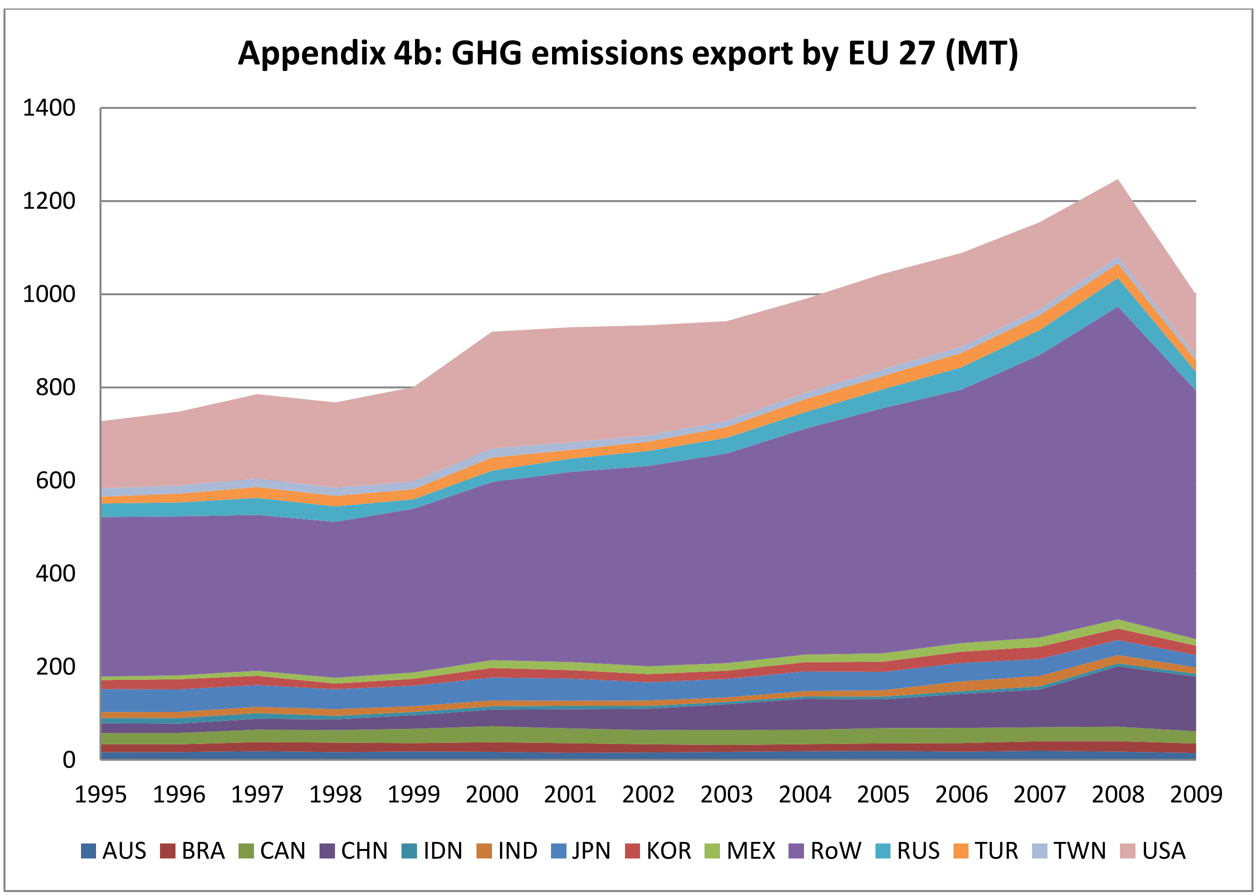

Appendix 2a: GHG emissions Import by China (MT)
1600
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN EU27 IDN IND JPN KOR MEX RoW RUS TUR TWN USA

