C Air Pollutant Emissions Database

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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).[11] 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).

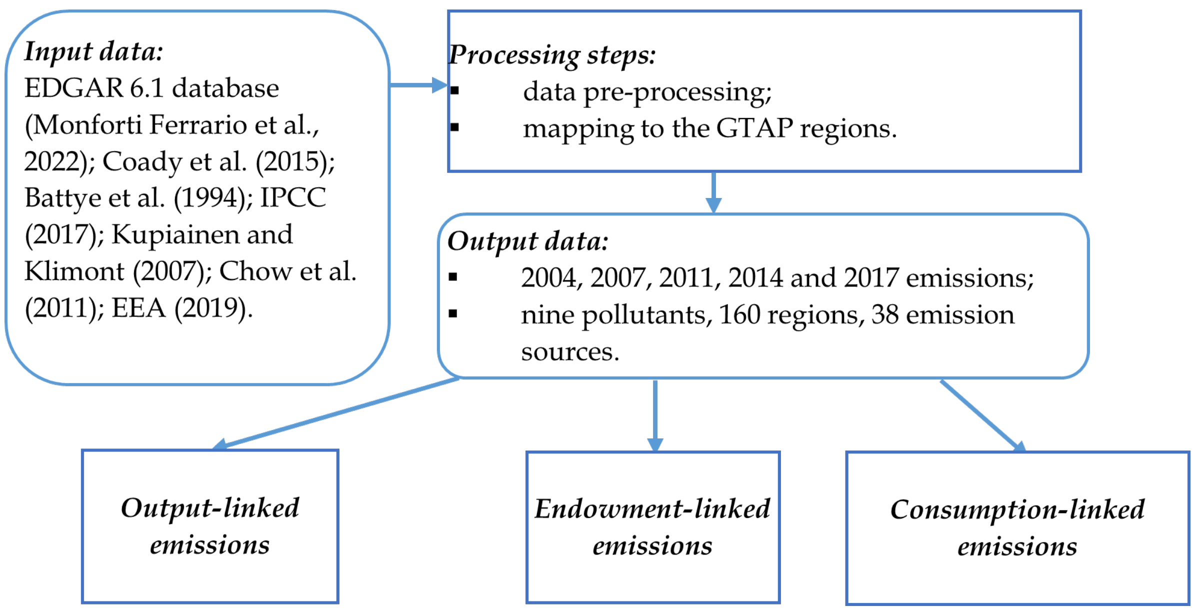
We construct the emissions database for 9 pollutants, 160 GTAP 11 Data Base regions and for the five benchmark years. Emissions are linked to economic activities and three sets of emission sources: consumption (by intermediate and final users), endowment use (land and capital) and output. To assist with 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 13.9 provides an overview of the database construction process.

Figure 13.9: 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 13.9 and 13.10, 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 13.9 and 13.10). 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 13.9 and 13.10). $SecMap$ 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 tonnes (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 13.9.

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 13.9), 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 13.9). 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 13.9).

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.

