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ESTIMATING CO_2 EMISSIONS EMBODIED IN FINAL DEMAND AND TRADE USING THE OECD ICIO 2015

METHODOLOGY AND RESULTS

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mentioning "Embodied CO_2" in the title of your message.

ABSTRACT

Reliable carbon emissions statistics are essential for formulating responses to climate change including global negotiations such as those concluded in Kyoto in 1997 or recently in Paris at COP21. Typically, emissions statistics are compiled according to production-based or territorial emission accounting methods: measuring emissions occurring within sovereign borders. However, these estimates do not account for global production chains i.e. the fact that emissions from many countries may be implicated in the production of final goods and services. The OECD has calculated and published estimates of CO_2 emissions embodied in final demand since the early 1990s as a contribution to a better understanding of how CO_2 emissions around the world are driven by global consumption patterns. Using the 2015 edition of the OECD Inter-Country Input-Output (ICIO) tables and detailed IEA CO_2 emissions from fuel combustion data, new estimates of emissions embodied in final demand and in international trade were generated using a more refined methodology than previous versions. After explaining the methodology in detail, some general results are described and examples given of how to use and interpret the derived indicators. Detailed results are available in OECD's database on embodied CO_2 emissions: http://oe.cd/io-co2.

* We would like to express our gratitude to the following colleagues who have contributed to the development of OECD consumption-based measures of CO_2 emissions over the years; notably contributions to previous versions of the data sets (2011 and 2013) and to the estimation of sectoral allocation of emissions: Nadim Ahmad, Antonios Katris, Asako Okamura, Karen Turner, Colin Webb and Shiguang Zhu. We also appreciate the close collaboration with our colleagues from the IEA, who provided important help with CO_2 emissions from fuel combustion data.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Reliable carbon emissions statistics are essential for formulating responses to climate change including global negotiations such as those concluded in Kyoto in 1997 or recently in Paris at COP21. Typically, emissions statistics are compiled according to production-based or territorial emission accounting methods: measuring emissions occurring within sovereign borders. However, these estimates do not account for global production chains i.e. the fact that emissions from many countries may be implicated in the production of final goods and services. The OECD has published estimates of CO_2 emissions embodied in final demand since the early 1990s to contribute to a better understanding of how CO_2 emissions around the world are driven by global consumption patterns

Using the 2015 edition of the OECD inter-country input-output (ICIO) tables and detailed IEA CO_2 emission data, the methodology for estimating emissions embodied in final demand and in trade was refined. We used the same basic input-output methodology that was applied to produce the 2009 and 2011 estimates i.e. multiplying production-based CO_2 intensities with a global Leontief inverse matrix to generate a CO_2 multiplier matrix which is subsequently applied to the global final demand matrix. The main improvements in the current version are: a higher industry and country resolution (due to the use of the 2015 Edition of the ICIO), a better matching of the IEA CO_2 data to the ICIO industries, the reallocation of non-resident emissions from final demand to their country of residency, and a new and refined algorithm to allocate transport emissions across industries.

The results show that most OECD countries remain net-importers of embodied CO_2 emissions. However, both production-based and consumption-based CO_2 emissions per capita are decreasing in a large number of OECD countries and for some countries, e.g. Germany, even in absolute terms. For non-OECD countries, emissions keep increasing. This is mainly due to a substantial increase in per capita consumption (final demand by households and government, gross fixed capital formation and changes in inventories). In both OECD and non-OECD countries, GDP per unit of emissions (presented as *CO_2 productivity* in the OECD's Green Growth indicators) is increasing, thus suggesting that, on average, one unit of output is being produced with lower CO_2 emissions. However, the disparities between OECD and non-OECD countries in per capita emissions and GDP per unit of emissions remain high.

This paper provides detailed documentation of the OECD's database on embodied CO_2 emissions which includes the following indicators:

- ***The production perspective***: total level of CO_2 emissions, per capita emissions and GDP per unit of emissions;
- ***The consumption-perspective***: total level of CO_2 emissions, per capita emissions, GDP per unit of emissions and CO_2 embodied final demand – shares by country of origin;
- ***Net-exports of embodied emissions***, i.e. the difference between production-based and consumption-based emissions.

Available on OECD.STAT at http://stats.oecd.org/Index.aspx?DataSetCode=IO_GHG_2015

1. Consumption-based carbon accounting at the OECD

Reliable carbon emissions statistics are essential for formulating responses to climate change including global negotiations such as those concluded in Kyoto in 1997 or in Paris in 2015. Typically, emissions statistics are compiled according to production-based or territorial emission accounting methods: measuring emissions occurring within sovereign borders. However, these estimates do not account for global production chains (international procurement of final and intermediate products) i.e. the fact that emissions from many countries may be implicated in the production of final goods and services. International outsourcing of production or, switching from domestic to international suppliers, may result in a reduction of a nation's emissions produced, but the change in global emissions will depend on whether the switch has been to foreign firms using relatively less carbon-intensive ('cleaner') or more carbon-intensive ('dirtier') energy inputs. To account for the origins of CO_2 emissions embodied in final demand, the OECD has developed consumption-based CO_2 emission accounts. These provide a useful complement to the traditional production-based emission estimates.

Box 1. What are consumption-based carbon emissions?

Terminology

The term **consumption-based emissions**, used in this document, designates emissions associated with final domestic demand, i.e. final consumption (households, non-profit institutions and government), gross fixed capital formation, changes in inventories and direct purchases abroad by residents. Such emissions can also be qualified as **demand-based emissions**. While the latter term better reflects the concept, the former is more commonly used, and in practice the two terms are often used as synonyms. Another term commonly used for public communication purposes is **carbon footprint**.

Production-based and **territorial emissions** are differentiated by the allocation of non-resident emissions. For territorial emissions, emissions for example associated with fuel-purchases by non-resident households and industries are allocated to the country where the fuel is purchased, while for production-based emissions these emissions are allocated to the country of residence. Note that production based emissions relate to emissions that are directly caused by the combustion of fossil fuels within a country, which includes all emissions generated by households and not only units classified as 'producers' in a national accounts sense.

Example

Consumption-based emission accounting, in contrast to **production-based or territorial emission** accounting, allocates carbon emitted along global production chains to those countries where the final product is eventually consumed. The difference between consumption- and production-based emissions is shortly explained here, using the example of a wooden table:

A wooden table is bought by a final consumer in France. It was transported by a German logistics company from Poland, where it was assembled from screws (produced in China) and wooden planks (produced in Lithuania). China provides the tools to cut the timber from Finland into wooden planks. The tools were manufactured from metal, which was produced in the UK using iron ore from Australia and machinery from Germany.

CO_2 is emitted at each step along the production chain: transport through Poland, Germany and France, assembly (using electricity) in Poland, cutting the timber (using diesel generators) in Finland, etc. These are production-based or territorial emissions. Consumption-based emissions are the exact same emissions, but allocated to the country of the final use of the wooden table, in this example France.

The complementary nature of such measures raises awareness among final consumers, governments and businesses about the indirect impacts of their actions with regard to emissions produced along global production chains. This may help reduce the psychological distance from climate change, which is one of the major obstacles to mitigation action in countries where the effects of climate change are not yet to be seen (Stoknes, 2015). Using both production-based and consumption-based measures helps identify whether and to what extent improvements in productivity and in decoupling are due to national policies or to the outsourcing of production. It can therefore provide a framework for understanding potential carbon leakage and associated competitiveness concerns. And last, but not least, it helps to better understand the common but differentiated responsibilities between countries (Wiedmann, 2009).

The OECD's inter-country input-output (ICIO) tables can be used to estimate these emissions along global value chains. The most prominent application of the ICIO is measuring Trade in Value Added (TiVA) (OECD, 2013a). The theoretical approach underlying the TiVA indicators can also be used to estimate consumption-based emissions and emissions embodied in international trade. Consumption-based CO_2 emissions, in contrast to territorial or production-based emissions, allocate emissions to those countries where the goods and services are eventually consumed. Similarly, emissions embodied in trade are those emissions that occur during the production of traded goods and services. To link consumption of goods and services and trade of goods and services to those industries and countries where emissions occur, the ICIO system needs to be extended to include CO_2 intensities for all countries and industries, i.e. CO_2 emissions per unit of production as well as direct emissions by final demand. The OECD was among the first to publish estimates of consumption-based CO_2 emissions in 1994 and has periodically updated the estimates since (Wyckoff and Roop, 1994; Ahmad and Wyckoff, 2003; Nakano et al., 2009; OECD, 2011; OECD, 2013b; and GGKP, 2013)[1].

The remainder of this paper is structured as follows. Section 2 summarises the theoretical approach taken to calculate the 2015 release of embodied CO_2 emissions and explains in detail the method used to estimate CO_2 emissions by industry. Section 3 presents some results at the country and industry level and guidance on how to analyse and interpret the data. Section 4 discusses the limitations and next steps.

2. Calculating emissions embodied in international trade and final consumption

The methodology used to estimate the origins of CO_2 emissions embodied in international trade and final demand resembles the methodology used to calculate the origins of *value added* embodied in international trade and final demand – the basis for many TiVA indicators. However, there are small, but important differences, which will be pointed out in the sections below. Compared to earlier releases of embodied CO_2 emissions estimates, here we also present results at the industry level and introduce the relevant methodology. Further, estimates of CO_2 emissions embodied in final and intermediate trade are available as well.

2.1 Basic methodology for calculating consumption-based emissions

CO_2 emissions, cc_i^{rs}, associated with final demand in country *s* emitted by industry *i* in country *r*, are calculated by multiplying the intensities of the production-based emissions (diagonalised vector **EF** of size NK, where *N* is the number of countries and *K* the number of industries) with the global Leontief inverse (**I-A**)$^{-1}$ (of size $NK \times NK$) and global final demand matrix (**Y** of size $NK \times N$) from the OECD ICIO:

$$\begin{bmatrix} \mathbf{cc}^{11} & \mathbf{cc}^{12} & \dots & \mathbf{cc}^{1N} \\ \mathbf{cc}^{21} & \mathbf{cc}^{22} & \dots & \mathbf{cc}^{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{cc}^{N1} & \mathbf{cc}^{N2} & \dots & \mathbf{cc}^{NN} \end{bmatrix} =$$

$$\begin{bmatrix} \widehat{\mathbf{EF}}^{1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \widehat{\mathbf{EF}}^{2} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \widehat{\mathbf{EF}}^{N} \end{bmatrix} \begin{bmatrix} \mathbf{I}-\mathbf{A}^{11} & \mathbf{A}^{12} & \dots & \mathbf{A}^{1N} \\ \mathbf{A}^{21} & \mathbf{I}-\mathbf{A}^{22} & \dots & \mathbf{A}^{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{N1} & \mathbf{A}^{N2} & \dots & \mathbf{I}-\mathbf{A}^{NN} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{y}^{11} & \mathbf{y}^{12} & \dots & \mathbf{y}^{1N} \\ \mathbf{y}^{21} & \mathbf{y}^{22} & \dots & \mathbf{y}^{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{y}^{N1} & \mathbf{y}^{N2} & \dots & \mathbf{y}^{NN} \end{bmatrix}$$

$$+ \begin{bmatrix} \widehat{\boldsymbol{FNLC}}^{1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \widehat{\boldsymbol{FNLC}}^{2} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \widehat{\boldsymbol{FNLC}}^{N} \end{bmatrix}$$

Vectors $\mathbf{cc}^{rs}$ represent the emissions produced in country *r* by industry associated with final demand of country *s*, while $\widehat{\mathbf{EF}}^{r}$ is a diagonalised vector of industry-specific emission intensities for country *r*, $\mathbf{A}^{rs}$ is the coefficient matrix of country *r*'s intermediate inputs into country *s*'s production and $\mathbf{y}^{rs}$ the demand of country *s* for final goods and services produced by country *r*, by industry. $\boldsymbol{FNLC}$ denotes direct emissions by final demand.

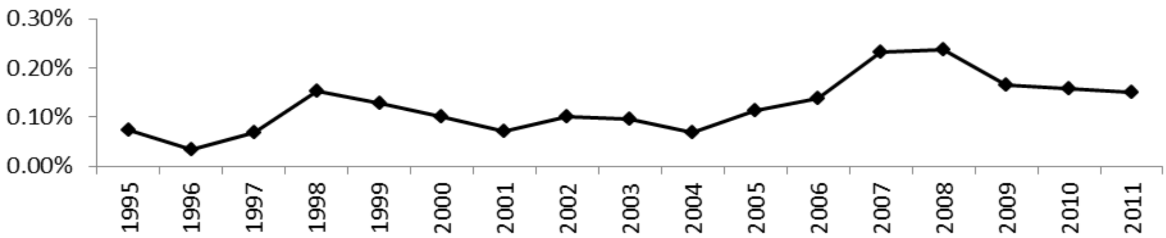
Consumption-based emissions of country *s* are then calculated as the column sum of column *s* in matrix **CC** plus direct emissions from final demand $FNLC^s = fnlc^s[re] + fnlc^s[pp]$, where $fnlc^s[re]$ are residential emissions (e.g. from burning gas) and $fnlc^s[pp]$ are emissions from private road transport. Similarly, production-based emission can be calculated as row sums of matrix **CC** (of size $NK \times N$) plus direct emissions from final demand $FNLC^s$, and discrepancies. In this case, as $\mathbf{cc}^{rs}$, are vectors where the number of rows equal to the number of industries, we get production-based emissions by country and industry. Direct emissions from final demand $FNLC^s$ are allocated to industries "*Coke, refined petroleum products and nuclear fuel*" (ISIC Rev. 3 Division 23, in case of emissions from private road transport) and to "*Electricity, gas and water supply*" (ISIC Rev. 3 Divisions 40-41, in case of residential emissions). The additional step of including direct emissions from final demand is the main difference to the methodology used for the TiVA indicators, where direct impacts of final demand did not have to be considered.

