B Complementary Greenhouse Gas Emissions Database

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B.1 Overview

This chapter documents the data sources and methodology used to develop the complementary greenhouse gas (GHG) emissions database for the GTAP 12. Emissions are reported for three types of non-CO_2 GHGs - methane (CH_4), nitrous oxide (N_2O) and the group of fluorinated gases (F-gases), and cover seven reference years – 2004, 2007, 2011, 2014, 2017, 2019 and 2023. In addition, CO_2 emissions from industrial processes are reported in the database. The FAOSTAT dataset is used for sourcing agricultural GHG emissions, while the EDGAR database is used to source non-agricultural GHG emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, intermediate input use by industries, and consumption by households. Selected categories of land use GHG emissions are reported separately without association with emission drivers.

B.2 Introduction

The core GTAP 12 Data Base (Aguiar et al. 2025) provides estimates of CO_2 emissions from fossil fuel combustion only. In 2022, over 28% of all GHGs were associated with non-CO_2 GHGs, including CH_4, N_2O and F-gases (Crippa et al. 2025).

Due to the important contribution of non-CO_2 GHG emissions to climate mitigation pathways, since GTAP Version 6, a special version of the GTAP non-CO_2 emissions dataset has been constructed. GTAP 6 non-CO_2 dataset (Rose and Lee 2009) with 2001 reference year was developed based on emission accounts provided in a detailed non-CO_2 and non-fossil fuel combustion CO_2 ("Other CO_2") greenhouse gas emissions database (Rose, Finn, et al. 2007).

For GTAP 7 and 8, a non-CO_2 emission dataset was developed by an extrapolation of Rose, Finn, et al. 2007 data to match each of the reference years. In GTAP 7, CH_4 and N_2O emission growth rates were used from the US US EPA 2006, while F-gases emission projections were based on output growth rates by regions from the GTAP database (Rose, Avetisyan, and Hertel 2010). For GTAP 8, however, applied emission growth rates are based on two other data sources: the EDGAR Version 4.2 dataset (Joint Research Centre of the European Commission (JRC) and Netherlands Environmental Assessment Agency (PBL) 2011) for non-agricultural emissions and the FAOSTAT for agricultural emissions (Ahmed et al. 2014).

Same data sources were used for the development of the GTAP 9 non-CO_2 GHG emissions dataset (Irfanoglu and Mensbrugghe 2015). Emissions were directly sourced from the two sources listed above (i.e., EDGAR and FAOSTAT) and mapped to three GTAP 9 reference years (2004, 2007 and 2011). As in EDGAR Version 4.2, the latest available data year is 2010, an emission

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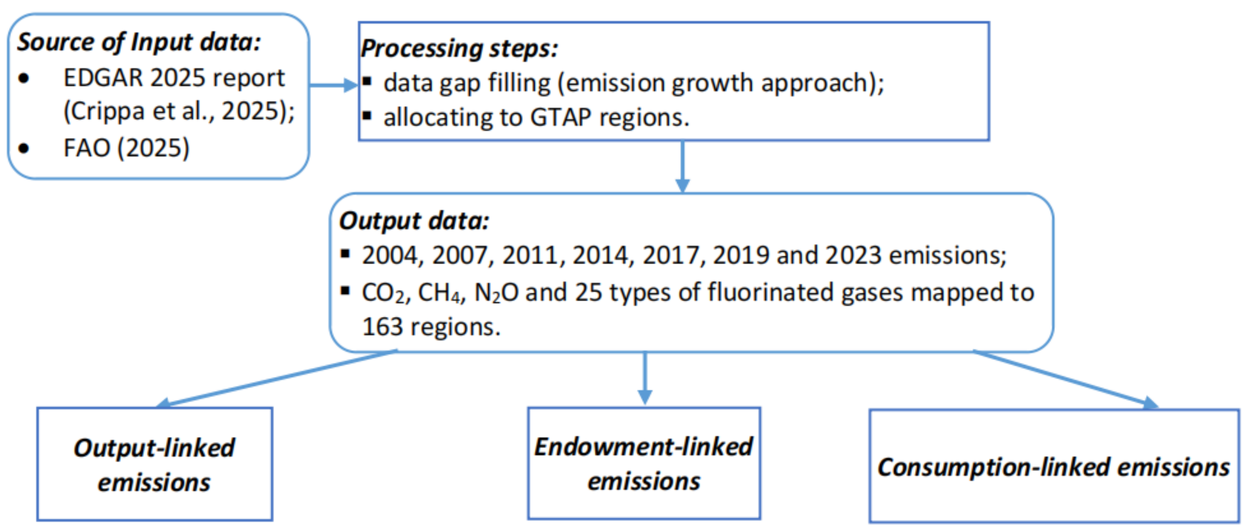
growth approach was used to project emissions from 2010 to 2011 levels, assuming that 2010-2011 emissions growth rate equals 2007-2010 emissions growth rate.

The GTAP 10 non-CO_2 emissions dataset construction followed the general approach outlined in Irfanoglu and Mensbrugghe 2015 with further updates and modifications (Chepeliev 2020). The GTAP 11 non-CO_2 emissions dataset is documented in Chepeliev 2024.

For the case of GTAP 12, we follow an overall approach developed in Chepeliev 2024, constructing emission accounts for the seven GTAP 12 reference years – 2004, 2007, 2011, 2014, 2017, 2019 and 2023. Selected updates and modifications are implemented compared to Chepeliev 2024 as discussed in detail below. FAOSTAT (FAO 2025) data is used to source agricultural non-CO_2 GHG emissions, while the EDGAR database (Crippa et al. 2025) is used to source non-agricultural GHG emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, input use by industries and consumption by households. Emissions from the input use by industries are further split into emissions from fossil fuel combustion and the rest of the emissions. The database also includes CO_2 emissions from industrial processes, e.g., cement and fertilizer production. Figure 13.2 outlines the general approach to the GTAP 12 complementary GHG emissions database construction. Selected categories of land use GHG emissions are reported without associating them with emission drivers.

Figure 13.2: GTAP 12 complementary GHG database construction process



Source: Developed by the author.
Note: In the final GTAP 12 complementary GHG database, emissions are provided in million metric tonnes (mmt), while global warming potentials for converting to CO_2 eq. are reported in a separate header.

B.3 Treatment of the agricultural emissions from FAOSTAT

FAOSTAT data on emissions is used as a main source for agricultural non-CO_2 GHG emissions, excluding energy use emissions.[3] Agricultural emissions in FAOSTAT are reported under 10 emission categories, which represent activities that produced such emissions. Table 13.3 provides a listing of such emission categories and their mapping to GHGs reported in the GTAP non-CO_2 database. FAOSTAT does not report agricultural emissions of fluorinated gases, but only N_2O and CH_4 emissions (Table 13.3, column 3). Three out of ten emission categories produce both GHGs, these include “Burning crop residues”, “Burning savanna” and “Manure management”, while the remaining seven categories produce either N_2O or CH_4.

Table 13.3: FAO emission categories mapped to GHGs and emission drivers

No.	Emission category code	Emission category description	Reported GHGs	Emission driver
1	BCRS	Burning crop residues	N_2O, CH_4	Output
2	BSAV	Burning savanna	N_2O, CH_4	Land
3	CLOS	Cultivation of organic soils	N_2O	Land
4	CRES	Crop residues	N_2O	Output
5	MPAS	Manure left on pastures	N_2O	Capital
6	MASL	Manure applied to soils	N_2O	Capital
7	SNTF	Synthetic fertilizers	N_2O	Input use of chemical products (“chm”)
8	RICC	Rice cultivation	CH_4	Land
9	MMNG	Manure management	N_2O, CH_4	Capital
10	EFRM	Enteric fermentation	CH_4	Capital

Source: Developed by the authors.

In addition, FAOSTAT reports data for 36 emission subcategories, which represent different agricultural commodities, types of land, etc. Their list is provided in Table 13.4. 237 countries and territories reported by FAOSTAT are matched to the GTAP countries (FAO 2025). To map the FAOSTAT data to GTAP Data Base, we first map each emission category to their corresponding emission driver (Table 13.3, column 5). Then each emission subcategory is mapped to GTAP commodities (Table 13.4, column 4).

For instance, FAOSTAT reports N_2O emissions from crop residues[4] (“CRES” category in Table 13.3) for “Barley” by countries (FAO 2025). Based on developed mappings, these emissions are associated with the output of GTAP “Cereal grains nec” (“gro”) sector. In this case, we use direct mapping, as no redistribution of emissions between sectors is performed. An example where

[3]Non-CO_2 GHG emissions from fossil fuel combustion in agriculture are sourced from the EDGAR dataset (see next Section).

[4]GHG emissions from crop residues consist of direct and indirect N_2O emissions from nitrogen (N) in crop residues and forage/pasture renewal left on agricultural fields by farmers.

Table 13.4: Emission subcategories reported in the FAOSTAT database and mapping to GTAP sectors

No.	Emission subcategory code	Emission subcategory description	GTAP sectors
1	56	Maize	gro
2	27	Rice, paddy	pdr
3	156	Sugar cane	c_b
4	15	Wheat	wht
5	44	Barley	gro
6	79	Millet	gro
7	116	Potatoes	v_f
8	176	Beans, dry	v_f
9	75	Oats	gro
10	71	Rye	gro
11	236	Soybeans	osd
12	83	Sorghum	gro
13	6760	Savanna	ctl, oap, rmk
14	6789	Woody savanna	ctl, oap, rmk
15	6791	Closed shrubland	ctl, oap, rmk
16	6792	Open shrubland	ctl, oap, rmk
17	6794	Grassland	ctl, oap, rmk
18	6727	Cropland organic soils	pdr, wht, gro, v_f, osd, c_b, pfb, ocr
19	6728	Grassland organic soils	ctl, oap, rmk
20	1107	Asses	ctl
21	1126	Camels	ctl
22	960	Cattle, dairy	rmk, ctl
23	961	Cattle, non-dairy	ctl
24	1016	Goats	ctl
25	1096	Horses	ctl
26	1110	Mules	ctl
27	976	Sheep	ctl
28	946	Buffaloes	ctl
29	1051	Swine, breeding	oap
30	1049	Swine, market	oap
31	1177	Llamas	ctl
32	1053	Chickens, broilers	oap
33	1052	Chickens, layers	oap
34	1068	Ducks	oap
35	1079	Turkeys	oap
36	3107	Synthetic Nitrogen fertilizers	pdr, wht, gro, v_f, osd, c_b, pfb, ocr

Description and codes of the GTAP 12 Data Base sectors are available at this link.
Source: Developed by the authors.

redistribution of emissions is implemented includes N_2O emissions from synthetic nitrogen fertilizer application ("SNTF" category in Table 13.3). These emissions are mapped to the eight GTAP agricultural sectors (listed in Table 13.4) and are associated with intermediate use of "Chemical products" (chm) by the corresponding sectors. We use the value of intermediate use of "chm" by these eight sectors to redistribute N_2O emissions. Such a mapping approach is applied to all non-CO_2 GHG emission flows sourced from FAOSTAT.

B.4 Treatment of the non-agricultural emissions from EDGAR

Non-agricultural emissions and energy-related agricultural emissions are sourced from the EDGAR 2025 report (Crippa et al. 2025). EDGAR reports emissions for 28 GHGs, including CO_2, CH_4, N_2O and 25 fluorinated gases. The database covers 223 countries, which are mapped to the GTAP countries, and reports emissions from international aviation and international shipping. These emissions are reported at the global level. We redistribute them by countries based on the value of exports reported in GTAP 12 for air transport (atp) and water transport (wtp), respectively, excluding exports of travelers' expenditures. It should be noted that the CO_2 emissions from fossil fuel combustion, including those from international aviation and navigation, are included in the standard GTAP Data Base, therefore, emissions sourced from EDGAR are complementary to the fossil fuel combustion CO_2 emissions.

EDGAR reports emissions for 38 IPCC categories, which are mapped to emission drivers (see Appendix). As agricultural emissions are covered by FAOSTAT, they are discarded from the EDGAR data processing steps to avoid double-counting.[5] Appendix provides the mapping between IPCC categories reported in EDGAR, GTAP emission drivers and emission agents. These mappings are used to associate EDGAR emissions with GTAP-based emission drivers and agents that produce these emissions as described in Section B.2.

To provide the reallocation of emissions from combustion-related energy use (IPCC category 1A), we use volumes of combusted energy and emission factors. We estimate emission weights by multiplying combustion-related energy use by corresponding emission factors (Table 13.5). For other IPCC categories, not included in 1A, we use corresponding GTAP values to assist with the redistribution. To redistribute emissions associated with non-energy products from fuels and solvent use across agents, we use the volume flow of white spirits, bitumen, lubricants and paraffin waxes reported in the detailed energy database.

[5]Fuel combustion emissions in agriculture are sourced from EDGAR.

Table 13.5: Emission factors for selected GHGs, g per mmBtu

Fuel type	GTAP sectors	CH_4 factor	N_2O factor
Coal and coke	coa	11	1.6
Natural gas	gas, gdt	1.0	0.1
Petroleum products	p_c, oil	3.0	0.6

Source: US EPA 2018.

