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ESTIMATING CARBON EMISSIONS EMBODIED IN FINAL DEMAND AND INTERNATIONAL GROSS TRADE USING THE OECD ICIO 2018

Norihiko YAMANO[1] and Joaquim GUILHOTO[1]

[1] OECD Directorate for Science Technology and Innovation

Abstract

Earlier OECD studies on carbon footprint analyses taking into account for global production networks have contributed to increase awareness of divergences in territorial or production-based and consumption-based carbon emissions. The differences in these measures are essential for formulating responses to international climate change negotiations. This paper provides the latest estimates of carbon emissions embodied in final demand and international gross trade of selected 65 economies for the period between 2005 and 2015 with a revised methodology of territorial and economic output-based emissions. Using the latest main data sources (2018 edition of the OECD Inter-Country Input-Output (ICIO) tables, the OECD Air Emissions Account under the System of Environmental-Economic Accounting (SEEA) and the 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. Namely, following extensions are included: 1) explicit distinctions between territorial, economic output, final demand-based emissions as well as emissions embodied in gross imports and exports, 2) estimates by major fuel combustion sources, 3) fuel purchases by non-resident industries (road transportation; international aviation and marine bunkers) and household (motor vehicles fuels consumption abroad)

Keywords: Inter-Country Input-Output; Consumption-based accounting, CO_2 emissions, International trade

1. Introduction

The earlier studies on consumption-based emissions (OECD, 2013, Wiebe and Yamano, 2016; Exiobase; EORA; WIOD; Owen et al.,) indicate that the deviations between territorial emission accounting greenhouse gas (GHG) and emissions embodied in final demand have been widening in many studies. Reliable emissions information for different types of emissions are increasingly referred by environment economics and climate change policy discussions (Wiedman, 2009).

Numerous literature on measuring GHGs from "consumption-based accounting" approaches have been recently published for different geographical coverages. However, the definitions of terms on production-based and consumption-based emissions could be slightly different for each studies. In this paper, we explicitly clarify the types of emissions into three allocation methods (Barrett, *et al.*, 2013)[1]

1) Territorial-based emission accounting (e.g. UNFCCC_GHG; IEA_CO2)

Fuel purchased and combusted in domestic territory. Fuels combusted by non-residents' motor vehicles are included here. In general, the international bunker fuels are separately estimated from domestic navigation and aviation emissions.

The industry dimension is defined by fuel users in domestic territory

2) Production-based emission accounting (e.g. SEEA-AEA; OECD 2016)

Production-based emissions in OECD study is differentiated from territorial emissions by the allocation fuels combusted for owned or leased motor vehicles of non-residents' households and land transportation industries and purchases on international bunker fuels by foreign aviation and marine operators. In principle, this type of emissions are following the definition of National Accounting Matrices including Environmental Accounts (NAMEA) or System of Environmental-Economic Accounting (SEEA) framework (UN, 2012).

The industry dimension is defined by fuel users by economic resident industries and households

3) Final demand-based emission accounting (demand-based emissions, hereafter)

The GHGs emitted at all production stages are captured in emissions embodied in final demand.

The type of household consumption and capital formation expenditures defines the product dimension and emissions sources industry by origin countries can be identified.

[1] Data links are available in the references section.

There are a variety of different GHG gas databases ranging from aggregated emissions for all countries in the world and high level of detail for individual countries. Table 1 summarises the existing international databases on greenhouse gas (GHG) emissions those based on the submissions from their members with customised questionnaires.

Table 1: International databases on greenhouse gas emissions and energy demand

Institution	Database	Target Countries	T/P
FAO	FAOSTAT Emissions database		T
IEA	World Energy Balances	143 countries and aggregate regions	T
IEA	CO_2 emissions from Fuel Combustion	142 countries and aggregate regions	T
Eurostat / OECD	Air Emissions Account (SEEA)	EU28 and other annex I countries	P
UNFCCC	Greenhouse Gas Inventory Data	All members Detailed (Annex I)	T

Note: See UNFCCC (https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-external-sources) for an overview of availability. T: territorial-based, P: production (economic resident)-based

Among the new features presented in this study, we highlight the following ones:

- Filling the gaps of IEA_CO2 databases for all countries to complete the coverage of CO_2 emissions from fuel combustions

- Complete allocation of CO_2 emissions from fuel combustion by non-resident households and industries. In earlier studies, the emissions from international bunkers were not distributed across operating transportation services providers due to the lack of industry details.

- CO_2 intensity for each bilateral trade borders. The database now enable to compare the emissions embodied in each bilateral trade pairs by specific product.

The remainder of this paper is structured as follows. Section 2 summarised the methodological approach taken to calculate the 2019 release of CO_2 emissions embodied in final demand and international trade (http://oe.cd/io-co2). The third section describes the detailed estimation steps for the production-based (fuel users by resident country) emissions. Section 4 presents the key results and the last section is summary.

2. Methodology

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 *value added* and employment embodied in international trade and final demand – the basis for many TiVA indicators (http://oe.cd/tiva). Emissions embodied in gross trade and final demand are calculated by similar equations using the vectors of production-based emissions and the output multipliers from the Inter-country Input-Output (ICIO) tables (See Table 2 for basic equations). However, the indicators need to be selected to avoid the double counting issues of emissions embodied in intermediate trade flows e.g. exported intermediate products could be used in domestic production processes. The differences between the demand-based and gross trade flows-based emissions are summarised using the three production stages (emission sector, intermediate and final producers) in a conceptual diagram of Figure 1.

Table 2: Basic equations for OECD's ICIO

Matrix	Size of the matrix	Description
X	$(N * K) \times 1$	**Gross output**, where x_i^r is the gross output from industry *i* in country *r*
Z	$(N * K) \times (N * K)$	**Intermediate consumption**, where z_{ij}^{rs} is the flow of goods from producing industry *i* in country *r to the purchasing industry j* in country *s*
A	$(N * K) \times (N * K)$	**Input coefficients**, calculated as $a_{ij}^{rs} = z_{ij}^{rs} / x_j^s$
B	$(N * K) \times (N * K)$	***Leontief inverse***, $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$, where the element b_{ij}^{rs} shows the direct and indirect requirements of inputs from industry *i* in country *r for the production of one unity of output to the final demand by industry j* in country *s*
Y	$(N * K) \times N$	**Final demand,** where the element $\boldsymbol{y}_i^{rs}$ shows the final demand of country *s* for goods and services produced by industry *i* in country *r*
TRD	$(N * K) \times N$	**Trade** matrices by exporting industry/country and importing country. The element $\boldsymbol{trd}_i^{rs}$ shows exports of products from industry *i* of country *r* to country *s* (imports of products from industry *I* of country *r* by country *s*).

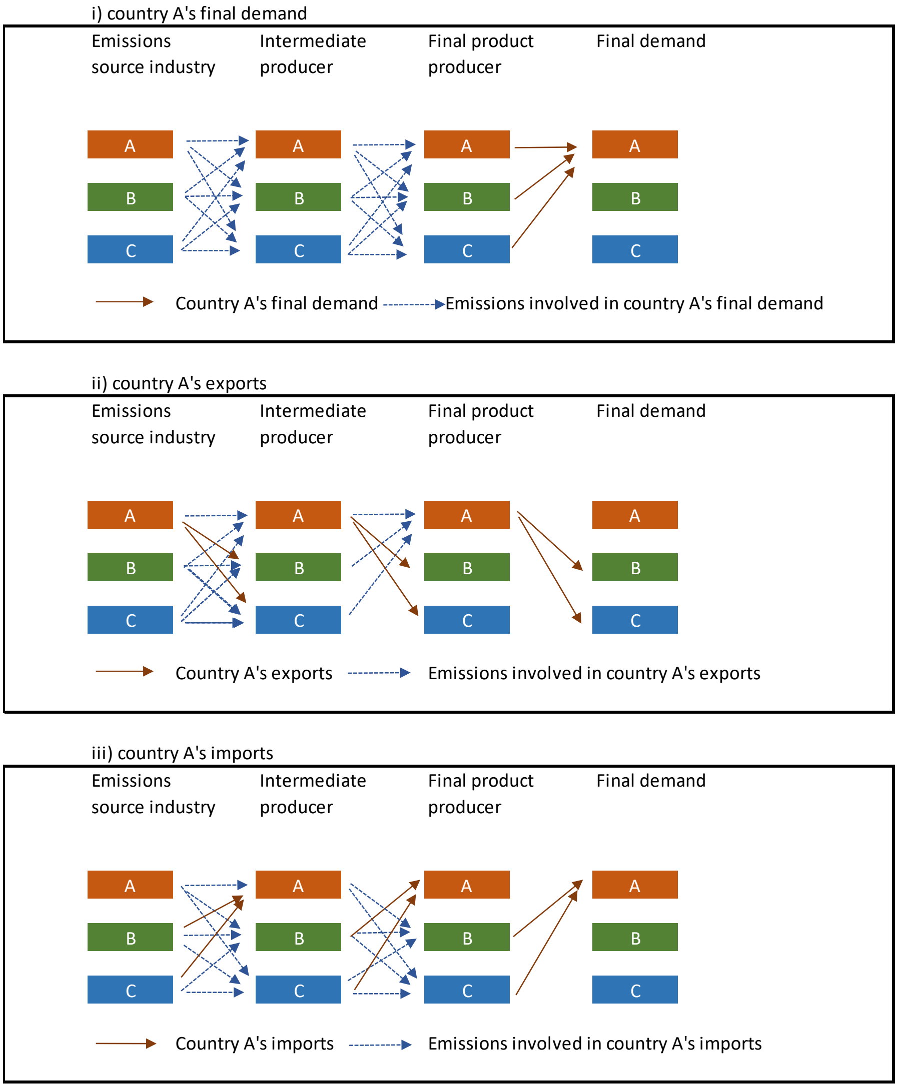
Note: *N* is number country and *K* is number of industry.