It is also possible to calculate consumption-based emissions by final demand industry, see Section 3.

Both, the estimation of $\widehat{\mathbf{EF}}^{r}$ and $FNLC^r$ from IEA 2015 CO_2 emissions data are described in detail in Appendix B. Appendix C argues why the IEA 2015 data is indeed the best data to be used here.

The ICIO system also reports discrepancies[2] as unspecified trade partners. For the calculations, these are represented as an additional column in the final demand matrix, thus resulting in an additional column of matrix **CC**. The data therefore includes consumption-based emissions of discrepancies to ensure that global CO_2 production equals global CO_2 consumption. Emissions allocated to discrepancies are no higher than 0.24% of global emissions, see Figure 1.

Figure 1: Emissions associated with discrepancies as a percentage of total global emissions



Source: OECD estimates based on the methodology described in this document

2.2 Calculating emissions embodied in final demand by industry or exports by industry

Section 2.1 described the basic approach to calculating consumption-based emissions at the country level. In addition to the country-level data, it is also interesting to analyse emissions embodied in the consumption of country *s* by final demand industry. To this end, the global final demand matrix needs to be manipulated a little: instead of having column vectors $\mathbf{y}^{rs}$, we need to create a global final demand matrix using matrix blocks of diagonalized vectors $\hat{\mathbf{y}}^{rs}$,

$$\hat{\mathbf{y}}^{rs} = \begin{bmatrix} y_1^{rs} & 0 & \dots & 0 \\ 0 & y_2^{rs} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & y_K^{rs} \end{bmatrix} \text{ and the global final demand matrix } \hat{\mathbf{Y}} = \begin{bmatrix} \hat{\mathbf{y}}^{11} & \hat{\mathbf{y}}^{12} & \dots & \hat{\mathbf{y}}^{1N} \\ \hat{\mathbf{y}}^{21} & \hat{\mathbf{y}}^{22} & \dots & \hat{\mathbf{y}}^{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{\mathbf{y}}^{N1} & \hat{\mathbf{y}}^{N2} & \dots & \hat{\mathbf{y}}^{NN} \end{bmatrix}.$$

The global final demand matrix $\hat{\mathbf{Y}}$ is of size $NK \times NK$. Thus, the resulting matrix $\widehat{\mathbf{CC}} = \mathbf{EF}\,(\mathbf{I} - \mathbf{A})^{-1}\,\hat{\mathbf{Y}}$ is also of size $NK \times NK$. cc_{ij}^{rs} is CO_2 emitted in industry *i* in country *r*, embodied in final goods/services of industry *j* consumed in country *s*. The column sums of this matrix now give consumption-based emissions by country and by final demand industry. Note that to have total consumption-based emissions, it is again necessary to add emissions from private road transport and residential emissions to consumption-based emissions of industries "*Coke, refined petroleum products and nuclear fuel*" and "*Electricity, gas and water supply*", respectively.

When replacing the global final demand matrix by the global (intermediate, final or total) trade matrix, the exact same method can be applied to calculate emissions embodied in (intermediate, final or total) international trade.

These calculations give the possibility of creating five-dimensional indicators relating production and final demand or production and exports. The dimensions are

- Year,
- Emitting country,
- Emitting industry,
- Final demand country / exporting country, and
- Final demand industry / exporting industry.

2.3 Estimation of CO_2 emissions factor using fuel combustion emissions and IO/SUT data sources

The CO_2 emission factors used in the OECD ICIO system to estimate consumption-based emissions are calculated from CO_2 emissions from fuel combustion data (IEA, 2015). This does not cover all CO_2 emitted globally - for example, it excludes CO_2 emissions from land use and land use change, CO_2 emitted from forest fires, fugitive emissions or emissions from industrial processes[3].

This section explains how to estimate, for each country r and year t, a vector of CO_2 emissions per unit of industry output and an emission factor $EF^{tr}[i]$ for each industry i. In addition, direct emissions from final demand (*fnlc*) have to be considered. These are residential emissions[4] (e.g. from using gas for cooking), $fnlc^{tr}[re]$, and direct emissions from private road transport (household consumption of petroleum products), $fnlc^{tr}[pp]$. Annex B includes additional figures and tables showing the methodology described below. Annex C describes the data in more detail and argues why this data compared to other data sources has been chosen[5].

Allocating CO_2 emissions by flow and fuel type to ICIO industries

The industry dimension of IEA CO_2 emissions from fuel combustion data is not fully compatible with industry activities present in Input-Output and Supply-Use tables and, thus, with the industry classification used in the ICIO system (see http://www.oecd.org/sti/ind/TiVA_2015_Industry_List.pdf). For example, emissions from Machinery (MACHINE) include *Fabricated metal products* and *Machinery and equipment* (ISIC Rev. 3 Divisions 28 to 33).

Table displays the correspondence between IEA CO_2 “flow” and ICIO industry. In the case of one IEA CO_2 flow corresponding to multiple ICIO industries, the emissions are allocated using total industry output as weights. For most flows, total emissions, that is the sum over all fuel types is used. For some flows, the allocation is significantly improved taking into account the data of CO_2 flow by fuel type. These flows are emissions from

- AUTOPROD = Unallocated autoproducers
- OTHEN = Other energy industry own use,
- DOMESAIR = Domestic aviation,
- RAIL = rail traffic, including industrial railways,
- PIPELINE = support and operation of pipelines transporting gases, liquids, slurries and other commodities,
- DOMESNAV = Domestic navigation,
- TRNONSPE = emissions from transport not elsewhere specified,
- NETRANS = non-energy use in transport

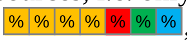
Emissions from these flows are allocated according to the concordance between fuel types and ICIO industries as displayed in Table A.4 in Annex B. Emissions from international marine and international aviation bunkers are not included in the calculations at this stage.

One exception is the emission flow *road transport*, as this includes emissions associated with fuel combustion by transport activities of all industries and direct emissions from private road transport. Allocation of these emissions to industries and households involves in several steps:

1. Total fuel (*Petroleum products* C23) used in one country as an intermediate input is calculated as the sum over all intermediate petroleum product imports and domestically produced petroleum products from industry C23 in the Input-Output table (orange parts of the intermediate input flow matrix in Figure A.1 in Annex B). This is also done for final consumption expenditure (the red parts of the final demand matrix in Figure A.1).

2. For each country, one vector of fuel use (inputs of industry C23) in monetary terms is created, with length N+2 (number of industries plus domestic final consumption expenditure plus non-resident expenditure on C23).
   Vector *fueldemand* 

   , see Figure A.1.

3. After allocating all emissions (except those from road transport) to industries, a vector of length N+3 containing shares of each industry in total emissions is calculated, with the share of road emissions in total emissions being the N+3 entry. Note that this vector only contains emissions from secondary fuel sources, i.e. only those fuels that are assumed to be sold by industry C23.
   Vector *percco2scdry* 

   , see Figure A.2 in Annex B.

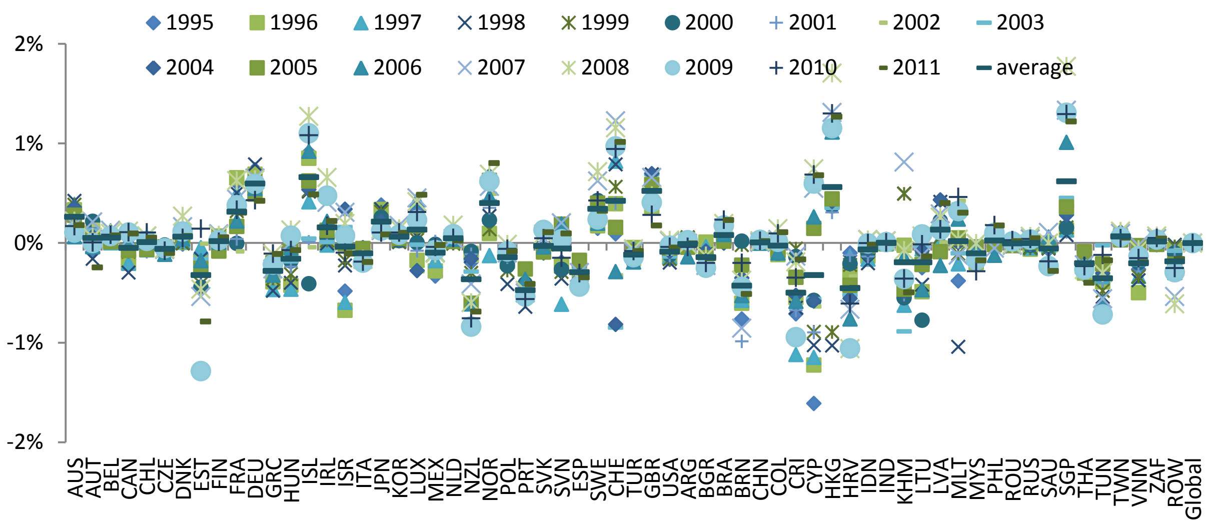
4. Multiplying total fuel demand, that is the sum of all entries of vector *fueldemand*, with the shares in vector *percco2scdry* results in a vector of monetary values of C23 fuel inputs *fueldemexroad* (assuming that the price for CO_2 associated with the fuel use is the same across industries).
   *fueldemexroad[i] = fueldemand[i] * percco2scdry[i]* for all $i \leq$ N+2
   This vector has size N+2. The share of emissions associated with road transport is omitted from this vector, but used in the next step.

5. The vector *fueldemexroad* is then subtracted from vector *fueldemand*, leaving the monetary values of demand for inputs from industry C23 that can be associated with demand for road transport fuel (i.e. the share of emissions indicated in blue in Figure A.2). This vector, *percfueldemroad*, is then used to calculate industry shares to allocate road emissions across industries.

The effect of reallocating emissions using non-resident expenditures

The emissions associated with fuel purchases by non-residents are reallocated to the country of residence of the non-residents. This is based on the non-resident expenditure columns of the final demand matrix of the ICIO, which are estimated using tourism satellite account data. This reallocation of non-resident expenditures is evident in the differences between the published IEA sectoral approach CO_2 emissions and the OECD CO_2 production perspective data (Figure 2). At the global level, the OECD estimates are equal to the IEA data (if not, there would be an inconsistency in the data). The country averages across years are between -0.5% and 0.7%. The highest deviations are for relatively small countries, where road emissions by residents abroad or by non-residents on the domestic territory are a relatively high share of the country's total emissions. For example, OECD countries with a deviation higher than 1% for at least one year are Estonia, Iceland and Switzerland.

Figure 2: Deviation of OECD CO_2 production perspective data from IEA sectoral approach CO_2 data



Note: The codes used for countries in ICIO are described in www.oecd.org/sti/ind/ICIO2015_Countries_Regions.pdf
Source: OECD estimates based on the methodology described in this document

Emission intensity by industry

The emission intensities by industry, the emission factors $EF_{tc}[i]$ at time *t* for country *c* and industry *i*, are calculated from total emissions by industry (excluding emissions by private road and residential emissions) divided by industry output from the OECD ICIO: $EF_{tc}[i]=CO2_{tc}[i] / PROD_{tc}[i]$.

Note that for China and Mexico, separate tables are provided in the ICIO to account for firm heterogeneity. In the case of China, a distinction is made between processing firms (export only), other exporters and domestic market only. For Mexico, *Global Manufacturers* (export only) are separated from other firms. For these countries, we assume the same industry CO_2 intensity across the split tables. The industry heterogeneity introduced in the ICIO for Mexico and China is still used in the underlying calculations.

For more detailed analysis, see http://oe.cd/io-co2.

3. Emissions embodied in international trade and final consumption: indicators

Annex A tables A.1 and A.2 present selected CO_2 emission indicators for all OECD and non-OECD economies included in the ICIO. The following indicators related to embodied CO_2 are available in the OECD.STAT database[6] :

- Three indicators using the production perspective
- Four indicators showing the consumption perspective
- One indicator of net-exports of embodied emissions, i.e. the difference between production-based and consumption-based emissions. If production-based emissions are higher than consumption-based emissions, net-exports are positive; if production-based emissions are lower than consumption-based emissions, net-exports are negative.

As explained in more detail in Annex B, the production-based numbers do not match the statistics published by IEA (IEA, 2015) due to the reallocation of road transport emissions associated with fuel purchases by non-residents. This affects mainly small countries with significant differences in fuel prices compared to their neighbouring countries. This indicator is available by country of origin of emissions (where CO_2 is emitted) and by partner-country (where the embodied emissions are consumed).

Similarly, consumption-based emissions are available for each country consuming embodied emissions by partner country where CO_2 was emitted. In addition, for the consumption-perspective, shares by country of origin are available for CO_2 embodied in final demand. Production-based and consumption-based emissions per capita as well as CO_2 emission productivity of GDP are available by country.