One distinctive feature of the EDGAR database is an explicit differentiation between fossil and bio emission sources. To take this into account, in selected cases, we modify the emission drivers for selected emission categories as indicated in Appendix. In the final GTAP database emissions from fossil and bio sources are aggregated, however, the distinction across drivers remains captured in the database.

The resulting database reports GHG emissions in million metric tonnes (mmt) and 100-year global warming potentials (GWPs) from the IPCC's Second, Fourth, Fifth, and Sixth Assessment Reports (AR2, AR4, AR5 and AR6, respectively). The GTAP 9 non-CO_2 GHG emissions dataset was using GWPs from the IPCC's AR2 (Irfanoglu and Mensbrugghe 2015), while GTAP 10 Data Base, as a default, was using GWPs from AR4 (Chepeliev 2020). In the GTAP 12, we provide users with an opportunity to perform a conversion to CO_2-eq. on their own, using either one of the provided GWP conversion factors or alternative approaches.[6] GWP values from the AR5, reported in the database files, do not include climate-carbon feedbacks (Intergovernmental Panel on Climate Change (IPCC) 2014). In those cases when GTAP regions do not emit any F-gases, global weighted average GWPs for F-gases are reported.

B.5 Land use GHG emissions

Since the standard GTAP database does not have a detailed representation of the land use accounts,[7] the GTAP 9 non-CO_2 GHG emissions dataset did not report land use emissions (Irfanoglu and Mensbrugghe 2015). GTAP 10 GHG emissions data included land use-related emissions as a separate account (without an explicit association with emission drivers) (Chepeliev 2020). A number of previous efforts have been linking land use change emissions with the GTAP Land Use and Land Cover Data Base, which provides a detailed accounting of the land use activities (e.g., Hertel et al. 2010). At the same time, accounting for all GHG emission sources is important for the proper tracking of the mitigation efforts and global warming estimates, for instance, in the case of linking the GTAP simulations with the climate model.

[6] Though all GWPs are region-generic, F-gases category has different composition by regions thus resulting in region-specific GWPs. GWPs for CH_4 and N_2O are uniform across regions.

[7] GTAP 12 Data Base reports payments for land as an endowment by sectors, but does not provide physical data on land use areas (e.g., cropland, forest land, grassland, etc.), afforestation/deforestation accounts or other land conversion activities.

In the current effort, we provide estimates of the land use GHG emissions by GTAP 12 Data Base regions based on the FAOSTAT database (FAO 2025). Some subcategories of the land use emissions are redistributed across GTAP activities. In particular, Emissions from drying pastureland and cropland are mapped to primary crops and livestock, respectively, based on the mappings provided in Table 13.4.

Table 13.6: Land use GHG emission categories reported in the FAOSTAT database

No.	Emission category (code)	Emission subcategory (code)	Reported GHGs
1.	Forest land (FrsLand)	Forest land (FrsLand)	CO_2
2.	Forest land (FrsLand)	Forest conversion (FrsConv)	CO_2
3.	Burning – biomass (BrnBiom)	Humid tropical forest (TropFrs)	N_2O, CH_4
4.	Burning – biomass (BrnBiom)	Other forest (OthFrs)	N_2O, CH_4
5.	Burning – biomass (BrnBiom)	Organic soils (OrgSoil)	CO_2, CH_4

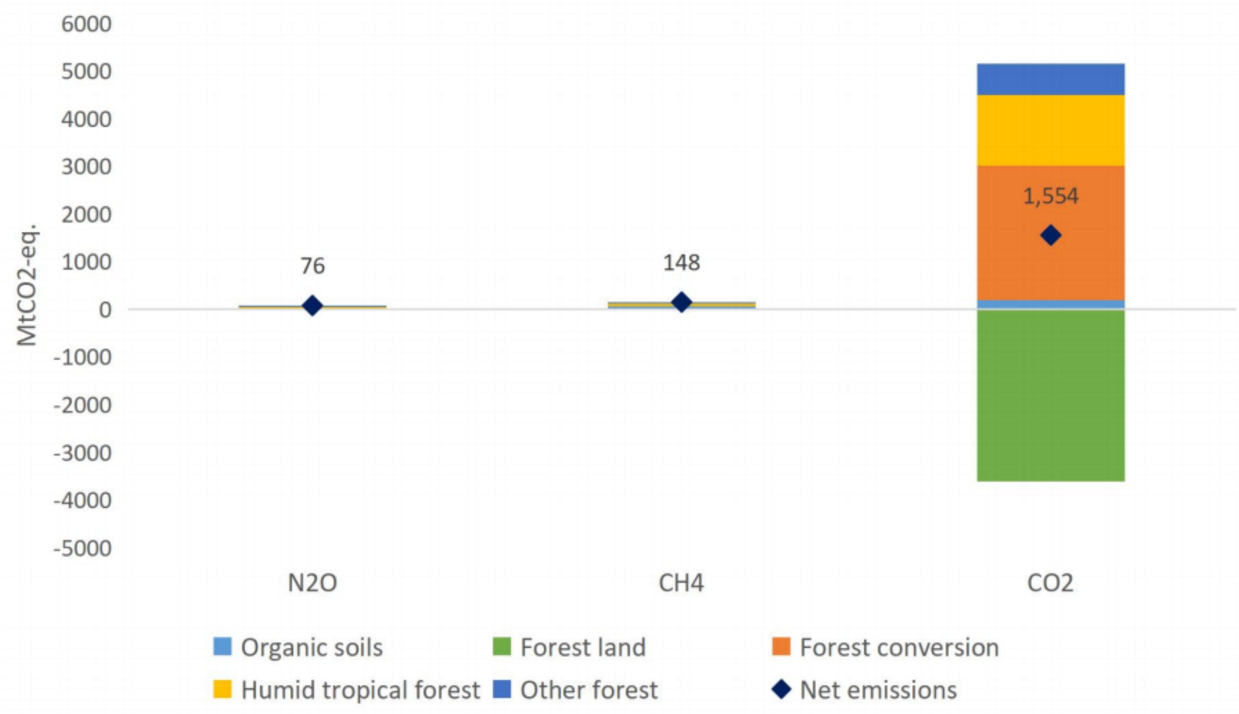
Source: FAO 2023.

Land use emissions from burning biomass are represented across land types (FAOSTAT emission categories) and are not mapped to drivers and agents. Treatment of the land use emission changes for the latter category is left up to the modelers, as different alternative assumptions could be implemented, taking into account features of the applied model and specifics of the policy simulation. For instance, one can impose exogenous trends on land use emissions based on the additional data sources, e.g., using the Shared Socioeconomic Pathways (SSPs) database (International Institute for Applied Systems Analysis (IIASA) 2025), assume these emissions stay at the reference year level (e.g., within the static model runs) or link to the land use activities if such representation is available in the model.

Based on the FAO land use change GHG emissions data (FAO 2025), we identify two emission categories and four subcategories of emissions that are not mapped to GTAP-based drivers (Table B.4). We map land use GHG emissions reported by countries in the FAO database to the 163 GTAP 12 regions.

In terms of land use emission sources, in 2023 forest conversion contributed over 52% of all emission increases - 2814 MtCO_2-eq. - CO_2 emissions only, followed by forest conversion (1486 MtCO_2-eq. or around 28% of the total increase) and other forest (659 MtCO_2-eq. or 12%) (Figure 13.3). These emissions have been to a large extent outweighed by CO_2 removals by forest land - negative emissions of 3603 MtCO_2-eq. Net CO_2 emissions increased by 1554 MtCO_2-eq. Humid tropical forests and other forests together contributed 160 MtCO_2-eq. emissions, split almost equally between N_2O and CH_4 (Figure 13.3). When estimated on the net basis, CO_2 accounted for 87.6% of all land use GHG emissions, followed by CH_4 with a share of 7.7%.

Figure 13.3: Distribution of global land use net GHG emissions in 2023 by gases and categories



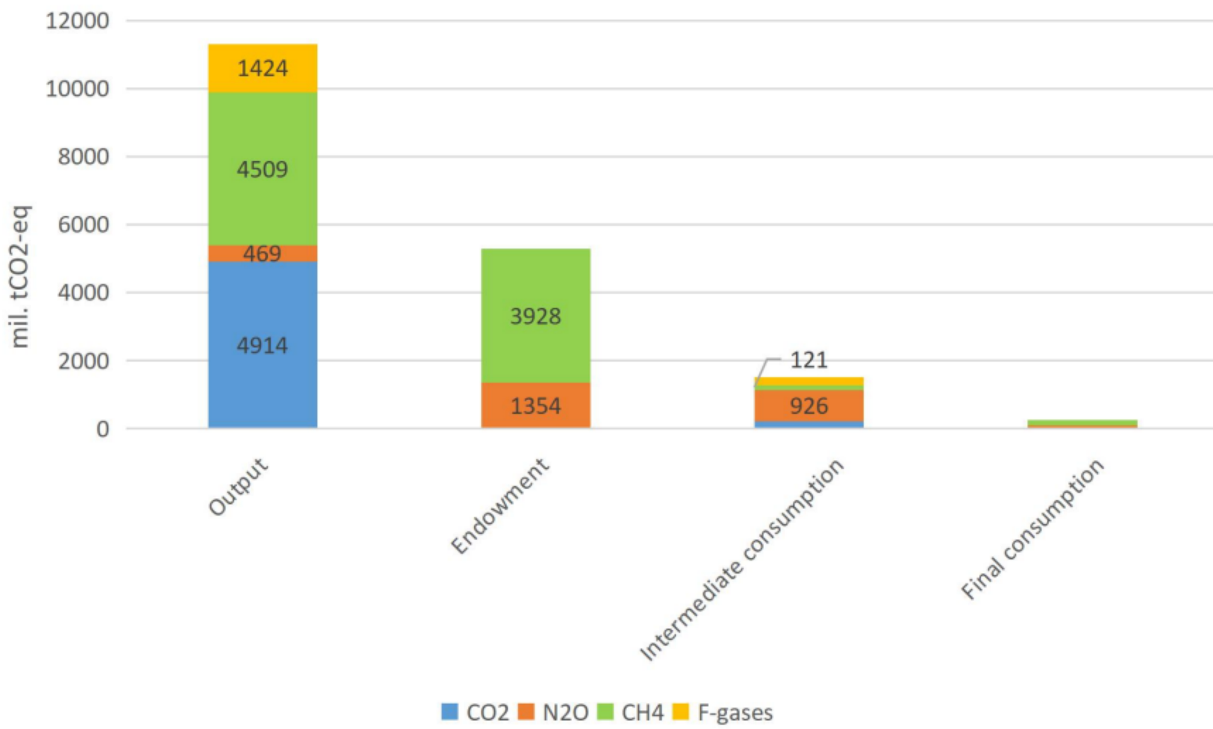
Notes: GWPs from AR6 are used for the conversion to CO_2 eq. Only land emissions that are not distributed across GTAP drivers are reported on the figure.
Source: FAO 2025.

B.6 Overview of the constructed database[8]

In terms of emission drivers, out of 18.3 billion tCO_2-eq. of complementary GHG emissions in 2023, around 62% are linked to output (Figure 13.4). CH_4 accounts for 47.5% of global complementary GHG emissions, followed by CO_2 (from non-combustion energy use, including fugitive emissions) – 28%, and N_2O - 15.4%, with the rest contributed by F-gases (9.1%).

[8]In this section we consider only GHG emissions distributed across GTAP-based drivers.

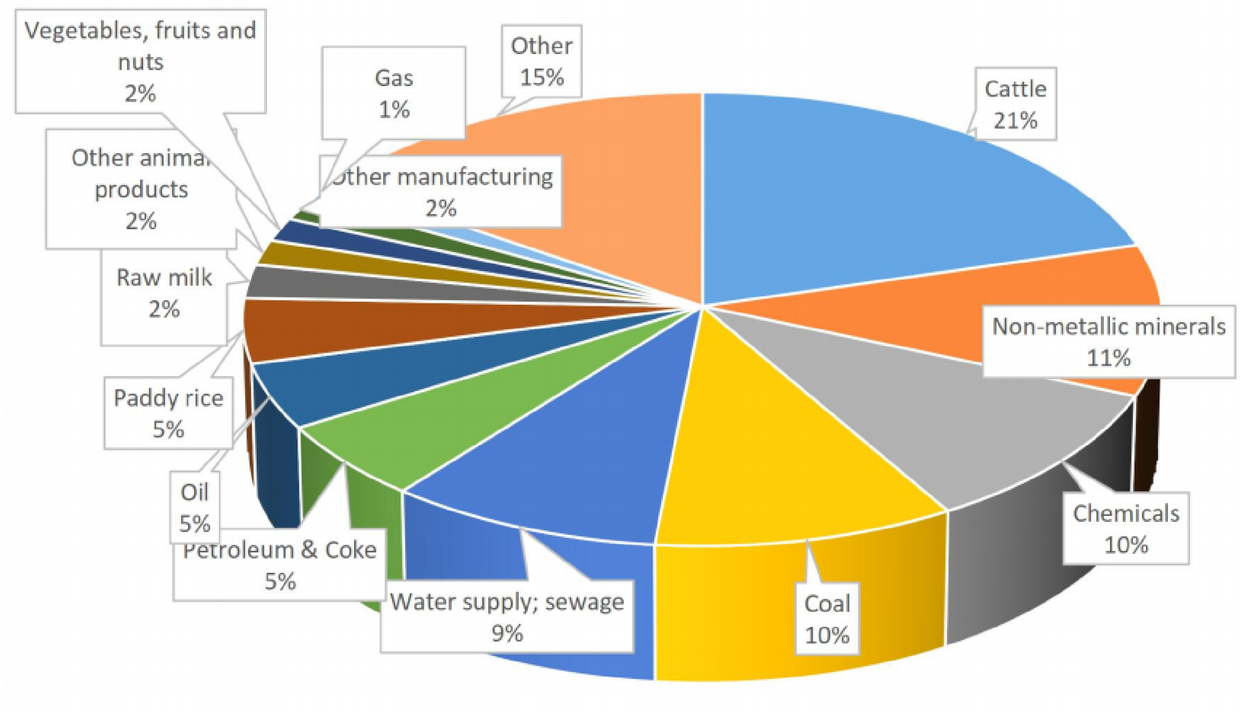
Figure 13.4: Distribution of the global complementary GHG emissions in 2023 by gases and drivers



Source: Estimated by the author based on the GTAP 12 complementary GHG emissions database.

