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FIGARO – Greenhouse gas emission estimates

Methodological note

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1 INTRODUCTION

This note documents the methodology applied for the estimation of greenhouse gas (GHG) emissions, produced by Eurostat in the framework of the FIGARO (Full International and Global Accounts for Research in input-Output) project.

In May 2021, Eurostat published for the first time the EU inter-country supply-use and input-output tables (EU-IC-SUIOTs). These tables represent all domestic and international flows in NACE Rev. 2 classification (64*64 activities/products). The dataset covers 45 countries (including the 27 EU Member States), plus a ‘rest of the world’ aggregate. These tables are updated on an annual basis, in line with the latest macroeconomics aggregates.

Also in 2021, Eurostat Unit E.2 started a pilot project to estimate carbon dioxide (CO₂) emissions accounts for the 45+1 geographical entities, which could serve as environmental extension to the FIGARO data set and enable Leontief-type modelling. For the 27 EU Member States, plus United Kingdom, Norway, Switzerland and Turkey, CO₂ emission accounts reported to Eurostat were available¹. For the remaining countries, a methodology was developed by Eurostat to estimate the respective CO₂ emission accounts.

In 2023, Eurostat started working on the estimation of other greenhouse gases (CH₄, N₂O, HFC, PFC and NF₃_SF₆). The methodology applied was based on the one developed for CO₂.

This note describes the methodology applied by Eurostat to obtain a complete set of estimates for all countries, with a breakdown by 64 production activities and one household category.

2 IDENTIFICATION OF THE TARGET VARIABLES

The greenhouse gas emission estimates are to be used as input for the production of greenhouse gas emission footprints through Leontief-type of modelling, by combining them with FIGARO’s Inter-country Input-Output tables (ICIOT).

In order to apply the modelling, the ‘target’ variables to be estimated need to match the required detail from the FIGARO ICIOT. This means a quite high detail by industry and country, necessarily covering the emissions from the entire world. This includes:

- Reference area: 27 EU Member States plus 15 non-EU countries and one ‘rest of the world’ aggregate².
- Air pollutants: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and nitrogen trifluoride and sulphur hexafluoride (NF₃_SF₆). Greenhouse gas (GHG) emissions are calculated by aggregating the emissions of individual pollutants.
- Time period: 2010 to $n-2$ (n being the current year)
- Unit: thousand tonnes of CO₂-equivalent

¹ CO₂ is included in European air emissions accounts (Regulation (EU) 691/2011)

² This refers to the estimation level, which differs from the published data, where other aggregates are also included (namely for EU, extra-EU and world).

- Industrial coverage: classification of economic activities NACE Rev. 2 (including households' activities) – NACE A*64 activities. Additionally, total emissions by households are also calculated (although not integrated in the ICIOT modelling, they are added on top to calculate the total footprint). This leads in total to 65 distinct classes at the most detailed level; no sub-totals or totals are calculated³.

3 DATA SOURCES AND ESTIMATION METHOD

The geographical coverage of FIGARO includes 46 countries/regions: 27 EU Member States, 18 non-EU countries and a 'rest of the world' block. For the EU Member States, Eurostat launches annually an AEA data collection, which is the primary source for the greenhouse gas emissions. Some European countries outside the EU also report AEA to Eurostat, although the dataset is not always complete. For the remaining countries, no official AEA is available to Eurostat.

This divides the countries in three groups, for which a separate procedure/methodology is needed:

- Countries report to Eurostat a complete AEA dataset (time and industry-wise) – see chapter 3.1;
- Countries report to Eurostat an incomplete AEA dataset (time and/or industry-wise) – see chapter 3.2;
- Countries do not report AEA to Eurostat – see chapter 3.3.

Table 1 presents the geographical coverage of the greenhouse gas emission estimates, as well as the countries included in each of the three groups mentioned above.