Table 3: CO_2 Emissions from fuel combustion

TI and TH	$1 \times N$	Territorial-based emissions where ti_i^r and th_i^r are the emissions calculated from the fuel purchases by industry *i* in country *r* by domestic and foreign industries and households respectively
DI	$(N * K) \times N$	Emissions allocated to fuel purchases by non-resident industries
DH	$(N * K) \times N$	Emissions allocated to fuel purchases by non-resident households
CFI	$1 \times (N * K)$	Fuel combustion by resident industries
EF	$1 \times (N * K)$	Emissions factor (emissions to output ratio), where $ef_i^r = cfi_i^r / x_i^r$ is the coefficient of CO_2 emissions from industry i's intermediate fuel consumption (cfi_i^r) to output (x_i^r) ratio in country *r*
CFH	$1 \times (N * K)$	Fuel combustion by resident households, where the element CFH_i^s shows emissions of fuel *i* consumption by household of country r

Note: N is number country and K is number of industry.

Figure 1: Emissions embodied in trade and final demand



2.1 Final demand-based emissions

Using the ICIO components (Table 2) and emissions variables (

Table 3), the emissions embodied in final demand of each country are estimated.

Output multiplier matrix (**B** in Table 2) of an ICIO system derives the domestic and foreign output of all upper stages by a unit final expenditure. The output vector generated in source country of all countries by final expenditure of country *s* is written as

$$\boldsymbol{X^{rs}} = \mathrm{B}\ \boldsymbol{Y^{s}}$$

where $\boldsymbol{X^{rs}}$ is the output of country *r* generated by final demand of country *s*.

The emissions embodied in the final demand of a country is, then, estimated by multiplying the emissions factor vector, output multiplier (Leontief inverse from ICIO system) and final demand vector of a target country. The relationship of territorial-base, production-based and demand-based emissions of country *s* are respectively written as:

- Territorial-based emissions: Industry (TI^s) and households (TH^s).
- Production-based emissions: $P^s = TI^s + \sum_s DI^{rs} - \sum_r DI^{rs}$;
- Emissions factor vector: $EF^s = (TI^s + \sum_s DI^{rs} - \sum_r DI^{rs})/X^s$
- Resident-based fuel combustion emissions at households:

$$HC^s = TH^s + \sum\nolimits_s DH^{rs} - \sum\nolimits_r DH^{rs}$$

- Emissions embodied in unit production (emissions multiplier):

$$\mathrm{eB} = \mathrm{diag}\ (\mathrm{EF})\ \mathrm{B}$$

- Production-based emissions: $C^{s\cdot} = EF^s * X^s + HC^s$
- Demand-based emissions: $C^{\cdot s} = \mathrm{eB}\ Y^{\cdot s} + HC^s$

Both, the estimation procedures of production-based emissions vectors ($\widehat{\mathrm{EF}}^r$ and HC^r) are described in next section. Demand-based emissions can be estimated using expanded matrix format for the efficient calculation as follows

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

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

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

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* i.e. fuel combusted in each industry in 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. $\boldsymbol{HC}$ denotes direct emissions by final demand e.g. combustions of fuels for motor vehicles by households and natural gas for residential use.

Demand-based emissions of country *s* are then calculated as the column sum of column *s* in matrix $\mathbf{CC}$ plus direct emissions from final demand HC^s. Similarly, production-based emission can be calculated as row sums of matrix $\mathbf{CC}$ (of size $NK \times N$) plus direct emissions from final demand HC^s. 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.

These calculations give the possibility of creating four-dimensional indicators relating emissions source industry and production of exports or final demand for each target year. The dimensions are

- Emitting country,
- Emitting industry,
- Final demand country and
- Final demand industry.

Thus, the world total emissions of demand-based and production-based emissions become equal.

$$\sum_r \sum_s \mathbf{cc}^{rs} + HCr = \sum_r \mathbf{EF}^r\, Xr + \mathrm{HCr}$$

where Xr is output of country *r*.

The production-based and final demand-based emissions are basis of the indicators presented in the OECD green growth indicators (OECD 2011; OECD 2014; OECD 2017). Carbon productivity indicators are defined from production-based and demand-based perspectives:

- *CO2 productivity (production-based)* calculated as real GDP generated per unit of CO2 emitted (USD/kg).
- *CO2 productivity (demand-based)* calculated as GDP generated per unit of CO_2 emitted from final demand (USD/kg).

2.2 Calculating emissions embodied in trade

Using the same emissions multiplier matrix of previous section, emissions embodied in the exports (imports) are estimated for trade flow as

$$C \;\; = \text{diag(EF) B } T$$

where C is vector of emissions source industry by country, EF is emissions factor vector, B is global Leontief inverse and T is a matrix of trade flows with element of bilateral trade flows. The example for the emissions embodied in exports of product 2 from country 1 to the rest of the world is written as

$$\begin{bmatrix} c_1^1 \\ c_1^2 \\ \vdots \\ c_K^N \end{bmatrix} = \widehat{\mathbf{EF}}\ \mathbf{B} \begin{bmatrix} 0 & 0 & \dots & 0 \\ 0 & t_2^{12} & \dots & t_2^{1,N} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 0 \end{bmatrix} \text{u}$$

where c_i^r is the emissions from industry *i* in country *r*, **EF** is global emissions factor vector, **B** is the global Leontief inverse (*NK* X *NK*), *N* is number country and *K* is number of industry, trade product *p* from country *r* to country *s* (import by *s*) is $t_p^{r,s}$ and u is an aggregation vector (row sum) with elements of 1 (*NK* x 1).

Then, the emissions embodied in imports of product K for country 2 is described as

$$\begin{bmatrix} c_1^1 \\ c_1^2 \\ \vdots \\ c_K^N \end{bmatrix} = \widehat{\mathbf{EF}}\ \mathbf{B} \begin{bmatrix} 0 & 0 & \dots & 0 \\ 0 & t_K^{12} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & t_K^{22} & \vdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & t_K^{N2} & \dots & 0 \end{bmatrix} \text{u}$$

where c_i^r is the vector of source CO_2 emissions by industry *i* in country *r* embodied in imported product K by country 2.

Using the same emissions factor and global Leontief structures, the emissions embodied in a specific country pair's gross trade flow can be estimated. The example of the emissions involved in the backward production stages of country 1's exports of product *K* to country 2 is

$$\begin{bmatrix} c_1^1 \\ c_1^2 \\ \vdots \\ c_K^N \end{bmatrix} = \widehat{\mathbf{EF}}\ \mathbf{B} \begin{bmatrix} 0 \\ t_K^{12} \\ \vdots \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

where c_i^r is the vector of source CO_2 emissions by industry *i* in country *r* embodied in imported product K by country 2 from country 1.

3. Estimation of CO_2 emissions factor

From the 2019 edition of OECD CO_2 emissions embodied in demand, the territorial-based emissions (fuel purchases in countries) and economic production-based emissions (fuel combusting entities) are more explicitly distinguished using detailed industry output databases from OECD ICIO system. The latest OECD ICIO system has 36 industries (Annex B).

3.1 Territorial-based emissions

Following the earlier versions of OECD demand-based emissions databases, the emissions from IEA CO2 emissions from fuel combustions database (IEA-CO2) remains as the main data source for territorial-based emissions. The detailed emissions by fuel product and by flow (fuel combusting sectors) for 140 individual countries and rest of the world are annually reported.[2]

In the latest edition of IEA-CO2, there are unique 34 flows (combustion sectors) and 46 fuel products for 137 individual economies that matches the target economies of the OECD ICIO database. To avoid the rounding errors and unreported detailed information, the original data are rescaled to the world total and national total emissions. The rescaling procedure takes following two steps:

i) World total emissions

$$CF_R^* = CF_W - \sum_c CF_c$$

ii) Country total emissions by fuel product and by flow

$$CF_{c,p,f}^* = CF_c^* \frac{CF_{c,p,f}}{\sum_p \sum_f CF_{c,p,f}}$$

where CF_c is CO_2 emissions from fuel combustion for country c's total emissions, CF_W is world total emissions, CF_R is rest of the world emissions (rest of 137 countries) and $CF_{c,p,f}$ is country c's emissions for fuel product *p* and flow *f*. * indicates rescaled result.

[2] IEA CO2 Emissions from Fuel Combustion (2018 edition), https://www.iea.org//statistics/

Table 4: Fuel products and flows (sectors) in IEA CO2 from fuel combustion database

CODE	PRODUCT
HARDCOAL	Hard coal (if no detail)
BROWN	Brown coal (if no detail)
ANTCOAL	Anthracite
COKCOAL	Coking coal
BITCOAL	Other bituminous coal
SUBCOAL	Sub-bituminous coal
LIGNITE	Lignite
PATFUEL	Patent fuel
OVENCOKE	Coke oven coke
GASCOKE	Gas coke
COALTAR	Coal tar
BKB	BKB
GASWKSGS	Gas works gas
COKEOVGS	Coke oven gas
BLFURGS	Blast furnace gas
OGASES	Other recovered gases
PEAT	Peat
PEATPROD	Peat products
OILSHALE	Oil shale
NATGAS	Natural gas
CRNGFEED	Crude/NGL/feedstocks (if no detail)
CRUDEOIL	Crude oil
NGL	Natural gas liquids
REFFEEDS	Refinery feedstocks
ADDITIVE	Additives/blending components
ORIMUL	Orimulsion
NONCRUDE	Other hydrocarbons
REFINGAS	Refinery gas
ETHANE	Ethane
LPG	Liquefied petroleum gases (LPG)
NONBIOGASO	Motor gasoline excl. biofuels
AVGAS	Aviation gasoline
JETGAS	Gasoline type jet fuel
NONBIOJETK	Kerosene type jet fuel excl. biofuels
OTHKERO	Other kerosene
NONBIODIES	Gas/diesel oil excl. biofuels
RESFUEL	Fuel oil
NAPHTHA	Naphtha
WHITESP	White spirit & SBP
LUBRIC	Lubricants
BITUMEN	Bitumen
PARWAX	Paraffin waxes
PETCOKE	Petroleum coke
ONONSPEC	Non-specified oil products
INDWASTE	Industrial waste
MUNWASTEN	Municipal waste (non-renew)
TOTAL*	Total