In terms of sectoral distribution, the cattle sector accounts for over one-fifth of all complementary GHG emissions at the global level in 2023, followed by non-metallic minerals (11%), chemicals (10%), coal (10%), and water supply and sewage (9%) (Figure 13.5). The top ten sectors contributed around 80% of all complementary GHGs at the global level (Figure 13.5). As discussed earlier, apart from the non-CO_2 GHG emissions, the current version of the emissions database also includes CO_2 emissions from non-combustion energy use activities. In the case of the 2023 reference year, CO_2 emissions from non-metallic minerals (cement) production represent around 38% of this category, fugitive emissions from fossil fuels – coal, oil, and gas (including flaring emissions) represent over 18%, and emissions from the chemical industry contribute around 20%. Appendix identifies IPCC categories that report CO_2 emissions from non-combustion energy use. These emissions complement the CO_2 emission accounts from fossil fuel combustion activities reported in the core GTAP Data Base.

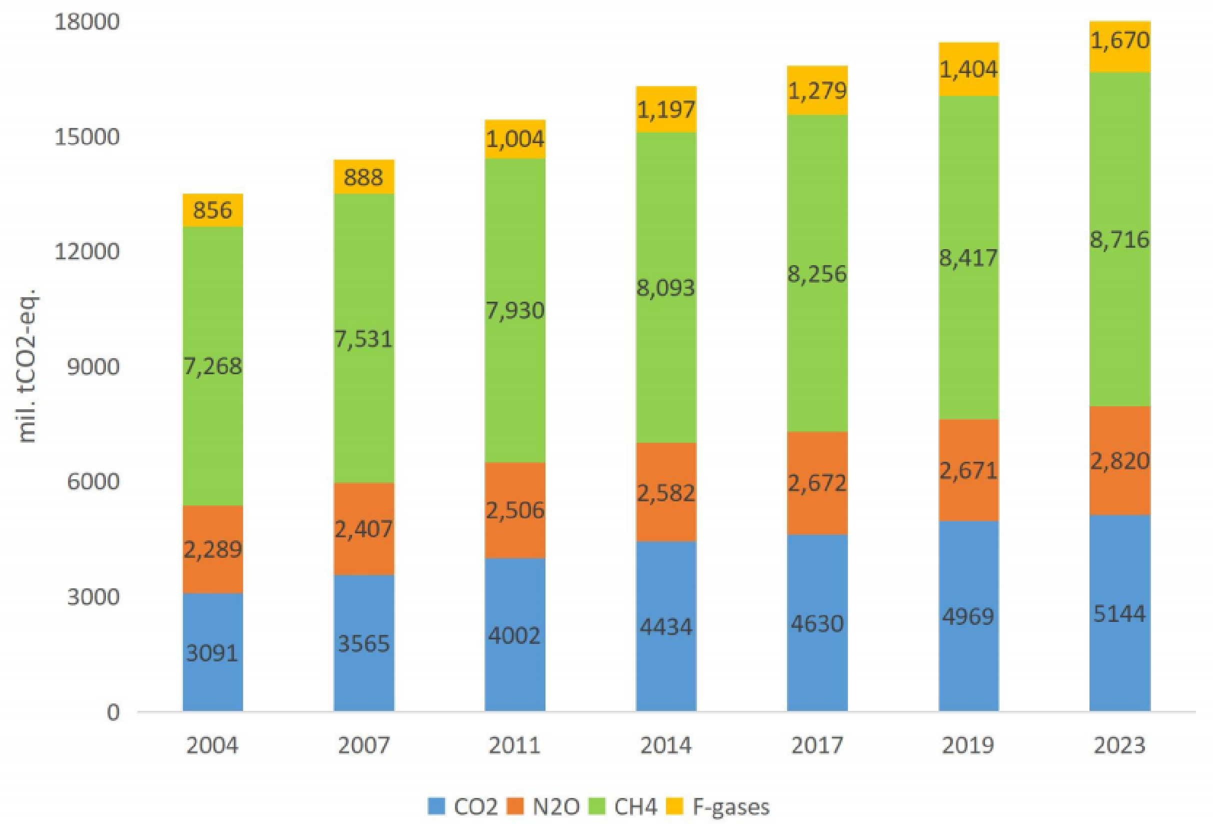
Figure 13.5: Distribution of the global complementary GHG emissions by GTAP sectors in 2023, %



Source: Estimated by the author based on the GTAP 12 complementary GHG emissions database.

In terms of changes over time, GHG emissions reported in the GTAP complementary GHG accounts show a consistent increase over time – from 13.5 billion tCO_2-eq. in 2004 to 18.4 billion tCO_2-eq. in 2023, with an annual average growth rate of around 1.6% (Figure 13.6). The most substantial growth during this period has been observed for the case of F-gases – on average 3.6% per year, followed by CO_2 emissions (from non-combustion energy use) – at a 2.7% annual growth rate. N_2O and CH_4 emissions have been growing at a substantially lower pace between 2004 and 2023 – 1.1% and 1% respective.

Figure 13.6: Global complementary GHG emissions by GTAP 12 reference years and gases



Source: Estimated by the author based on the GTAP 12 complementary GHG emissions database.

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Appendix. Mapping between EDGAR emission categories and GTAP emission drivers

Table 13.7: Mapping between EDGAR emission categories and GTAP emission drivers

No.	IPCC 2006 category code	Category description	GTAP emission drivers (for the case of bio emissions, if different)	GTAP emission agents
1	1A1A	Main Activity Electricity and Heat Production	coa, oil, gas, p_c, gdt (frs, lum)	ely
2	1A1BC	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries	coa, oil, gas, p_c, gdt (frs, lum)	coa, oil, gas, p_c, gdt
3	1A2	Manufacturing Industries and Construction	coa, oil, gas, p_c, gdt (Output)	oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf, cns
4	1A3A	Civil Aviation	coa, oil, gas, p_c, gdt (p_c)	atp
5	1A3B_ _NORES	Road Transportation no resuspension	coa, oil, gas, p_c, gdt (p_c)	otp, HHs [9]
6	1A3C	Railways	coa, oil, gas, p_c, gdt (p_c)	otp
7	1A3D	Water-borne Navigation	coa, oil, gas, p_c, gdt (p_c)	wtp
8	1A3E	Other Transportation	coa, oil, gas, p_c, gdt (p_c)	otp

Continued on next page

[9] In the case of households, 1A3B emissions are linked to the "p_c" use only.

Table 13.7: Mapping between EDGAR emission categories and GTAP emission drivers (continued)

No.	IPCC 2006 category code	Category description	GTAP emission drivers (for the case of bio emissions, if different)	GTAP emission agents
9	1A4	Residential and other sectors	coa, oil, gas, p_c, gdt (frs)	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, frs, fsh, wtr, trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg, edu, hht, dwe, HHs [10]
10	1A5	Non-Specified	coa, oil, gas, p_c, gdt (frs)	trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg, edu, hht, dwe
11	1B1*	Solid Fuels	Output	coa [11]
12	1B2*	Oil and Natural Gas	Output	oil, gas, p_c, gdt
13	2A1*	Cement production	Output	nmm
14	2A2*	Lime production	Output	nmm
15	2A3	Glass Production	Output	nmm
16	2A4*	Other Process Uses of Carbonates	Output	nmm
17	2B*	Chemical Industry	Output	chm
18	2C*	Metal Industry	Output	i_s, nfm
19	2D*	Non-Energy Products from Fuels and Solvent Use	p_c - white spirit, bitumen, lubricants, paraffin waxes (Output)	p_c, nmm
20	2E	Electronics Industry	Output	ele
21	2F	Product Uses as Substitutes for Ozone-Depleting Substances	Output	chm, ele, eeq, ome
22	2G	Other Product Manufacture and Use	chm, bph	ofd, hht
23	3A1	Enteric Fermentation	NA	NA

Continued on next page

[10]In the case of households, 1A4 emissions are linked to the use of “coa”, “oil”, “gas” and “gdt”.

[11]In the cases when mapping of “1B1” emissions to “coa” only results in the emission intensities much higher than the world/region average, these emissions are additionally redistributed between “oil”, “gas” , “p_c”, “gdt” and “ely” activities. This impacts mostly small fossil fuel producers in Africa.

Table 13.7: Mapping between EDGAR emission categories and GTAP emission drivers (continued)

No.	IPCC 2006 category code	Category description	GTAP emission drivers (for the case of bio emissions, if different)	GTAP emission agents
24	3A2	Manure Management	NA	NA
25	3C1	Emissions from biomass burning	NA	NA
26	3C2	Liming	nmm	pdr, wht, gro, v_f, osd, c_b, pfb, ocr
27	3C3	Urea application	chm	pdr, wht, gro, v_f, osd, c_b, pfb, ocr
28	3C4	Direct N_2O Emissions from managed soils	NA	NA
29	3C5	Indirect N_2O Emissions from managed soils	NA	NA
30	3C6	Indirect N_2O Emissions from manure management	NA	NA
31	3C7	Rice cultivations	NA	NA
32	4A	Solid Waste Disposal	Output	wtr
33	4B	Biological Treatment of Solid Waste	Output	wtr
34	4C*	Incineration and Open Burning of Waste	Output	coa, oil, gas, oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, p_c, chm, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf, wtr
35	4D	Wastewater Treatment and Discharge	Output	wtr

Continued on next page

Table 13.7: Mapping between EDGAR emission categories and GTAP emission drivers (continued)

No.	IPCC 2006 category code	Category description	GTAP emission drivers (for the case of bio emissions, if different)	GTAP emission agents
36	4E	Other	Output	coa, oil, gas, oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, p_c, chm, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf, wtr
37	5A	Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	NA	NA
38	5B	Fossil fuel fires	Output	coa, oil

Note: "NA" corresponds to agricultural emission categories. These emissions are sourced from FAOSTAT dataset FAO 2025, therefore we do not process these emission categories from EDGAR dataset. "*" identifies IPCC categories that report CO2 emissions from non-combustion energy use.
Source: Developed by the author based on IPCC 2008 and Crippa et al. 2025.

C Air Pollutant Emissions Database

Maksym Chepeliev[12]

C.1 Overview

With a major contribution to premature mortality and morbidity levels, ambient air pollutant emission is one of the most severe global health risk factors (Cohen et al. 2017).[13] Representation of air pollutant emission flows in global economic models is thus an important element of a consistent assessment of health and environmental policies. Still, while greenhouse gas emissions are usually well represented in many global economic databases and models, air pollutant emission accounts in most cases are not included. In this Chapter we describe the methodology used to produce a global air pollutant emissions dataset consistent with the GTAP Data Base version 11. The developed air pollutant emission accounts are largely based on the EDGAR database (Monforti Ferrario et al. 2022), include five reference years (2004, 2007, 2011, 2014 and 2017), cover 160 regions and 65 sectors. Emissions are linked to economic activities and three sets of emission sources: consumption (by intermediate and final users), endowment use (land) and output. In addition to the non-land use sources, emissions from land use activities are estimated by land cover type, based on the volume of burned biomass and emission factors. The emissions database can be readily incorporated in GTAP-based computable general equilibrium models, enabling assessments of a wide range of policy questions, including the health co-benefits from climate mitigation policies.

C.2 Introduction

In recent years, a number of studies have contributed to the assessment of air pollutant emissions-related externalities at the regional and global scales. According to the Global Burden of Disease study (Cohen et al. 2017), in 2015 ambient air pollutant emissions caused 4.2 million deaths and a loss of 103.1 million disability-adjusted life-years, making it the fifth-ranked global risk factor. In terms of the welfare costs of mortality and illnesses associated with outdoor air pollutant emissions, global estimates range between $2.7-3.2 trillion for 2015 (Coady et al. 2015; OECD 2016). This is equivalent to 40% of global expenditures on health and is 10 times higher than global investment in renewable energy (WB 2017; FS 2017).

With such a high magnitude of air pollutant emissions-related externalities, implementing more stringent environmental policies (e.g., emissions taxation or elimination of energy subsidies) may result in significant co-benefits from reduced mortality and morbidity, as well as increased labor productivity (Vandyck et al. 2018; Markandya et al. 2018). While CO_2 and non-CO_2 greenhouse gas (GHG) emissions are usually well represented in many global economic databases and models, air pollutant emission accounts in many cases are not included. One of the reasons behind this situation is that unlike carbon budget estimates from changes in GHG emissions, health

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impacts from changes in air pollutant emissions have to be accessed using specialized modelling tools and techniques (e.g., Van Dingenen et al. 2018; IIASA 2017).