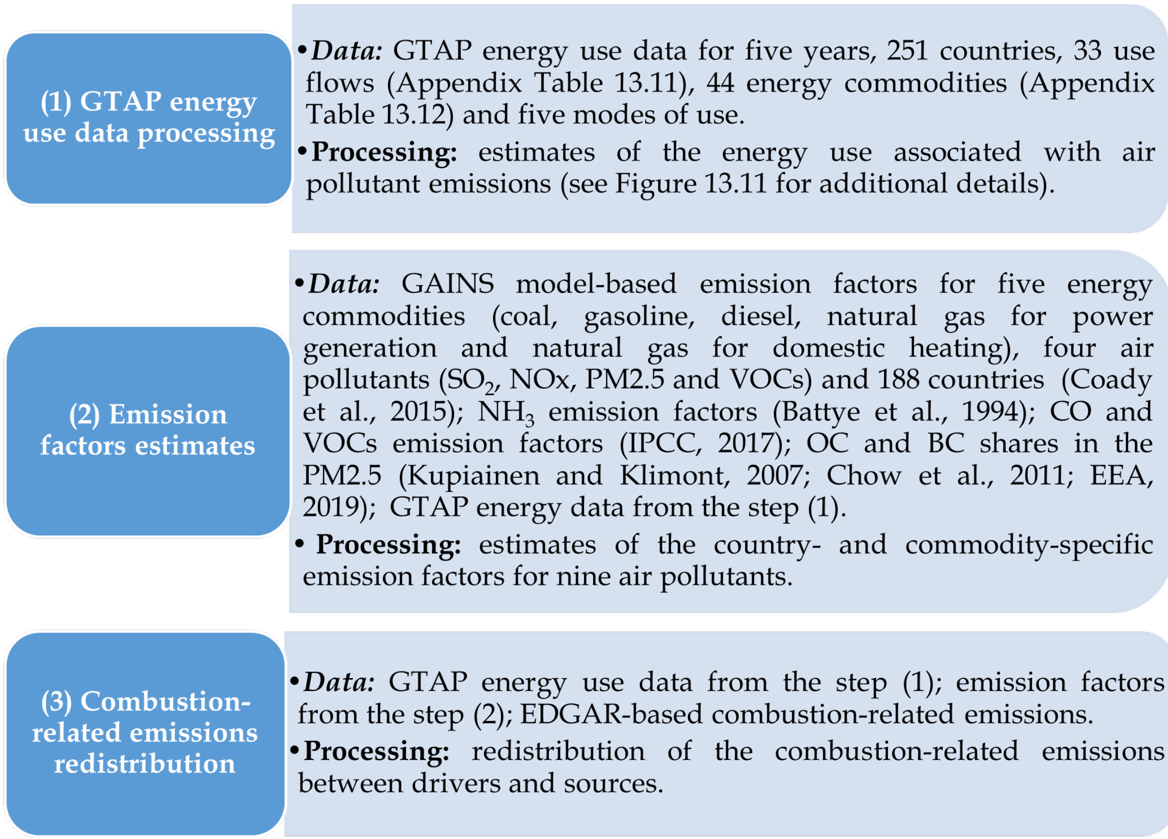
Fossil fuel combustion emissions: overall approach and energy flow estimates

A different treatment is applied to the IPCC categories associated with the fossil fuels' combustion (IPCC categories without "#" sign in the Appendix Table 13.9). Figure 13.10 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 13.11 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 13.10: Steps to redistribute the fuel combustion-related emissions