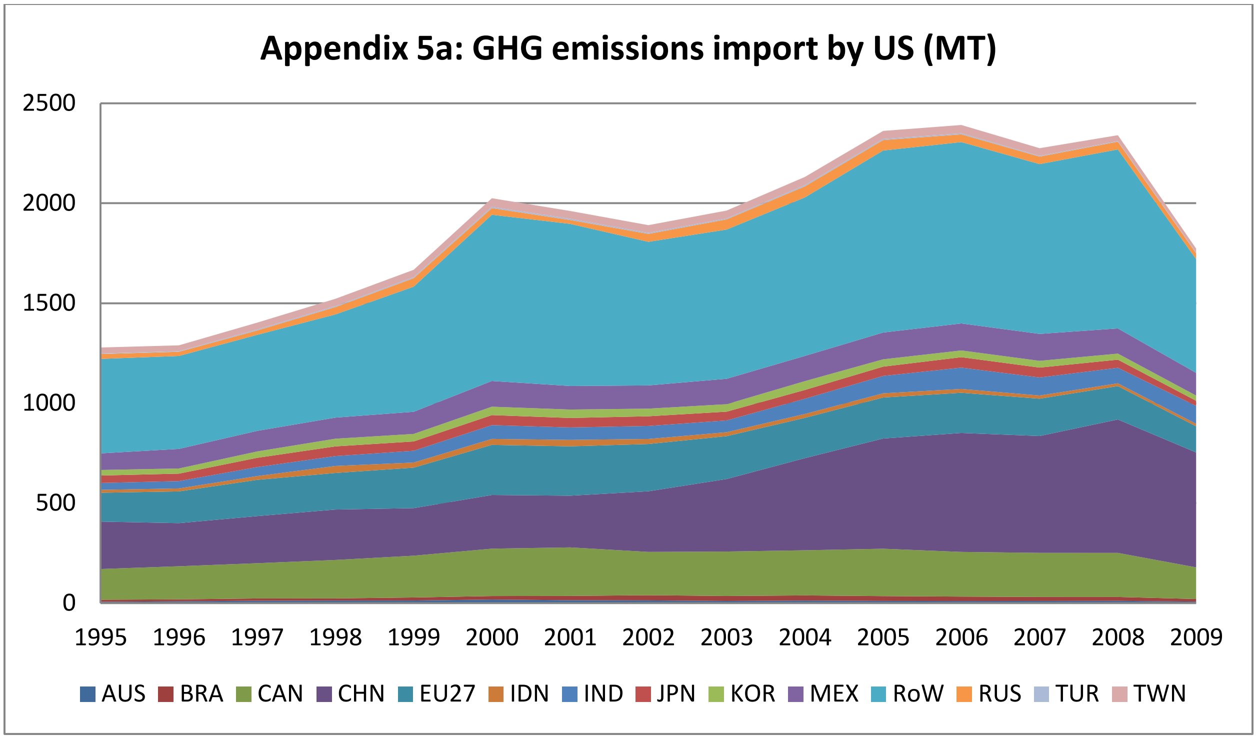

Appendix 2b: GHG emissions export by China (MT)
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN EU27 IDN IND JPN KOR MEX RoW RUS TUR TWN USA