Table 1: CO_2 indicators related to the OECD ICIO available on OECD.STAT

Indicator	Name	Unit	Dimension
PROD_CO2	Production-based emissions	million t	C, P
PROD_PCCO2	Production-based emissions per capita	kg/capita	C
PROD_GDPPPPCO2	GDP (PPP) per unit of production-based emissions	USD/ million t	C
FD_CO2	Consumption-based emissions	million t	C, P
FD_CO2_SH	CO2 embodied final demand, shares by country of origin	%	C, P
FD_PCCO2	Consumption-based emissions per capita	kg/capita	C
FD_GDPPPPCO2	GDP (PPP) per unit of consumption-based emissions	USD/ million t	C
NET_CO2	Net exports of embodied CO2	million t	C, P

Notes: all indicators are available on an annual basis between 1995 and 2011. C = Country, P = Partner country

Additional indicators calculated for this analysis are listed in Table 2 and cover CO_2 emissions embodied in final demand (industry and country) by country and industry of origin (FDCO2_BSCI), CO_2 emissions embodied in exports (industry and country) by country and industry of origin (EXCO2_BSCI), domestic emissions embodied in exports (EXGR_DCO2) and foreign emissions embodied in exports (EXGR_FCO2) and their respective shares in total emissions embodied in exports (EXGR_DCO2SH, EXGR_FCO2SH).

Table 2: Additional CO_2 indicators related to the OECD ICIO

Indicator	Name	Unit	Dimension
FDCO2_BSCI	CO2 embodied in final demand by source country and industry	million t	CO,IO,CF,IF
EXCO2_BSCI	CO2 embodied in exports by source country and industry	million t	CO,IO,CE,IE
EXGR_DCO2	Domestic emissions embodied in exports	million t	C
EXGR_DCO2SH	Domestic emissions embodied in exports (share in total emissions embodied in exports)	%	C
EXGR_FCO2	Foreign emissions embodied in exports	million t	C
EXGR_FCO2SH	Foreign emissions embodied in exports (share in total emissions embodied in exports)	%	C

Notes: all indicators are available on an annual basis between 1995 and 2011. C = Country, P = Partner country, CO = Country of origin, CF = Final demand country, IO = Industry of origin, IF = Final demand industry, IE = Exporting industry

Next, this section presents some general trends of the development of consumption-based and production-based emissions, using different indicators

- Levels of consumption- and production-based emissions (PROD_CO2 and FD_CO2)
- Per capita consumption- and production-based emissions (PROD_PCCO2 and FD_PCCO2)
- CO_2 productivity, i.e. GDP in PPP per unit of consumption- and production-based CO_2 emissions (PROD_GDPPPPCO2 and FD_GDPPPPCO2)
- Cumulative consumption- and production-based emissions
- The share of foreign CO2 emissions embodied in domestic final demand (FD_CO2_SH).

This is followed by more detailed industry results highlighting some possibilities for the use of the data for more specific analyses at the country and/or sector levels:

- Shares of industry and country of origin of CO_2 emissions embodied in Germany's final demand for motor vehicles in 2011 (based on FDCO2_BSCI)
- Shares of industry and country of final demand of CO_2 emitted by Mexico's electricity, gas and water industry in 2011 (based on FDCO2_BSCI)
- A comparison of per capita production-based emissions and per capita consumption-based emissions by industry aggregates (based on FDCO2_BSCI, UN population data)

The last part of the section presents results related to CO_2 embodied in exports:

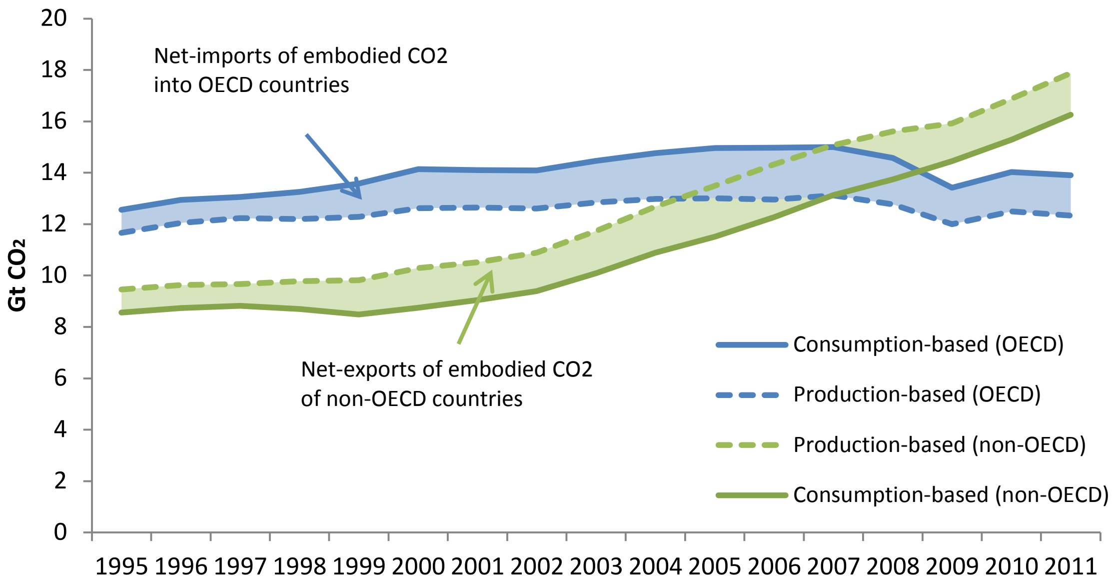
- Emissions embodied in exported products by product (based on EXCO2_BSCI)
- Average emission intensity of exports.

3.1 Consumption-based emissions at the country level

3.1.1 Aggregate emissions - OECD v Non-OECD

Trends in the difference between production-based and consumption-based carbon emissions are highlighted in Figure 3. While OECD countries in total have been and still are embodied carbon net-importers (the solid blue line representing consumption-based emissions is above the dashed blue line representing production-based emissions), the non-OECD economies are net-exporters. Note, that the shaded blue (OECD net imports) and green (non-OECD net exports) areas have the exact same size, i.e. OECD net-imports are non-OECD net-exports of embodied carbon. Net-imports of OECD countries doubled between 1995 and 2005, peaked between 2005 and 2007 and then decreased after the global economic crisis.

Figure 3: CO_2 emissions from fuel combustion (OECD and non-OECD countries)

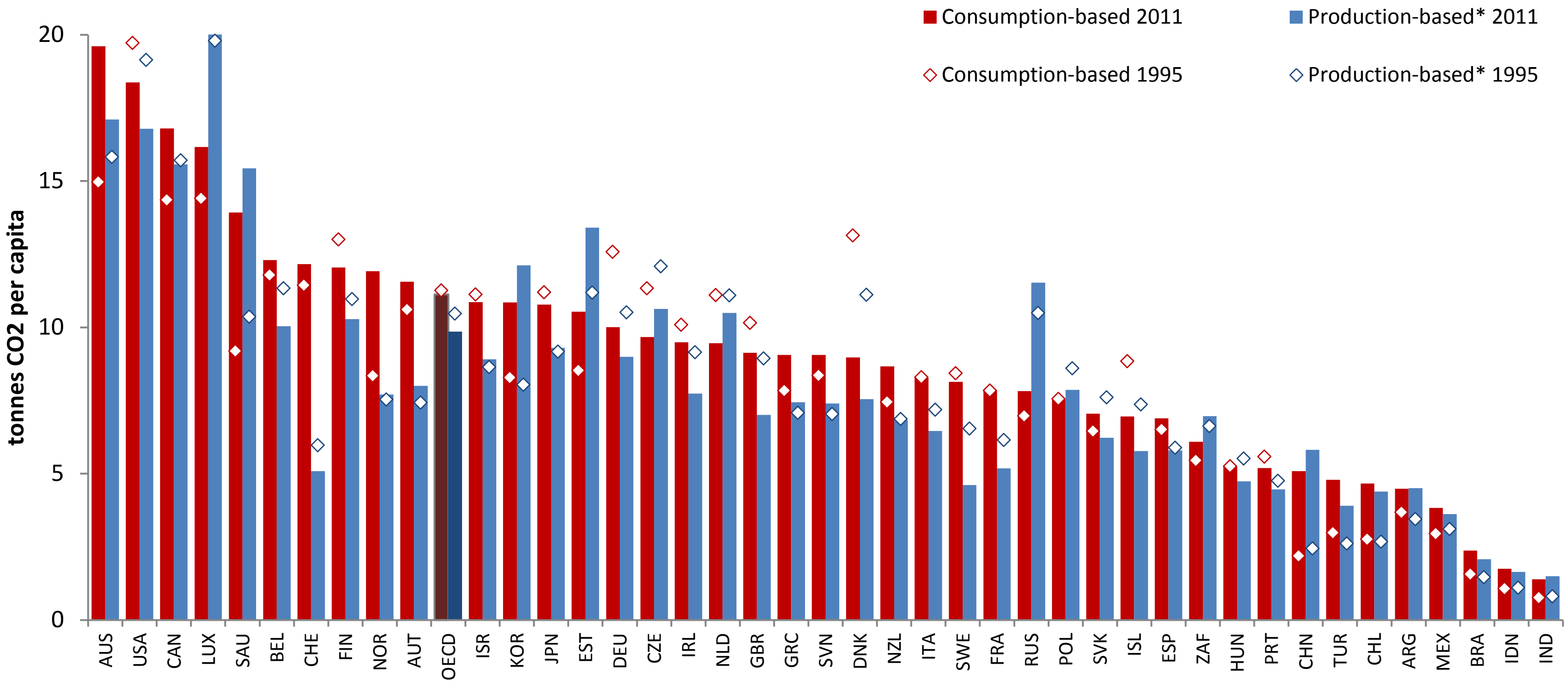


Source: OECD estimates based on the methodology described in this document.

3.1.2 Per capita emissions

Figure 4 shows per capita production- and consumption-based emissions for all OECD and G20 countries. The countries are ordered according to consumption-based emissions in 2011. If the red bar representing consumption-based emissions is larger than the blue bar representing production-based emissions, the country is a net-importer of CO_2 emissions. On average, OECD countries are net-importers, but not all OECD countries are net-importers of embodied carbon. Similarly, not all non-OECD economies are net-exporters of embodied carbon. For example, The Netherlands and Korea are net-exporters of emissions while Brazil is a net-importer of emissions. However, the difference in per capita emissions between OECD and non-OECD economies remains large. The average of the three countries with highest per capita consumption-based emissions (Australia, United States, and Canada) is ten times higher than that of the three countries with lowest per capita emissions (Brazil, Indonesia and India). This Figure illustrates that per- capita emissions show a very different picture of the distribution of CO2 emissions around the globe, compared to the simple aggregates shown above.

Figure 4: Per capita CO_2 emissions from fuel combustion



* Production-based estimates after reallocation of emissions from non-resident expenditures on fuel

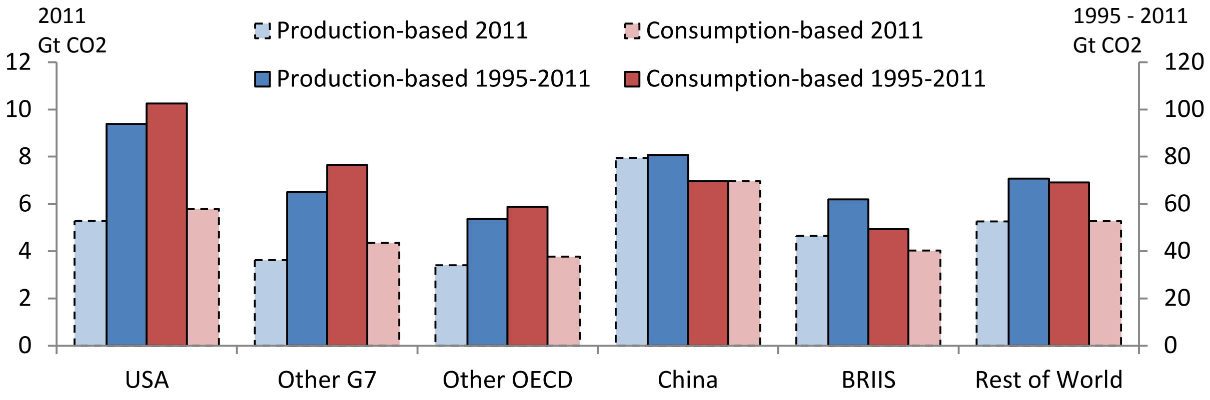
Source: OECD estimates based on the methodology described in this document and population data from UN (2015).

3.1.3 Cumulative emissions

The overall picture of CO_2 emissions can be further completed by, e.g. cumulative emissions over time and CO_2 productivity, i.e. PPP dollar of production / consumption per kg CO_2 emissions.

CO_2 emissions remain in the atmosphere for a long time (up to 100 years), so when determining responsibilities and burden sharing, it may be useful to look beyond annual emissions and consider cumulative (historic) emissions. Although the overall ranking of countries and regions is generally the same whether 2011 emissions or 1995 to 2011 cumulative emissions are considered, a notable difference is that China and the United States switch places (Figure 5). While in 2011 China was the single highest CO_2 emitter, both in production and in consumption terms (light colours in the background), in cumulative terms, the US had far higher emissions between 1995 and 2011.