	CODE	FLOW
*	MAINPROD	Main activity electricity and heat production
	MAINELEC	Main activity electricity plants
	MAINCHP	Main activity CHP plants
	MAINHEAT	Main activity heat plants
	EPOWERPLT	"Own use in electricity, CHP and heat plants"
*	AUTOPROD	Unallocated autoproducers
	AUTOELEC	Autoproducer electricity plants
	AUTOCHP	Autoproducer CHP plants
	AUTOHEAT	Autoproducer heat plants
	OTHEN	Other energy industry own use
*	TOTIND	Manufacturing industries and construction
	IRONSTL	Iron and steel
	CHEMICAL	Chemical and petrochemical
	NONFERR	Non-ferrous metals
	NONMET	Non-metallic minerals
	TRANSEQ	Transport equipment
	MACHINE	Machinery
	MINING	Mining and quarrying
	FOODPRO	Food and tobacco
	PAPERPRO	"Paper, pulp and printing"
	WOODPRO	Wood and wood products
	CONSTRUC	Construction
	TEXTILES	Textile and leather
	INONSPEC	Non-specified industry
*	TOTTRANS	Transport
	ROAD	Road
	DOMESAIR	Domestic aviation
	RAIL	Rail
	PIPELINE	Pipeline transport
	DOMESNAV	Domestic navigation
	TRNONSPE	Non-specified transport
	RESIDENT	Residential
	COMMPUB	Commercial and public services
	AGRICULT	Agriculture/forestry
	FISHING	Fishing
	ONONSPEC	Non-specified other
	MARBUNK	Memo: International marine bunkers
	AVBUNK	Memo: International aviation bunkers
*	CO2FCOMB	CO2 Fuel combustion

* subtotals not used in rescaling balancing procedure

3.2 Economic output (production)-based emissions

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*. Out of total 34 flows in the IEA-CO2 database, 11 flows have "one-to-many" relationship with the ICIO industry list (Table 5). These aggregate flows should be allocated to corresponding sectors to estimate the complete emissions factor. The rest of the flows in IEA-CO2 database is fully compatible with specific individual industry in OECD system.

Table 5: Concordance between CO2 flows and OECD ICIO industry classification

	IEA CF flow	Flow	ICIO industry
	MAINELEC	Main activity electricity plants	D35T39
	MAINCHP	Main activity CHP plants	
	MAINHEAT	Main activity heat plants	
	EPOWERPLT	"Own use in electricity, CHP and heat plants"	
*	AUTOELEC	Autoproducer electricity plants	
*	AUTOCHP	Autoproducer CHP plants	
*	AUTOHEAT	Autoproducer heat plants	
*	OTHEN	Other energy industry own use	
	IRONSTL	Iron and steel	D24
*	CHEMICAL	Chemical and petrochemical	D19, D20T21
	NONFERR	Non-ferrous metals	D24
	NONMET	Non-metallic minerals	D23
*	TRANSEQ	Transport equipment	D29, D30
*	MACHINE	Machinery	D26,D27,D28
*	MINING	Mining and quarrying	D05T06,D07T08
	FOODPRO	Food and tobacco	D10T12
	PAPERPRO	Paper, pulp and printing	D17T18
	WOODPRO	Wood and wood products	D16
	CONSTRUC	Construction	D41T43
	TEXTILES	Textile and leather	D13T15
	INONSPEC	Non-specified industry	D10T31
*	ROAD	Road	all sectors
	DOMESAIR	Domestic aviation	D49T53
	RAIL	Rail	
	PIPELINE	Pipeline transport	
	DOMESNAV	Domestic navigation	
	TRNONSPE	Non-specified transport	
	RESIDENT	Residential	Households
*	COMMPUB	Commercial and public services	services ex. Transp.
	AGRICULT	Agriculture/forestry	D01T03
	FISHING	Fishing	
*	ONONSPEC	Non-specified other	
	MARBUNK	Memo: International marine bunkers	Domestic and foreign D49T53
	AVBUNK	Memo: International aviation bunkers	

Note: * indicates "one-to-many" correspondence

Autoproducer of electricity and other energy industries

The difference between main Activity and autoproducer of electricity and other energy sources is defined as:[3] “Main Activity supply undertakings generate electricity and/or heat for sale to third parties, as their primary activity whereas autoproducer undertakings generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity.”

The main industries those use the energy input to generate electricity and heat are commodity type manufacturing industries.[4] There four aggregate flows in IEA-CO2: Autoproducer electricity plants, autoproducer CHP plants, autoproducer heat plants, and Other energy industry own use. The largest auto producer industries are steel producers from coal related gases (coking coal, other bitumen coal and blast furnace gas) . Coal fuel products of these autoproducers are allocated to steel industry (ISIC4-241) and other type of fuel combustion by these autoproducers are allocated to based on the fuel combustion by other material manufacturing industries.

Transportation

- Road

The emissions for road transportation in IEA-CO2 includes the emissions from fuel combustion from all industries and household in one flow. It is required to separate this number to fuel combusting industries and households for the economic output-based emissions calculation.

The consumption patterns of gasoline and diesel fuels by industries and households are available from the detailed input-output tables for few countries (Australia, Brazil, Canada, Japan and Korea). The emissions from road transportation activities are allocated by the sales shares of gasoline and diesel fuel to resident industries and households for these countries.

For the rest of the countries those do not provide sufficient details of fuel products transactions, the share of gasoline and diesel (light oil) to total petroleum products share for each industry are applied (Table 6).

$$ER^{s} = CFR \frac{Z(D19,s)xREFroad\_D19(s)}{\sum_{s}(Z(D19,s)xREFroad\_D19(s))}$$

where *CFR* is the reported emissions from fuel combustion for road transportation,

z(D19,i) is petroleum consumption by industry and household *s* from balanced use table of the 2018 OECD ICIO system, REFroad_D19(s) is the road transportation fuel to total petroleum input by sector *s* from reference countries.

[3] https://www.iea.org/statistics/resources/questionnaires/faq/#three

[4] The Federation of Electric Power Companies of Japan, Electricity Statistics Information, http://www5.fepc.or.jp/tok-bin-eng/kensaku.cgi

Table 6: Examples of detailed level input-output table for fuel combustion by industries and household

A: Japan 2014 (trillion JPY)

	Agriculture (D01)	…	Land transport (D49)	…	Public administration (D84)	Household consumption	total intermediate and household use
Gasoline	61		28		36	4,976	7,489
Diesel/light oils	111		1,273		18	311	4,202
Other petroleum products	80		990		28	1,644	12,809
Total use of petroleum produc	252		2,291		82	6,932	24,500
Road transport fuel / total petroleum use by industry	68%		57%		65%	76%	48%
Road emissions users	1%		11%		0%	45%	100%

Source: METI, Extended I-O table

B: Canada 2013 (million CAD)

	Agriculture (D01)	…	Land transport (D49)	…	Public administration (D84)	Household consumption	total intermediate and household use
Gasoline	1,225		499		1,257	42,791	111,935
Diesel/light oils	1,595		12,259		1,115	892	33,768
Other petroleum products	207		270		841	3,939	50,375
Total use of petroleum produc	3,027		13,029		3,213	47,621	196,079
Road transport fuel / total petroleum use by industry	93%		98%		74%	92%	74%
Road emissions users	2%		9%		2%	30%	100%

Source: StatCan, Use table

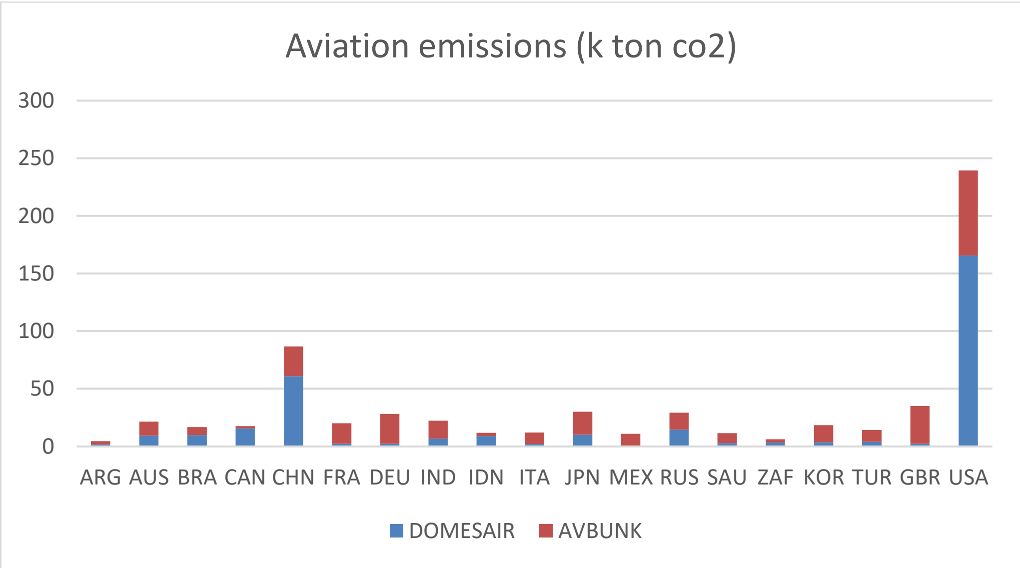
Converting the territorial emissions to resident production-based emissions are adjusted by the direct purchases abroad and direct purchases by non-resident expenditures of gasoline and diesel in balance of payment travel, national accounts household consumption expenditures and detailed input-output / supply use tables.

If the detailed fuel purchase information by non-residents are not available, the underlying balanced data for direct purchases of OECD ICIO system is used to allocate the non-residents expenditures.