Table 1 - Geographical coverage of GHG estimates

			Complete Eurostat's AEA available (see chapter 3.1)	Incomplete Eurostat's AEA available (see chapter 3.2)	No Eurostat's AEA available (see chapter 3.3)
1-27	EU27	European Union	x		
28	UK	United Kingdom			x
29	US	United States			x
30	AR	Argentina			x
31	AU	Australia			x
32	BR	Brazil			x
33	CA	Canada			x
34	CH	Switzerland		x	

³ This refers to the estimation level, which differs from the published data, where aggregates are also included (e.g. total industries, total industries plus households, etc.).

35	CN	China			x
36	ID	Indonesia			x
37	IN	India			x
38	JP	Japan			x
39	KR	South Korea			x
40	MX	Mexico			x
41	NO	Norway		x	
42	RU	Russia			x
43	SA	Saudi Arabia			x
44	TR	Turkey		x	
45	ZA	South Africa			x
46	RoW	Rest of the World			x
		Count	28	3	15

3.1 Eurostat's annual AEA

Air emissions accounts record flows of gaseous and particulate materials emitted into the atmosphere as a result of economic activity. [Eurostat's annual AEA](#) are one of the European [environmental-economic accounts](#). They offer a detailed breakdown for 64 emitting industries (production activities), plus households, as defined in the national accounts of EU countries. Eurostat collects the accounts annually (see Annex I of [Regulation 691/2011](#)).

AEA data are normally published in December and cover the necessary time period to be estimated in the context of this FIGARO related exercise: 2010 to one year before the year when data are reported. This means that the European AEA data for year $n-2$ (n being the current year), i.e. the last reference year needed for the footprint calculations, are already available before the FIGARO tables are disseminated (normally available in July the year after).

Eurostat's annual AEA are multi-dimensional data cubes including several hundreds of data points per time period and geographical entity. It includes the following five dimensions:

- GEO – geopolitical entity (reporting)
- TIME – reference year
- AIRPOL – 7 air pollutants and 6 greenhouse gases (13 substances plus groupings) – the six greenhouse gases, all expressed in CO₂-equivalents, are CO₂, N₂O, CH₄, HFC, PFC, and

NF₃_SF₆. In addition, the gases N₂O and CH₄ are also available in their simple mass weight, i.e. not converted into CO₂-equivalents.

- NACE_R2 – classification of economic activities NACE Rev. 2 (including households' activities) – NACE A*64 plus three classes of households' activities – this leads in total to 67 distinct classes at the most detailed level; in addition several sub-totals and totals.
- UNIT – unit of measure – tonnes and thousand tonnes

Whenever available, [Eurostat's annual AEA](#) is the primary source for the estimation of FIGARO-based carbon footprints. Whenever the AEA dataset was complete for all necessary industries and years, figures were used exactly as reported.

For the methodology applied to countries presenting an incomplete AEA, see the next section.

3.2 Methodology for countries reporting incomplete AEA to Eurostat

The data reported to Eurostat in the AEA data collection is complete for all EU Member States. However, this is not always the case for other European countries (EFTA members, EU candidate countries, potential EU candidates), some of which are also reporting AEA to Eurostat. An incomplete dataset means that not all reference years or not all NACE divisions for a given reference year are reported.

For the other countries having missing reference years or NACE in the AEA dataset, Eurostat developed a gap-filling procedure.

Before gap-filling, a preparatory step is necessary. NACE divisions including emissions from other NACE, as well as NACE divisions having their emissions reported 'elsewhere', need to be both changed to 'not available' (e.g. if NACE A01 and A02 are reported together in NACE A01, both NACE would be changed to 'not available').

In order to gap-fill, Eurostat used as auxiliary data the estimates produced for those countries. These estimates were produced applying the same procedure as for the countries for which AEA was not available (see chapter 3.3).