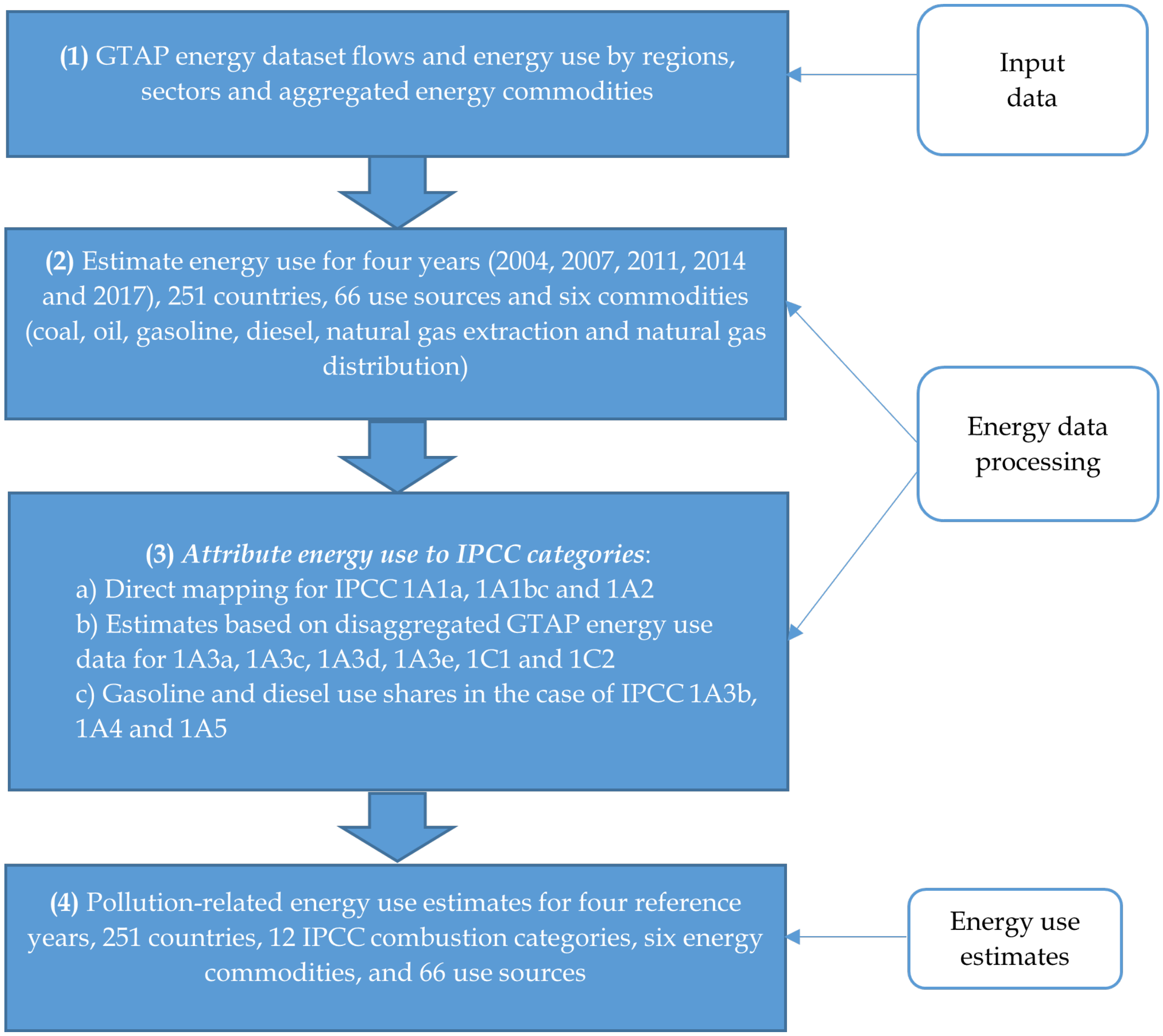


Source: Author.

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 13.9), 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 13.11: 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 13.9). 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 13.13.

Road transportation IPCC category is mapped to the other transportation activity and households (Appendix Table 13.9). 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 tonnes 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 13.11).

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 13.11). 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 13.14. 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 13.15). Out of the 14 IPCC categories, only eight have available emission factors for CO, which we map to the GTAP use categories (Appendix Table 13.15). 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 13.16). IPCC-based estimation of the CO emission factors finalizes the Step 2 of the emissions redistribution process (Figure 13.11). 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 13.10). 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 13.11) 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 13.15); 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 13.17 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 13.16 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 tonnes.

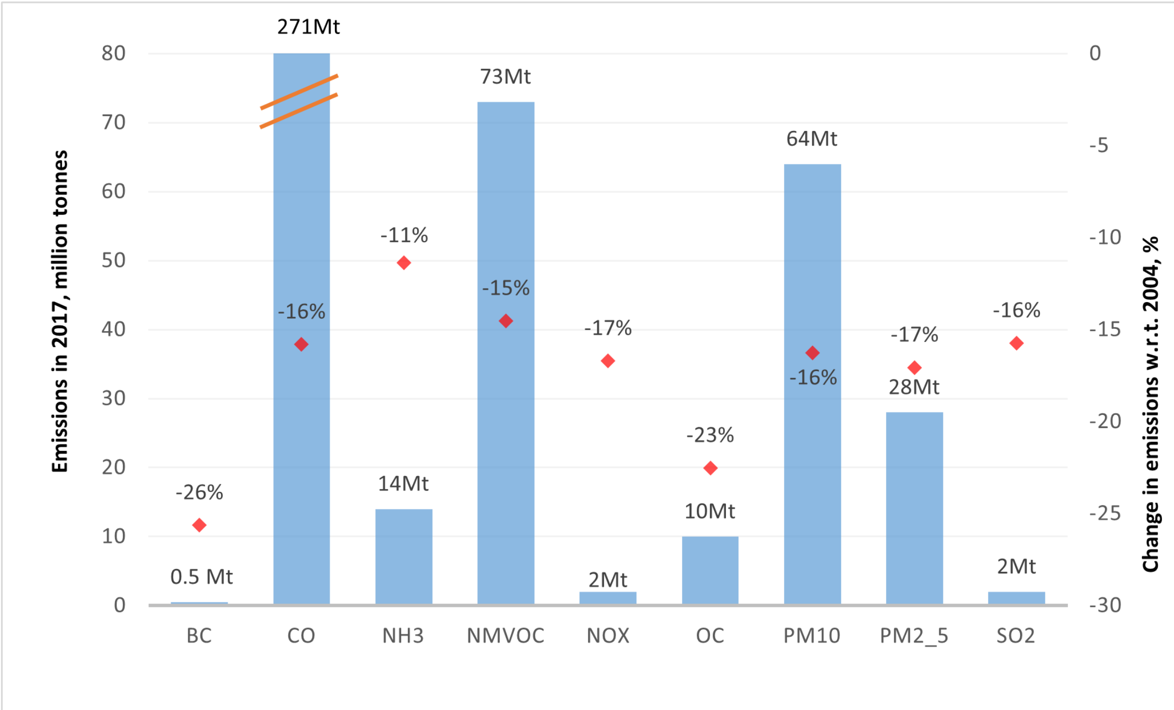
Appendix Table 13.18 provides a summary of assumptions regarding the value of emission factors by land cover type. These emission factors are primarily based on Akagi et al. 2011 and are complemented by estimates from Yokelson et al. 2013 and Hu et al. 2018. As the literature suggests (e.g. Akagi et 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 13.12). 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 13.19). 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 13.12: Global air pollutant emissions from forests and organic soils burning