- International aviation bunkers

Emissions from international aviation bunkers account for most of emissions from aviation industry for geographically smaller countries (Figure 2). In the geographically larger economies e.g. United States, Canada, China and Brazil, the share of fuel purchased by foreign air transportation operators are separated by scheduled routes from flightstat database (Table 7). Combining the airline nationality and airports location data with the scheduled routes data, the routes data are reorganized by airline nationality, departure country and destination country.

Figure 2: Emissions from domestic and international aviation fuel combustion



Source: IEA (2018) CO_2 emissions from fuel combustion

https://developer.flightstats.com/api-docs/historical-flight-status/v3

Table 7: Collected flight information

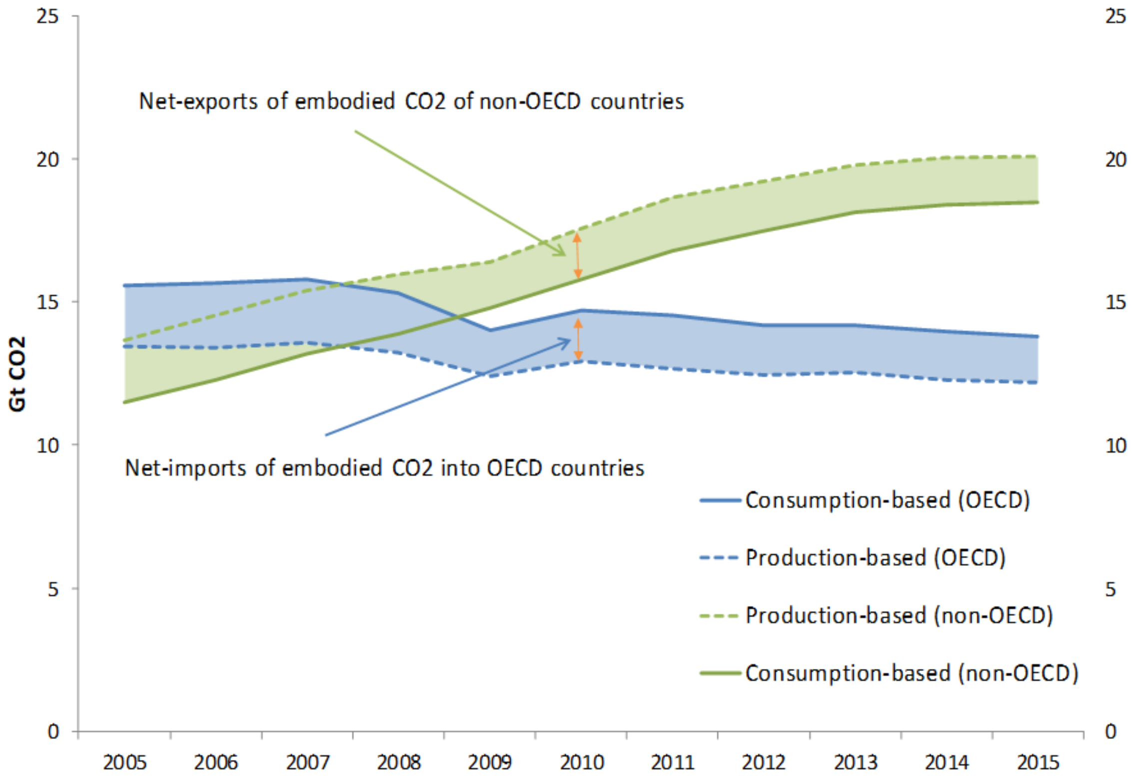
	No. of observation	Country/Nationality
Airports	12348	225
Airlines	6062	205
Flight routes	66178	

4. Result

Drawing on the production-based and consumption-based emissions of this study,

Figure 3 compares aggregate OECD and aggregate non-OECD production-based emissions, where CO_2 is allocated to the location in which the goods or services are produced; and, consumption-based emissions i.e. where CO_2 is allocated to the locations in which consumption occurs. Net imports of CO_2 emissions from fuel combustion by OECD countries from non-OECD countries are estimated to have fallen from 2.1 to 1.6 Gigatonnes (Gt) between 2005 and 2015.

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



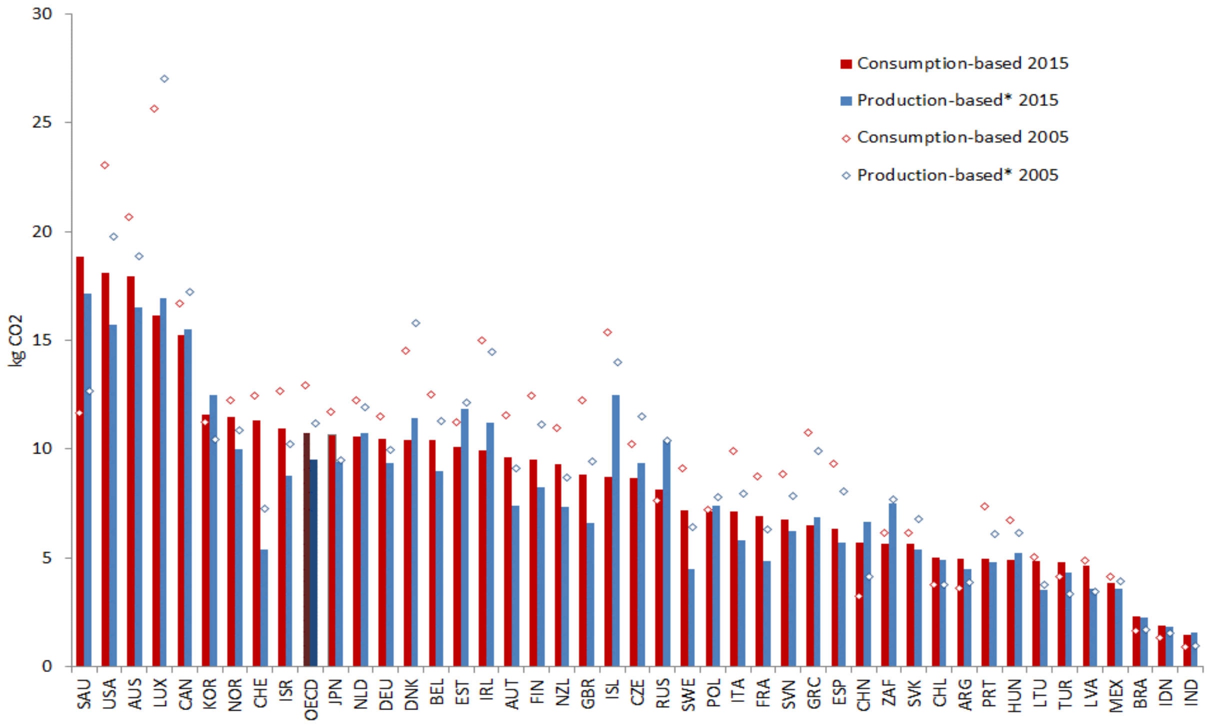
Source: Estimation based on OECD's Inter-Country Input-Output (ICIO) Database (2018) and IEA (2018)

Figure 4 examines production-based and consumption-based CO_2 emissions *per capita*, based on fuel combustion. One encouraging feature of this chart is the decline over the period 2005-2015. CO_2 emissions embodied in goods and services cross border imports for most countries are generally decreasing particularly for Asian economies while the export intensities of some countries are stable (e.g. Canada) or slightly increased (e.g. Japan). The main reasons for decreases in the CO_2 intensity in the imported products are due to the decreased carbon intensity in the exported products from China and other emerging economies (Figure 6).

Figure 5, complementing

Figure 3, presents the share of CO_2 emitted abroad, sourced from OECD and non-OECD regions, embodied in final demand. The data reveal that the overall decline in the imports of CO_2 did not happen in a uniform way; some countries, intentionally or not, are still following a strategy that outsources emissions.

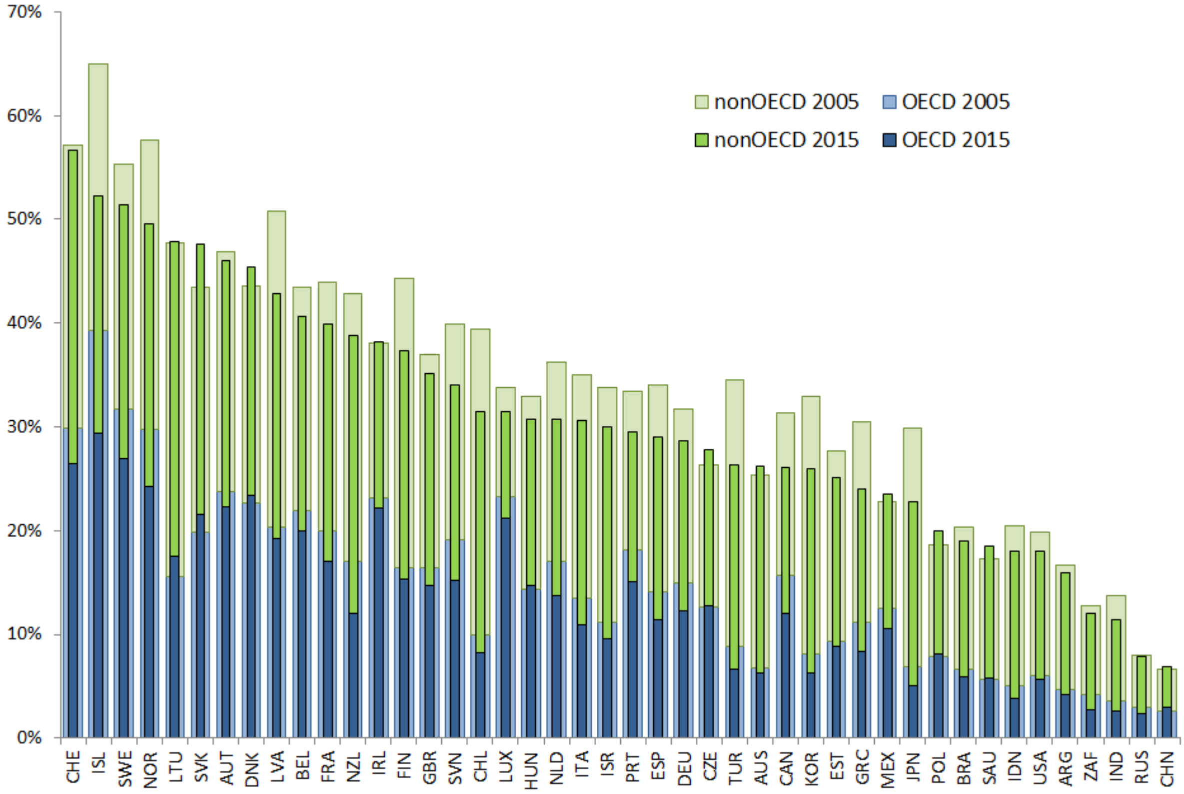
Figure 4. **Per capita CO_2 emissions from fuel combustion**



Source: Estimation based on OECD (2019) CO2 emissions embodied in international trade and final demand and UN Population prospects (2017)

CO_2 emissions embodied in goods and services cross border imports for most countries are generally decreasing particularly for Asian economies while the export intensities of some countries are stable (e.g. Canada) or slightly increased (e.g. Japan). The main reasons for decreases in the CO2 intensity in the imported products are due to the decreased carbon intensity in the exported products from China and other emerging economies (Figure 6).