Figure 5: Comparison of annual CO_2 emissions and cumulative CO_2 emissions



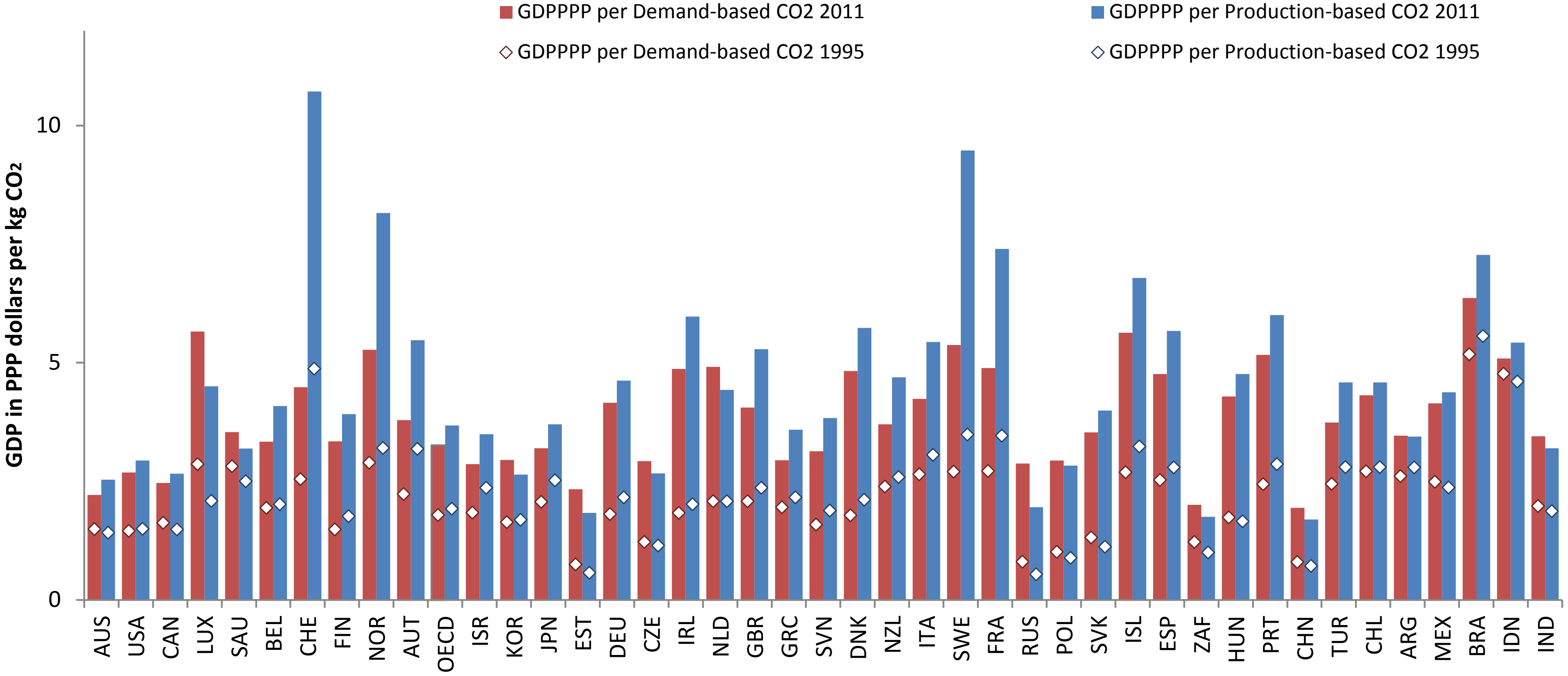
BRIIS: Brazil, Russian Federation, India, Indonesia and South Africa

Source: OECD estimates based on the methodology described in this document.

3.1.4 CO_2 productivity (GDP per kg of CO_2 emitted)[7]

Higher GDP to CO_2 emissions ratios (sometimes referred to as CO_2 productivity) indicate higher production or consumption per unit of CO_2 emitted – see Figure 6 where the countries are shown in the same order as in the per capita emissions (Figure 4). While there are large differences in GDP per CO_2 emitted in production, the variation in the ratio of GDP to consumption of CO_2 across OECD and G20 countries is significantly lower. On the one hand, this reflects very different energy production systems across countries. On the other hand, it shows that, through international trade and global production chains, the GDP to consumption-based CO_2 ratio becomes more uniform across countries. Also, as mentioned in the OECD's work on green growth indicators, GDP is not the most appropriate variable to be related to measures reflecting final demand. However, real disposable income data, which would be a better alternative, are not available for all countries.

Figure 6: CO_2 productivity: GDP in PPP per kg CO_2 emissions from fuel combustion



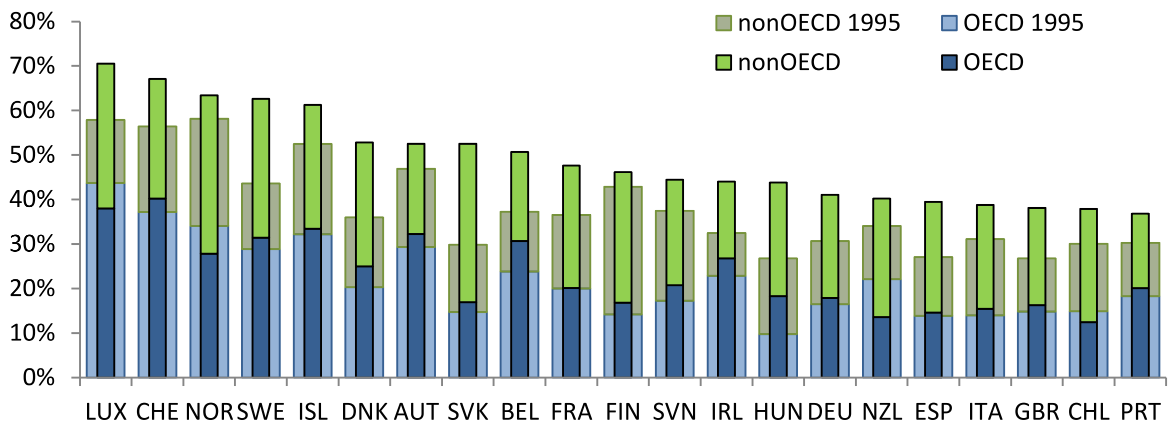
Source: OECD estimates based on the methodology described in this document.

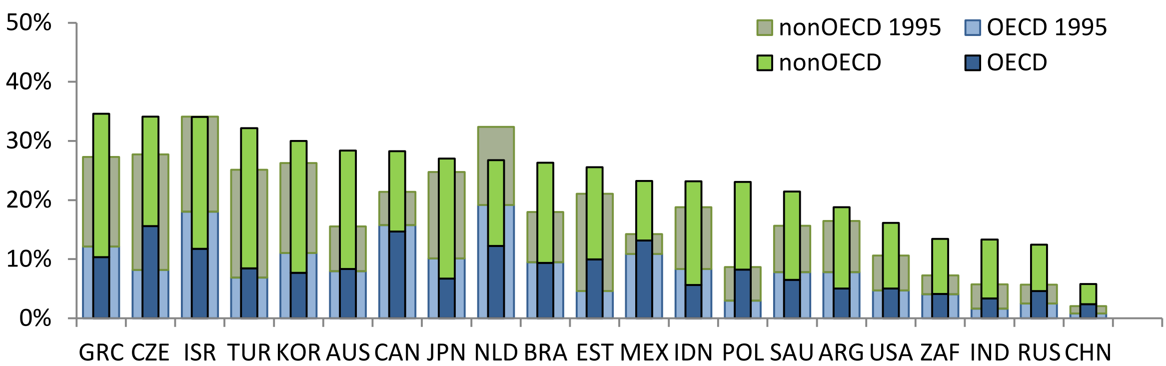
The GDP to consumption-based CO_2 ratio of the OECD countries is between 2.2 and 5.8 PPP dollars consumption per 1kg CO_2 emissions. The lowest GDP to CO_2 ratio can be found in China, where for less than 2 PPP dollars of both production and consumption one kg of CO_2 is emitted. The countries with high GDP to production-based CO_2 are those countries with a high share of renewables (mainly hydro) in their electricity mix, e.g. Switzerland (CHE), Norway (NOR), and Sweden (SWE). Here, 10 PPP dollars' worth of goods and services can be produced for each 1kg of CO_2 emitted.

3.1.5 Foreign emissions in domestic final demand

The share of renewables or other low-carbon energy carriers such as nuclear power also has an influence on the share of foreign CO_2 embodied in domestic final demand (Figure 7). Countries with high shares of renewables in domestic electricity production, such as those cited above (Switzerland, Norway, Sweden), as well as Iceland, Denmark and Austria, have higher shares of foreign emissions embodied in their domestic final demand. For other OECD countries, the total share in 2011 was between 30% and 50%. This rose by about 10% points between the mid-90s and 2011, mainly due to an increase in CO_2 originating from non-OECD countries, as they became more active participants in global value chains. In Figure 7 this is illustrated by an increase in the green part of the bar representing non-OECD origin of emissions, while the blue part of bars representing OECD origin remains constant.

Figure 7: Share of CO_2 emitted abroad in total CO_2 embedded in domestic final demand



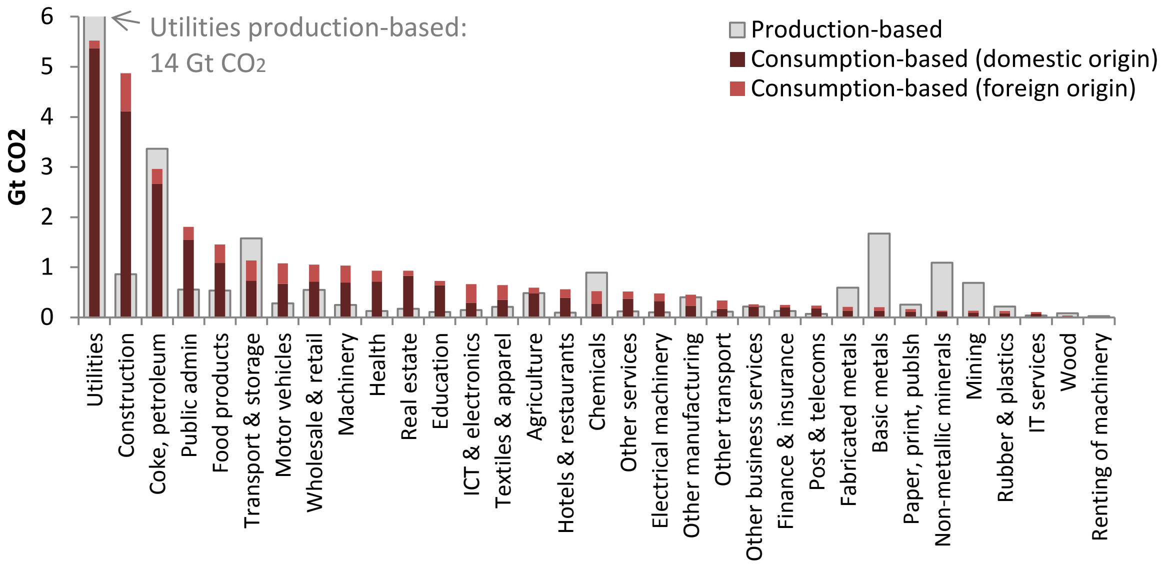


Source: OECD estimates based on the methodology described in this document.

3.2 Emissions embodied in final demand by industry

Emissions can also be analysed at the industry level from both the production and the consumption perspective (Figure 8). Production-based emissions by industry are those emissions directly emitted by industries. The figure is truncated at 6Gt of emissions, but global production-based emissions of the utilities industry, i.e. electricity, gas and water supply, amount to a total of 14Gt, which is almost half of the total global CO_2 emissions from fuel combustion.

Figure 8: Global production and consumption-based emissions at the industry level



Source: OECD estimates based on the methodology described in this document.

The red bar in the foreground represents emissions embodied in final goods/services associated with these industries, split into the domestic and foreign origin of the emissions. For some manufactured goods, at the end of highly globalised production chains, such as the *Motor vehicles*, *ICT and electronics*, *Textiles and apparel* or *Chemicals*, the share of foreign emissions embodied in final goods was more than 40% on average.

Conversely, most of the industries with higher production-based emissions than emissions embodied in their final goods/services can be found further upstream in the value chain, e.g. *Basic metals*, *Non-metallic mineral products* and *Chemicals*. Other industries, such as *Motor vehicles*, *ICT and electronics*, and *Textiles and apparel* produce a higher share of final goods, so that the consumption-based emissions of these industries are higher than the production-based emissions.

As described in Section 2.2, the industry level results have five dimensions. Figure 9 shows the origin of emissions by country (columns) and industry (rows) embodied in Germany's demand for motor vehicles in 2011. The figure is two-dimensional fixing three of the five dimensions (year, country and industry of final demand):

- Year: 2011
- Emitting country: in columns
- Emitting industry: in rows
- Country of final demand: Germany
- Industry of final demand: *Motor vehicles*

Those industries with the highest share in embodied emissions are coloured: *Chemicals*, *Non-metallic minerals*, *Basic metals*, *Motor vehicles* and *Electricity gas and water supply*. The width of each column represents the share of each country in the emissions embodied in Germany's demand for motor vehicles: The largest share of CO_2 is emitted in Germany itself, followed by China, Russia, Poland, India, USA and Czech Republic.

With this data, it is also possible to determine the destination of emissions from the producer's perspective, i.e. who ultimately consumes the CO_2 emitted by a certain industry in a certain country? Figure 10 shows this for Mexico's *Electricity, gas and water supply* industry (utilities):

- Year: 2011
- Emitting country: Mexico
- Emitting industry: *Electricity, gas and water supply* industry (utilities)
- Country of final demand: in columns
- Industry of final demand: in rows

Not surprisingly, the largest share of emissions is embodied in final demand for electricity, gas and water supply in Mexico itself. The second largest share is embodied in Mexico's final demand for *Food products, beverages and tobacco*. Then, with approximately equal shares Mexico's final demand for *Construction*, *Wholesale and retail trade*, *Hotels and restaurants*, *Transport and storage* and *Public administration*. US final demand for *Motor vehicles* has the highest foreign share of embodied CO_2 emitted by Mexico's utility industry, followed by *Construction*, *Hotels and restaurants* and *Food products beverages and tobacco*. Other countries with visible shares are Canada and Japan, with most of the emissions embodied in final demand for *Motor vehicles* and *Construction*, respectively.