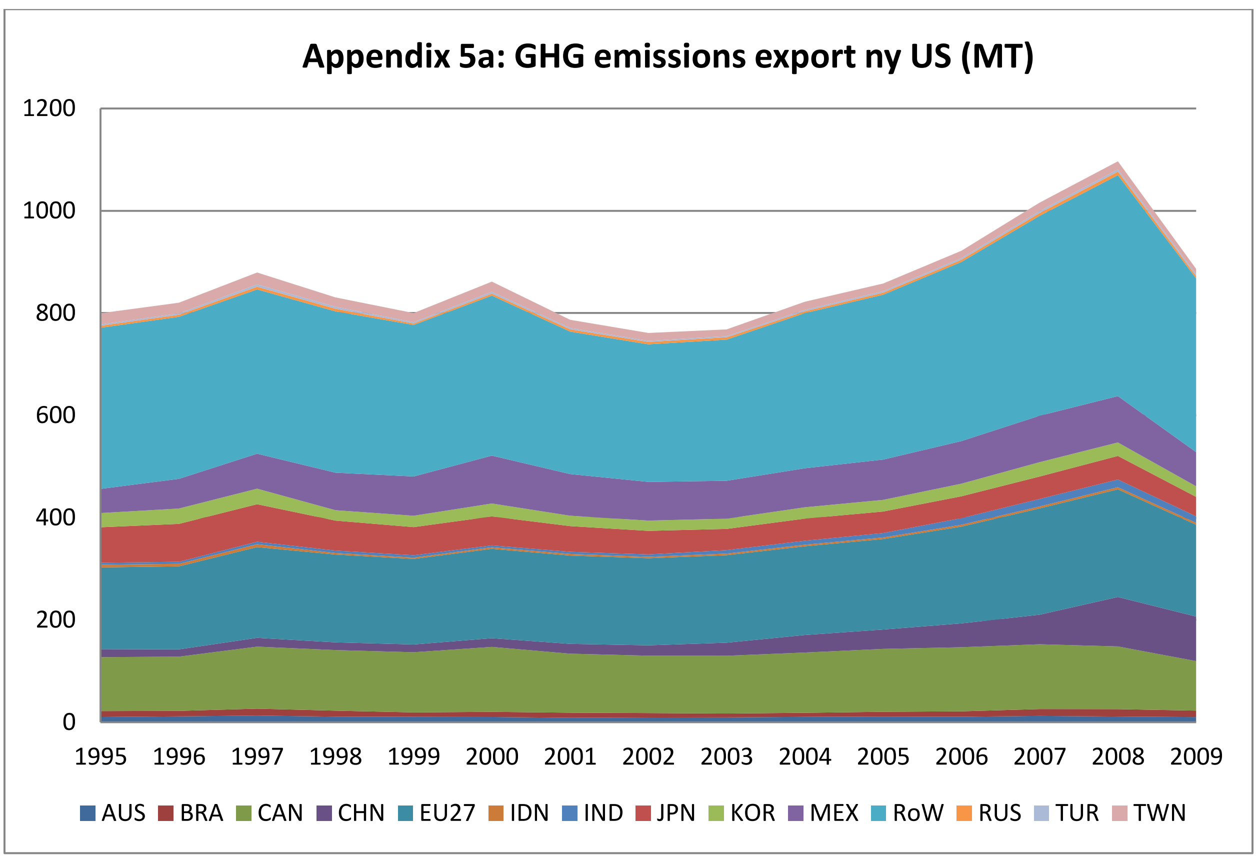

Appendix 3a: GHG emissions imports by India (MT)
400
350
300
250
200
150
100
50
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN EU27 IDN JPN KOR MEX RoW RUS TUR TWN USA


Appendix 3b: GHG emissions exports by India (MT)
500
450
400
350
300
250
200
150
100
50
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN EU27 IDN JPN KOR MEX RoW RUS TUR TWN USA


Appendix 4a: GHG emissions import by EU 27 (MT)
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN IDN IND JPN KOR MEX RoW RUS TUR TWN USA


Appendix 4b: GHG emissions export by EU 27 (MT)
1400
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN IDN IND JPN KOR MEX RoW RUS TUR TWN USA


Appendix 5a: GHG emissions import by US (MT)
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN EU27 IDN IND JPN KOR MEX RoW RUS TUR TWN


Appendix 5a: GHG emissions export ny US (MT)
1200
1000
800
600
400
200
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
AUS BRA CAN CHN EU27 IDN IND JPN KOR MEX RoW RUS TUR TWN