In this Chapter we describe the methodology used to produce an air pollutant emissions dataset consistent with the Global Trade Analysis Project (GTAP) 11 Data Base (Aguiar et al. 2022), which reports data for five benchmark years: 2004, 2007, 2011, 2014 and 2017. This effort complements the complementary GTAP GHG emission accounts (Chapter 13B) and CO_2 emissions data from fossil fuels combustion, integrated in the standard GTAP Data Base (Chapter 13A).

Several sources for the global air pollutant emissions data are available, which can be used for the construction of GTAP-consistent emission accounts either separately or combined. In our effort to construct the air pollutant emission accounts consistent with the GTAP Data Base, we impose several criteria on the source data. First, we are aiming for a global dataset with (at least) country-level coverage. Second, the underlying emissions dataset should be based on a standardized methodology and with regular updates, to support future releases of the GTAP Data Base. Third, the database should distinguish sources of air pollutant emissions, which can be further linked to economic activities, as presented in the GTAP Data Base.

Considering the aforementioned criteria, we have chosen to rely on the EDGAR Version 6.1 database as a main source of air pollutant emissions (Monforti Ferrario et al. 2022). The EDGAR database reports data for nine pollutants: black carbon (BC), carbon monoxide (CO), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), nitrogen oxides (NOx), organic carbon (OC), particulate matter 10 (PM_{10}), particulate matter 2.5 ($PM_{2.5}$) and sulfur dioxide (SO_2). For estimates of the underlying energy volumes, both EDGAR and GTAP rely on the extended energy balances developed by the International Energy Agency (IEA 2022; Monforti Ferrario et al. 2022; Chapter 12).

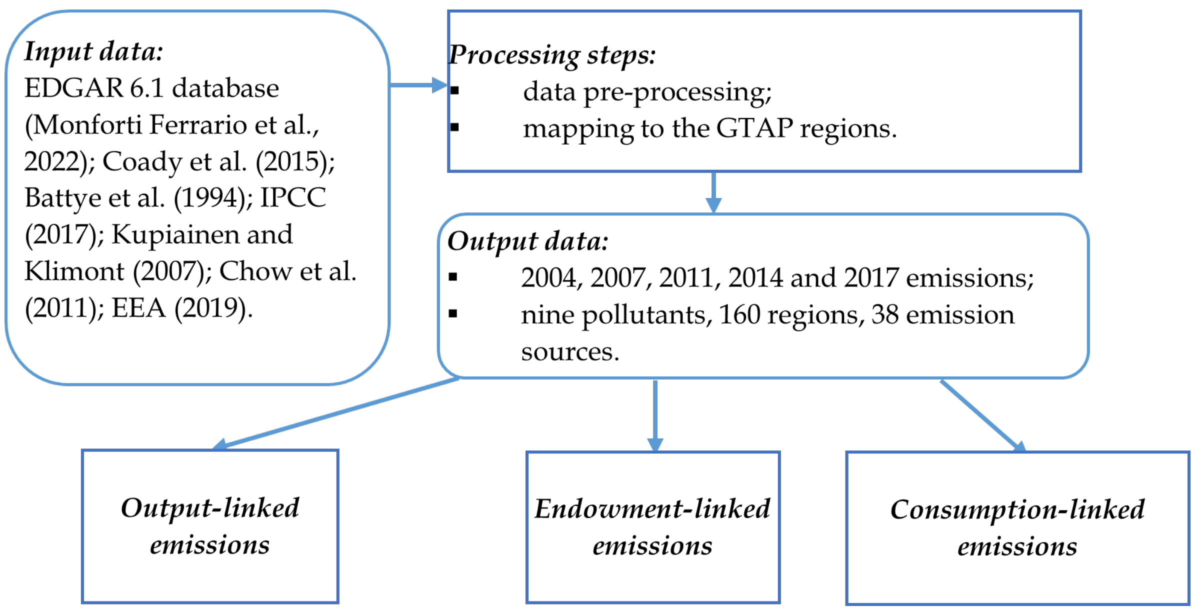
We construct the emissions database for 9 pollutants, 160 GTAP 11 Data Base regions and for the five benchmark years. Emissions are linked to economic activities and three sets of emission sources: consumption (by intermediate and final users), endowment use (land and capital) and output. To assist with emissions allocation between consumption-based sources, the IIASA GAINS-based model emission factors are used (Coady et al. 2015). In addition, emissions from land use activities (biomass burning) are estimated by land cover type, based on the volume of burned biomass (FAO 2023) and emission factors. These emissions are reported separately without association to emission drivers.

One distinctive feature of the GTAP 11 air pollution database compared to the GTAP 10 air pollution database discussed in Chepeliev 2021 is a larger share of emissions associated with burning wood (primarily input from the “frs” sector in the GTAP Data Base). This is caused by the fact that the EDGAR 6.1 database (Monforti Ferrario et al. 2022), unlike earlier versions of EDGAR, now explicitly distinguishes between bio- and fossil-based emissions for all pollutants thus allowing for a more refined mapping of the former category to the GTAP emission drivers. In most cases, bio-based emissions are associated with the use of woody biomass in GTAP and thus lead increasing volumes of emissions associated with the corresponding flows in GTAP 11 (compared to the GTAP 10 air pollution database).

C.3 Air pollutant emissions data mapping to the GTAP Data Base

This section provides a description of the approach used to link the EDGAR-based air pollutant emissions data with the GTAP 11 Data Base. In this effort, we associate each pollution flow with one of the four sets of emission sources: output by industry, endowment by industry, input use by industry and input use by households. To provide a more accurate allocation of emissions between different types of fossil fuel consumption by industry and households we use the GAINS-based emission factors, reported in Coady et al. 2015, IPCC-sourced emission factors provided in IPCC 2017, as well as BC and OC emission factors based on multiple data sources (Kupiainen and Klimont 2007; Chow et al. 2011; EEA 2019). Figure 13.7 provides an overview of the database construction process.

Figure 13.7: GTAP air pollutant emissions database construction process



Notes: This figure excludes treatment of the land use emissions (discussed separately).
Source: Author.

The EDGAR v6.1 database reports emissions from fossil fuel and bio sources. We use this distinction to provide a more consistent mapping of the emissions reported in the EDGAR to the GTAP emission drivers. As the GTAP energy database (Chapter 12) does not report energy flows for biomass or biofuels use, we apply different mappings for the fossil- and bio-based flows. These are reported in Appendix Tables 13.8 and 13.9, respectively.

Air pollutant emissions associated with output by industries

In the case of output-driven categories, emissions are redistributed between corresponding emitting sectors proportionally to the value of sectoral output (Appendix Tables 13.8 and 13.9). With the defined mapping between IPCC categories and the GTAP emission sources, as well as mapping between the IPCC categories and the GTAP emission drivers, output-associated emissions (APQO) are estimated according to the following formula:

$$APQO_{t,e,k,r} = \sum_{c \in \{SecMap_{c,k,e} and DriveMap_{c,Output,e}\}} \frac{EmiReg_{t,e,c,r} ValRedist_{c,e} ValOutpt_{t,k,r}}{sum_{i \in \{SecMap_{c,i,e}} \} ValRedist_{c,e} ValOutpt_{t,i,r}},$$

where t is the set of years (2004, 2007, 2011, 2014 and 2017); e is the set of 9 air pollutants; k, i represent the 65 GTAP sectors; r represents the set of 160 GTAP regions; c is the set of IPCC emission categories. $ValRedist$ identifies cases with emissions redistributed proportionally to GTAP values (such categories are indicated by "#" in Appendix Tables 13.8 and 13.9). $SecMap$ provides the mapping between IPCC categories and GTAP emission sources, while $DriveMap$ provides the mapping between IPCC categories and GTAP emission drivers. $EmiReg$ represents EDGAR-sourced emissions in million metric tons (Mmt) and $ValOutpt$ provides value of output in million USD.

An example of the emissions associated with output includes emissions from the production of pulp, paper, food and drink. These emissions are redistributed proportionally to the values of output of the ten GTAP sectors that represent corresponding activities and are listed in the Appendix Table 13.8.

Air pollutant emissions associated with endowment by industries

Endowment sources account for the smallest share of pollution in all cases. All endowment-driven IPCC pollution categories are redistributed between drivers and sectors proportionally to the GTAP value flows (Appendix Table 13.8), which is similar to the output-driven pollution treatment:

$$APQE_{t,e,m,k,r} =$$

$$\sum_{c \in \{SecMap_{c,k,e} and DriveMap_{c,m,e}\}} \frac{EmiReg_{t,e,c,r} ValRedist_{c,e} Costs_{t,m,k,r}}{\sum_{i \in \{SecMap_{c},i,e,j \in DriveMap_{c,j,e}\}} ValRedist_{c,e} Costs_{t,j,i,r}},$$

where m, j are defined over the set of endowment drivers (land and capital), used for emissions reallocation; Costs coefficient represents the cost structure in million USD. In the database there are two cases of the endowment-linked emissions. The first instance includes emissions from the cultivation of rice, which are linked to the land endowment in the GTAP rice sector (Appendix Table 13.8). The second case includes emissions from manure in pasture, land and paddock. In the latter case emissions are redistributed proportionally to the values of the capital endowment in the three GTAP livestock and animal-related sectors – cattle, raw milk and other animal products (Appendix Table 13.8).

Air pollutant emissions associated with consumption

Non-combustion emissions

Consumption-related pollution reallocation is treated in two ways. In the case of pollution linked to the consumption of chemical products the treatment is similar to the endowment- and output-driven pollution, both for firms ($APQF$) and households ($APQP$):

$$APQF_{t,e,k,j,r} = \sum_{c \in \{SecMap_{c,j,e} and DriveMap_{c,"k",e}\}} \frac{EmiReg_{t,e,c,r} ValRedist_{c,e} Costs_{t,k,j,r}}{\sum_{s \in \{SecMap(c,s,e)\}, i \in \{DriveMap_{c,i,e}\}} ValRedist_{c,e} Costs_{t,i,s,r}},$$

where k, i, j represent the 65 GTAP sectors; s is the set of emission sources and includes traded commodities and households.

$$APQP_{t,e,k,r} = \sum_{c \in \{SecMap_{c,"HHs",e} and DriveMap_{c,"k",e}\}} \frac{EmiReg_{t,e,c,r} ValRedist_{c,e} Costs_{t,k,"HHs",r}}{\sum_{s \in \{SecMap_{c,s,e}\}, i \in \{DriveMap_{c,i,e}\}} ValRedist_{c,e} Costs_{t,i,s,r}},$$

where the “HHs” label identifies households.

An example of the non-combustion consumption-related emissions associated with both firms’ and households’ consumption includes emissions from the non-energy use of lubricants and waxes. In this case emissions are redistributed between all sectors and households proportionally to the value of the use of chemical products by these agents.

Fossil fuel combustion emissions: overall approach and energy flow estimates

A different treatment is applied to the IPCC categories associated with the fossil fuels’ combustion (IPCC categories without “#” sign in the Appendix Table 13.8). Figure 13.8 provides an overview of the general approach to the fuel combustion-related emission redistribution.

In the case of combustion-related emissions, in the first step, we estimate energy use associated with air pollutant emissions. In the case of some IPCC pollution categories, we assume that all energy use is associated with the corresponding pollution, while in other cases a share of all energy use is considered. We consider only such energy use that is associated with energy combustion and exclude fuel feed-stocks that are transformed or exported, which, for instance, is the case for petroleum industry with high volumes of oil transformation. Figure 13.9 provides an overview of the energy data processing steps for the fuel combustion-related emissions treatment.

The GTAP 11 Data Base energy data is not as disaggregated as required for the development of the air pollutant emissions database development, therefore we apply an additional disaggregation. This is the case for petroleum products, which are reported in aggregate in the GTAP

Figure 13.8: Steps to redistribute the fuel combustion-related emissions

(1) GTAP energy use data processing

- ***Data:*** GTAP energy use data for five years, 251 countries, 33 use flows (Appendix Table 13.11), 44 energy commodities (Appendix Table 13.12) and five modes of use.
- **Processing:** estimates of the energy use associated with air pollutant emissions (see Figure 13.11 for additional details).

(2) Emission factors estimates

- ***Data:*** GAINS model-based emission factors for five energy commodities (coal, gasoline, diesel, natural gas for power generation and natural gas for domestic heating), four air pollutants (SO_2, NOx, PM2.5 and VOCs) and 188 countries (Coady et al., 2015); NH_3 emission factors (Battye et al., 1994); CO and VOCs emission factors (IPCC, 2017); OC and BC shares in the PM2.5 (Kupiainen and Klimont, 2007; Chow et al., 2011; EEA, 2019); GTAP energy data from the step (1).
- **Processing:** estimates of the country- and commodity-specific emission factors for nine air pollutants.