The gap-filling procedure goes as follows:

- If a reference year is completely missing, a bottom-up approach is followed. This means that the most detailed NACE divisions are estimated by applying the same year-on-year change rates as in the auxiliary data (i.e. as in the estimates produced for those countries – see 3.3). The superior totals are then calculated accordingly, through the respective sum.
- If only certain NACE divisions are 'not available' for a given reference year (i.e. if a total is available, but more detailed NACE sectors are 'not available'), then a top-down approach is followed. In such case, the relative contributions to the total of each NACE division in the auxiliary data are used to split the total through the NACE categories below.

The result is a complete dataset which will serve as environmental extension to the calculation of carbon footprints for the concerned countries.

3.3 Methodology for countries which do not report AEA to Eurostat

3.3.1 AEA data published by countries

In the case of the United Kingdom, Eurostat uses data published online⁴ by UK's Office for National Statistics.

3.3.2 Estimation for countries without AEA

For countries not having available AEA with the necessary level of detail, Eurostat developed an estimation method, which uses as main source the estimates available in JRC's [EDGAR database](#). For CO₂, in order to calculate emissions according to the residence principle, these are complemented with two additional data sources: air and maritime transport emissions made available by the OECD. In the next chapters, this method is described in more detail.

3.3.2.1 EDGAR database

The starting point for the estimation procedure is the [EDGAR](#) database. EDGAR is a global database of anthropogenic emissions of greenhouse gases and air pollution, developed and maintained by the Joint Research Centre (JRC) of the European Commission. EDGAR provides independent emission estimates⁵ compared to what is reported by European Member States or by Parties under the United Nations Framework Convention on Climate Change (UNFCCC), using international statistics and a consistent IPCC methodology.

In the EDGAR database, emissions are available for the 45 countries included in FIGARO. Emissions by the 'rest of the world' can be calculated as the difference between the world total and the sum of the emissions by those 45 countries.

EDGAR does not report emissions by the NACE categories. EDGAR has a breakdown of up to 24 industries⁶ in line with the IPCC categories. Therefore, the classification used by EDGAR needs to be matched to the NACE activities. The pollutant-specific correspondence tables between the industrial classification of EDGAR and NACE rev. 2 classification are available in the Annexes.

There are two types of NACE allocation:

- 1-to-1: emissions from one industry from the EDGAR dataset are allocated to only one NACE rev.2 division (or households)

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<https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsatmosphericemissionsgreenhousegasemissionsbyeconomicsectorandgasunitedkingdom>

⁵ See also [EDGARv6.0 website](#), Crippa et al. (2021) or the [DOI link](#).

⁶ The breakdown differs for each pollutant.

- 1-to-N: emissions from one industry from the EDGAR dataset are allocated to more than one NACE rev.2 divisions (or households)

The second type of allocations (1-to-N) requires a distribution key, specifying the percentages to allocate to each NACE (or households).

The standard procedure to develop a distribution key for NACE allocation is to derive a distribution key for each NACE concerned, which is calculated as follows:

$$AEA_{EU} / P1_{EU} * P1_C \quad (\text{eq. 2})$$

where, for a given period⁷, AEA_{EU} are the emissions of the respective NACE division in the EU (in thousand tonnes), $P1_{EU}$ is the monetary output of the same NACE division in the EU (in euros) and $P1_C$ is the monetary output of the NACE division in country C.

Table 2 – Example of the calculation of a distribution key for ‘Other Process Uses of Carbonates’ (code 2.A.4), as obtained from EDGAR. The allocation between NACE C17 and C18 is based on the calculated distribution key

		EDGAR		
		2.A.4 Other Process Uses of Carbonates		
		$AEA_{EU} / P1_{EU} * P1_C$ (in kt)	Distribution key	
NACE	C20+C23	Total	14 579.5	1.0
	C20	Manufacture of paper and paper products	12 146.3	0.8
	C23	Printing and reproduction of recorded media	2 433.2	0.2

For the EDGAR item ‘road transport no resuspension (1.A.3.b_noRES)’, a specific calculation is applied, replacing the AEA component in eq. 2 with data obtained from PEFA⁸:

$$PEFA_{EU_P14\&P17} / P1_{EU} * P1_C \quad (\text{eq. 3})$$

where, for a given period⁷, $PEFA_{EU_P14\&P17}$ is the emission-relevant energy use of ‘motor spirit (without bio)’ and ‘transport diesel (without bio)’ by the concerned NACE division in the EU (in terajoules) (obtained from Eurostat’s PEFA), $P1_{EU}$ is the monetary output of the same NACE division in the EU (in million euros) and $P1_C$ is the monetary output of the NACE division in country C (in million euros).