Figure 5: Share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand

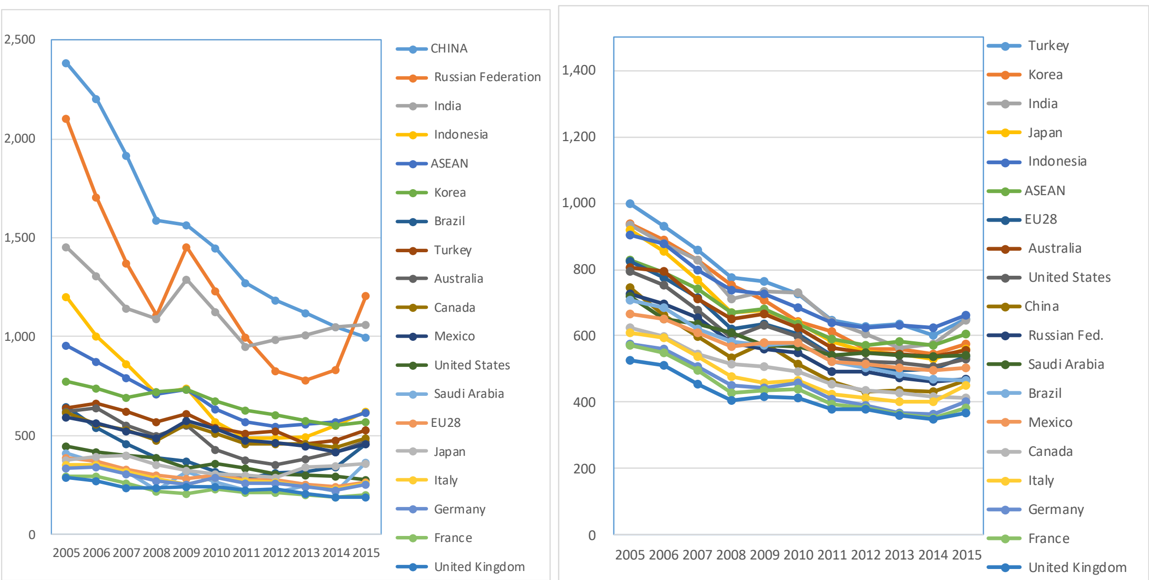


Source: OECD (2019) CO2 emissions embodied in international trade and final demand

Figure 6: CO_2 intensity in exports and imports (selected economies for 2005 to 2015, tonne CO_2 / USD)

Panel A: CO_2 intensity in exports

Panel B: CO_2 intensity gross imports



Source: OECD (2019) CO_2 emissions embodied in international trade and final demand

5. Summary

To obtain the latest estimation of CO_2 emissions from fuel combustion, embodied in final demand and international gross trade, for 65 economies in the period from 2005 to 2015, this paper makes full use of the data availability; in doing so, it presents novelties in relation to previous estimation, which, in our believe, allows for better and improved results.

On the databases work, the novelties are mainly related to the allocation of emissions to industries, and to residents and non-residents: a) from the productive structure and demand side, we have made use of the underlining ICIO system of Inter-Country Use Tables, (ICUT), which considers 198 economies with details for 75 products and 75 industries; b) from the CO_2 fuel combustion emissions side we have made full use of the IEA database, considering the 138 countries which match the countries in the ICUT database, and also considering emissions of international bunker fuels. From the use of this more detailed information is was possible to better allocate emissions to road transportation and filling the gaps to estimate territorial emissions. The revised production-based emissions are now fully compatible (in principle) with the national accounts framework (SEEA) by adjusting non-resident households and non-resident transportation operators (road, aviation and marine). The resulting allocation of emissions to the more detailed set of industries and countries were then aggregate to match the 36 industries and 65 economies considered in the ICIO system, which was then used to estimate CO_2 emissions, from fuel combustion, embodied in final demand and international gross trade. These series of indicators on gross exports and final demand now includes bilateral and industrial dimensions.

The distinction between production-based and consumption-based emissions is directly relevant for on-going policy discussions. Recognizing that developed countries were principally responsible for the high levels of GHGs in the atmosphere at the time of signing of the Kyoto Protocol in 1997, the Protocol placed a heavier burden on developed nations under the principle of "common but differentiated responsibilities." (See Rose et al., 1998; Ringius et al., 2002). This language has spawned a lively debate about what constitutes a “fair” allocation of rights to emit GHGs and the burden associated with its mitigation, and such debates have informed subsequent negotiations at meetings of the Conference of the Parties (COPs).

Even if consumption-based emissions accounting is not considered to be appropriate for the allocation of rights and burdens, it can be helpful to better understand the forces that are driving trends and patterns in global emission levels. Indeed, a comparison of disaggregated production-based and consumption-based measures of emissions is arguably the most appropriate means to assess the importance of carbon leakage in a world of heterogeneous climate policy settings. Countries with ambitious climate mitigation targets may achieve decoupling of production-based emissions from economic growth by offshoring domestic production abroad, with some of the emissions coming home through the “back door” in the form of carbon-intensive imports (Weber and Peters, 2009).

The next steps to be follow in this work will be related to the inclusion of other Greenhouse Gas Emissions (GHG) in the estimation and also to make a more complete integration with the Air Emissions Accounts.

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UNFCC_GHG: UNFCCC, GHG data from UNFCCC
https://unfccc.int/process-and-meetings/transparency-and-reporting/greenhouse-gas-data/ghg-data-unfccc/ghg-data-from-unfccc

SEEA-AEA: System of Environmental Economic Account
EUROSTAT Air emissions accounts
https://ec.europa.eu/eurostat/web/environment/emissions-of-greenhouse-gases-and-air-pollutants/air-emissions-accounts

OECD Air emissions accounts
https://stats.oecd.org/Index.aspx?QueryId=72560

Annex A: ICIO 2018 Country Coverage

	Code	Country		Code	Country
1	AUS	Australia	37	ARG	Argentina
2	AUT	Austria	38	BRA	Brazil
3	BEL	Belgium	39	BRN	Brunei Darussalam
4	CAN	Canada	40	BGR	Bulgaria
5	CHL	Chile	41	KHM	Cambodia
6	CZE	Czech Republic	42	CHN	China (People's Republic of)
7	DNK	Denmark	43	COL	Colombia
8	EST	Estonia	44	CRI	Costa Rica
9	FIN	Finland	45	HRV	Croatia
10	FRA	France	46	CYP	Cyprus
11	DEU	Germany	47	IND	India
12	GRC	Greece	48	IDN	Indonesia
13	HUN	Hungary	49	HKG	Hong Kong, China
14	ISL	Iceland	50	KAZ	Kazakhstan
15	IRL	Ireland	51	MYS	Malaysia
16	ISR	Israel	52	MLT	Malta
17	ITA	Italy	53	MAR	Morocco
18	JPN	Japan	54	PER	Peru
19	KOR	Korea	55	PHL	Philippines
20	LVA	Latvia	56	ROU	Romania
21	LTU	Lithuania	57	RUS	Russian Federation
22	LUX	Luxembourg	58	SAU	Saudi Arabia
23	MEX	Mexico	59	SGP	Singapore
24	NLD	Netherlands	60	ZAF	South Africa
25	NZL	New Zealand	61	TWN	Chinese Taipei
26	NOR	Norway	62	THA	Thailand
27	POL	Poland	63	TUN	Tunisia
28	PRT	Portugal	64	VNM	Viet Nam
29	SVK	Slovak Republic	65	ROW	Rest of the World
30	SVN	Slovenia			
31	ESP	Spain			
32	SWE	Sweden			
33	CHE	Switzerland			
34	TUR	Turkey			
35	GBR	United Kingdom			
36	USA	United States			