(3) Combustion-related emissions redistribution

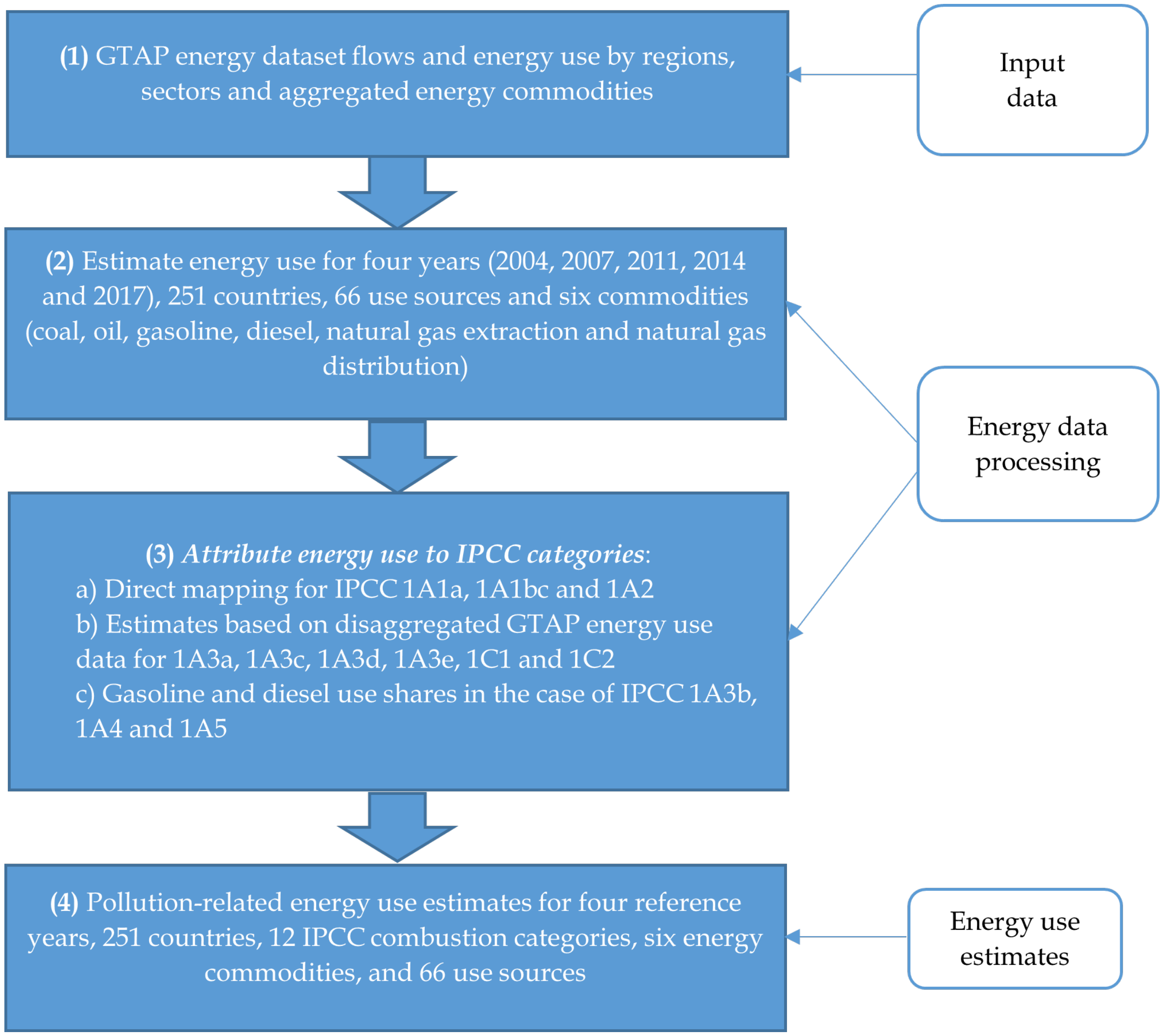
- ***Data:*** GTAP energy use data from the step (1); emission factors from the step (2); EDGAR-based combustion-related emissions.
- **Processing:** redistribution of the combustion-related emissions between drivers and sources.

Source: Author.

11 Data Base, while available emission factors are differentiated for gasoline and diesel. We also need energy use data at a country level (rather than by composite regions). To implement this, we use the GTAP 11 energy dataset (EDS) (Chapter 12) with the corresponding flows reported in the GTAP 11 Data Base energy module. The EDS data provides energy use by years, countries, 33 use flows, 44 energy commodities and five modes of use. Using these two data sources we estimate energy use for four reference years (2004, 2007, 2011, 2014 and 2017), 251 countries, 66 use sources (65 GTAP 11 Data Base sectors and households) and six commodities (coal, oil, gasoline, diesel, natural gas extraction and natural gas distribution).

Using the mappings between IPCC emission sources, emission drivers and the GTAP use sources (Appendix Table 13.8), we allocate estimated energy use flows to the IPCC categories. In the case of public electricity and heat production, other energy industries, as well as manufacturing industries and construction, we assume that the EDGAR-based emissions are redistributed based on all energy use volumes and one-to-many or one-to-one mapping from the IPCC codes to the GTAP use categories is applied. For instance, in the case of coal use in public electricity and heat production, we assume that the emissions are redistributed (in this case only between drivers, as the public electricity and heat production is mapped to a single GTAP sector) based on the coal use data.

Figure 13.9: GTAP energy data processing for the fuel combustion-related emission estimates



Source: Author.

In the case of transportation activities – domestic aviation, road transportation, rail transportation, inland navigation, other transportation, international aviation and international navigation – there is no available one-to-many or one-to-one mapping from the IPCC to GTAP use categories. For instance, GTAP's other transportation sector includes rail, road and other transportation IPCC categories (Appendix Table 13.8). Similarly, air transportation includes both domestic and international aviation. To estimate energy use flows for such categories we use EDS data. A list of the corresponding IPCC categories and mapping to the EDS commodities are provided in the Table 13.12.

Road transportation IPCC category is mapped to the other transportation activity and households (Appendix Table 13.8). To provide a more consistent reallocation of the emission flows, we assume that all gasoline is associated with road transportation activities by households, however, not all diesel is used for road transportation. Therefore, we assume that in the case of households use, the share of diesel used for road transportation equals the share of diesel used for road transportation in total national diesel consumption. For instance, if country A consumes 100 tons of oil equivalent (toe) of diesel fuel of which 80 toe (or 80%) is consumed by road transportation, then we assume that in the case of households the share of diesel used for the road transportation equals 80%, while the remaining 20% is used for the other purposes (e.g., heating).

Finally, in the case of households under residential and other sectors category, we assume that no emissions are associated with gasoline use (as the gasoline-related emissions are attributed to road transportation activities). The share of diesel associated with emissions by households within this category equals "1" less the share of diesel associated with the road transportation use (this would be 0.2 in case of the example above). This step finalizes the GTAP energy data processing for combustion-related emission estimates (Figure 13.9).

Fossil fuel combustion emissions: estimates of emission factors and emissions redistribution

In general, energy use statistics alone could be enough to redistribute the air pollutants between drivers and sectors based on an assumption of uniform emission factors for different energy commodities and industrial processes. But, as the literature suggests (Coady et al. 2015; IPCC 2017), this is not the case, as emission factors vary significantly across commodities and activities. We combine multiple data sources (Battye et al. 1994; Coady et al. 2015; IPCC 2017; Kupiainen and Klimont 2007; Chow et al. 2011; EEA 2019) to derive country-, sector-, energy commodity- and pollutant-specific emission factors.

The International Monetary Fund (IMF) energy subsidies database (Coady et al. 2015) provides emission factors for 188 countries, five energy commodities (coal, gasoline, diesel, natural gas for power generation and natural gas for domestic heating) and four air pollutants (SO_2, NOx, $PM_{2.5}$ and VOCs) based on the IIASA GAINS model. We first estimate weighted average emission factors for seven aggregate regions, five energy commodities and four air pollutants to gap-fill the country cases with unavailable data. For each country with unavailable emission factors, we further use emission factors from the corresponding aggregate region. As the weights for the aggregate region-average emission factors, we use the energy data flows estimated in Step 1 (Figure 13.9). Emission factors for natural gas for domestic heating are applied to natural gas used by households. In the case of natural gas used by industrial users and commercial consumers we apply the emission factors for natural gas used in power generation.

We further map four air pollutants from Coady et al. 2015 to seven air pollutants reported in the EDGAR dataset. The corresponding mapping is provided in the Appendix Table 13.13. In the case of the BC and OC emissions, we further adjust the $PM_{2.5}$ emission factors based on the percentage shares of BC and OC in total $PM_{2.5}$ mass. The corresponding BC and OC mass shares are estimated for six energy commodities (coal, oil, gasoline, diesel, natural gas extraction and natural gas distribution) and 66 emission sources based on Kupiainen and Klimont (2007), Chow et al. (2011) and EEA (2019).

In the case of emission factors for ammonia (NH_3), we use data from Battye et al. 1994 and assume that these factors are uniform across countries. For the conversion of emission factors to uniform units (kt/PJ) we use data on the density of the corresponding fuels (Unitrove 2007; Unitrove 2017b). The energy content of fuels is sourced from Unitrove 2017a. In the case of natural gas, we use the emission factors for utility and industrial boilers for all sectors except for households; for residential users we apply the emission factors of commercial boilers (Battye et al. 1994).

To derive the CO emission factors, we use the IPCC (2017) database. In the IPCC database, emission factors for combustion activities are provided for the 14 IPCC categories (Appendix Table 13.14). Out of the 14 IPCC categories, only eight have available emission factors for CO, which we map to the GTAP use categories (Appendix Table 13.14). In some cases, the IPCC database reports identical emission factors for several IPCC categories (e.g., 1A4A, 1A4B, 1A4C1).

In terms of the emission drivers, out of the 23 fuels reported in the IPCC emission factors database for CO, only 10 have non-zero values and we map them to the six energy commodities for further emissions redistribution (Appendix Table 13.15). IPCC-based estimation of the CO emission factors finalizes the Step 2 of the emissions redistribution process (Figure 13.9). As Coady et al. 2015 do not provide VOCs emission factors for natural gas and coal combustion, we use the IPCC values to gap fill this dataset.

We do not map emission factors related to the biomass combustion, as in the GTAP energy dataset all energy flows associated with the biomass or biofuel use are discarded from the construction process (Chapter 13). We use corresponding value flows to redistribute the bio-based emissions (Appendix Table 13.9). Once available within the GTAP Data Base accounting framework, a reliance on the biomass energy flows could improve the treatment of the bio-based emissions redistribution.

To assist with the combustion-related emissions allocation, we estimate emission weights multiplying combustion-related energy use by the corresponding emission factors to derive the $EFEmiReg$ values. With the processed energy use data and estimated emission factors, we move to the Step 3 (Figure 13.9) and redistribute combustion-related emissions ($ENCOMBEMI$):

$$ENCOMBEMI_{t,r,b,f,s,e} = \frac{EmiReg_{t,e,b,r} EFEmiReg_{t,r,b,f,s,e}}{\sum_{q,v} EFEmiReg_{t,r,b,q,v,e}},$$

where b is the set of air pollutant emission categories in the IPCC emission factors database associated with fossil fuel combustion (Appendix Table 13.14); f, q represent the set of six energy commodities (coal, oil, gasoline, diesel, natural gas extraction and natural gas distribution) associated with air pollutant emissions; s, v correspond to emission sources.

An example of the combustion-related emissions includes emissions from the other energy industries (excluding electricity and heat production). In the GTAP Data Base, the corresponding set of industries is represented by five sectors – mining of coal, oil and gas, production of petroleum products and distribution of gas. The EDGAR-sourced emissions for this category are redistributed between the corresponding five GTAP sectors and four fossil fuel commodities (coal, oil, gas and petroleum products) based on the sector and commodity-specific emission weights, as discussed above.

International aviation and navigation emissions are redistributed between countries based on the value of exports reported in GTAP 11 Data Base for air transport and water transport respectively, excluding exports of travelers' expenditures. These emissions are further mapped to drivers and users and added to the consumption-related emissions. Under such treatment, for example, air pollutant emissions associated with a ship leaving from Rotterdam is accounted in the country of the ship's destination.

After this step, we have redistributed over 99.9% of emissions reported in the EDGAR database. However, as was identified, there are some cases (less than 0.1% of the global air pollutant emissions) where EDGAR-reported emissions corresponding to the combustion-related drivers and users in the GTAP Data Base, have no energy consumption. To deal with such cases, we map such instances to users with non-zero energy consumption. Appendix Table 13.16 provides the mapping.

Finally, the redistributed emissions from the fossil fuel combustion (ENCOMBEMI) are mapped to the emissions associated with the consumption by households (APQP) and firms (APQF).

C.4 Land use emissions

EDGAR v6.1 does not report emissions from large scale biomass burning and activities of land use, land-use change and forestry. To complement the are pollutant database with these emissions, we use the FAO-reported volumes of biomass burning by land cover type and emission factors compiled from several sources. Figure 13.14 provides an overview of the biomass burned (dry matter) by land cover types (FAO, 2023). Volumes of the burned biomass declined by around 18% between 2004 and 2017, reaching 1,692 million tons.