Appendix 6: Detailed results of emissions intensity decomposition by regions

Decomposition of changes in PBEs and DBEs: Canada

	PBEs intensity			DBEs intensity				
	Total	Tech	Structure	Total	Tech (source)	comp (source)	Tech (comm)	Stru (comm)
1996	-1.6	-3.9	2.4	-1.9	-2.0	0.1	-1.7	-0.2
1997	-4.1	-4.3	0.3	-3.9	-3.3	-0.6	-3.9	0.0
1998	0.2	4.1	-3.8	-0.2	0.2	-0.4	1.5	-1.6
1999	-5.6	-2.6	-2.9	-2.1	-1.9	-0.2	-1.0	-1.0
2000	-12.1	-14.6	2.4	-4.8	-5.0	0.2	-5.6	0.8
2001	-11.3	-13.7	2.4	-4.5	-5.0	0.6	-4.1	-0.4
2002	-12.7	-13.0	0.2	-6.6	-7.3	0.7	-5.5	-1.1
2003	-23.5	-25.7	2.1	-15.6	-16.5	0.9	-15.4	-0.2
2004	-33.1	-35.8	2.6	-23.8	-25.0	1.2	-24.0	0.1
2005	-41.1	-44.9	3.9	-31.1	-33.0	1.8	-31.5	0.3
2006	-48.9	-51.6	2.7	-38.4	-40.6	2.2	-37.9	-0.4
2007	-51.9	-53.8	1.9	-43.1	-45.5	2.3	-42.0	-1.1
2008	-56.1	-58.1	1.9	-47.6	-50.6	3.0	-46.2	-1.4
2009	-52.9	-54.9	2.0	-43.6	-46.8	3.3	-42.9	-0.6

Decomposition of changes in PBEs and DBEs: China

	PBEs intensity			DBEs intensity				
	Total	Tech	Structure	Total	Tech (source)	comp (source)	Tech (comm)	Stru (comm)
1996	-13.0	-11.8	-1.2	-10.7	-11.6	0.9	-10.7	0.0
1997	-23.3	-25.0	1.7	-20.6	-22.3	1.6	-20.6	-0.1
1998	-26.3	-27.3	0.9	-23.2	-24.4	1.2	-22.6	-0.6
1999	-32.4	-33.6	1.1	-29.2	-30.3	1.1	-28.4	-0.9
2000	-39.3	-38.9	-0.4	-36.8	-37.6	0.7	-35.3	-1.5
2001	-44.4	-42.7	-1.7	-41.6	-42.1	0.5	-39.6	-2.0
2002	-46.0	-43.3	-2.8	-43.9	-44.0	0.1	-41.2	-2.7
2003	-48.2	-47.0	-1.2	-46.3	-45.8	-0.5	-42.1	-4.2
2004	-49.9	-56.7	6.8	-48.4	-48.4	0.0	-44.5	-3.9
2005	-54.4	-62.2	7.8	-52.1	-52.3	0.3	-47.1	-5.0
2006	-60.2	-62.9	2.7	-57.0	-57.4	0.3	-50.8	-6.2
2007	-67.5	-71.0	3.5	-64.0	-64.7	0.7	-57.9	-6.1
2008	-73.0	-75.7	2.7	-71.0	-70.8	-0.1	-65.5	-5.4
2009	-74.3	-75.4	1.2	-71.4	-71.9	0.5	-65.3	-6.1

Decomposition of changes in PBEs and DBEs: EU 27

	PBEs intensity			DBEs intensity				
	Total	Tech	Structure	Total	Tech (source)	comp (source)	Tech (comm)	Stru (comm)
1996	0.0	0.3	-0.3	-1.3	-1.3	0.0	-0.7	-0.6
1997	4.0	5.9	-1.9	1.6	1.6	0.0	2.7	-1.2
1998	-0.5	3.6	-4.1	0.9	0.8	0.1	3.0	-2.0
1999	-2.9	6.8	-9.8	1.8	1.2	0.6	6.6	-4.7
2000	2.9	12.2	-9.3	10.0	8.5	1.6	14.5	-4.5
2001	3.2	12.4	-9.2	9.4	7.7	1.7	14.2	-4.8
2002	-5.8	4.0	-9.8	-0.4	-2.1	1.7	5.1	-5.5
2003	-21.2	-12.0	-9.2	-14.8	-16.5	1.8	-9.3	-5.5
2004	-31.8	-23.7	-8.1	-24.8	-26.8	2.1	-19.6	-5.1
2005	-35.5	-29.5	-6.0	-28.0	-30.9	2.8	-23.7	-4.3
2006	-40.2	-35.8	-4.5	-32.5	-35.9	3.3	-28.9	-3.7
2007	-48.9	-44.9	-4.0	-40.7	-44.3	3.6	-37.1	-3.5
2008	-54.0	-52.0	-2.0	-45.6	-49.9	4.3	-43.0	-2.5
2009	-50.7	-46.9	-3.8	-45.1	-48.8	3.7	-40.5	-4.7