Figure 9: Germany's demand for motor vehicles: origin of emissions by country and industry – 2011

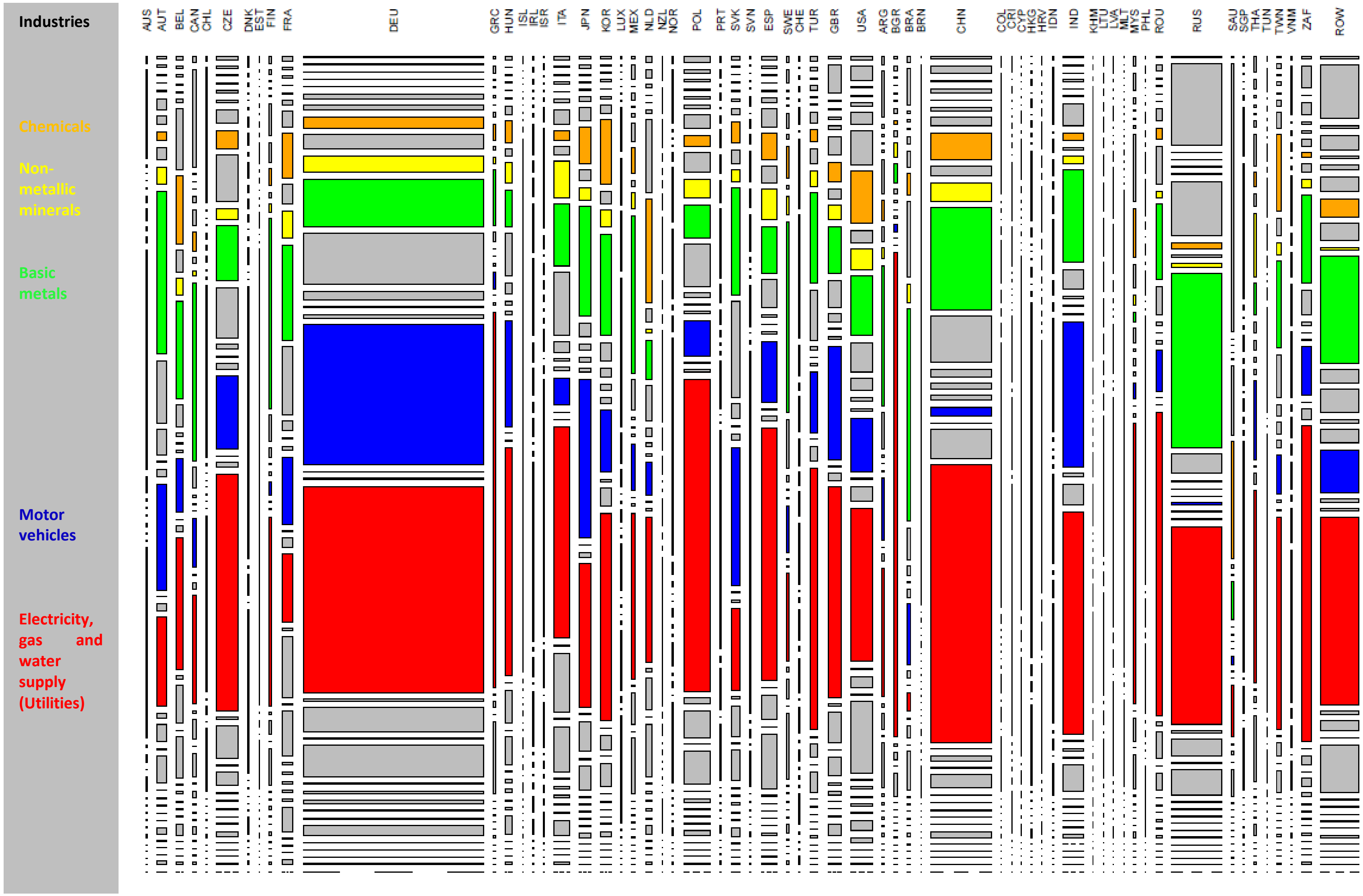
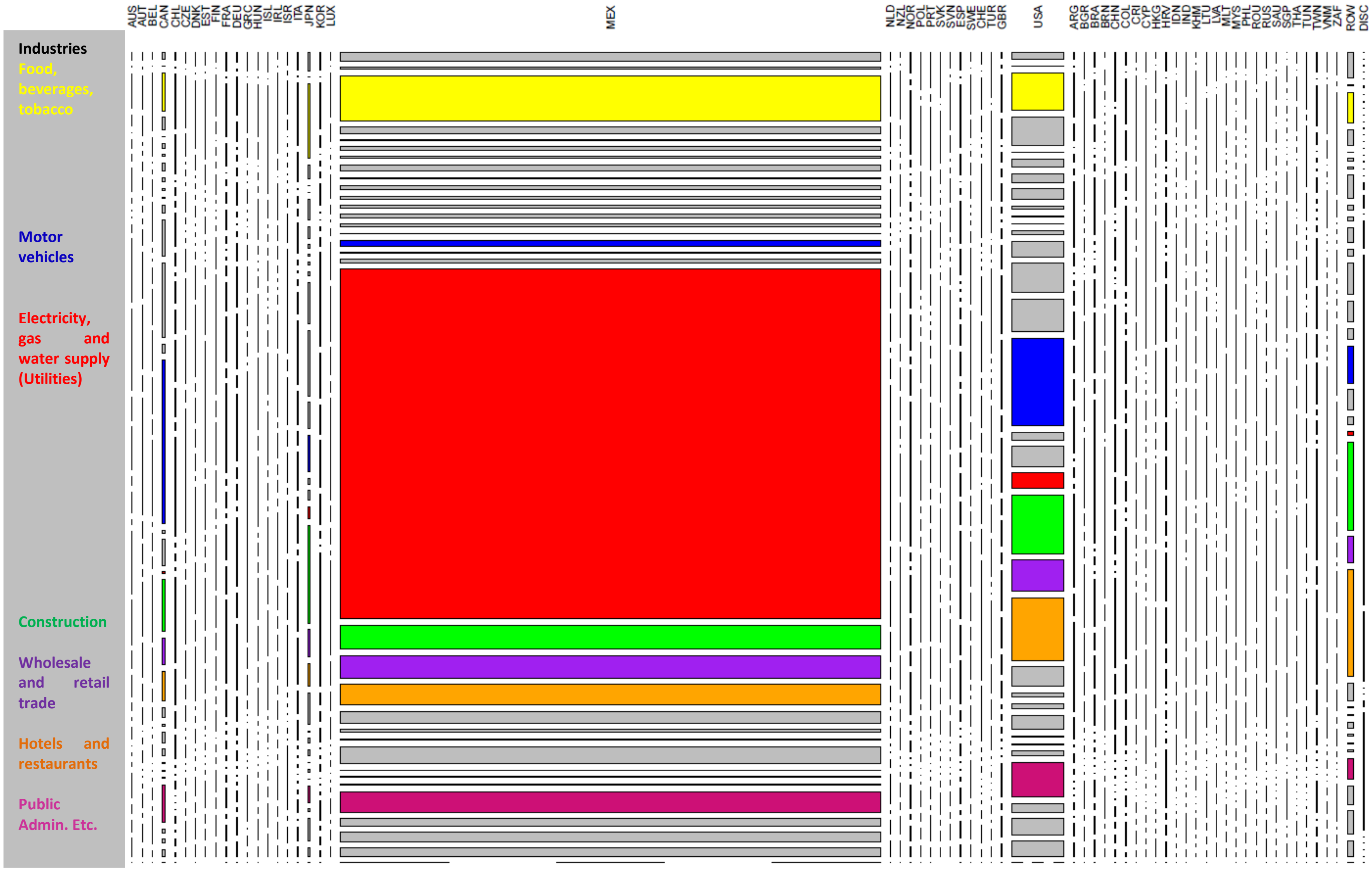


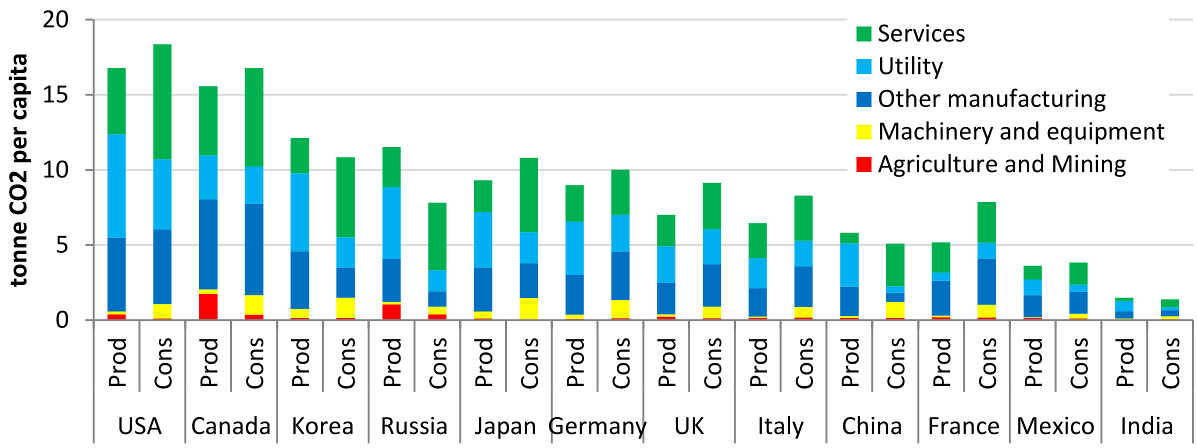
Figure 10: CO_2 emissions of Mexico's utilities industry by final demand country and industry – 2011



Using these detailed data on origin and destination of CO_2 emissions makes it possible to compare consumption patterns and their CO_2 intensity across countries. Figure 11 shows per capita production-based CO_2 emissions and per capita consumption-based CO_2 emissions for the G7 and other selected countries by five industry groups: *Agriculture and mining*, *Machinery and equipment*, *Other manufacturing*, *Utilities* and *Services*. The countries are ordered according to total consumption-based CO_2 emissions. The contribution of each industry varies significantly across countries. In the United States, not only the share of emissions from the utilities industry but also the absolute level of emissions embodied in utilities consumption was large compared to, for example, Canada. In Canada, the share of low carbon electricity technologies is higher than in the United States. This also explains why the CO_2 embodied in final demand for services is lower than in the United States. However, in Canada the per capita emissions embodied in final demand for manufacturing products is higher than in the United States, mainly due to higher per capita and per USD emissions for products of *Coke, refined petroleum products and nuclear fuel* industry (ISIC Rev.3 Division 23), which includes automotive fuels.

Generally, countries with the same level of development within a region seem to have a similar pattern of the composition of CO_2 emissions embodied in final demand. This holds for Korea and Japan and to some extent for the EU countries displayed in Figure 11. Exceptions include Germany, with higher per capita emissions embodied in the final demand for *Machinery and equipment* (their investment in machinery and other manufactured products, is higher than that of all their neighbouring countries e.g. 4 times larger per capita than the UK and twice as large as France) – and, France with a lower share for *Utilities* due to use of nuclear power as a primary source of electricity. The convergence of per capita emissions embodied in certain goods within a region partly reflects increasing globalisation (or regionalisation) of production resulting in similar products being sold within a region coming from the same or very similar production chains.

Figure 11: Per capita production-based and consumption-based emissions by product (2011)

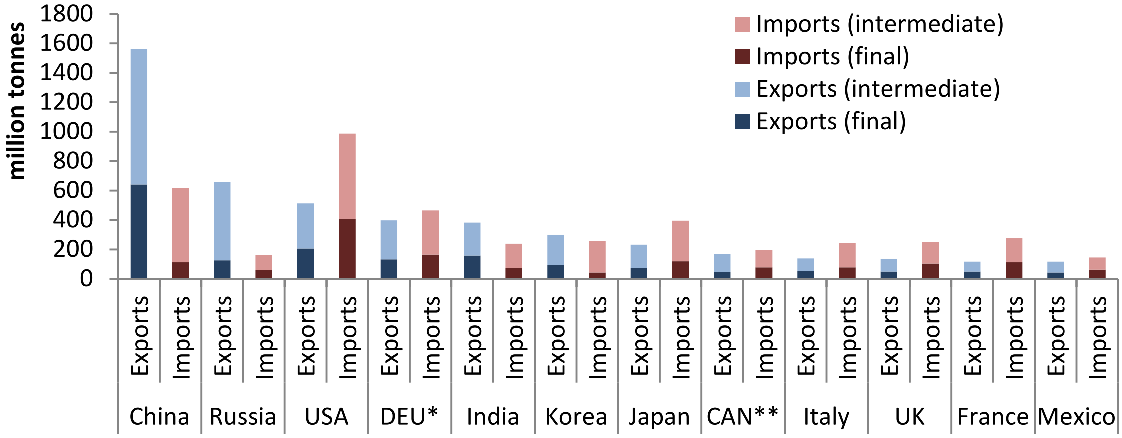


Source: OECD estimates based on the methodology described in this document.