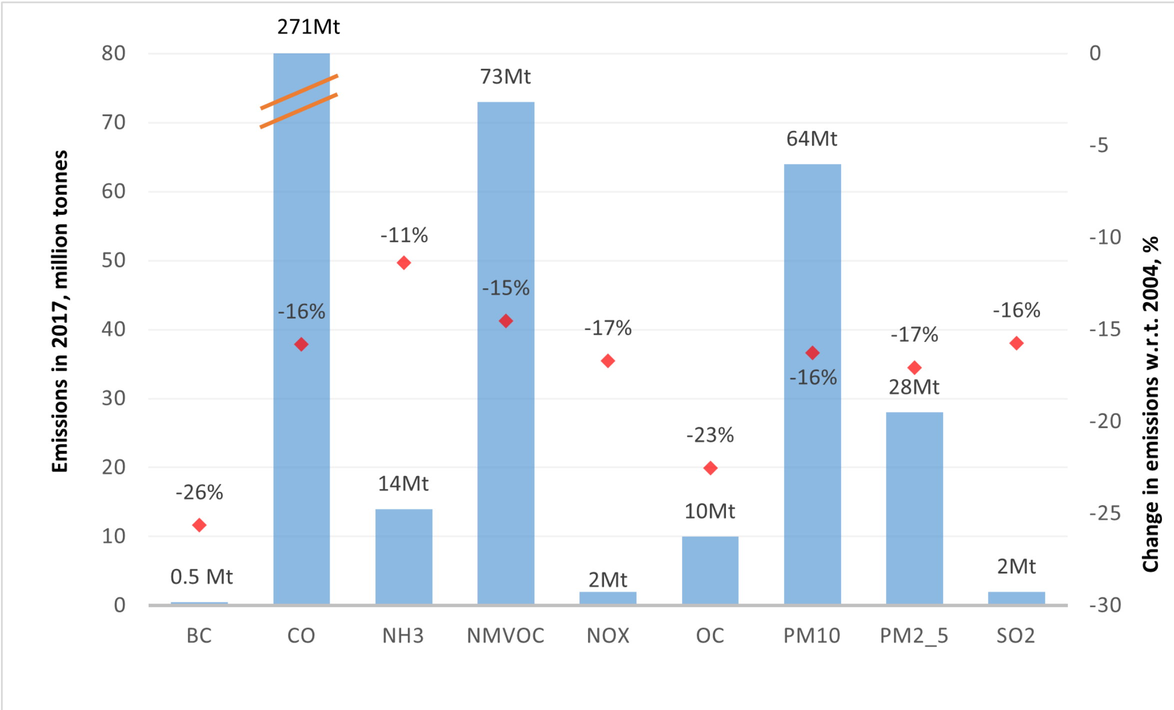
Appendix Table 13.17 provides a summary of assumptions regarding the value of emission factors by land cover type. These emission factors are primarily based on Akagi et al. 2011 and are complemented by estimates from Yokelson et al. 2013 and Hu et al. 2018. As the literature suggests (e.g., Akagi et al. 2011), there is large uncertainty regarding estimated emission factors, so implied estimates of land use-related air pollutant emissions should be used with caution.

Estimates suggest that in the case of all pollutants, over the analyzed time horizon, the highest emission levels were observed in 2004. Emissions across all substances have been declining at a rate of around 1% to 2% per year during 2004-2017 (Figure 13.10). On average (over all pollutants and reference years), organic soils contribute almost 80% of all air pollutant emissions from forests and organic soils combustion (Appendix Table 13.18). This share reaches 93% in the case of SO_2 and 96% in the case of NH_3 in 2017.

C.5 Overview of the air pollutant emissions database

In this section we provide an overview of the air pollutant emissions linked to the GTAP emission drivers, i.e.,emissions that are not associated with the forests and organic soils burning. Over the

Figure 13.10: Global air pollutant emissions from forests and organic soils burning



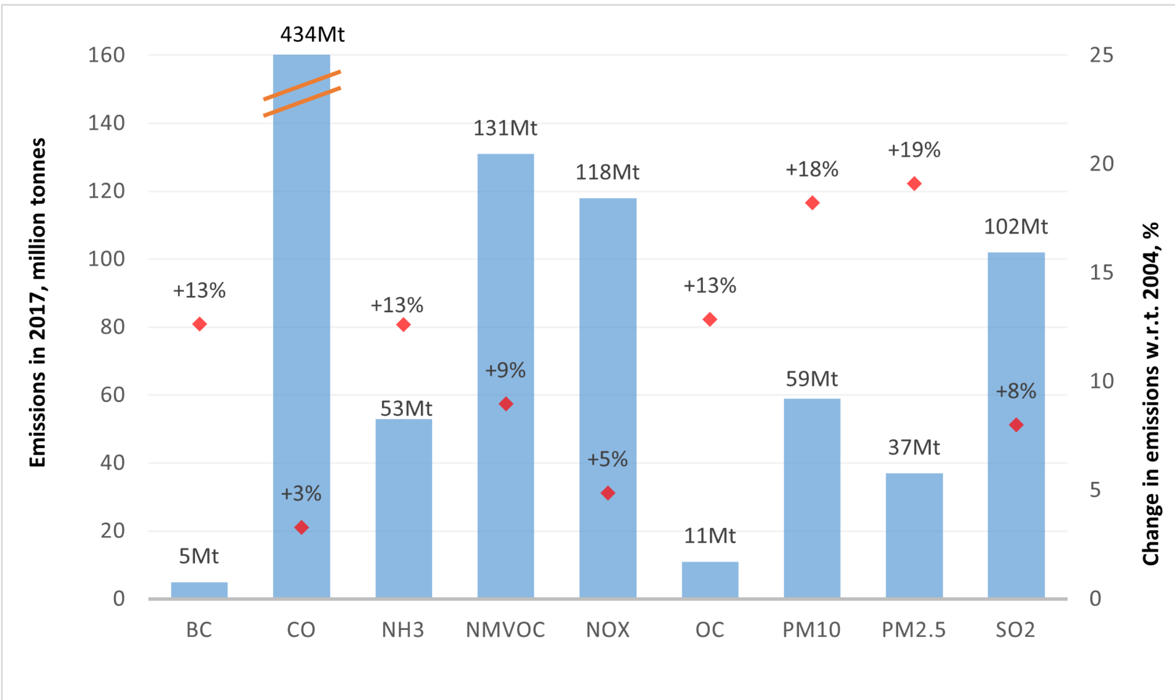
Notes: Columns represent the level of emissions in 2017 (primary vertical axis); diamonds report change in the level of emissions w.r.t. 2004 (secondary vertical axis).
Source: Estimated by author based on FAO 2023; Akagi et al. 2011; Yokelson et al. 2013; Hu et al. 2018.

2004-2017 period global air pollutant emissions have been increasing steadily for all pollutants with the highest growth rates observed for $PM_{2.5}$ (on average 1.4% per year), followed by PM_{10} (1.3% per year) and OC (0.9% per year) (Figure 13.11).

At the global level, consumption is the most common driver of pollution (Figure 13.12). In the case of all 9 air pollutants, intermediate and final consumption accounts for at least 58% of all emissions. Output is the second most important pollution driver for all substances. Only in the case of NH_3 emissions, the endowment driver provides a relatively substantial contribution (13%) to the total volume of emissions, with the corresponding emission flows being associated with land and capital inputs.

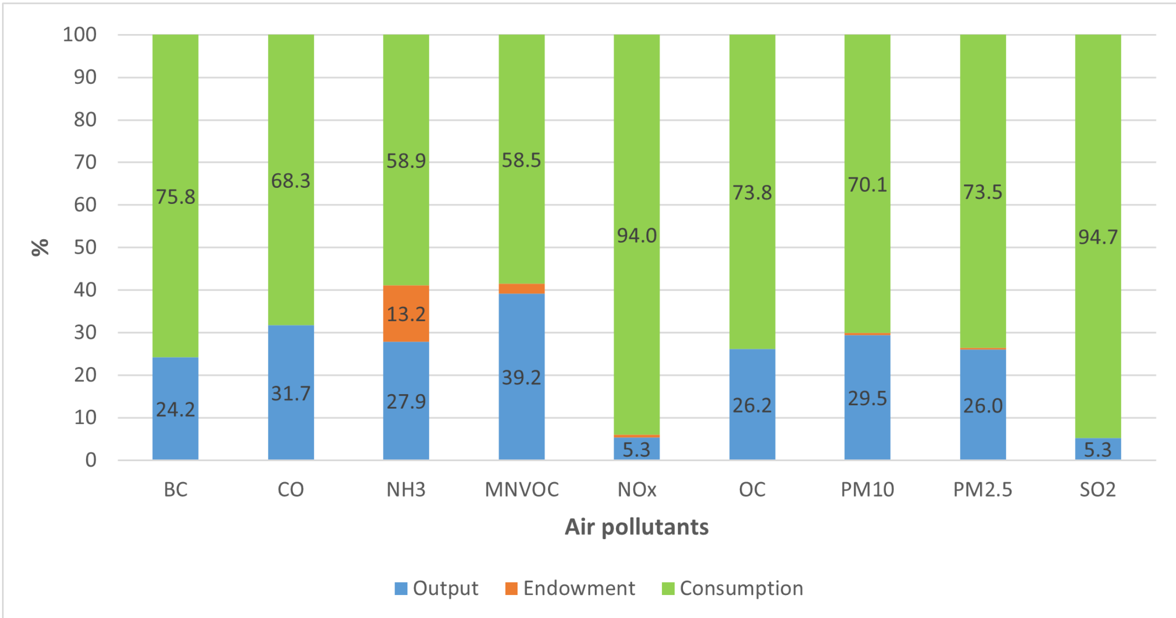
At the sectoral level, key emitters largely vary by air pollutants. Based on the 2017 data, in the case of six pollution categories (BC, CO, NMVOC, OC, PM_{10} and $PM_{2.5}$), households are the key contributors, accounting for at least 27% of all emissions (Figure 13.13). Electricity generation activity is the largest contributor in the case of two pollutants (NOx, and SO_2), reaching almost 43% in the case of SO_2 emissions. At the global level, contribution of the top five key emitting sectors ranges between 52% (for NMVOC) to 75%-76% (for SO_2 and NOx) (Figure 13.13).

Figure 13.11: Global emissions in 2017 by air pollutants



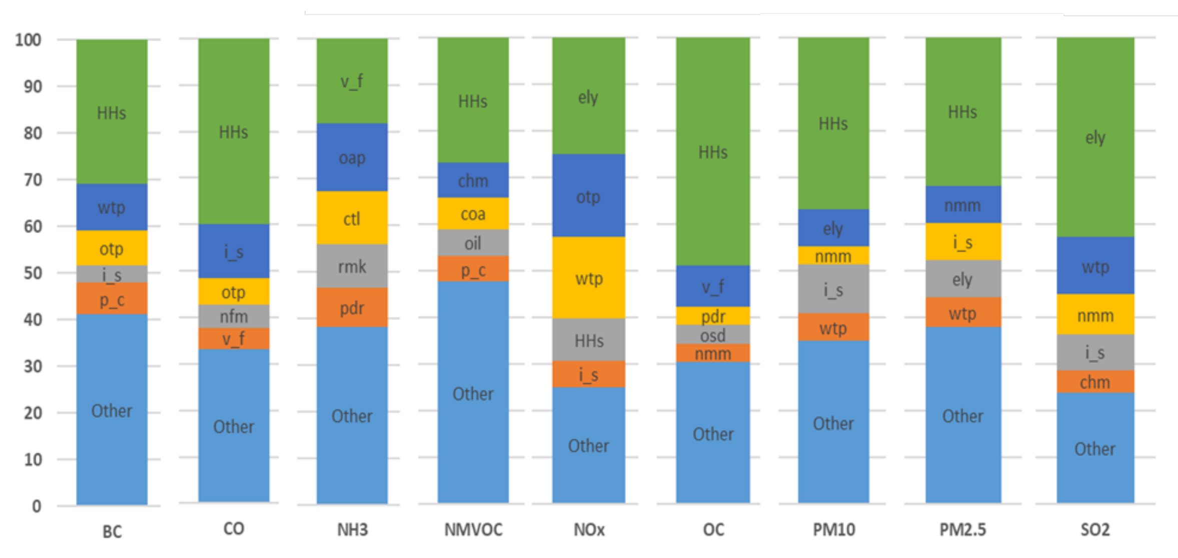
Notes: Emissions from forests and organic soils are not reported on this figure. The red diamond represents the percent changes in emission in 2014 relative to the 2004 levels.
Source: Estimated by author based on EDGAR v6.1 database (Monforti Ferrario et al. 2022) and GTAP 11 air pollutant emissions database.

Figure 13.12: Global average distribution of air pollutants by source (2004, 2007, 2011, 2014 and 2017 weighted average)



Note: Emissions from forests and organic soils are not reported in this figure.
Source: Author's estimates based on EDGAR v6.1 database (Monforti Ferrario et al. 2022) and GTAP 11 air pollutant emissions database.

Figure 13.13: Distribution of global emissions by users in 2017, %



Notes: The top five contributors are explicitly identified for each pollutant, the rest of the users are labeled "Other". Sectoral labels follow definitions provided at . "HHs" stands for households. Emissions from forests and organic soils are not reported in this figure.
Source: Author's estimates based on GTAP 11 air pollutant emissions database.