Decomposition of changes in PBEs and DBEs: India

	PBEs intensity			DBEs intensity				
	Total	Tech	Structure	Total	Tech (source)	comp (source)	Tech (comm)	Stru (comm)
1996	-1.0	-0.4	-0.7	-2.4	-2.4	0.0	-2.7	0.3
1997	-6.5	-4.4	-2.1	-6.9	-7.1	0.2	-5.5	-1.5
1998	-4.9	-3.1	-1.8	-6.2	-6.3	0.1	-3.8	-2.4
1999	-6.1	-0.5	-5.6	-8.4	-8.9	0.4	-3.9	-4.5
2000	-8.5	-0.6	-8.0	-11.4	-11.9	0.5	-5.9	-5.5
2001	-9.6	-0.6	-9.0	-11.6	-12.1	0.5	-6.0	-5.6
2002	-13.7	-3.7	-10.0	-14.7	-15.0	0.3	-8.3	-6.3
2003	-24.4	-12.9	-11.5	-23.6	-23.8	0.2	-17.6	-6.0
2004	-32.9	-16.9	-16.0	-31.8	-31.8	0.0	-25.0	-6.8
2005	-41.4	-24.8	-16.7	-40.0	-39.9	0.0	-33.6	-6.3
2006	-46.1	-28.4	-17.7	-45.1	-44.6	-0.5	-39.1	-6.2
2007	-54.8	-36.7	-18.1	-53.4	-53.1	-0.3	-47.2	-6.4
2008	-56.7	-36.2	-20.4	-56.1	-55.7	-0.4	-48.6	-7.7
2009	-53.7	-31.3	-22.4	-53.5	-53.5	0.0	-45.3	-8.3

Decomposition of changes in PBEs and DBEs: United States

	PBEs intensity			DBEs intensity				
	Total	Tech	Structure	Total	Tech (source)	comp (source)	Tech (comm)	Stru (comm)
1996	-3.3	-3.7	0.4	-2.8	-2.9	0.1	-2.9	0.1
1997	-6.8	-5.2	-1.6	-5.9	-6.0	0.1	-5.6	-0.3
1998	-11.6	-5.6	-6.1	-8.6	-8.7	0.1	-6.7	-1.8
1999	-16.5	-12.5	-4.0	-13.1	-13.4	0.3	-10.5	-2.6
2000	-20.3	-20.4	0.1	-15.2	-15.9	0.7	-13.7	-1.4
2001	-22.4	-26.5	4.1	-18.0	-18.8	0.8	-17.0	-1.0
2002	-25.3	-18.8	-6.5	-21.3	-22.4	1.1	-17.9	-3.4
2003	-28.5	-23.1	-5.4	-24.1	-25.6	1.5	-21.8	-2.3
2004	-32.9	-27.4	-5.4	-27.7	-29.4	1.7	-25.8	-1.9
2005	-37.6	-35.1	-2.4	-31.1	-33.4	2.2	-30.3	-0.8
2006	-41.6	-37.9	-3.8	-35.3	-37.8	2.5	-34.7	-0.5
2007	-43.2	-40.6	-2.7	-38.2	-40.8	2.6	-37.5	-0.6
2008	-46.1	-47.5	1.4	-41.6	-44.5	2.9	-41.4	-0.2
2009	-46.4	-41.7	-4.6	-44.1	-46.8	2.7	-42.1	-2.1

References

Ang, B.W., Choi, K.H. (1997). Decomposition of aggregate energy and gas emission intensities for industry: A refined Divisia index method. *Energy Journal* 18(3), 59-73.