3.3 Emissions embodied in imports and exports

CO_2 emissions embodied in imports and exports can also be estimated for intermediate and final products separately. Figure 12, which displays the top embodied CO_2 exporting countries, reveals that most of the emissions embodied in international trade are present in intermediate products (the lighter shaded parts of the bars in Figure 12). The big differences between emissions embodied in exports and emissions embodied in imports for China and Russia can be explained by the very high emission intensity of exported products, relative to the emission intensity of products imported from their trading partners, such as Germany or Japan.

Figure 12: Emissions embodied in imports and exports (selected countries, 2011)



* DEU = Germany ** CAN = Canada

Source: OECD estimates based on the methodology described in this document.

Despite the convergence in the emission intensity of exported products between 2000 and 2011 (Table 3**)**, the differences between countries remain high: Russia's CO_2 intensity per unit of exports is more than twice the world average in 2011 and China's and India's are still about twice as high as the world average, while European countries have a CO_2 intensity of exports far below the world average (50% to 80% of world average). In light of these findings, Kander et al. (2015) proposed an additional measure to compare the CO_2 emissions of countries: technology adjusted consumption-based CO_2 emissions. These are calculated using global average emission intensities of exports when subtracting emissions embodied in exports from domestically produced CO_2. This allocates relatively more emissions to countries with high CO_2 intensity and relatively lower emissions to countries with a low CO_2 intensity of exports.

Table 3: Global discrepancy in CO_2 intensity of exports (kg CO_2 per USD of gross exports)[8]

	WOR	RUS	CHN	IND	MEX	CAN	KOR	USA	ITA	DEU	GBR	FRA	JPN
2000	0.84	7.81	1.99	2.32	0.56	0.71	0.86	0.57	0.49	0.53	0.36	0.41	0.31
2005	0.64	2.83	1.70	1.30	0.47	0.51	0.66	0.43	0.35	0.37	0.26	0.29	0.36
2011	0.44	1.25	0.87	0.90	0.39	0.34	0.56	0.32	0.26	0.31	0.21	0.20	0.29

Source: OECD estimates

4. Limitations and next steps

There are two general problems with this approach to consumption-based emissions are. Firstly, emissions data used here are not collected according to the same methodologies as economic activity data, i.e. the emissions data do not entirely comply with the principles of national accounts data. The OECD is working with countries to implement the *System of Environmental-Economic Accounting* (EC et al., 2014) into national statistical practice. This standard ensures compliance between economic and environmental data. Unfortunately, this data is not yet available in the ISIC Rev. 3 classification. Secondly, the use of industry averages may introduce biases in two directions, both over- and underestimating emissions. In addition, the underlying ICIO is in nominal terms, thus changes in emission intensities could partly reflect changes in prices between and within countries. The unit prices of combustion fuels that industries and households face will change over time, and so will the relative prices of fuel substitutes within a country. This can be overcome by using both tables in monetary terms and in physical flows.

More specific current limitations include:

I. Road emissions are not allocated across industries using data on detailed gasoline and diesel consumption. Instead, ICIO data on the aggregate level of *Coke, refined petroleum products and nuclear industry* (ISIC Rev.3 Division 23) are used.
II. No re-allocation of emissions associated with intermediate non-resident purchases of road transportation fuel.
III. The methodology does not account for emissions from international bunker fuels (aviation and maritime). While these only amount to 3% to 3.5% of global CO_2 emissions from fuel combustion (calculations based on IEA, 2015), conceptually their omission is particularly noteworthy. In effect, the methodology accounts for differences in emissions in alternative production sites along the chain, but not the emissions directly associated with the international fragmentation of production through international freight transport. The importance of this omission is, of course, the greater the more spatially extended GVCs are and the greater the variation there is in international freight transport emissions. For example, there is good evidence that different types of vessels are used within emission control areas (ECAs), than is the case for routes which cross ECAs. See OECD/ITF (2016) for a discussion of the case of sulphur.
IV. The exclusion of carbon emissions not included in the IEA data, i.e. from IPCC source/sink categories other than 1A (non-fuel combustion of CO_2), due to difficulties of matching to industry classification and the (non-)availability of data from non-Annex I oil producing countries.
V. The exclusion of greenhouse gases other than CO_2, due to data availability and difficulties of matching to economic activities and industry classification.
VI. Lenzen and Treloar (2004) argue that CO_2 emissions embodied in capital goods used for production should actually be reallocated along global production chains to consumption. This aspect has not been considered in the calculations presented here. This would require an estimation of the CO_2 embodied in the current capital stock and calculation of related depreciation of the capital stock.

Referring to the points made above, the related next steps include:

I. Using more detailed data to allocate emissions from road transport, if available. This is for example the case for Japan.
II. This issue will not be solved in the near future due to data limitations. It may be possible to improve the estimates when emission data compiled under the SEEA (and ISIC Rev.4) become more widely available, and the ICIO has been transferred to ISIC Rev.4 classification.
III. Using additional data on international transport from other institutions e.g. the International Transport Forum (ITF), International Maritime Organization (IMO), and International Civil Aviation Organization (ICAO).
IV. Filling the gaps of emissions data from non-Annex I countries.
V. Estimate a capital formation matrix and endogenise the emissions embodied in capital goods.

Finally, future releases of the OECD ICIO could include a more detailed industry list to improve current and enable additional footprint calculations, e.g. demand-based material flows, including raw materials embodied in international trade and final demand.

ANNEX A TABLE A.1: DATA FOR SELECTED CO_2 INDICATORS FOR 1995 AND 2011 – OECD COUNTRIES

	Consumption-based emissions						Production-based emissions						Net-exports	
	FD_CO2 million t		FD_PCCO2 t / capita		FD_GDPPPPCO2 PPP$ / kg CO_2		PROD_CO2 million t		PROD_PCCO2 t / capita		PROD_GDPPPPCO2 PPP$ / kg CO_2		NET_CO2 million t	
	1995	2011	1995	2011	1995	2011	1995	2011	1995	2011	1995	2011	1995	2011
AUS	271.2	445.9	15.0	19.6	1.5	2.2	286.7	389.0	15.8	17.1	1.4	2.5	15.5	-56.9
AUT	84.7	97.4	10.6	11.6	2.2	3.8	59.3	67.5	7.4	8.0	3.2	5.5	-25.4	-29.9
BEL	119.8	135.4	11.8	12.3	1.9	3.3	115.2	110.5	11.3	10.0	2.0	4.1	-4.6	-24.8
CAN	420.6	579.4	14.4	16.8	1.6	2.5	460.1	537.2	15.7	15.6	1.5	2.7	39.5	-42.2
CHL	39.9	80.8	2.8	4.7	2.7	4.3	38.6	76.1	2.7	4.4	2.8	4.6	-1.2	-4.7
CZE	117.2	102.6	11.3	9.7	1.2	2.9	124.9	112.8	12.1	10.6	1.1	2.7	7.7	10.2
DNK	68.8	50.0	13.1	9.0	1.8	4.8	58.1	42.1	11.1	7.6	2.1	5.7	-10.6	-7.9
EST	12.2	13.6	8.5	10.5	0.7	2.3	16.0	17.4	11.2	13.4	0.6	1.8	3.8	3.7
FIN	66.4	64.9	13.0	12.0	1.5	3.3	56.0	55.4	11.0	10.3	1.8	3.9	-10.4	-9.5
FRA	454.8	499.4	7.8	7.9	2.7	4.9	356.4	329.7	6.1	5.2	3.5	7.4	-98.4	-169.8
DEU	1046.1	830.0	12.6	10.0	1.8	4.2	874.2	745.4	10.5	9.0	2.2	4.6	-171.9	-84.6
GRC	83.6	100.7	7.8	9.1	1.9	2.9	75.5	82.7	7.1	7.4	2.2	3.6	-8.1	-18.0
HUN	54.3	52.5	5.2	5.3	1.7	4.3	57.1	47.4	5.5	4.7	1.7	4.8	2.8	-5.2
ISL	2.4	2.2	8.8	7.0	2.7	5.6	2.0	1.9	7.4	5.8	3.2	6.8	-0.4	-0.4
IRL	36.4	42.9	10.1	9.5	1.8	4.9	33.0	35.0	9.1	7.7	2.0	6.0	-3.4	-7.9
ISR	59.3	81.9	11.1	10.9	1.8	2.9	46.0	67.2	8.6	8.9	2.4	3.5	-13.2	-14.7
ITA	472.6	503.3	8.3	8.3	2.6	4.2	409.1	392.3	7.2	6.5	3.1	5.4	-63.5	-111.0
JPN	1393.8	1372.2	11.2	10.8	2.1	3.2	1141.0	1184.4	9.2	9.3	2.5	3.7	-252.8	-187.8
KOR	369.8	528.9	8.3	10.9	1.6	2.9	358.8	590.5	8.0	12.1	1.7	2.6	-11.0	61.6
LUX	5.9	8.3	14.4	16.2	2.9	5.7	8.1	10.5	19.8	20.3	2.1	4.5	2.2	2.1
MEX	281.7	456.8	3.0	3.8	2.5	4.1	296.0	432.4	3.1	3.6	2.4	4.4	14.3	-24.4
NLD	171.2	157.7	11.1	9.5	2.1	4.9	171.0	174.9	11.1	10.5	2.1	4.4	-0.2	17.2
NZL	27.4	38.2	7.4	8.7	2.4	3.7	25.2	30.2	6.9	6.8	2.6	4.7	-2.1	-8.1
NOR	36.4	58.9	8.3	11.9	2.9	5.3	32.8	38.1	7.5	7.7	3.2	8.2	-3.5	-20.8
POL	290.7	289.2	7.6	7.6	1.0	2.9	330.7	300.6	8.6	7.9	0.9	2.8	39.9	11.4
PRT	56.3	55.0	5.6	5.2	2.4	5.2	48.0	47.4	4.8	4.5	2.9	6.0	-8.3	-7.7
SVK	34.6	38.4	6.5	7.1	1.3	3.5	40.8	33.9	7.6	6.2	1.1	4.0	6.2	-4.5
SVN	16.6	18.7	8.4	9.1	1.6	3.1	14.0	15.3	7.0	7.4	1.9	3.8	-2.6	-3.4
ESP	256.7	320.7	6.5	6.9	2.5	4.8	232.0	269.5	5.9	5.8	2.8	5.7	-24.7	-51.2
SWE	74.4	76.9	8.4	8.1	2.7	5.4	57.7	43.6	6.5	4.6	3.5	9.5	-16.7	-33.3
CHE	80.3	96.2	11.4	12.2	2.5	4.5	41.9	40.3	6.0	5.1	4.9	10.7	-38.4	-56.0
TUR	174.4	350.0	3.0	4.8	2.4	3.7	152.6	285.5	2.6	3.9	2.8	4.6	-21.8	-64.5
GBR	588.8	570.3	10.2	9.1	2.1	4.1	518.5	437.3	8.9	7.0	2.4	5.3	-70.3	-133.0
USA	5286.0	5784.4	19.7	18.4	1.4	2.7	5130.3	5286.1	19.1	16.8	1.5	2.9	-155.7	-498.2