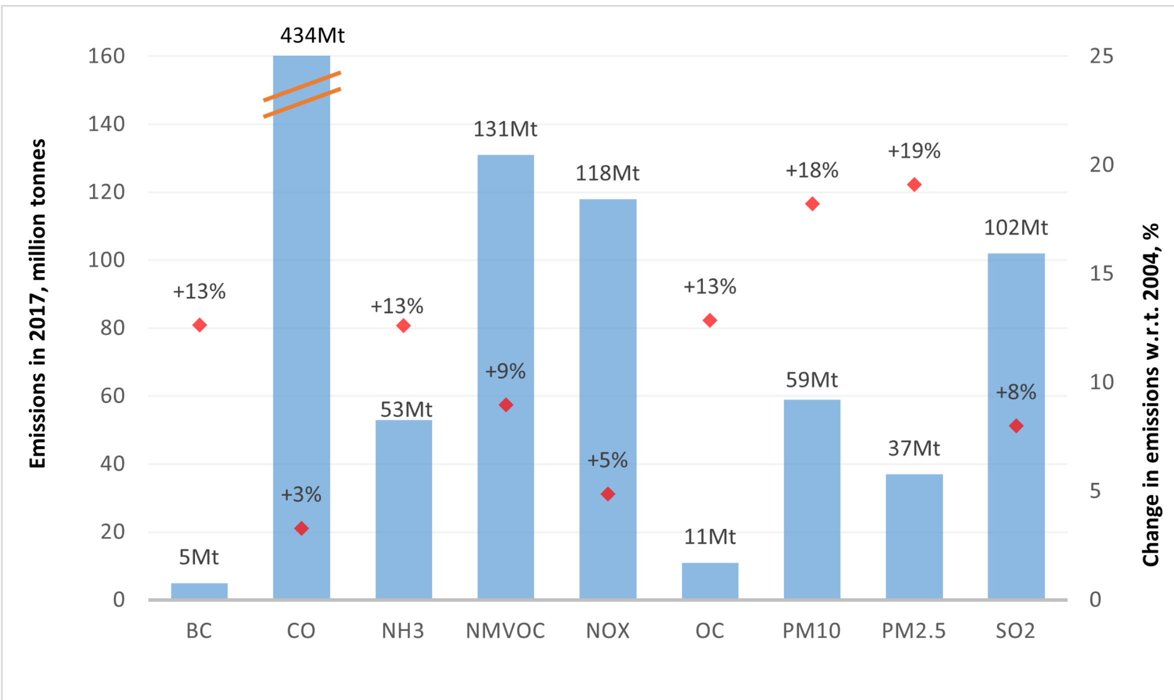
Notes: Columns represent the level of emissions in 2017 (primary vertical axis); diamonds report change in the level of emissions w.r.t. 2004 (secondary vertical axis).
Source: Estimated by author based on FAO 2023; Akagi et al. 2011; Yokelson et al. 2013; Hu et al. 2018.

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 13.13).

At the global level, consumption is the most common driver of pollution (Figure 13.14). 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.