Ang, B.W., Huang, H.C., Mu, A.R. (2009). Properties and linkages of some index decomposition analysis methods. *Energy Policy* 37, 4624-4632.

Ang, B.W., Mu, A.R., Zhou, P. (2010). Accounting frameworks for tracking energy efficiency trends. *Energy Economics* 32, 1200-1219.

Ang, B.W., Zhang, F.Q. (2000). A survey of index decomposition analysis in energy and environmental studies. *Energy* 25, 1149-1176.

Boyd, G.A., McDonald, J.F., Ross, M., Hanson, D.A. (1987). Separating the changing composition of US manufacturing production from energy efficiency improvement: a Divisia index approach. *Energy Journal* 8(2), 77-96.

Elliott, J., Foster, I., Kortum, S., Jush, K.G., Minson, T., Weisbach, D., (2012) "Unilateral Carbon Taxes, Border Tax Adjustments, and Carbon Leakage" the Law School, the university of Chicago.

Ghosh, Madanmohan, Deming Luo, Muhammad Shahid Siddiqui and Yunfa Zhu (2012), 'Border tax adjustments in the climate policy context: CO2 versus broad-based GHG emission targeting', *Energy Economics* (2012), Vol 34. (sp 2): S154-S167.

Grasso, Marco and J. Timmons Roberts (2013), A Fair Compromise to Break the Climate Impasse: A Major Economies Forum Approach to Emissions Reductions Budgeting, Policy Paper 2013-02, Brookings Institution.

IPCC. 2006 ipcc guidelines for national greenhouse gas inventories. IPCC Reports, IPCC - Intergovernmental Panel on Climate Change, 2007. URL http://www.ipccnggip.iges.or.jp/public/index.html.

Le Quéré C, et al. (2009), Trends in the sources and sinks of carbon dioxide, Nat Geosci 2:831-836.

Peters, Minx Jan C., Webler C. L., and Edenhofer (2011), "Growth in emission transfers via international trade from 1990 to 2008", PNAS open access edition available at http://www.pnas.org/content/early/2011/04/19/1006388108.

Peters, P. Glen and Hertwich (2008a), "CO_2 Embedded in International Trade with Implications for Global Climate Policy", *Policy Analysis*, Vol. 42(5), pp- 1401-1407.

Peters, P. Glen and Hertwich (2008b),"Post-Kyoto greenhouse gas inventories: production versus consumption", *Climatic Change*, 2008, 86: 51-66.

Raupach MR, et al. (2007), Global and regional drivers of accelerating CO_2 emissions, *Proc Natl Acad Sci* USA 104:10288-10293.

Sue Wing, I and Richard S. Eckaus (???), The Decline in U.S. Energy Intensity: Its Origins and Implications for Long-Run CO2 Emission Projections.

Sue Wing, I. (2008). Explaining the declining energy intensity of the U.S. economy. *Resource and Energy Economics*, 30 , 21-49.

Sue Wing, I. and R.S. Eckaus (2004). Explaining Long-Run Changes in the Energy Intensity of the U.S. Economy, MIT Joint Program on the Science and Policy of Global Change Report No. 116, Cambridge MA.

Timmer, Marcel P. (ed) (2012), "The World Input-Output Database (WIOD): Contents, Sources and Methods", WIOD Working Paper Number 10, downloadable at http://www.wiod.org/publications/papers/wiod10.pdf

Weber, Christopher L. and Glen P. Peters (2009), "Climate change policy and international trade: Policy considerations in the US", *Energy Policy*, 2009, 37, 432-440.

Wiedmann, Thomas (2009), "A Review of Recent Multi-regional Input-Output Models used for Consumption-based Emission and Resource Accounting", *Ecological Economics*, 69: 211-222.

WIOD (2012), The World Input-Output Database (WIOD): Contents, Sources and Methods Edited by Marcel Timmer (University of Groningen). http://www.wiod.org/database/index.htm.

Zhang, Y. (2009). "Structural decomposition analysis of sources of decarbonizing economic development in China; 1992-2006". *Ecological Economics*, 68 , 2399-2405.