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Appendix

Table 13.8: Mapping between EDGAR fossil-based air pollutant emission sources, emission drivers and GTAP sectors

No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
1	2	3	4	5[14]	6	7[15]	8
1	1A1a	Public electricity and heat production	Consumption (coa, oil, gas, gdt, p_c)	40	Mapped to the electricity sector as heat production in GTAP is part of the electricity sector	ely	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
2	1A1bc	Other Energy Industries	Consumption (coa, oil, gas, gdt, p_c)	10, 11, 23, 27 (40)	ISIC 40 is excluded as a non-primary source for this category. ISIC 27 emissions are attributed to 1A2 only.	coa, oil, gas, p_c, gdt	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
3	1A2	Manufacturing Industries and Construction	Consumption (coa, oil, gas, gdt, p_c)	15-22, 24-37, 45 (10-14, 23)	ISIC 10-11 and 23 are excluded as non-primary sources and to avoid overlapping with 1A1bc. ISIC 12-14 are included to complement sectoral coverage of 1A1a and 1A1bc.	oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, cns	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
4	1A3a	Domestic aviation	Consumption (coa, oil, gas, gdt, p_c)	62	1-to-1 correspondence with GTAP sector	atp	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)

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[14] ISIC Rev. 3.1 codes are derived from EUROSTAT 2015, unless otherwise noted. ISIC codes in round brackets suggest possible (non-primary) mapping.

[15] GTAP use sources include 65 sectors and households.

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
5	1A3b_NORES	Road transportation (no resuspension)	Consumption (coa, oil, gas, gdt, p_c)	01-99, H. transport	Emissions are attributed to Other transportation and households	otp, HHs[16]	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
6	1A3b_RES#	Road transportation (resuspension)	Output		Emissions are linked to road transportation only	otp	
7	1A3c	Rail transportation	Consumption (coa, oil, gas, gdt, p_c)	60	1-to-1 correspondence with GTAP sector	otp	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
8	1A3d	Inland navigation	Consumption (coa, oil, gas, gdt, p_c)	61, 05	While EUROSTAT 2015 maps ISIC 05 into 1A3d category, IPCC guidelines (Houghton et al. 1997) excludes fishing from 1A3d category.	wtp	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
9	1A3e	Other transportation	Consumption (coa, oil, gas, gdt, p_c)	60	1-to-1 correspondence with GTAP sector. Mainly pipeline transport and non-specified transportation.	otp	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)

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[16] In the case of households, 1A3B emissions are linked to the “p_c” use only.

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
10	1A4	Residential and other sectors	Consumption (coa, oil, gas, gdt, p_c)	01-05, 50-99 (40), House-holds	ISIC 40 is excluded as non-primary source. Transport sectors are excluded as non-primary contributors. ISIC 41 is added for water distribution activities coverage	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, frs, fsh, wtr, trd, afs, whs, cmn, ofi, ins, obs, rsa, ros, osg, edu, hht, dwe, HHs[17]	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
11	1A5	Other	Consumption (coa, oil, gas, gdt, p_c)	50-99, (40)	ISIC 40 is excluded as non-primary source. Transport sectors are excluded as non-primary contributors. ISIC 41 is added for water distribution activities coverage	wtr, trd, afs, whs, cmn, ofi, ins, obs, rsa, ros, osg, edu, hht, dwe	Energy use data; emission factors (Coady et al. 2015; IPCC 2017)
12	1B1#	Fugitive emissions from solid fuels	Output	10, 23, 27 (24, 26, 40)	Mainly associated with coal, mapped only to ISIC 10 (in line with Irfanoglu and Mensbrugghe 2016)	coa[18]	Direct attribution

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[17] In the case of households, 1A4 emissions are linked to the use of “coa”, “oil”, “gas” and “gdt”.

[18] For a number of country cases, in particular in Africa, relatively large 1B1 emissions are associated with small values of coal and/or coke output, leading to the emission intensities of the corresponding flows being over 1000 times higher than the world average. For these specific country cases we have redistributed 1B1 emissions between coa, oil, gas, p_c, gdt and ely uses.

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
13	1B2#	Fugitive emissions from oil and gas	Output	11, 23, 40, 50, (60, 63)	Emission is associated only with ISIC 11, 23 and 40. Due to the highly aggregated trade sector ("trd") in GTAP Data Base, we exclude ISIC 50 code from mapping.	gas, oil, gdt, p_c	Distribute proportionally to output
14	1C1	Memo: International aviation	Consumption (coa, oil, gas, gdt, p_c)	62*		atp	Distributed by regions based on the value of exports[19]
15	1C2	Memo: International navigation	Consumption (coa, oil, gas, gdt, p_c)	61*		wtp	Distributed by regions based on the value of exports
16	2A1#	Cement production	Output	26		nmn	Direct attribution
17	2A2#	Lime production	Output	26		nmn	Direct attribution
18	2A4#	Production of other minerals	Output	26		nmn	Direct attribution
19	2A7#	Other (mineral products)	Output	26		nmn	Direct attribution
20	2B#	Production of chemicals	Output	24	Taking into account GTAP sectoral splits, all emissions are attributed to ISIC 24.1, 24.2	chm	Direct attribution
21	2C#	Production of metals	Output	27		i_s, nfm	Distributed proportionally to output values
22	2D#	Production of pulp/paper/food/-drink	Output	15, 20, 21		cmt, omt, vol, mil, pcr, sgr, ofd, b_t, lum, ppp	Distributed proportionally to output values

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[19] Fugitive emissions from international navigation are mapped to the fuel use in water transportation sector.

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
23	2G#	Non-energy use of lubricants/waxes	Consumption of chemical products (“chm”)	-		All sectors, including HHs	Distributed proportionally to chemical products use
24	3A#	Solvent and other product use: paint	Consumption of chemical products (“chm”)	20-22, 24-36, 45, 50, H. other	ISIC 24.3 is excluded as it is a minor part of “tex” sector	lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, cns, trd, afs, HHs	Distributed proportionally to chemical products use
25	3B#	Solvent and other product use: degrease	Consumption of chemical products (“chm”)	27, 28, 32, 93		i_s, nfm, fmp, ele, ros	Distributed proportionally to chemical products use
26	3C#	Solvent and other product use: chemicals	Consumption of chemical products (“chm”)	17, 19, 24, 25, 45		tex, lea, chm, bph, rpp, cns	Distributed proportionally to chemical products use
27	3D#	Solvent and other product use: other	Consumption of chemical products (“chm”)	15, 20, 22, 26, 34-36, 50, 85, H. other		b_t, lum, ppp, nmm, mvh, otn, omf, trd, afs, osg, edu, hht, HHs	Distributed proportionally to chemical products use
28	4B#	Manure management	Output	1		ctl, oap, rmk	Distributed proportionally to output
29	4C#	Rice cultivation	Endowment (land)	1		pdr	Direct mapping
30	4D1#	Direct soil emissions	Consumption of chemical products (“chm”)	1		pdr, wht, gro, v_f, osd, c_b, pfb, ocr	Distributed proportionally to chemical products consumption

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
31	4D2#	Manure in pasture/range/-paddock	Endowment (capital)	1		ctl, oap, rmk	Distributed proportion-ally to capital use
32	4D4#	Other direct soil emissions	Consumption of chemical products (“chm”)	1		pdr, wht, gro, v_f, osd, c_b, pfb, ocr	Distributed proportion-ally to chemical products consump-tion
33	4F#	Agricultural waste burning	Output	1		pdr, wht, gro, v_f, osd, c_b, pfb, ocr	Distributed proportion-ally to sectoral output
34	6A#	Solid waste disposal on land	Output	75, 90		wtr	Direct mapping
35	6B#	Wastewater handling	Output	10-45, 90	ISIC 90 is assumed to be key contributor, others are ignored	wtr	Direct mapping
36	6C#	Waste incineration	Output	01, 10-37, 75, 90, 93	Agricultural sectors are excluded and it is assumed that all agricultural waste burning is associated with 4F	coa, oil, gas, oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, p_c, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, wtr	Distributed proportion-ally to sectoral output
37	6D#	Other waste handling	Output	01, 90		pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, wtr	Distributed proportion-ally to sectoral output

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	ISIC Rev. 3 code	Comments on sectoral mapping	GTAP 11 use sources mapping	Source for emissions distribution
38	7A#	Fossil fuel fires	Output		Fossil-fuel fires are assumed to be mainly associated with coal mining and oil extraction	coa, oil	Distributed proportion-ally to sectoral output

Notes: *Authors' assumptions on coding; # indicates IPCC categories with emission distribution based on GTAP value data.
Source: Developed by authors.

Table 13.9: Mapping between EDGAR bio-based air pollutant emission sources, emission drivers and GTAP sectors

No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	Comments on sectoral mapping (ISIC 3.1 codes are reported)	GTAP 11 use sources mapping	Source for emissions distribution
1	2	3	4	6	7	8
1	1A1a	Public electricity and heat production	Consumption (frs, lum)	Mapped to the electricity sector as heat production in GTAP is part of the electricity sector	ely	Distributed proportionally to intermediate consumption
2	1A1bc	Other Energy Industries	Consumption (frs, lum)	ISIC 40 is excluded as a non-primary source for this category. ISIC 27 emissions are attributed to 1A2 only.	coa, oil, gas, p_c, gdt	Distributed proportionally to intermediate consumption
3	1A2	Manufacturing Industries and Construction	Output	ISIC 10-11 and 23 are excluded as non-primary sources and to avoid overlapping with 1A1bc. ISIC 12-14 are included to complement sectoral coverage of 1A1a and 1A1bc. Output is used as the main driver to avoid instances of non-energy intermediate use in specific sectors (e.g. "frs" and "lum" use in construction industry)	oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, cns	Distributed proportionally to output
4	1A3b_NORE	Road transportation (no resuspension)	Consumption (p_c)		Emissions are attributed to Other transportation	otp
5	1A3b_RES	Road transportation (resuspension)	Output		Emissions are linked to road transportation only	otp
6	1A3c	Rail transportation	Consumption (p_c)	60	1-to-1 correspondence with GTAP sector	otp
7	1A3d	Inland navigation	Consumption (p_c)	61, 05	While EUROSTAT 2015 maps ISIC 05 into 1A3d category, IPCC guidelines (Houghton et al. 1997) excludes fishing from 1A3d category.	wtp

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	Comments on sectoral mapping (ISIC 3.1 codes are reported)	GTAP 11 use sources mapping	Source for emissions distribution
8	1A3e	Other transportation	Consumption (p_c)	60	1-to-1 correspondence with GTAP sector. Mainly pipeline transport and non-specified transportation.	otp
9	1A4	Residential and other sectors	Consumption (frs)	Literature suggests that in the case of residential and other non-agricultural sectors, the main source of $PM_{2.5}$ bio emissions in the major emitting countries – China, India and Nigeria – is the households' consumption of the solid biomass for cooking and heating purposes (Zhang and Cao 2015; Nagar et al. 2017; Chowdhury et al. 2019). Therefore, 1A4 emissions are mapped to households' consumption of the solid biomass ('frs') in the GTAP framework.	HHs	Distributed proportionally to consumption
10	1B1	Fugitive emissions from solid fuels	Output	Following IPCC (2019), four sources of fugitive emissions for biomass are identified, these include emissions arising during the production of charcoal and biochar, emissions during the production of wood pellets and emissions from the transformation of biomass into syngas, and, then into liquid hydrocarbons fuels.	chm, lum, gdt	Direct attribution

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No.	IPCC 1996 code	Air pollutant emissions source description	Emission driver	Comments on sectoral mapping (ISIC 3.1 codes are reported)	GTAP 11 use sources mapping	Source for emissions distribution
11	1B2	Fugitive emissions from oil and gas	Output	11, 23, 40, 50, (60, 63)	Emission is associated only with ISIC 11, 23 and 40. Due to the highly aggregated trade sector ("trd") in GTAP Data Base, we exclude ISIC 50 code from mapping.	gas, oil, gdt, p_c
12	1C2	Memo: International navigation	Consumption (p_c)	There are some small volumes of bio-based emissions associated with international navigation. These are assumed to be coming from combustion of bio fuel.	wtp	
13	2C	Production of metals	Output		i_s, nfm	Distributed proportionally to output values
14	4F	Agricultural waste burning	Output		pdr, wht, gro, v_f, osd, c_b, pfb, ocr	Distributed proportionally to sectoral output
15	6C	Waste incineration	Output	Agricultural sectors are excluded and it is assumed that all agricultural waste burning is associated with 4F	coa, oil, gas, oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, p_c, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, wtr	Distributed proportionally to sectoral output

Notes: *Authors' assumptions on coding.

Source: Developed by authors.

