

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-CO₂ GHGs - methane (CH₄), nitrous oxide (N₂O) and the group of fluorinated gases (F-gases), and cover seven reference years – 2004, 2007, 2011, 2014, 2017, 2019 and 2023. In addition, CO₂ 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 CO₂ emissions from fossil fuel combustion only. In 2022, over 28% of all GHGs were associated with non-CO₂ GHGs, including CH₄, N₂O and F-gases (Crippa et al. 2025).

Due to the important contribution of non-CO₂ GHG emissions to climate mitigation pathways, since GTAP Version 6, a special version of the GTAP non-CO₂ emissions dataset has been constructed. GTAP 6 non-CO₂ dataset (Rose and Lee 2009) with 2001 reference year was developed based on emission accounts provided in a detailed non-CO₂ and non-fossil fuel combustion CO₂ ("Other CO₂") greenhouse gas emissions database (Rose, Finn, et al. 2007).

For GTAP 7 and 8, a non-CO₂ emission dataset was developed by an extrapolation of Rose, Finn, et al. 2007 data to match each of the reference years. In GTAP 7, CH₄ and N₂O emission growth rates were used from the 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-CO₂ 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

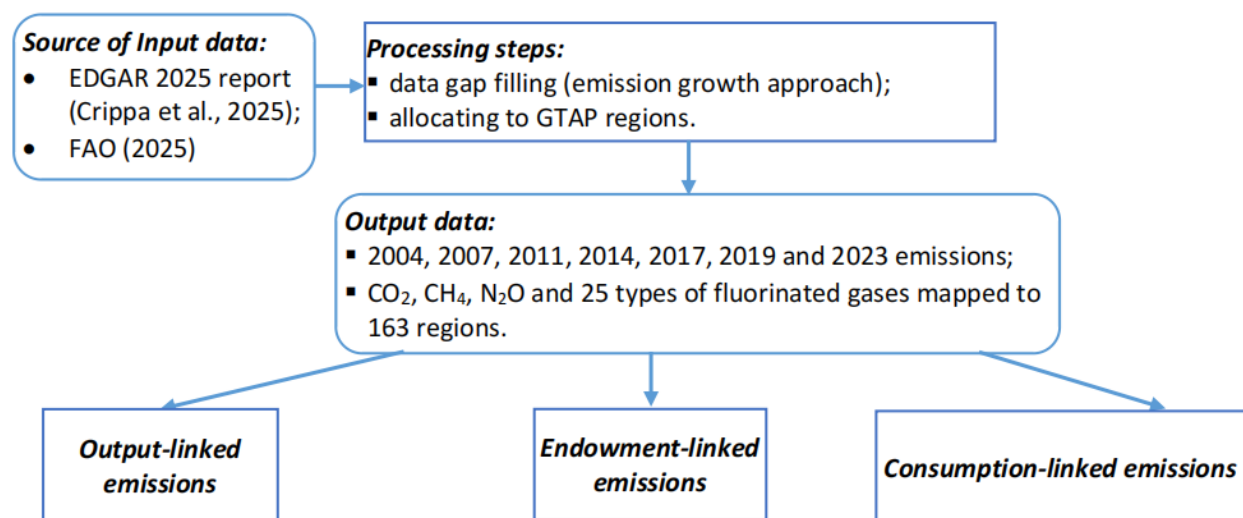
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growth approach was used to project emissions from 2010 to 2011 levels, assuming that 2010-2011 emissions growth rate equals 2007-2010 emissions growth rate.

The GTAP 10 non-CO₂ emissions dataset construction followed the general approach outlined in Irfanoglu and Mensbrugghe 2015 with further updates and modifications (Chepeliev 2020). The GTAP 11 non-CO₂ 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-CO₂ 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 CO₂ 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 CO₂ 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-CO₂ 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-CO₂ database. FAOSTAT does not report agricultural emissions of fluorinated gases, but only N₂O and CH₄ 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 N₂O or CH₄.