ANNEX A TABLE A.2: DATA FOR SELECTED CO_2 INDICATORS FOR 1995 AND 2011 – NON-OECD ECONOMIES

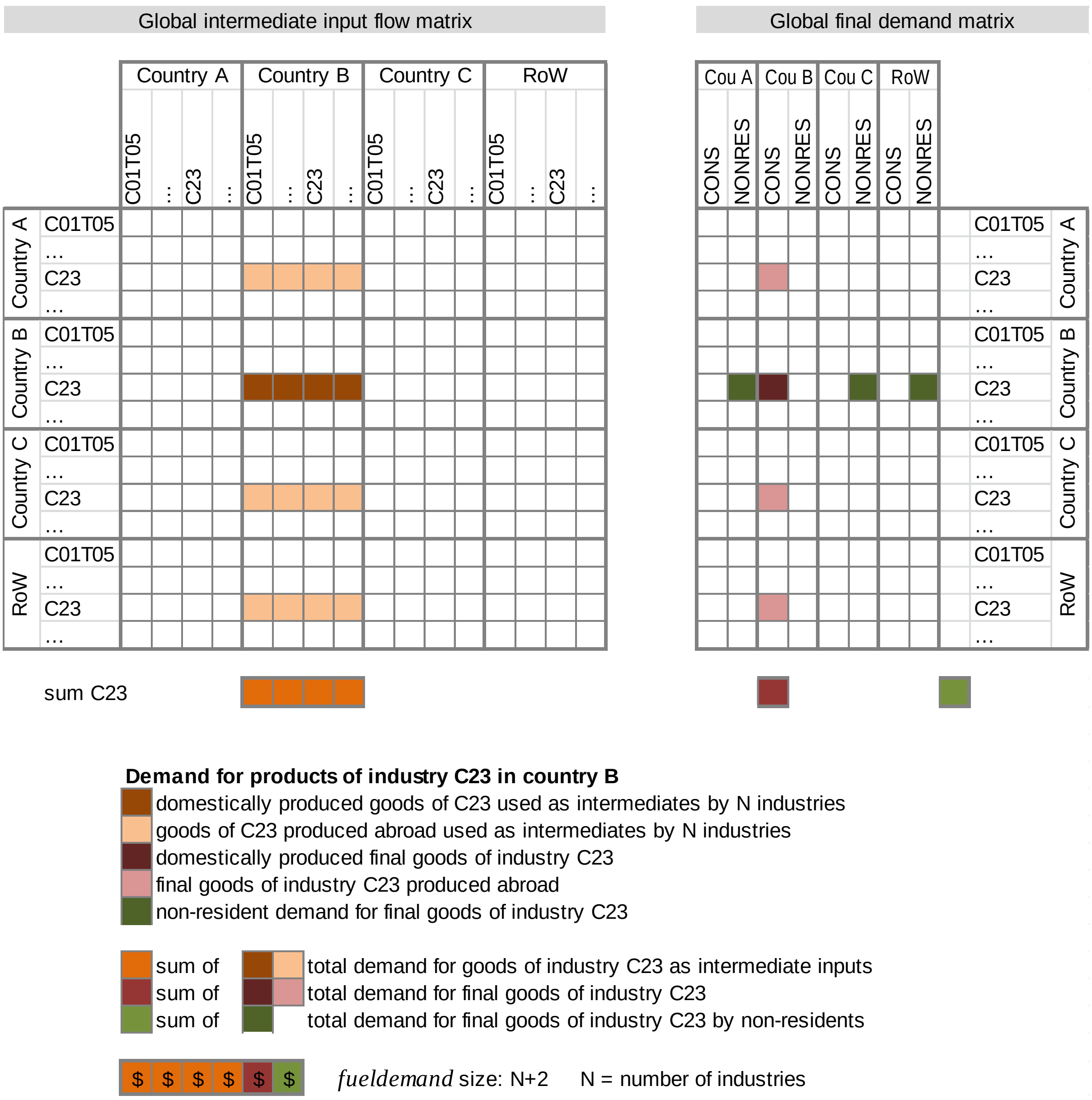
	Consumption-based emissions						Production-based emissions						Net-exports	
	FD_CO2 million t		FD_PCCO2 t / capita		FD_GDPPPPCO2 PPP$ / kg CO_2		PROD_CO2 million t		PROD_PCCO2 t / capita		PROD_GDPPPPCO2 PPP$ / kg CO_2		NET_CO2 million t	
	CHN	**2705.03**	**6960.58**	**2.18583**	**5.08651**	**0.79535**	**1.93891**	**3021.58**	**7956.28**	**2.44162**	**5.81412**	**0.71202**	**1.69626**	**316.545**
ARG	128.2	182.7	3.7	4.5	2.6	3.5	119.9	183.7	3.4	4.5	2.8	3.4	-8.3	1.0
BGR	28.3	37.7	3.4	5.1	1.6	3.0	53.2	49.0	6.4	6.7	0.9	2.3	25.0	11.3
BRA	253.4	467.1	1.6	2.4	5.2	6.4	235.7	408.9	1.5	2.1	5.6	7.3	-17.7	-58.2
BRN	4.7	5.7	15.9	14.1	3.6	5.1	4.5	8.2	15.1	20.2	3.8	3.6	-0.2	2.5
CHN	2705.0	6960.6	2.2	5.1	0.8	1.9	3021.6	7956.3	2.4	5.8	0.7	1.7	316.5	995.7
COL	71.3	87.2	2.0	1.9	3.2	6.1	58.4	67.9	1.6	1.4	3.9	7.9	-13.0	-19.3
CRI	6.7	10.7	1.9	2.3	3.2	5.6	4.4	6.7	1.3	1.4	4.9	9.0	-2.3	-4.0
CYP[1]	7.3	9.6	8.6	8.6	1.5	2.9	4.9	7.0	5.8	6.3	2.2	4.0	-2.4	-2.6
HKG	83.2	77.3	13.5	10.9	1.7	4.6	36.2	46.2	5.9	6.5	4.0	7.7	-47.0	-31.1
HRV	17.5	22.1	3.7	5.1	2.2	4.0	15.8	18.7	3.4	4.3	2.4	4.7	-1.7	-3.4
IDN	206.5	426.5	1.1	1.7	4.8	5.1	214.1	400.2	1.1	1.6	4.6	5.4	7.6	-26.2
IND	729.1	1694.2	0.8	1.4	2.0	3.5	772.5	1828.7	0.8	1.5	1.9	3.2	43.4	134.5
KHM	2.6	6.7	0.2	0.5	3.4	5.7	1.5	4.0	0.1	0.3	5.8	9.6	-1.1	-2.7
LTU	15.7	18.7	4.3	6.1	1.4	3.7	14.1	13.3	3.9	4.4	1.6	5.1	-1.5	-5.4
LVA	10.8	10.2	4.3	4.9	1.4	4.0	8.9	7.4	3.6	3.6	1.7	5.6	-1.9	-2.8
MLT	2.4	2.6	6.1	6.1	2.4	3.7	2.3	2.5	5.9	5.8	2.4	3.9	-0.1	-0.1
MYS	87.1	152.9	4.2	5.3	2.4	4.0	85.2	192.0	4.1	6.7	2.5	3.2	-1.9	39.1
PHL	60.7	89.0	0.9	0.9	3.3	6.1	56.9	76.8	0.8	0.8	3.5	7.1	-3.8	-12.2
ROU	100.3	83.0	4.4	3.8	1.2	4.2	117.5	81.7	5.1	3.7	1.0	4.3	17.2	-1.3
RUS	1036.6	1122.2	7.0	7.8	0.8	2.9	1558.2	1654.0	10.5	11.5	0.5	2.0	521.6	531.8
SAU	170.6	386.7	9.2	13.9	2.8	3.5	192.4	428.6	10.4	15.4	2.5	3.2	21.8	41.9
SGP	45.4	48.1	13.0	9.3	2.5	8.1	39.1	50.9	11.2	9.8	2.9	7.6	-6.3	2.8
THA	148.6	225.0	2.5	3.4	2.7	3.8	139.7	240.7	2.4	3.6	2.8	3.5	-8.9	15.7
TUN	16.4	24.2	1.8	2.3	2.4	4.5	14.2	21.8	1.6	2.0	2.8	5.0	-2.3	-2.4
TWN	168.2	205.1	7.9	8.8	2.3	3.8	158.4	264.2	7.5	11.4	2.5	2.9	-9.7	59.1
VNM	28.4	125.2	0.4	1.4	3.8	3.3	27.7	134.1	0.4	1.5	3.9	3.1	-0.6	8.9
ZAF	225.9	316.1	5.5	6.1	1.2	2.0	274.4	361.7	6.6	7.0	1.0	1.8	48.5	45.6
ROW	2199.6	3465.4	1.5	1.7	0.0	0.0	2231.5	3366.8	1.5	1.7	0.0	0.0	31.9	-98.6

1. Note by Turkey: The information in this document with reference to « Cyprus » relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the “Cyprus issue”.

Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

ANNEX B: FIGURES AND TABLES EXPLAINING THE ESTIMATION OF CO_2 EMISSIONS FACTOR USING FUEL COMBUSTION EMISSIONS AND IO/SUT DATA SOURCES

Figure A.1: Creating the vector *fueldemand*



C01T05 Agriculture, hunting, forestry and fishing
C23 Coke, refined petroleum products and nuclear fuel

Figure A.2: Vector *percco2scdry*

%	%	%	%	%	%	%

percco2scdry size: N+3 N = number of industries

- Secondary emissions by N industries except emissions associated with road transport
- Secondary emissions by households except emissions associated with road transport
- Secondary emissions by non-residents except emissions associated with road transport
- Emissions associated with road transport

as a share of total secondary emissions (i.e. emissions associated with fuels sold by C23)

Table A.3: Concordance between CO_2 flows and ICIO industry classification (ISIC Rev. 3)

IO Classification		MAINELEC	MAINCHP	MAINHEAT	EPOWERPLT	AUTOPROD	OTHEN	IRONSTL	NONFERR	CHEMICAL	NONMET	TRANSEQ	MACHINE	MINING	FOODPRO	PAPERPRO	WOODPRO	CONSTRUC	TEXTILES	INONSPEC	NEINTREN	ROAD	DOMESAIR	RAIL	PIPELINE	DOMESNAV	TRNONSPE	NETRANS	RESIDENT	COMMPUB	AGRICULT	FISHING	ONONSPEC	NEOTHER	AVBUNK	MARBUNK
Agriculture, hunting, forestry and fishing	C01T05						1															1									1	1				
Mining and quarrying	C10T14						1							1							1	1														
Food products, beverages and tobacco	C15T16						1								1						1	1														
Textiles, textile products, leather and footwear	C17T19					1													1		1	1														
Wood and products of wood and cork	C20						1										1				1	1														
Pulp, paper, paper products, printing and publishing	C21T22					1										1					1	1														
Coke, refined petroleum products and nuclear fuel	C23					1				1											1	1														
Chemicals	C24					1				1											1	1														
Rubber & plastics products	C25						1			1											1	1														
Other non-metallic mineral products	C26					1					1										1	1														
Basic metals	C27					1		1	1												1	1														
Fabricated metal products, except machinery & equipment	C28					1		1	1				1								1	1														
Machinery & equipment, nec	C29						1						1								1	1														
Computer, electronic and optical equipment	C30,32,33						1						1								1	1														
Electrical machinery & apparatus, nec	C31						1						1								1	1														
Motor vehicles, trailers & semi-trailers	C34						1					1									1	1														
Other transport equipment	C35						1					1									1	1														
Manufacturing nec; recycling (include Furniture)	C36T37						1													1	1	1														
Electricity, gas and water supply	C40T41	1	1	1	1		1														1	1														
Construction	C45						1											1			1	1														
Wholesale & retail trade; repairs	C50T52																					1								1			1	1		
Hotels & restaurants	C55																					1								1			1	1		
Transport and storage	C60T63																					1	1	1	1	1	1	1							1	1
Post & telecommunications	C64																					1								1			1	1		
Financial intermediation	C65T67																					1								1			1	1		
Real estate activities	C70																					1								1			1	1		
Renting of machinery & equipment	C71																					1								1			1	1		
Computer & related activities	C72																					1								1			1	1		
Other Business Activities	C73T74																					1								1			1	1		
Public admin. & defence; compulsory social security	C75																					1								1			1	1		
Education	C80																					1								1			1	1		
Health & social work	C85																					1								1			1	1		
Other community, social & personal services	C90T93																					1								1			1	1		
Private households with employed persons	C95																																			
Household final consumption	PrivHH																					1							1							

ICIO industry classification in ISIC Rev. 3

Table A.4: Concordance CO_2 fuel types and ICIO industries

		Mining and quarrying	Coke, refined petroleum products and nuclear fuel	Chemicals	Basic metals	Manufacturing nec; recycling (include Furniture)	Electricity, gas and water supply	Other community, social & personal services
		C10T14	C23	C24	C27	C36T37	C40T41	C90T93
Hard coal (if no detail)	HARDCOAL	1						
Brown coal (if no detail)	BROWN	1						
Anthracite	ANTCOAL	1						
Coking coal	COKCOAL	1						
Other bituminous coal	BITCOAL	1						
Sub-bituminous coal	SUBCOAL	1						
Lignite	LIGNITE	1						
Patent fuel	PATFUEL		1					
Coke oven coke	COKEOVGS		1					
Gas coke	GASCOKE		1					
Coal tar	COALTAR			1				
BKB	BKB	1						
Gas works gas	GASWKSGS						1	
Coke oven gas	OVENCOKE		1					
Blast furnace gas	BLFURGS				1			
Other recovered gases	OTHKERO				1			
Peat	PEAT	1						
Peat products	PEATPROD	1						
Oil shale	OILSHALE	1						
Natural gas	NATGAS	1						
Crude/NGL/feedstocks (if no detail)	CRNGFEED	1						
Crude oil	CRUDEOIL	1						
Natural gas liquids	NGL						1	
Refinery feedstocks	REFFEEDS		1					
Additives/blending components	ADDITIVE	1						
Orimulsion	ORIMUL			1				
Other hydrocarbons	NONCRUDE			1				
Refinery gas	REFINGAS		1					
Ethane	ETHANE			1				
Liquefied petroleum gases (LPG)	LPG	1						
Motor gasoline excl. bio	NONBIOGASO		1					
Aviation gasoline	AVGAS		1					
Gasoline type jet fuel	JETGAS		1					
Kerosene type jet fuel excl. bio	NONBIOJETK		1					
Other kerosene	OGASES		1					
Gas/diesel oil excl. bio	NONBIODIES		1					
Fuel oil	RESFUEL		1					
Naphtha	NAPHTHA		1					
White spirit & SBP	WHITESP		1					
Lubricants	LUBRIC		1					
Bitumen	BITUMEN		1					
Paraffin waxes	PARWAX		1					
Petroleum coke	PETCOKE		1					
Non-specified oil products	ONONSPEC		1					
Industrial waste	INDWASTE					1		
Municipal waste (non-renew)	MUNWASTEN							1
Total	TOTAL							

ANNEX C: DATA SOURCES FOR CARBON EMISSIONS AT THE NATIONAL AND INDUSTRY LEVEL

Data sources

There are a variety of different databanks on carbon emissions ranging from emissions reported at a country level for all countries in the world to emissions reported in high level of detail for individual countries. The emission data used as an extension to an ICIO system should be comparable across countries and structured similarly to allow for similar processing for inclusion in an ICIO. The UNFCCC website provides an overview on existing international databases on greenhouse gas (GHG) emissions[9]. The main (primary) data sources for GHG emissions are

- UNFCCC (primary) https://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php
- OECD/IEA 2015 (primary) IEA's CO_2 emissions from fuel combustionhttp://www.iea.org/publications/freepublications/publication/name,43840,en.html
- EDGAR (not primary) (http://edgar.jrc.ec.europa.eu/index.php#)
- CDIAC (primary) http://cdiac.ornl.gov/CO2_Emission/

The differences between the compilation procedures are the use of emission inventory or the use of data on energy use combined with emission factors. While the UNFCCC data is based on emission inventories that are reported by individual countries and created using the IPCC guidelines (IPCC, 2006), the OECD/IEA data is based on detailed energy balances that differentiate between the uses of various energy carriers by different activities from which emissions can be calculated using emission factors given in the 1996 IPCC guidelines (the most recent edition of the IEA 2015 data is based on the 2006 IPCC guidelines, but the data used for the calculations presented here were still based on 1996 guidelines). This latter method is based on the IPCC Tier 1 sectoral approach.