Annex B: ICIO 2018 Industry

N.	Code	Industry	ISIC Rev.4
1	D01T03	Agriculture, hunting, forestry and fishing	01, 02, 03
2	D05T06	Mining and extraction of energy producing products	05, 06
3	D07T08	Mining and quarrying of non-energy producing products	07, 08
4	D09	Services to mining and quarrying	09
5	D10T12	Food products, beverages and tobacco	10, 11, 12
6	D13T15	Textiles, textile products, leather and footwear	13, 14, 15
7	D16	Wood and products of wood and cork	16
8	D17T18	Paper products and printing	17, 18
9	D19	Coke and refined petroleum products	19
10	D20T21	Chemicals and chemical products	20, 21
11	D22	Rubber and plastics products	22
12	D23	Other non-metallic mineral products	23
13	D24	Basic metals	24
14	D25	Fabricated metal products	25
15	D26	Computer, electronic and optical equipment	26
16	D27	Electrical machinery and apparatus, nec	27
17	D28	Machinery and equipment, nec	28
18	D29	Motor vehicles, trailers and semi-trailers	29
19	D30	Other transport equipment	30
20	D31T33	Manufacturing nec; repair of machinery and equipment	31, 32, 33
21	D35T39	Electricity, gas, water supply, sewerage, waste and remediation services	35,36, 37, 38, 39
22	D41T43	Construction	41, 42, 43
23	D45T47	Wholesale and retail trade; repair of motor vehicles	45, 46, 47
24	D49T53	Transportation and storage	49, 50, 51, 52, 53
25	D55T56	Accommodation and food services	55, 56
26	D58T60	Publishing, audiovisual and broadcasting activities	58, 59, 60
27	D61	Telecommunications	61
28	D62T63	IT and other information services	62, 63
29	D64T66	Financial and insurance activities	64, 65, 66
30	D68	Real estate activities	68
31	D69T82	Other business sector services	69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82
32	D84	Public admin. and defence; compulsory social security	84
33	D85	Education	85
34	D86T88	Health and social work	86, 87, 88
35	D90T96	Other community, social and personal services	90, 91, 92, 93,94,95, 96
36	D97T98	Private households with employed persons	97, 98

ISIC Rev. 4 codes https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

Annex C : Indicators available online (http://oe.cd/io-co2)

Core indicators
FD_CO2: CO2 emissions embodied in domestic final demand, by source country and industry
PROD_CO2: CO2 emissions based on domestic production
EXGR_TCO2: Total CO2 emissions embodied in gross exports
IMGR_TCO2: Total CO2 emissions embodied in gross imports
FD_PCCO2: CO2 emissions embodied in domestic final demand per capita
PROD_PCCO2: CO2 emissions per capita based on domestic production
EXGR_TCO2int: Intensity of CO2 emissions embodied in total gross exports
IMGR_TCO2int: Intensity of CO2 emissions embodied in gross imports

Additional indicators
BALCO2_FD: CO2 embodied in final demand, balance
FFD_DCO2: Domestic CO2 emissions embodied in foreign final demand
DFD_FCO2: Foreign CO2 emissions embodied in domestic final demand
FD_CO2_SH: CO2 emissions embodied in domestic final demand, shares by country and industry of origin (emitter)
FFD_DCO2pSH: Domestic CO2 emissions embodied in foreign final demand, partner shares
DFD_FCO2pSH: Foreign CO2 emissions embodied in domestic final demand, partner shares
EXGR_DCO2: Domestic CO2 emissions embodied in gross exports
EXGR_DCO2pSH: Domestic CO2 emissions embodied in gross exports, partner shares
EXGR_FCO2: Foreign CO2 emissions embodied in gross exports
EXGR_FCO2pSH: Foreign CO2 emissions embodied in gross exports, partner shares
EXGR_TCO2pSH: Total CO2 emissions embodied in gross exports, partner shares
EXGR_INTDCO2: Domestic CO2 emissions embodied in gross exports of intermediate products
EXGR_INTDCO2pSH: Domestic CO2 emissions embodied in gross exports of intermediate products, partner shares
EXGR_INTFCO2: Foreign CO2 emissions embodied in gross exports of intermediate products
EXGR_INTFCO2pSH: Foreign CO2 emissions embodied in gross exports of intermediate products, partner shares
EXGR_INTTCO2: Total CO2 emissions embodied in gross exports of intermediate products
EXGR_INTTCO2pSH: Total CO2 emissions embodied in gross exports of intermediate products, partner shares
EXGR_INTTCO2int: Intensity of CO2 emissions embodied in total gross exports of intermediate products
EXGR_FNLDCO2: Domestic CO2 emissions embodied in gross exports of final products
EXGR_FNLDCO2pSH: Domestic CO2 emissions embodied in gross exports of final products, partner shares
EXGR_FNLFCO2: Foreign CO2 emissions embodied in gross exports of final products
EXGR_FNLFCO2pSH: Foreign CO2 emissions embodied in gross exports of final products, partner shares
EXGR_FNLTCO2: Total CO2 emissions embodied in gross exports of final products
EXGR_FNLTCO2pSH: Total CO2 emissions embodied in gross exports of final products, partner shares
EXGR_FNLTCO2int: Intensity of CO2 emissions embodied in total gross exports of final products
IMGR_DCO2: Domestic CO2 emissions embodied in gross imports
IMGR_DCO2SH: Domestic CO2 emissions share of gross imports
IMGR_FCO2: Foreign CO2 emissions embodied in gross imports
BALCO2_GR: CO2 embodied in gross exports, balance
Note: Definitions of each indicators are available at metadata section of
https://stats.oecd.org/Index.aspx?DataSetCode=IO_GHG_2019

Annex D: Production and consumption-based emissions (2005 and 2015)

	Production-based		Consumption-based		Production-based emissions per capita		Consumption-based emissions per capita	
	2005	2015	2005	2015	2005	2005	2015	2015
	(mton CO2)				(Kilograms per capita, Thousands)			
OECD member	13,424.7	12,204.2	15,563.1	13,781.2	11.2	9.5	13.0	10.8
Australia	382.1	392.5	418.4	426.4	18.9	16.5	20.7	17.9
Austria	75.3	64.3	95.3	83.4	9.1	7.4	11.5	9.6
Belgium	118.9	101.3	131.7	117.8	11.3	9.0	12.5	10.4
Canada	555.4	556.4	539.8	547.9	17.2	15.5	16.7	15.2
Chile	61.3	86.7	61.1	89.2	3.8	4.9	3.8	5.0
Czech Republic	118.3	99.3	104.7	91.8	11.5	9.4	10.2	8.7
Denmark	85.7	64.9	78.7	59.4	15.8	11.4	14.5	10.4
Estonia	16.5	15.6	15.2	13.3	12.2	11.9	11.2	10.1
Finland	58.5	45.2	65.4	52.3	11.1	8.3	12.4	9.5
France	385.4	311.9	536.2	445.0	6.3	4.8	8.8	6.9
Germany	814.1	765.7	940.2	853.4	10.0	9.4	11.5	10.4
Greece	112.3	76.9	121.6	73.0	9.9	6.9	10.8	6.5
Hungary	62.3	50.9	68.1	48.3	6.2	5.2	6.8	4.9
Iceland	4.1	4.1	4.5	2.9	14.0	12.5	15.4	8.7
Ireland	60.9	52.8	63.3	46.7	14.5	11.2	15.0	9.9
Israel	67.7	71.0	83.8	88.3	10.2	8.8	12.7	10.9
Italy	466.7	346.8	584.5	423.0	7.9	5.8	9.9	7.1
Japan	1,220.8	1,202.3	1,502.0	1,361.0	9.5	9.4	11.7	10.6
Korea	509.6	632.5	546.9	584.8	10.5	12.5	11.2	11.6
Latvia	7.8	7.1	10.9	9.2	3.5	3.6	4.9	4.6
Lithuania	12.6	10.3	16.8	14.2	3.8	3.5	5.0	4.8
Luxembourg	12.4	9.6	11.7	9.1	27.1	16.9	25.6	16.1
Mexico	423.6	453.0	449.4	485.5	3.9	3.6	4.1	3.9
Netherlands	195.6	181.7	200.8	179.2	12.0	10.7	12.3	10.6
New Zealand	35.9	33.9	45.5	42.8	8.7	7.4	11.0	9.3
Norway	50.3	52.0	56.6	59.6	10.9	10.0	12.2	11.5
Poland	298.7	283.7	276.6	273.8	7.8	7.4	7.2	7.2
Portugal	64.6	50.1	77.9	51.7	6.1	4.8	7.4	5.0
Slovak Republic	36.7	29.2	33.1	30.6	6.8	5.4	6.1	5.6
Slovenia	15.7	12.9	17.7	14.0	7.8	6.2	8.9	6.7
Spain	354.0	263.3	411.7	293.8	8.0	5.7	9.3	6.3
Sweden	57.8	43.8	82.7	70.2	6.4	4.5	9.1	7.2
Switzerland	53.7	44.9	92.4	94.2	7.2	5.4	12.5	11.3
Turkey	227.1	336.9	281.6	374.9	3.3	4.3	4.1	4.8
United Kingdom	569.1	430.8	737.4	575.8	9.4	6.6	12.2	8.8
United States	5,833.6	5,020.0	6,798.8	5,794.5	19.8	15.7	23.0	18.1
Non-OECD	13,644.9	20,071.8	11,506.5	18,494.8	2.6	3.3	2.2	3.0
Argentina	152.3	195.0	141.2	216.0	3.9	4.5	3.6	5.0
Brazil	321.1	461.2	312.8	475.4	1.7	2.2	1.7	2.3
Brunei Darussalam	5.2	6.7	4.1	6.4	14.1	16.1	11.2	15.3
Bulgaria	47.1	43.6	39.3	34.8	6.1	6.1	5.1	4.8
Cambodia	3.0	8.8	6.2	12.6	0.2	0.6	0.5	0.8
China (People's Republic of)	5,478.1	9,280.8	4,261.0	7,977.9	4.1	6.6	3.2	5.7
Colombia	56.5	82.8	63.6	97.4	1.3	1.7	1.5	2.0
Costa Rica	6.2	8.0	9.0	13.5	1.5	1.7	2.1	2.8
Croatia	19.3	15.3	24.4	17.1	4.4	3.6	5.6	4.0
Cyprus	10.4	7.3	10.9	7.9	10.1	6.3	10.6	6.8
Hong Kong, China	59.4	70.4	71.8	104.3	8.7	9.7	10.5	14.4
India	1,081.1	2,043.4	1,021.7	1,918.8	0.9	1.6	0.9	1.5
Indonesia	343.7	479.4	304.4	484.6	1.5	1.9	1.3	1.9
Kazakhstan	157.9	226.5	101.2	180.2	10.2	12.8	6.5	10.2
Malaysia	170.1	238.4	123.6	209.5	6.6	7.8	4.8	6.8
Malta	3.6	3.1	3.0	2.6	8.8	7.3	7.3	6.1
Morocco	42.6	59.2	46.5	66.6	1.4	1.7	1.5	1.9
Peru	28.7	49.2	31.3	63.6	1.0	1.6	1.1	2.0
Philippines	76.6	110.8	79.3	135.2	0.9	1.1	0.9	1.3
Romania	93.2	71.0	87.7	72.5	4.3	3.6	4.1	3.6
Russian Federation	1,495.8	1,487.6	1,099.2	1,167.5	10.4	10.3	7.7	8.1
Saudi Arabia	303.4	541.4	279.2	595.1	12.7	17.2	11.7	18.9
Singapore	73.4	122.4	51.0	70.5	16.4	22.1	11.3	12.7
South Africa	375.6	414.5	300.6	313.5	7.7	7.5	6.2	5.7
Chinese Taipei	269.4	268.2	235.1	210.9	11.9	11.4	10.4	9.0
Thailand	213.5	267.7	196.8	235.4	3.3	3.9	3.0	3.4
Tunisia	21.5	27.5	21.6	29.1	2.1	2.4	2.1	2.6
Viet Nam	82.1	173.3	78.2	152.5	1.0	1.9	0.9	1.6
Rest of the World	2,654.0	3,308.3	2,502.0	3,623.5	1.5	1.6	1.4	1.7