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 ₂ O, CH ₄	Output
2	BSAV	Burning savanna	N ₂ O, CH ₄	Land
3	CLOS	Cultivation of organic soils	N ₂ O	Land
4	CRES	Crop residues	N ₂ O	Output
5	MPAS	Manure left on pastures	N ₂ O	Capital
6	MASL	Manure applied to soils	N ₂ O	Capital
7	SNTF	Synthetic fertilizers	N ₂ O	Input use of chemical products (“chm”)
8	RICC	Rice cultivation	CH ₄	Land
9	MMNG	Manure management	N ₂ O, 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 N₂O emissions from crop residues⁴ (“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

³Non-CO₂ GHG emissions from fossil fuel combustion in agriculture are sourced from the EDGAR dataset (see next Section).

⁴GHG emissions from crop residues consist of direct and indirect N₂O 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 N₂O 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 N₂O emissions. Such a mapping approach is applied to all non-CO₂ 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 CO₂, CH₄, N₂O 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 CO₂ 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 CO₂ 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.

⁵Fuel 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 ₂ O 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-CO₂ 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 CO₂-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-CO₂ 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.

⁶Though all GWPs are region-generic, F-gases category has different composition by regions thus resulting in region-specific GWPs. GWPs for CH₄ and N₂O are uniform across regions.

⁷GTAP 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 ₂ O, CH ₄
4.	Burning – biomass (BrnBiom)	Other forest (OthFrs)	N ₂ O, CH ₄
5.	Burning – biomass (BrnBiom)	Organic soils (OrgSoil)	CO ₂ , CH ₄

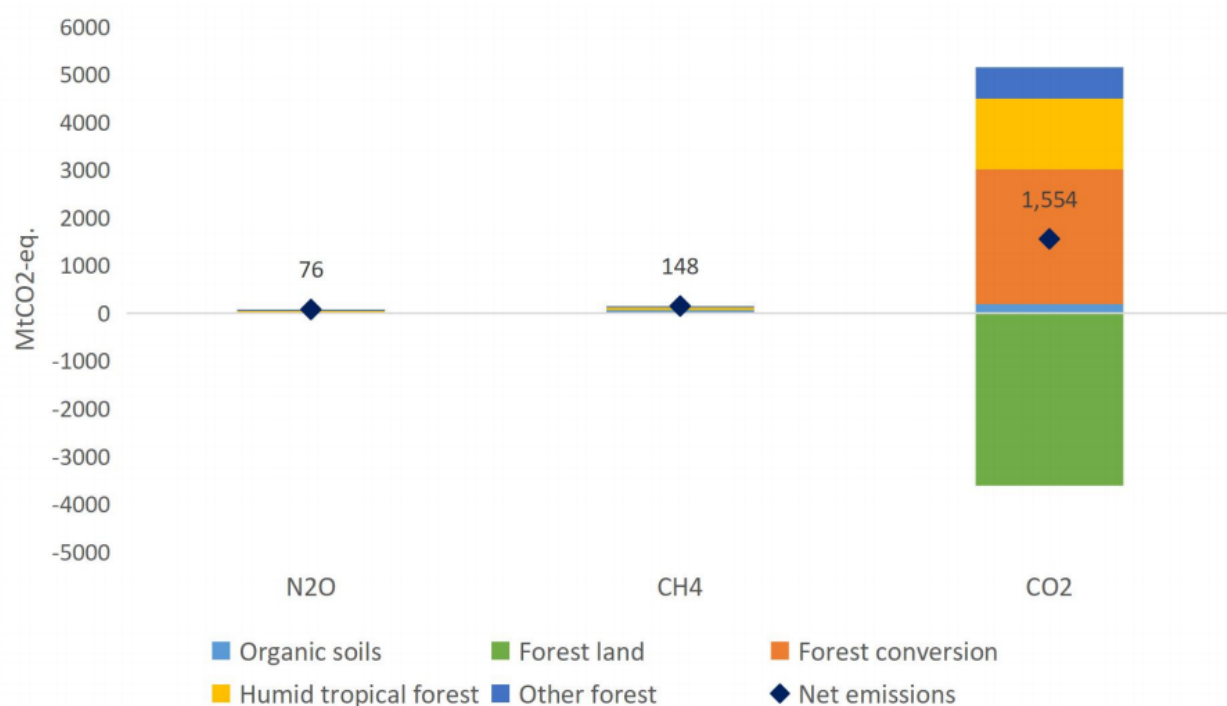
Source: FAO 2023.