The method described cannot be applied for the allocation to households, since there is no monetary output (P1) for private households. The following methodology is therefore applied:

- For CO₂:

⁷ Distribution keys are based on the figures from the maximum number of years where data are available for the three necessary variables (P1, AEA and PEFA). For example, in 2021, distribution keys were calculated based on the aggregated figures for the period 2014-2018.

⁸ Eurostat’s [Physical Energy Flow Accounts](#)

- The item ‘road transport no resuspension (1.A.3.b_noRES)’ is multiplied by coefficient 0.6;
 - The coefficient for ‘Residential and other sectors (1.A.4)’ is country-specific and was calculated based on UNFCCC data for the respective country and calculating the share of CRF 1.A.4.b (residential) in CRF 1.A.4. For non-Annex I countries, since data are not available with such detail, EU figures were used to obtain the coefficients;
 - For ‘Non-Energy Products from Fuels and Solvent Use (2.D)’, the coefficient 0.053 is applied.
- For CH₄:
 - The item ‘1.A.3.b_noRES Road transport no resuspension’ is multiplied by coefficient 0.6;
 - For item ‘1.A.4 Other sectors’, coefficients are calculated based on UNFCCC data for the EU and calculating the share of CRF ‘1.A.4.b Residential’ in ‘1.A.4 Other Sectors’. For non-Annex I countries, the share was calculated based on EU figures.
- For N₂O:
 - The item ‘1.A.3.b_noRES road transport no resuspension’ is multiplied by coefficient 0.6;
 - Coefficients for item ‘1.A.4 Other sectors’ are calculated based on UNFCCC data for the EU and calculating the share of CRF 1.A.4.b (residential) in ‘1.A.4 Other Sectors’. For non-Annex I countries, the share was calculated based on EU figures.
- For HFC:
 - The coefficients for item ‘2.F Product Uses as Substitutes for Ozone Depleting Substances’ are calculated based on EU figures obtained from AEA (total HH/(total HH+NACE));
 - For item ‘2.G Other Product Manufacture and Use’, the coefficient applied is 0.045.
- For PFC:
 - For item ‘2.G Other Product Manufacture and Use’, the coefficient applied is 0.052.
- For NF₃_SF₆:
 - For item ‘2.G Other Product Manufacture and Use’, the coefficient applied is 0.087.

For these items, the remaining emissions are allocated to NACE divisions based on the method described in the previous paragraphs.

Emissions by the ‘rest of the world’ are calculated as the difference between the world total and the sum of the emissions by the 45 countries being estimated.

3.3.2.2 CO₂ from maritime navigation

Carbon dioxide (CO₂) emissions from water transport services (NACE H50) follow a specific estimation method. The starting point are the EDGAR items ‘water-borne navigation (1.A.3.d)’ and ‘international maritime bunkers’.

The procedure for the item ‘water-borne navigation (1.A.3.d)’ is straightforward since the same figure obtained from EDGAR is attributed to NACE H50 of the respective country.

Concerning the item ‘international marine bunkers’, Eurostat applies a distribution key which is calculated based on the data obtained from the dataset [OECD maritime transport CO₂ emissions \(experimental\)](#).

This experimental dataset includes annual, quarterly, and monthly carbon dioxide emissions from maritime transport. These are estimated by the OECD based on a consistent methodology across countries and include emissions from both domestic and international voyages. The source for the estimations is ship-tracking information collected via Automatic Identification System (AIS) transponders, covering all large vessels (above 300 gross tonnage) around the world, accessed via the United Nations Global Platform.