Annex E: Emissions embodied in gross exports and imports

		Total CO2 in exports		Total CO2 in imports	
		2005	2015	2005	2015
		mton CO2	mton CO2	mton CO2	mton CO2
Australia	TOTAL	83.35	110.41	119.44	143.74
	of which, Manuf.	34.77	41.12	86.16	110.24
	of which, Services	23.71	23.06	22.67	28.36
Austria	TOTAL	45.06	46.77	65.08	66.25
	of which, Manuf.	33.04	35.63	39.75	39.32
	of which, Services	9.43	9.27	14.61	16.34
Belgium	TOTAL	75.41	70.60	87.83	86.55
	of which, Manuf.	48.81	43.83	57.16	50.64
	of which, Services	20.17	24.06	20.25	26.09
Canada	TOTAL	241.93	218.81	225.68	208.96
	of which, Manuf.	135.97	112.08	164.38	156.07
	of which, Services	39.46	30.24	38.57	34.92
Chile	TOTAL	31.60	35.48	31.51	38.01
	of which, Manuf.	9.19	9.21	20.91	30.19
	of which, Services	10.24	5.98	5.13	5.15
Czech Republic	TOTAL	60.26	62.08	46.94	54.80
	of which, Manuf.	45.30	44.10	32.64	39.73
	of which, Services	9.08	9.76	6.07	6.93
Denmark	TOTAL	60.06	57.07	52.97	51.46
	of which, Manuf.	13.78	10.51	25.85	21.33
	of which, Services	42.22	43.16	24.82	26.64
Estonia	TOTAL	7.50	8.70	6.23	6.38
	of which, Manuf.	3.61	4.14	3.91	4.29
	of which, Services	2.78	2.99	1.43	1.44
Finland	TOTAL	39.08	25.03	46.02	32.00
	of which, Manuf.	33.20	19.55	30.62	19.70
	of which, Services	4.77	4.50	8.17	7.34
France	TOTAL	157.30	129.70	306.66	261.31
	of which, Manuf.	112.37	87.29	198.73	169.04
	of which, Services	35.56	34.12	70.86	64.33
Germany	TOTAL	290.29	322.42	413.05	407.03
	of which, Manuf.	239.09	252.30	265.96	275.21
	of which, Services	41.52	55.43	84.63	81.43
Greece	TOTAL	34.43	31.16	44.28	27.57
	of which, Manuf.	10.34	12.81	28.50	15.79
	of which, Services	23.09	17.52	8.84	4.82
Hungary	TOTAL	35.53	37.23	41.50	34.73
	of which, Manuf.	26.30	23.51	30.61	25.07
	of which, Services	7.44	11.00	5.57	5.21
Iceland	TOTAL	3.32	3.84	3.67	2.54
	of which, Manuf.	1.13	1.36	2.19	1.52
	of which, Services	2.02	2.32	1.35	0.84
Ireland	TOTAL	39.15	46.68	41.17	40.46
	of which, Manuf.	23.17	19.59	22.93	18.05
	of which, Services	14.55	25.11	15.47	20.00
Israel	TOTAL	22.08	20.72	38.10	37.87
	of which, Manuf.	11.51	11.31	19.77	22.37
	of which, Services	9.38	8.67	9.42	10.96
Italy	TOTAL	153.77	134.33	271.01	210.17
	of which, Manuf.	122.59	104.83	181.09	138.77
	of which, Services	27.76	24.25	41.54	32.47
Japan	TOTAL	240.14	262.78	519.52	421.01
	of which, Manuf.	194.50	211.16	344.65	282.92
	of which, Services	43.34	50.67	93.01	72.54
Korea	TOTAL	248.45	347.94	285.21	299.73
	of which, Manuf.	197.89	293.16	198.00	213.85
	of which, Services	49.78	53.52	42.29	45.52
Latvia	TOTAL	3.79	4.04	6.92	6.12
	of which, Manuf.	1.70	1.55	4.22	3.62
	of which, Services	1.84	2.07	1.30	1.22
Lithuania	TOTAL	7.15	8.54	11.41	12.47
	of which, Manuf.	5.01	5.41	5.26	5.67
	of which, Services	1.70	2.63	2.34	3.17
Luxembourg	TOTAL	8.85	10.56	9.17	11.35
	of which, Manuf.	2.54	1.75	3.49	1.94
	of which, Services	5.95	8.64	4.68	8.51
Mexico	TOTAL	130.77	175.48	157.08	208.10
	of which, Manuf.	93.47	134.55	127.28	175.34
	of which, Services	15.36	18.75	24.93	27.84
Netherlands	TOTAL	98.75	95.93	103.67	93.36
	of which, Manuf.	52.17	49.52	53.32	47.60
	of which, Services	33.42	32.37	29.87	29.07
New Zealand	TOTAL	13.08	13.15	22.96	22.31
	of which, Manuf.	7.15	7.94	15.69	15.86
	of which, Services	4.39	3.44	5.75	5.09
Norway	TOTAL	37.07	33.87	43.20	41.14
	of which, Manuf.	10.83	7.75	27.18	26.81
	of which, Services	16.56	14.84	12.90	11.37
Poland	TOTAL	93.61	101.23	71.54	91.67
	of which, Manuf.	63.02	70.41	42.67	64.35
	of which, Services	20.39	22.49	10.63	13.03
Portugal	TOTAL	19.59	24.49	33.06	26.40
	of which, Manuf.	12.65	16.46	22.05	16.66
	of which, Services	5.87	6.71	4.02	3.64
Slovak Republic	TOTAL	29.76	30.72	26.19	32.24
	of which, Manuf.	24.16	26.89	18.43	23.04
	of which, Services	4.31	3.18	3.07	3.66
Slovenia	TOTAL	9.75	8.72	11.79	9.82
	of which, Manuf.	6.67	5.78	9.37	7.60
	of which, Services	1.89	1.93	1.42	1.44
Spain	TOTAL	117.75	101.03	177.29	133.15
	of which, Manuf.	74.05	68.02	123.01	92.75
	of which, Services	37.85	25.03	27.86	18.87
Sweden	TOTAL	44.33	30.33	69.13	56.56
	of which, Manuf.	33.87	20.56	45.12	33.76
	of which, Services	9.24	8.36	17.32	16.71
Switzerland	TOTAL	41.62	43.44	80.13	92.27
	of which, Manuf.	26.40	27.88	51.61	61.52
	of which, Services	14.33	15.33	18.45	24.32
Turkey	TOTAL	62.95	101.56	117.94	140.48
	of which, Manuf.	50.12	75.63	95.68	114.72
	of which, Services	11.00	20.55	13.20	16.29
United Kingdom	TOTAL	150.16	128.90	315.41	271.42
	of which, Manuf.	90.40	74.91	215.20	190.11
	of which, Services	45.42	41.84	79.63	63.58
United States	TOTAL	528.10	558.47	1,497.65	1,343.80
	of which, Manuf.	327.72	338.02	1,111.22	1,038.61
	of which, Services	169.62	188.04	206.89	190.18