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 MtCO₂-eq. - CO₂ emissions only, followed by forest conversion (1486 MtCO₂-eq. or around 28% of the total increase) and other forest (659 MtCO₂-eq. or 12%) (Figure 13.3). These emissions have been to a large extent outweighed by CO₂ removals by forest land - negative emissions of 3603 MtCO₂-eq. Net CO₂ emissions increased by 1554 MtCO₂-eq. Humid tropical forests and other forests together contributed 160 MtCO₂-eq. emissions, split almost equally between N₂O and CH₄ (Figure 13.3). When estimated on the net basis, CO₂ accounted for 87.6% of all land use GHG emissions, followed by CH₄ 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 CO₂ eq. Only land emissions that are not distributed across GTAP drivers are reported on the figure.

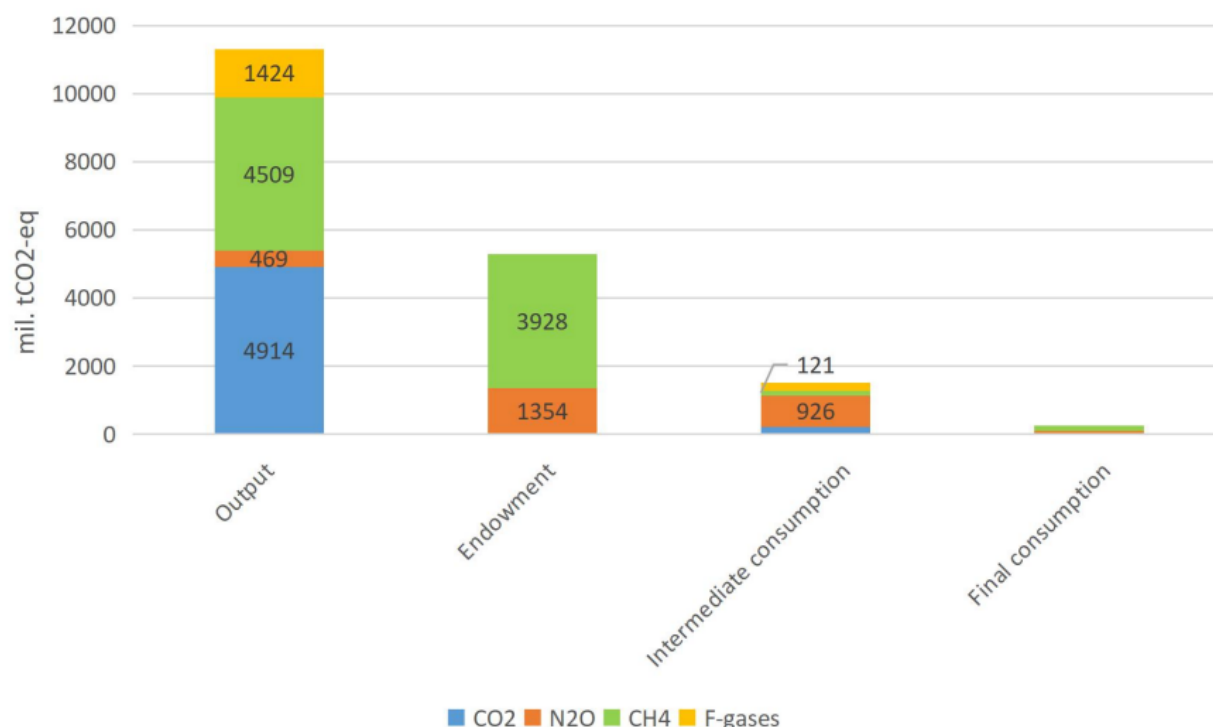
Source: FAO 2025.