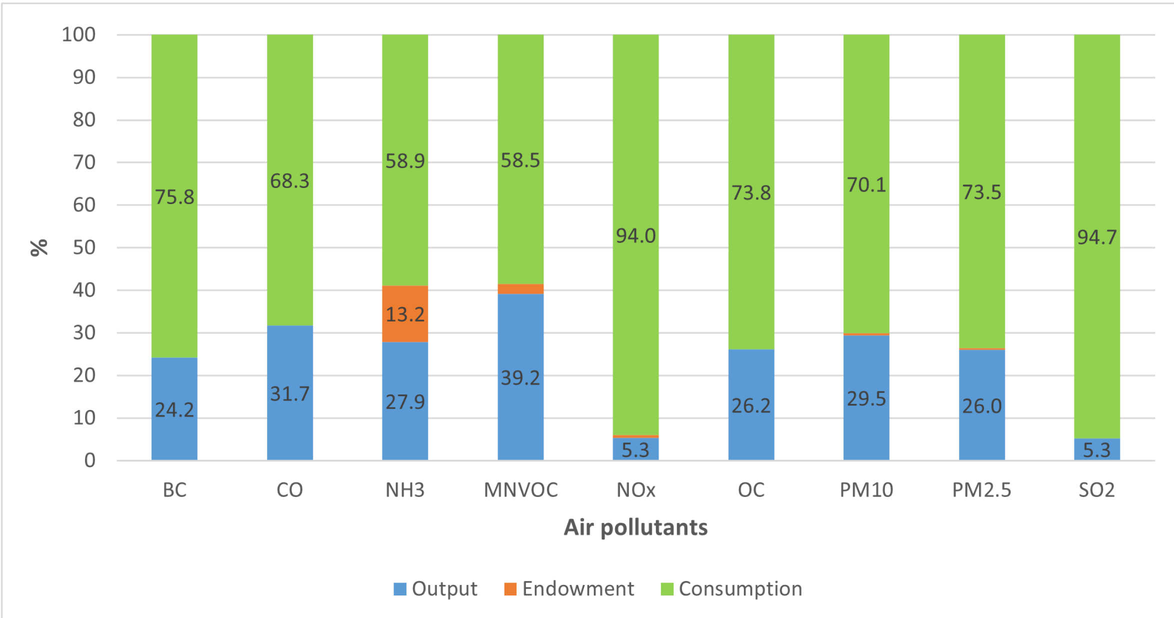
At the sectoral level, key emitters largely vary by air pollutants. Based on the 2017 data, in the case of six pollution categories (BC, CO, NMVOC, OC, PM_{10} and $PM_{2.5}$), households are the key contributors, accounting for at least 27% of all emissions (Figure 13.15). Electricity generation activity 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 13.15).

Figure 13.13: Global emissions in 2017 by air pollutants



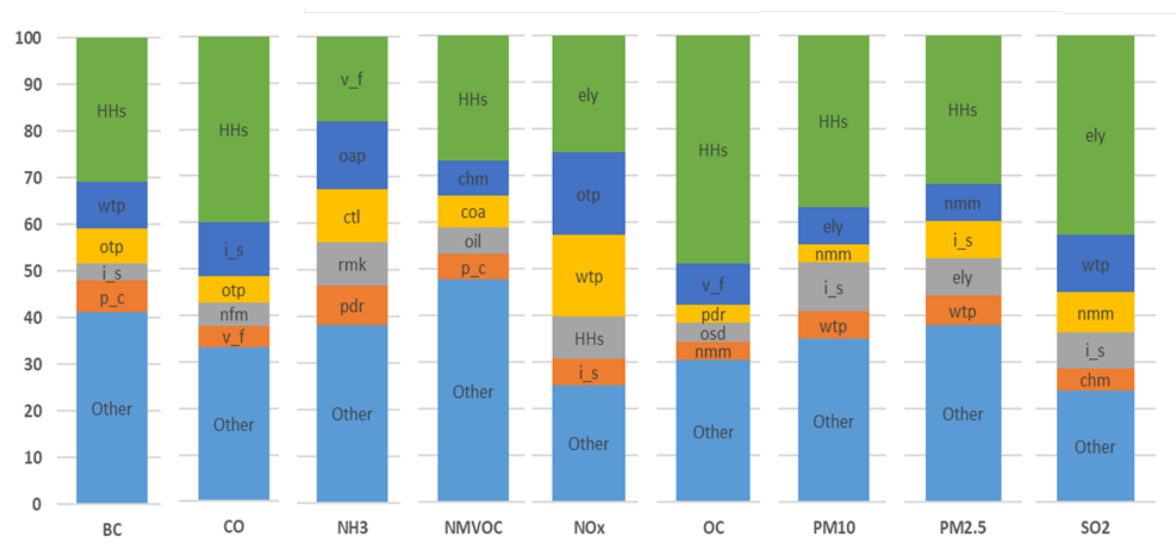
Notes: Emissions from forests and organic soils are not reported on this figure. The red diamond represents the percent changes in emission in 2014 relative to the 2004 levels.
Source: Estimated by author based on EDGAR v6.1 database (Monforti Ferrario et al. 2022) and GTAP 11 air pollutant emissions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