		Total CO2 in exports		Total CO2 in imports	
		2005	2015	2005	2015
		mton CO2	mton CO2	mton CO2	mton CO2
Argentina	TOTAL	39.18	21.29	28.14	42.24
	of which, Manuf.	21.88	11.96	16.27	27.65
	of which, Services	6.65	5.28	5.34	8.32
Brazil	TOTAL	84.54	103.91	75.77	117.17
	of which, Manuf.	60.99	64.22	49.79	85.54
	of which, Services	10.87	13.80	9.91	18.94
Brunei Darussalam	TOTAL	2.67	2.44	1.61	2.12
	of which, Manuf.	0.06	0.02	0.86	1.62
	of which, Services	0.54	0.64	0.58	0.43
Bulgaria	TOTAL	19.45	24.43	11.74	15.71
	of which, Manuf.	9.34	13.07	6.49	9.63
	of which, Services	6.35	5.12	1.86	2.53
Cambodia	TOTAL	1.76	3.49	4.89	7.25
	of which, Manuf.	0.91	1.51	3.76	4.54
	of which, Services	0.36	1.40	0.69	1.73
China (People's Republic of)	TOTAL	1,665.38	2,190.26	447.92	881.42
	of which, Manuf.	1,504.89	2,022.75	311.79	573.73
	of which, Services	101.78	114.90	72.05	154.25
Colombia	TOTAL	13.85	21.50	21.10	36.09
	of which, Manuf.	8.22	9.76	17.35	30.56
	of which, Services	1.36	1.55	2.81	4.27
Costa Rica	TOTAL	3.19	3.08	5.97	8.61
	of which, Manuf.	1.59	1.76	4.67	7.10
	of which, Services	1.26	1.03	1.15	1.26
Croatia	TOTAL	6.32	5.41	11.89	7.32
	of which, Manuf.	3.13	2.49	7.25	4.39
	of which, Services	2.09	1.87	1.73	1.25
Cyprus	TOTAL	4.75	4.43	5.23	5.00
	of which, Manuf.	0.36	0.54	2.74	1.70
	of which, Services	4.29	3.73	2.27	3.16
Hong Kong, China	TOTAL	54.00	57.54	65.99	91.12
	of which, Manuf.	18.03	15.30	23.66	55.97
	of which, Services	29.85	41.03	40.21	31.41
India	TOTAL	229.68	431.50	170.39	307.34
	of which, Manuf.	174.18	350.81	120.14	219.22
	of which, Services	47.52	76.40	25.73	37.82
Indonesia	TOTAL	120.36	111.59	81.03	116.89
	of which, Manuf.	79.55	73.03	58.41	89.47
	of which, Services	16.39	15.50	14.07	20.44
Kazakhstan	TOTAL	83.17	76.69	26.41	30.43
	of which, Manuf.	23.29	19.15	19.24	23.46
	of which, Services	7.25	7.17	4.00	4.32
Malaysia	TOTAL	141.41	141.11	95.75	112.54
	of which, Manuf.	103.69	100.30	72.90	85.88
	of which, Services	21.00	27.02	17.63	21.19
Malta	TOTAL	2.69	2.75	2.07	2.24
	of which, Manuf.	0.72	0.52	1.28	1.22
	of which, Services	1.94	2.19	0.75	0.96
Morocco	TOTAL	11.27	14.70	15.14	22.02
	of which, Manuf.	4.93	6.33	9.66	14.85
	of which, Services	5.44	6.48	2.74	5.02
Peru	TOTAL	9.82	11.33	12.43	25.88
	of which, Manuf.	5.19	5.49	8.80	19.97
	of which, Services	0.79	2.02	2.22	4.65
Philippines	TOTAL	22.21	30.32	24.79	54.40
	of which, Manuf.	11.80	15.54	17.50	41.17
	of which, Services	8.68	13.25	5.59	10.34
Romania	TOTAL	32.28	25.91	26.82	27.43
	of which, Manuf.	27.14	15.53	14.43	18.56
	of which, Services	3.93	8.33	3.85	3.47
Russian Federation	TOTAL	512.83	449.48	115.93	128.75
	of which, Manuf.	325.11	245.04	77.91	92.55
	of which, Services	77.64	93.46	23.38	25.03
Saudi Arabia	TOTAL	75.62	76.73	55.03	131.75
	of which, Manuf.	49.91	51.36	41.82	93.68
	of which, Services	10.49	15.10	11.08	34.44
Singapore	TOTAL	96.87	153.06	74.00	100.56
	of which, Manuf.	58.06	69.73	30.84	43.72
	of which, Services	37.72	83.05	32.17	47.88
South Africa	TOTAL	121.61	156.19	47.13	55.64
	of which, Manuf.	88.98	107.52	31.21	40.47
	of which, Services	14.48	15.94	10.23	10.22
Chinese Taipei	TOTAL	199.66	195.04	165.13	137.88
	of which, Manuf.	180.03	168.32	121.72	95.54
	of which, Services	19.16	26.25	22.14	21.31
Thailand	TOTAL	129.71	173.75	115.12	145.40
	of which, Manuf.	94.55	122.34	78.78	106.57
	of which, Services	31.08	48.00	22.52	26.27
Tunisia	TOTAL	8.15	7.89	8.19	9.50
	of which, Manuf.	5.45	5.74	6.19	6.87
	of which, Services	1.97	1.71	1.38	1.95
Viet Nam	TOTAL	49.99	131.35	46.01	110.56
	of which, Manuf.	31.57	107.08	37.72	90.88
	of which, Services	7.87	14.00	5.31	13.72
Rest of the World	TOTAL	819.87	702.53	666.02	1,015.35
	of which, Manuf.	330.30	299.92	484.54	737.05
	of which, Services	148.86	162.84	120.66	214.91
OECD member countries	TOTAL	863.78	1,273.77	2,998.42	2,854.82
	of which, Manuf.	579.07	844.45	2,125.20	2,128.03
	of which, Services	233.54	336.32	397.07	413.86
Non-OECD economies	TOTAL	2,998.42	2,854.82	863.78	1,273.77
	of which, Manuf.	2,125.20	2,128.03	579.07	844.45
	of which, Services	397.07	413.86	233.54	336.32

Annex F: Domestic and foreign emissions embodied in domestic and foreign demand

Table F.1: Share of CO2 emitted abroad in total CO2 embodied in domestic final demand
(as % of total demand-based emissions)

	2005	2015		2005	2015		2005	2015
OECD member	17.4%	18.1%	Mexico	22.7%	26.9%	Croatia	38.5%	32.4%
Australia	25.4%	29.9%	Netherlands	36.2%	35.1%	Cyprus	37.6%	42.6%
Austria	46.9%	52.6%	New Zealand	42.8%	44.3%	Hong Kong, China	61.2%	64.7%
Belgium	43.5%	46.4%	Norway	57.6%	56.6%	India	13.8%	13.1%
Canada	31.3%	29.8%	Poland	18.7%	22.8%	Indonesia	20.4%	20.6%
Chile	39.4%	36.0%	Portugal	33.4%	33.8%	Kazakhstan	17.9%	15.2%
Czech Republic	26.3%	31.8%	Slovak Republic	43.5%	54.3%	Malaysia	31.3%	28.3%
Denmark	43.6%	52.0%	Slovenia	39.9%	39.0%	Malta	39.9%	44.3%
Estonia	27.7%	28.6%	Spain	34.1%	33.1%	Morocco	26.2%	26.5%
Finland	44.3%	42.6%	Sweden	55.4%	58.7%	Peru	32.4%	36.6%
France	43.9%	45.6%	Switzerland	57.2%	64.7%	Philippines	24.7%	32.7%
Germany	31.7%	32.8%	Turkey	34.5%	30.1%	Romania	23.1%	28.2%
Greece	30.5%	27.4%	United Kingdom	37.0%	40.1%	Russian Federation	8.0%	9.0%
Hungary	32.9%	35.1%	United States	19.9%	20.6%	Saudi Arabia	17.3%	21.1%
Iceland	65.0%	59.8%	Non-OECD	4.9%	4.9%	Singapore	60.6%	60.9%
Ireland	38.1%	43.6%	Argentina	16.7%	18.3%	South Africa	12.8%	13.7%
Israel	33.8%	34.3%	Brazil	20.4%	21.7%	Chinese Taipei	37.3%	35.3%
Italy	35.0%	34.9%	Brunei Darussalam	29.2%	29.2%	Thailand	34.3%	34.1%
Japan	29.8%	26.0%	Bulgaria	21.8%	26.5%	Tunisia	27.3%	24.4%
Korea	32.9%	29.7%	Cambodia	59.9%	44.8%	Viet Nam	37.5%	38.4%
Latvia	50.8%	48.9%	China, PR	6.6%	7.9%	Rest of the World	21.5%	24.6%
Lithuania	47.8%	54.7%	Colombia	29.6%	34.0%			
Luxembourg	33.7%	36.0%	Costa Rica	49.8%	52.1%			

Table F.2: Share of domestic CO2 emissions consumed by foreign economies
(as % of total production-based emissions)

	2005	2015		2005	2015		2005	2015
OECD member	4.2%	7.5%	Mexico	18.0%	21.6%	Croatia	22.1%	24.2%
Australia	18.3%	23.9%	Netherlands	34.6%	35.9%	Cyprus	34.2%	37.9%
Austria	32.8%	38.4%	New Zealand	27.5%	29.7%	Hong Kong, China	53.1%	47.8%
Belgium	37.4%	37.6%	Norway	52.3%	50.3%	India	18.5%	18.4%
Canada	33.3%	30.9%	Poland	24.7%	25.5%	Indonesia	29.5%	19.8%
Chile	39.5%	34.1%	Portugal	19.7%	31.6%	Kazakhstan	47.4%	32.5%
Czech Republic	34.8%	36.9%	Slovak Republic	49.0%	52.0%	Malaysia	50.1%	37.0%
Denmark	48.2%	56.1%	Slovenia	31.9%	33.7%	Malta	50.2%	53.6%
Estonia	33.3%	39.2%	Spain	23.3%	25.4%	Morocco	19.5%	17.4%
Finland	37.7%	33.7%	Sweden	36.1%	33.8%	Peru	26.4%	18.0%
France	21.9%	22.3%	Switzerland	26.3%	26.0%	Philippines	22.1%	17.9%
Germany	21.1%	25.1%	Turkey	18.8%	22.2%	Romania	27.7%	26.7%
Greece	24.7%	31.1%	United Kingdom	18.3%	19.9%	Russian Federation	32.4%	28.5%
Hungary	26.6%	38.5%	United States	6.6%	8.4%	Saudi Arabia	23.9%	13.3%
Iceland	61.5%	71.9%	Non-OECD	19.8%	12.4%	Singapore	72.7%	77.5%
Ireland	35.7%	50.1%	Argentina	22.7%	9.5%	South Africa	30.2%	34.8%
Israel	18.0%	18.2%	Brazil	22.5%	19.3%	Chinese Taipei	45.2%	49.1%
Italy	18.6%	20.7%	Brunei Darussalam	43.9%	32.6%	Thailand	39.5%	42.0%
Japan	13.7%	16.2%	Bulgaria	34.8%	41.3%	Tunisia	26.8%	19.7%
Korea	28.0%	35.0%	Cambodia	18.8%	21.1%	Viet Nam	40.5%	45.8%
Latvia	30.8%	33.9%	China, PR	27.4%	20.9%	Rest of the World	26.0%	17.4%
Lithuania	30.1%	37.5%	Colombia	20.6%	22.3%			
Luxembourg	37.2%	39.0%	Costa Rica	27.4%	18.9%			