EDGAR is in itself not a primary data source for emission data; rather it is an important supplementary source, which builds on OECD/IEA and IPCC data. EDGAR adjusts the OECD/IEA data "for incomplete or inconsistent time trends"[10]; in addition it uses emission factors provided by the IPCC.

There are a variety of other statistical databanks providing information on carbon emissions; however most only report territorial emission at the country level, which is not sufficient here; see for example the data provided by the United Nations Statistical Division for the Millennium Development Goal indicators or the environmental indicators. For European countries, the European Environment Agency (EEA) provides National Accounting Matrices with Environmental Accounts (NAMEA) and Eurostat has recently published SEEA data by industry, using the NACE Rev. 2 (ISIC Rev. 4) classification, based on air emission accounts which are now mandatory for the EU countries. Similar datasets are also available for some other OECD countries and large emerging economies. Still, this data is not readily available for many of the countries included in the OECD ICIO and given the difference in the sector classification of the OECD ICIO and the existing NAMEAs/SEEA data, we chose to directly use one of the primary data sources, i.e. IEA (2015) CO_2 emissions from fuel combustion.

Table A.5 lists the source of the territorial carbon emission data used in different existing global ICIO/MRIO systems to estimate consumption-based emissions.

Table A.5: CO_2 data used in existing ICIO/MRIO databases[11]

Database	Emission data	Source
EORA	EDGAR	Lenzen et al. (2012); Lenzen et al. (2013)
EXIOBASE / CREEA	IEA Energy balances combined with TNO Emission Assessment Model, IPCC and EMEP/EEA emission factors	Tukker et al. (2009)
GRAM	IEA Energy balances and IEA CO_2 emissions from fuel combustion	Bruckner et al. (2012); Wiebe et al. (2012a); Wiebe et al. (2012b)
GTAP	IEA energy data and GTAP's energy volume data using IPCC Tier 1 data	Davis and Caldeira (2010); Peters (2008); Peters et al. (2011); Peters and Solli (2010)
OECD	IEA CO_2 emissions from fuel combustion	Ahmad and Wyckoff (2003); Nakano et al. (2009)
WIOD	NAMEAs and EDGAR, IEA Energy balances combined with IPCC emission factors	Timmer et al. (2015)

According to Peters and Solli (2010), p. 108, *"the officially reported emissions data to UNFCCC is not suitable for economic modelling as it is not consistent with the principles used in the System of National Accounts."* In addition to this, the ease of using emission data within the OECD-ICIO system is an equally important factor. The ease of use is primarily given by the availability of emission data at the industry classification of the ICIO system. Given the industry detail available in the OECD/IEA emission data in addition to this data being "in-house", the OECD/IEA CO2 emissions from fuel combustion data is used to complement the OECD ICIO system with an emission extension. However, OECD/IEA database only covers emissions of IPCC emission category 1A. The emissions from the remaining categories are neatly collected in the EDGAR database, which can also be used to fill the gaps in the 1A emission data.

Important: Both OECD/IEA and EDGAR indicate that the emissions provided in their databases may not amount to the exact same total as reported by countries to the UNFCCC. The IEA reports deviations of up to 5% for the Annex I countries and larger deviations for some of the other countries (IEA, 2015 p.I.4 and I.5). PBL (2013) Table A1.1, p.48, report the deviations for selected countries to be between -2% and +13% as an average across years of the EDGAR data from the UNFCCC data.

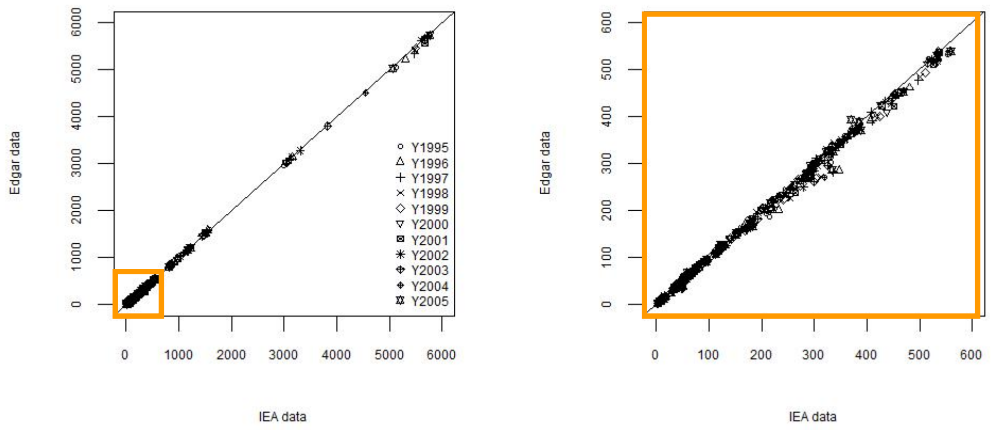
Uncertainty in CO_2 emission data

A large part of the differences in consumption-based emission accounts between the various databases can be traced back to using different input data, i.e. data that is used to construct the ICIO system and the production-based emissions data (Owen et al., 2014). The discussion above is therefore complemented with a short overview of the differences between the IEA and Edgar emissions data.

The following graphs show the differences between IEA and EDGAR CO_2 data for the IPCC source/sink category 1A emissions. The graphs have been taken from a report to the European Commission DG CLIMA (Ricardo AEA / GWS, 2014) and compare the data for a set of countries almost congruent with the set of OECD ICIO countries. Figure A.3 shows that the Edgar emissions data tends to be slightly lower than the IEA data (points are below the diagonal). This is also confirmed by Figure A.4 and Figure A.5 showing the percentage deviation of IEA data from Edgar data across years and across countries, with median and mean being greater than zero. The box-plots in Figure A.4 show that 50% of all country observations have an almost zero difference, there are however some outliers. These can be identified from

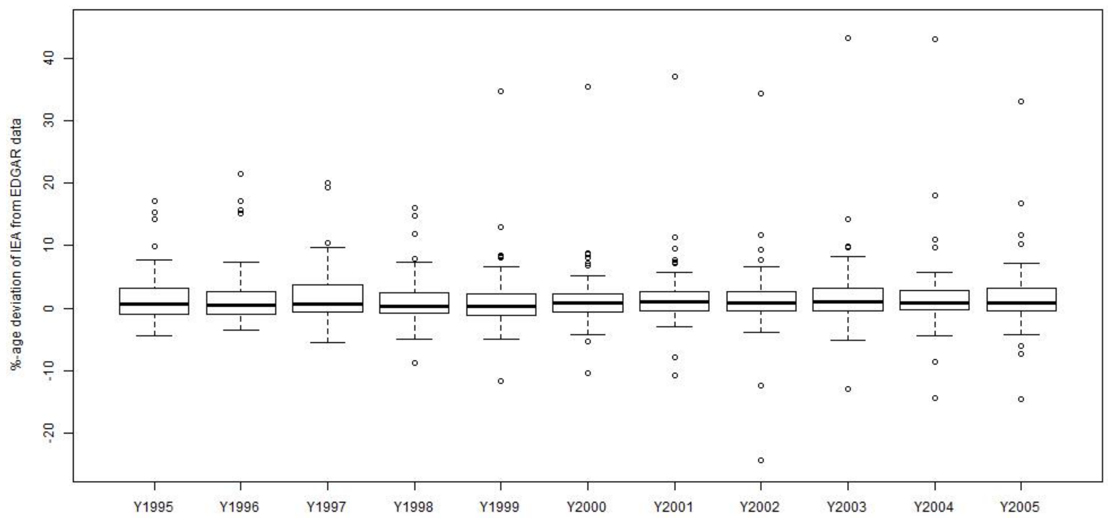
Figure A.5: Singapore, Poland, Viet Nam, New Zealand, Indonesia, Chile (negative) and Estonia (single negative outlier in 2002).

Figure A.3: Absolute deviation between EDGAR and IEA data (Mt CO_2)



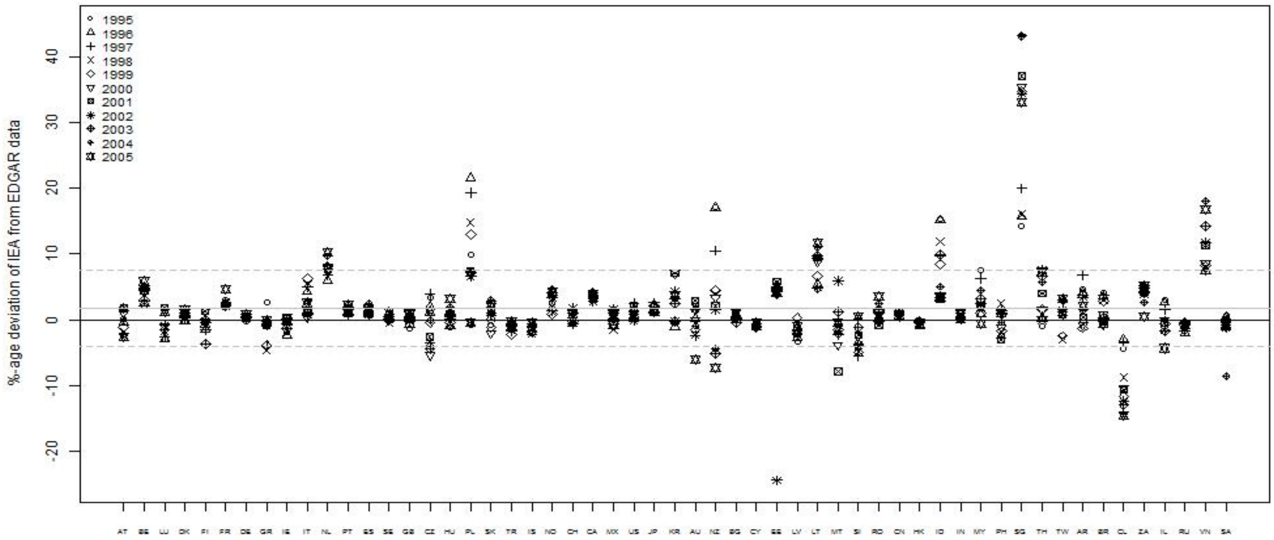
Source: based on Ricardo AEA / GWS (2014)

Figure A.4: Relative deviation between EDGAR and IEA data by year



Source: based on Ricardo AEA / GWS (2014)

Figure A.5: Relative deviation between EDGAR and IEA data by country



Source: based on Ricardo AEA / GWS (2014)

NOTES

1. See also OECD Green growth and sustainable development.

2. Discrepancies occur during the set-up of the system due to conflicting trade data, i.e. reported exports of the countries do not equal reported imports.

3. IPCC (1996), p.1.3 defines the CO2 emissions from fuel combustion activities (IPCC source/sink category 1A): "*Total emissions of all greenhouse gases from all fuel combustion activities as described further below. CO2 emissions from combustion of biomass fuels are not included in totals for the energy sector. They may not be net emissions if the biomass is sustainably produced. If biomass is harvested at an unsustainable rate (that is, faster than annual regrowth), net CO2 emissions will appear as a loss of biomass stocks in the Land-Use Change and Forestry module. Other greenhouse gases from biomass fuel combustion are considered net emissions and are reported under Energy. (Sum of I A 1 to I A 5). Incineration of waste for waste-to-energy facilities should be reported here and not under Section 6C. Emissions based upon fuel for use on ships or aircraft engaged in international transport (1 A 3 a i and 1 A 3 d i) should, as far as possible, not be included in national totals but reported separately*."

4. IEA (2015), p.10: "*Residential contains all emissions from fuel combustion in households. This corresponds to IPCC Source/Sink Category 1 A 4 b*."

5. The IEA's data seem to be the most appropriate source of data to be used for estimating consumption-based emissions using the OECD's ICIO, as the data is available for all countries in the ICIO at an industry level corresponding to the industry classification of the ICIO. The IEA data is in ISIC Rev. 4 classification. But as the industries are highly aggregated, the data is still generally compatible with the ICIOs ISIC revision 3 classification. See ISIC Rev 3 to ISIC Rev 4 concordance.

6. See http://stats.oecd.org/Index.aspx?DataSetCode=IO_GHG_2015

7. These indicators are published as part of the Green Growth indicators (OECD, 2011; GGKP, 2013): http://stats.oecd.org/Index.aspx?DataSetCode=GREEN_GROWTH

8. Average CO_2 embodied per USD of export at total industry level of each country is calculated by dividing total CO_2 embodied in gross exports by total gross exports.

9. See https://unfccc.int/ghg_data/ghg_data_non_unfccc/items/3170.php

10. See http://edgar.jrc.ec.europa.eu/methodology.php

11. This table has been cross-checked with ongoing (since February 2016) research at NTNU, Trondheim, where the team is in close contact with the owners of the different databases.

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