Figure 13.14: 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 13.15: 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 13.9: 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[12]	6	7[13]	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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[12]ISIC Rev. 3.1 codes are derived from EUROSTAT 2015, unless otherwise noted. ISIC codes in round brackets suggest possible (non-primary) mapping.
[13]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[14]	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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[14] 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), Households	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[15]	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[16]	Direct attribution

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

[16] 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[17]
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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[17] 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 13.10: 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 13.11: 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 13.12: 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 13.13: 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 13.14: 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 13.15: 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 13.16: 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”)

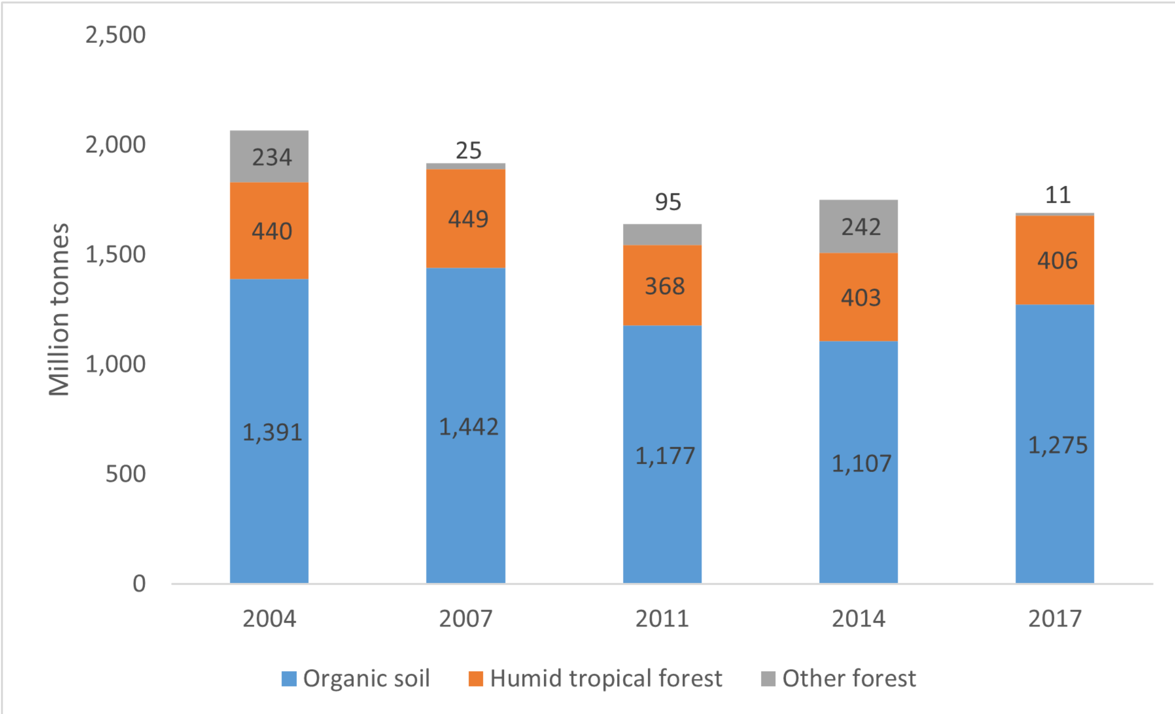
Notes: *Natural gas (301) and Natural gas liquids (302), as well as Other bituminous coal (318) and Undifferentiated coal (S01) have identical emission factors. Therefore, for the mapping purposes only one representative product from each pair is used.
Source: Based on IPCC 2017.

Table 13.17: 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 13.16: Biomass burned (dry matter) by land cover types and years, million tonnes



Source: FAO 2023.

Table 13.18: 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 13.19: Emissions from biomass burning in 2017, million tonnes

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.