B.6 Overview of the constructed database⁸

In terms of emission drivers, out of 18.3 billion tCO₂-eq. of complementary GHG emissions in 2023, around 62% are linked to output (Figure 13.4). CH₄ accounts for 47.5% of global complementary GHG emissions, followed by CO₂ (from non-combustion energy use, including fugitive emissions) – 28%, and N₂O - 15.4%, with the rest contributed by F-gases (9.1%).

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

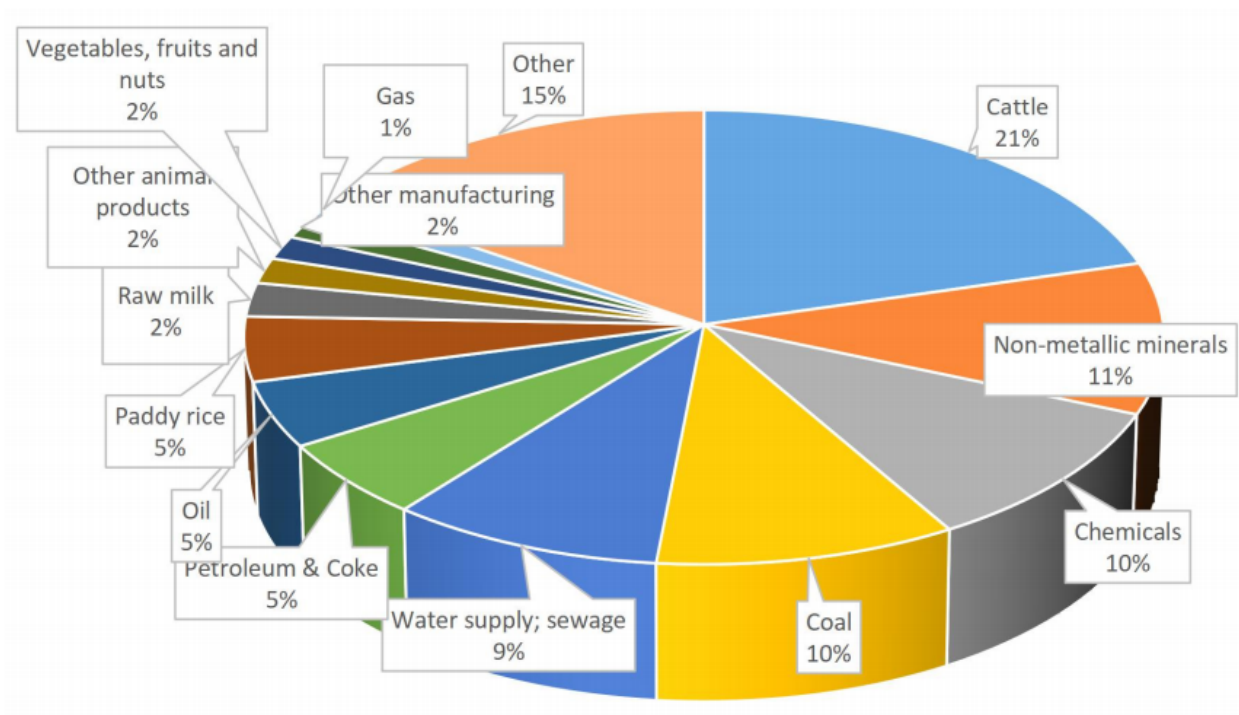
Figure 13.4: Distribution of the global complementary GHG emissions in 2023 by gases and drivers



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-CO₂ GHG emissions, the current version of the emissions database also includes CO₂ emissions from non-combustion energy use activities. In the case of the 2023 reference year, CO₂ 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 CO₂ emissions from non-combustion energy use. These emissions complement the CO₂ emission accounts from fossil fuel combustion activities reported in the core GTAP Data Base.