The extraction details are described in Table 3.

Table 3 – Extraction details of emissions from maritime transport (OECD database)

Parameter	Selection
Vessel type	All vessels
Country	All
Measure	tonnes of CO ₂ -equivalent OECD estimation
Time & Frequency	Annual

The following calculation is applied:

- Based on the OECD data, a year- and country-specific share is calculated by dividing the respective emissions by the global emissions (i.e. total for all countries, for that year).
- These shares are then multiplied by the values available in EDGAR for ‘international marine bunkers’, to obtain country- and year-specific emissions, which are then allocated to NACE H50.

3.3.2.3 CO₂ from aviation

The OECD maintains and regularly updates an [air transport CO₂ emissions database](#), which includes annual, quarterly and monthly information on CO₂ emissions related to aviation flights. Emissions are estimated for 186 countries, following both territory and residence principles. The main source used for the estimation of these CO₂ emissions is a database compiled by the International Civil Aviation Organisation (ICAO) with all commercial passenger and freight flights around the world.

Carbon dioxide emissions by NACE H51, following the residence principle (as applied in AEA), are directly available from this dataset. The OECD dataset includes data from 2013 onwards. For this time period, Eurostat extracts the data from the OECD database to attribute to NACE H51 of the respective country. Table 4 shows the extraction details.

Additionally, estimates by NACE H51 for all countries are aggregated to calculate a world total. Based on the difference between these emissions and the sum of the emissions by the 45 countries being estimated, one can obtain the emissions by NACE H51 in the ‘rest of the world’.

For the period 2010 to 2012, Eurostat starts from the 2013 figure for NACE H51 and applies year-on-year change rates based on EDGAR emissions ‘virtually’ allocated to NACE H51 (see 3.3.2.1).

Table 4 – Extraction details of emissions from air transport (OECD database)

Parameter	Selection
Source of emissions	Air transport - Industry H51 (ISIC rev.4): (A)+(B)+(D)+(E)+(F)
Pollutant	Carbon dioxide
Measure	tonnes of CO ₂ -equivalent
Flight type	All flights
Frequency	Annual
Seasonality	Non-seasonally adjusted

4 FUTURE WORK

Eurostat plans to estimate GHG emissions accounts for the 46 FIGARO countries/regions on a regular basis. To facilitate this annual process, the above-described estimation methodology has been implemented in form of EXCEL tools.

5 ANNEXES

Annex 1 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for CO₂

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
1.A.1.a	Main Activity Electricity and Heat Production	D
1.A.1.bc	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries	C19, C24, D
1.A.2	Manufacturing Industries and Construction	B to C18, C20 to C33, E36 to F
1.A.3.a	Civil Aviation	H51 (see chapter 3.3.2.3)
1.A.3.b_noRES	Road Transportation no resuspension	All NACE except U, households
1.A.3.c	Railways	H49
1.A.3.d	Water-borne Navigation ⁹	H50 (see chapter 3.3.2.2)
1.A.3.e	Other Transportation	H49
1.A.4	Residential and other sectors	A01 to A03, G45 to G47, H52 to T, households
1.A.5	Non-Specified	D, G45 to T
1.B.1	Solid Fuels	C19, C24
1.B.2	Oil and Natural Gas	B, C19 to C21, D
2.A.1	Cement production	C23
2.A.2	Lime production	C23
2.A.3	Glass Production	C23
2.A.4	Other Process Uses of Carbonates	C20, C23
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
2.D	Non-Energy Products from Fuels and Solvent Use	C16 to G45, households
3.C.2	Liming	A01
3.C.3	Urea application	A01
4.C	Incineration and Open Burning of Waste	A01, B to C33, E37-E39, M74-M75, Q86, Q87_Q88, S96
5.B	Fossil fuel fires	B

⁹ CO₂ emissions from maritime navigation are described in chapter 3.3.2.2.