Table 13.10: Concordance between GTAP energy dataset industries and GTAP sectors

No.	GTAP energy dataset (EDS) use flows	Use flow names
1	Exp	Export
2	IntlMarBnkr	International marine bunkers
3	IntlAvBnkr	International aviation bunkers
4	Elect_Gen	Electricity generation
5	P_C_Transfm	Petroleum and coal transformation
6	Gas_Transfm	Gas transformation
7	Coal	Coal mines
8	CrudeOils	Crude oil
9	NatGas	Natural gas
10	IronXSteel	Iron and steel
11	ChemXPetro	Chemical and petrochemical
12	FidStok4CRP	Petrochemical feed-stocks
13	NonFeroMetal	Non-ferrous metals
14	NonMetalMinr	Non-metallic minerals
15	TranspEqpmt	Transport equipment
16	MachineryMf	Machinery
17	MiningXQuary	Mining and quarrying
18	FoodXTabaco	Food and tobacco
19	PapXPulpXPrn	Paper, pulp and printing
20	WoodXWudProd	Wood and wood products
21	ConstrctnInd	Construction
22	TextlXLether	Textile and leather
23	NonSpecfInd	Non-specified industry
24	DomAviaTrnsp	Domestic air transport
25	RoadTransp	Road transport
26	RailTransp	Rail transport
27	PipelnTransp	Pipeline transport
28	HomeOwnShips	Internal navigation
29	NonSpecTrnsp	Non-specified transport
30	AgriForFish	Agriculture, forestry and fishery
31	ComXPubServ	Commercial and public services
32	HouseHolds	Households
33	MilitaryUse	Military use

Source: Based on IEA 2017; McDougall and Chepeliev 2021.

Table 13.11: Concordance between disaggregated GTAP energy dataset (EDS) commodities and aggregated energy commodities reported in the standard GTAP Data Base

No.	GTAP EDS commodity code	GTAP EDS commodity description	Corresponding aggregated GTAP energy commodity
1	AntCoal	Anthracite	coa
2	CokCoal	Coking coal	coa
3	BitCoal	Other bituminous coal	coa
4	SubCoal	Sub-bituminous coal	coa
5	Lignite	Lignite	coa
6	PatFuel	Patent fuel	coa
7	OvenCoke	Coke oven coke	p_c
8	GasCoke	Gas coke	p_c
9	CoalTar	Coal tar	p_c
10	BKB	Brown coal briquettes	coa
11	GasWksGs	Gas works gas	gas
12	CokeOvGs	Coke oven gas	p_c
13	BlFurGs	Blast furnace gas	p_c
14	OGases	Other recovered gases	p_c
15	Peat	Peat	coa
16	PeatProd	Peat products	coa
17	OilShale	Oil shale and oil stands	oil
18	NatGas	Natural gas	gas
19	CrudeOil	Crude oil	oil
20	NGL	Natural gas liquids	gas
21	RefFeeds	Refinery feedstocks	p_c
22	Additive	Additives/blending components	crp
23	NonCrude	Other hydrocarbons	crp
24	RefinGas	Refinery gas	p_c
25	Ethane	Ethane	p_c
26	LPG	Liquefied petroleum gases	p_c
27	NonBioGaso	Motor gasoline excluding bio	p_c
28	AvGas	Aviation gasoline	p_c
29	JetGas	Gasoline type jet fuel	p_c
30	NonBioJetK	Kerosene type jet fuel excl. bio	p_c
31	OthKero	Other Kerosene	p_c
32	NonBioDies	Gas/diesel oil excluding bio	p_c
33	ResFuel	Fuel oil	p_c
34	Naphtha	Naphtha	p_c
35	WhiteSp	White spirit and industrial spirit (SPB)	p_c
36	Lubric	Lubricants	p_c
37	Bitumen	Bitumen	p_c
38	ParWax	Paraffin waxes	p_c
39	PetCoke	Petroleum coke	p_c
40	ONonSpec	Non-specified oil products	p_c
41	Electr	Electricity	ely
42	Heat	Heat	ely

Source: Based on IEA 2017; McDougall and Chepeliev 2021.

Table 13.12: Correspondence between IPCC categories and GTAP energy dataset commodities

IPCC category code	IPCC category description	GTAP EDS use flow code	GTAP EDS use flow description
1A3a	Domestic aviation	DomAviaTrnsp	Domestic air transport
1A3c	Rail transportation	RailTransp	Rail transport
1A3d	Inland navigation	HomeOwnShips	Internal navigation
1A3e	Other transportation	PipelnTransp	Pipeline transport
1A3e	Other transportation	NonSpecTrnsp	Non-specified transport
1C1	Memo: International aviation	IntlAvBnkr	International aviation bunkers
1C2	Memo: International navigation	IntlMarBnkr	International marine bunkers

Source: Author.

Table 13.13: Correspondence between air pollutants with available emission factors and EDGAR dataset air pollutants

No.	EDGAR database pollutants	EDGAR database pollutant name	Air pollutants with available emission factors	Emission factors source
1	BC	Black carbon	$PM_{2.5}$ + estimates of the BC share	Kupiainen and Klimont 2007; EEA 2019; Coady et al. 2015
2	CO	Carbon monoxide	CO	IPCC 2017
3	NH_3	Ammonia	NH_3	Battye et al. 1994
4	NMVOC	Non-methane volatile organic compounds	Volatile organic compounds (VOCs)	Coady et al. 2015
5	NOx	Nitrogen oxides	NOx	Coady et al. 2015
6	OC	Organic carbon	$PM_{2.5}$ + estimates of the OC share	Kupiainen and Klimont 2007; Chow et al. 2011; EEA 2019; Coady et al. 2015
7	PM_{10}	Particulate matter 10	$PM_{2.5}$	Coady et al. 2015
8	$PM_{2.5}$	Particulate matter 2.5	$PM_{2.5}$	Coady et al. 2015
9	SO_2	Sulfur dioxide	SO_2	Coady et al. 2015

Source: Author.

Table 13.14: Correspondence between IPCC combustion-related categories in the IPCC emission factor database and GTAP sectors

No.	IPCC category code	IPCC category description	Fossil fuel combustion emission factors data availability for CO	GTAP use categories
1	1A	Fuel combustion activities	-	-
2	1A1	Energy industries	+	coa, oil, gas, p_c, ely, gdt
3	1A2	Manufacturing industries and construction	+	oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, mvh, otn, ele, eeq, ome, omf, cns
4	1A3A	Civil aviation	+	atp
5	1A3A1	International aviation (international bunkers)	-	-
6	1A3A2	Domestic aviation	-	-
7	1A3B_NORES	Road transportation (no resuspension)	+	otp
8	1A3C	Railways	+	otp
9	1A3D	Navigation	+	wtp
10	1A4A	Commercial/institutional	+ (database provides identical emission factors for all three IPCC categories)	wtr, trd, afs, whs, cmn, ofi, ins, obs, rsa, ros, osg, edu, hht, dwe
11	1A4B	Residential	+ (database provides identical emission factors for all three IPCC categories)	HHs
12	1A4C1	Stationary emission in agriculture/forestry/fishing	+ (database provides identical emission factors for all three IPCC categories)	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, frs, fsh
13	1A4C2	Off-road vehicles and other machinery emission in agriculture/forestry/fishing	-	-
14	1A5B	Other mobile emission	+	-

Source: Based on IPCC 2017.

Table 13.15: Correspondence between IPCC database fuels and six energy commodities for air pollutant emission estimates

No	IPCC database fuel code	IPCC fuel code description	Air pollutant emissions database fuels
1	111	Wood/wood waste	-
2	112	Charcoal	-
3	205	Diesel oil	Diesel (“dsl”)
4	208	Motor gasoline	Gasoline (“gsl”)
5	301	Natural gas*	Gas extraction and distribution (“gas”, “gdt”)
6	302	Natural gas liquids*	-
7	318	Other bituminous coal*	-
8	322	Other oils	Oil (“oil”)
9	329	Other solid biomass	-
10	S01	Undifferentiated coal*	Coal (“coa”)

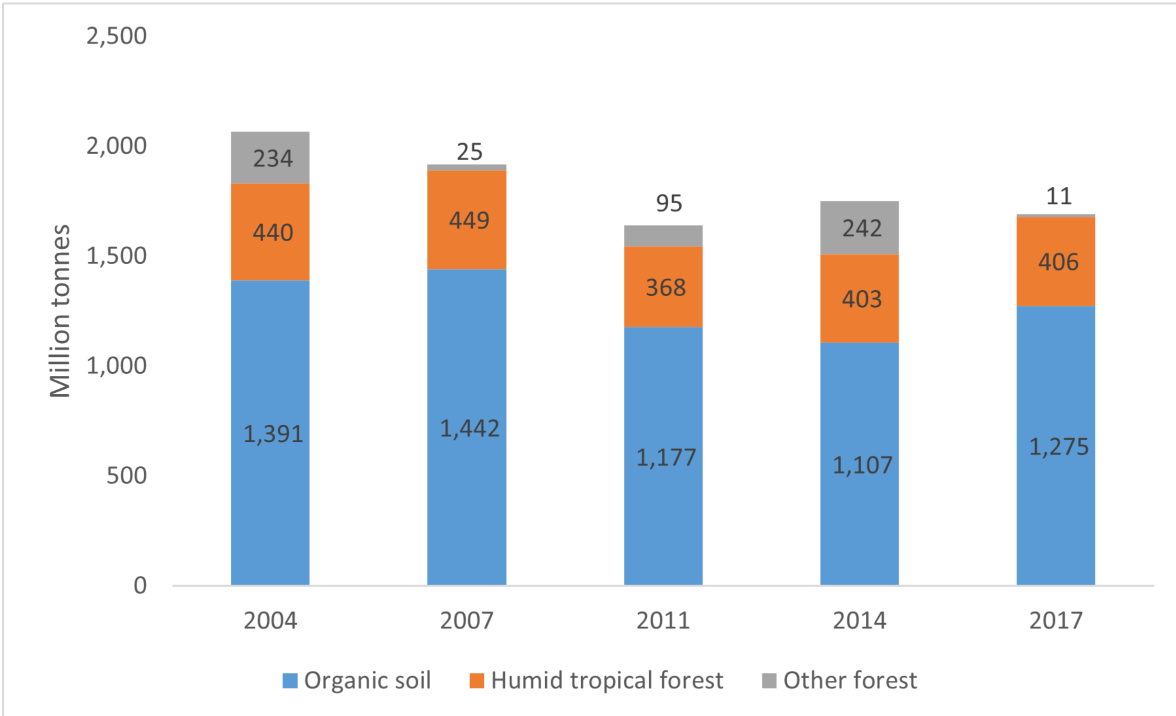
Notes: *Natural gas (301) and Natural gas liquids (302), as well as Other bituminous coal (318) and Undifferentiated coal (S01) have identical emission factors. Therefore, for the mapping purposes only one representative product from each pair is used.
Source: Based on IPCC 2017.

Table 13.16: IPCC correspondence for additional air pollutants redistribution between GTAP users and drivers

No.	IPCC pollution categories with cases of zero-energy use data in GTAP Data Base and non-zero emissions in EDGAR database		IPCC pollution categories used for emissions redistribution	
1	X1A3a	Domestic aviation	X1A4	Residential and other sectors
2	X1A3d	Inland navigation	X1A4	Residential and other sectors
3	X1A1bc	Other Energy Industries	X1A2	Manufacturing Industries and Construction
4	X1A3c	Rail transportation	X1A3b_NORES	Road transportation (no resuspension)
5	X1A3e	Other transportation	X1A3b_NORES	Road transportation (no resuspension)

Source: Author.

Figure 13.14: Biomass burned (dry matter) by land cover types and years, million tons



Source: FAO 2023.

Table 13.17: Emission factors for biomass burning (dry matter), g kg-1

No.	Pollutant	Pollutant name	Organic soils	Humid tropical forest	Other forest
1	BC	Black carbon	0.2	0.52	0.56
2	CO	Carbon monoxide	182	93	122
3	NH_3	Ammonia	10.8	1.33	2.46
4	NMVOC	Non-methane volatile organic compounds	48.7	26	27
5	NOx	Nitrogen oxides	0.8	2.55	1.12
6	OC	Organic carbon	6.23	4.71	9.15
7	PM_{10}	Particulate matter 10	44.00*	18.5	30.49*
8	$PM_{2.5}$	Particulate matter 2.5	19.17*	9.1	15
9	SO_2	Sulfur dioxide	1.76*	0.4	1.06*

Notes: Emission factors (EFs) not marked by "*" are sourced from Akagi et al. 2011. In the case of Other forest category, EFs for Extratropical forest are used, which represent a weighted average of boreal and temperate forest EFs (Akagi et al. 2011). SO_2 EFs for Organic soils and Other forest categories are sourced from Yokelson et al. 2013 PM_{10} and $PM_{2.5}$ EFs for Organic soils are sourced from Hu et al. 2018, using estimates for boreal and temperate peat. PM_{10} EF for Other forest is derived from $PM_{2.5}$ emission factor assuming the same composition of particulate (i.e. ration of $PM_{2.5}$ and PM_{10} EFs) as in the case of Humid tropical forest.
Source: Based on Akagi et al. 2011; Yokelson et al. 2013; Hu et al. 2018.

Table 13.18: Emissions from biomass burning in 2017, million tons

No.	Pollutant	Pollutant name	Humid tropical forest	Other forest	Organic soils
1	BC	Black carbon	0.2	0	0.3
2	CO	Carbon monoxide	37.5	1.4	232
3	NH_3	Ammonia	0.5	0	13.8
4	NMVOC	Non-methane volatile organic compounds	10.5	0.3	62.1
5	NOx	Nitrogen oxides	1	0	1
6	OC	Organic carbon	1.9	0.1	7.9
7	PM_{10}	Particulate matter 10	7.5	0.3	56.1
8	$PM_{2.5}$	Particulate matter 2.5	3.7	0.2	24.4
9	SO_2	Sulfur dioxide	0.2	0	2.2

Source: Estimated by author.