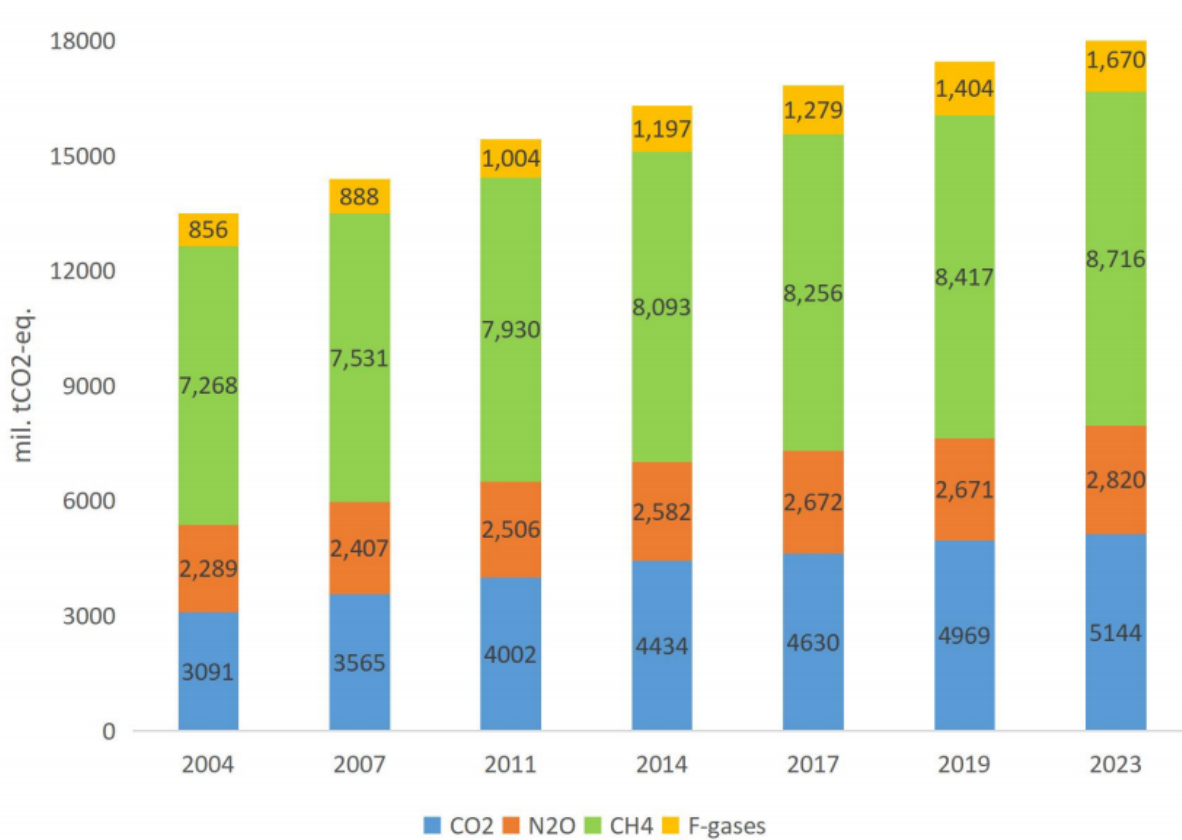
Figure 13.5: Distribution of the global complementary GHG emissions by GTAP sectors in 2023, %



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 tCO₂-eq. in 2004 to 18.4 billion tCO₂-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 CO₂ emissions (from non-combustion energy use) – at a 2.7% annual growth rate. N₂O and CH₄ 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

⁹In 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	nm
14	2A2*	Lime production	Output	nm
15	2A3	Glass Production	Output	nm
16	2A4*	Other Process Uses of Carbonates	Output	nm
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, nm
20	2E	Electronics Industry	Output	ele
21	2F	Product Uses as Substitutes for Ozone-Depleting Substances	Output	chm, ele, eq, ome
22	2G	Other Product Manufacture and Use	chm, bph	ofd, hht
23	3A1	Enteric Fermentation	NA	NA

Continued on next page

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

¹¹In 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 ₂ O Emissions from managed soils	NA	NA
29	3C5	Indirect N ₂ O Emissions from managed soils	NA	NA
30	3C6	Indirect N ₂ O 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

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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 ₂ O emissions from the atmospheric deposition of nitrogen in NO _x and NH ₃	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.