Annex 2 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for CH₄

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
1.A.1.a	Main Activity Electricity and Heat Production	D
1.A.1.bc	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries	C19, C24, D
1.A.2	Manufacturing Industries and Construction	B to C18, C20 to C33, E36 to F
1.A.3.a	Civil Aviation	H51
1.A.3.b_noRES	Road Transportation no resuspension	All NACE except U, H53 and J61; households
1.A.3.c	Railways	H49
1.A.3.d	Water-borne Navigation	H50
1.A.3.e	Other Transportation	H49
1.A.4	Residential and other sectors	A01 to A03, households
1.A.5	Non-Specified	D, G45 to T
1.B.1	Solid Fuels	B, C19
1.B.2	Oil and Natural Gas	B, C19, D, H49
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
3.A.1	Enteric Fermentation	A01
3.A.2	Manure Management	A01
3.C.1	Emissions from biomass burning	A01
3.C.7	Rice cultivations	A01
4.A	Solid Waste Disposal	E37-E39
4.B	Biological Treatment of Solid Waste	E37-E39
4.C	Incineration and Open Burning of Waste	E37-E39
4.D	Wastewater Treatment and Discharge	E37-E39
5.B	Fossil fuel fires	B

Annex 3 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for N₂O

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
1.A.1.a	Main Activity Electricity and Heat Production	D
1.A.1.bc	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries	C19, C24, D
1.A.2	Manufacturing Industries and Construction	B to C18, C20 to C33, E36 to F
1.A.3.a	Civil Aviation	H51
1.A.3.b_noRES	Road Transportation no resuspension	All NACE except U, H53 and J61; households
1.A.3.c	Railways	H49
1.A.3.d	Water-borne Navigation	H50
1.A.3.e	Other Transportation	H49
1.A.4	Residential and other sectors	A01 to A03, G45 to H49, H53 to T, households
1.A.5	Non-Specified	D, G45 to T
1.B.1	Solid Fuels	B, C19, C24, D, G47, H49, H52
1.B.2	Oil and Natural Gas	B, C19, C24, D, G47, H49, H52
2.B	Chemical Industry	C20
2.G	Other Product Manufacture and Use	C10-C12, C16, C18, C23, C29 to C31_C32, G45
3.A.2	Manure Management	A01
3.C.1	Emissions from biomass burning	A01
3.C.4	Direct N ₂ O Emissions from managed soils	A01
3.C.5	Indirect N ₂ O Emissions from managed soils	A01
3.C.6	Indirect N ₂ O Emissions from manure management	A01
4.B	Biological Treatment of Solid Waste	E37-E39
4.C	Incineration and Open Burning of Waste	E37-E39
4.D	Wastewater Treatment and Discharge	E37-E39
5.A	Indirect N ₂ O emissions from the atmospheric deposition of nitrogen in NO _x and NH ₃	A01
5.B	Fossil fuel fires	B

Annex 4 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for HFC

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
2.E	Electronics Industry	C26
2.F	Product Uses as Substitutes for Ozone Depleting Substances	All NACE; households
2.G	Other Product Manufacture and Use	All NACE; households

Annex 5 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for PFC

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
2.E	Electronics Industry	C26
2.F	Product Uses as Substitutes for Ozone Depleting Substances	A01, A03, C10-C12, C19 to C21, C27, E37-E39, G46, G47, I, J61, M72, O to Q87_Q88, R93, S96
2.G	Other Product Manufacture and Use	C20, C26, C30, C33, J61, Q86, S95, households

Annex 6 – Industrial classification in EDGAR and correspondence to NACE rev. 2 classification for NF3_SF6

Industries in EDGAR database		Code in NACE rev.2.1 classification
Code	Label	
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
2.E	Electronics Industry	C26
2.F	Product Uses as Substitutes for Ozone Depleting Substances	All NACE
2.G	Other Product Manufacture and Use	C13-C15, C16, C22, C23, C25, C27, C31-C32, D, E37-E39, F, M72, Q86, households