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TECHNICAL NOTE

Climate Watch country greenhouse gas emissions data and methodology

Mengpin Ge and Johannes Friedrich

CONTENTS

Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

Suggested Citation: Ge, M., and J. Friedrich. 2024. "Climate Watch country greenhouse gas emissions data and methodology." Technical Note. Washington, DC: World Resources Institute. Available online at: doi.org/10.46830/writn.20.00105.

ABSTRACT

The availability of open, high-quality, consistent, and comprehensive greenhouse gas (GHG) emissions data is essential to understanding the global trend in GHG emissions, and for countries to see their emission profiles, compare their impacts with those of other countries, identify mitigation opportunities, and reduce emissions.

Drawing data from several published datasets, Climate Watch Country Greenhouse Gas Emissions Data (the "Climate Watch dataset")[1] offer comprehensive and comparable emissions data for 193 countries plus the European Union starting in 1990. The latest available data usually have a three-year lag; for example, in 2023, we reported emissions data from 2020.

This technical note details the sources and methodologies used to compile GHG inventories at the country and global levels in the Climate Watch dataset. The dataset includes emissions of all GHGs across all sectors, namely, energy; industrial processes; agriculture; waste; and land use, land-use change and forestry (LULUCF). It also addresses the limitations and uncertainties associated with using emissions data.

The dataset, which is updated annually, can be viewed, explored, and downloaded on the Climate Watch website (https://www.climatewatchdata.org/ghg-emissions).

We make several additional inventories available on the Climate Watch platform: We republish the official data reported by national governments to the United Nations Framework Convention on Climate Change, and emissions data published by academic researchers from the Potsdam Institute for Climate Impact Research and the Global Carbon Project. This technical note describes only the Climate Watch dataset.

INTRODUCTION

The objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize greenhouse gas (GHG) concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations 1992). Availability of reliable GHG emissions data is essential for countries to assess efforts to address climate change, and track the progress of achieving their individual and collective mitigation contributions toward the objective of the Convention. There are various data sources for GHG emissions, including official inventories published by national governments and estimates published by other organizations.

Countries that are parties to the UNFCCC report their national inventories regularly to the secretariat. The reporting requirements for GHG inventories are different for Annex I and non-Annex I parties.[2] Annex I parties report their GHG inventories annually, in the form of common reporting format tables. Non-Annex I parties report their GHG inventories in their national communications and biennial update reports. Those submissions are made available through the UNFCCC website (UNFCCC 2022). Due to the different capacity and reporting requirements, not all parties have a complete inventory. Besides official inventory reports, several sources of country-level emissions data are available and widely used, such as carbon dioxide (CO_2) emissions data provided by the International Energy Agency (IEA) and agriculture and land use emissions data provided by the Food and Agriculture Organization of the United Nations (FAO), among others. However, none of those datasets provides a comprehensive and comparable dataset.

Climate Watch Country Greenhouse Gas Emissions Data (hereinafter referred to as the "Climate Watch dataset") leverage respected non-UNFCCC data sources to create a comprehensive greenhouse gas inventory by sector across countries by applying a consistent methodology—not to replace existing sources of GHG emissions data but to complement them with comprehensive coverage and comparability across countries.

As of May 2023, the Climate Watch dataset contains GHG emissions data for 194 out of 198 parties to the UNFCCC for the period 1990–2020, covering emissions of the seven GHGs—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—from major sources and sinks (energy; industrial processes; agriculture; land use, land-use change and forestry (LULUCF); and waste). This technical note explains the data sources and methodology used for compiling the Climate Watch dataset.

The technical note proceeds as follows. The next section, "Data sources," explains the sources used in more detail. The following section, "Emissions by sector," describes the compilation of sector-level emissions data. Aggregation of individual gases and total GHG emissions are shown in the fourth section, "Greenhouse gases," and "Discussion" reviews the uncertainties and limitations associated with estimating and compiling these GHG data.

Table 1 gives an overview of the data included in the Climate Watch dataset:

- Sectors available
- How sectors map to the categorizations in the Intergovernmental Panel on Climate Change's (IPCC's) *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006)
- Greenhouse gases covered in each sector
- Sources of data used

DATA SOURCES

This section describes the data sources we used and the preprocessing we performed to compile the Climate Watch dataset. Among the various existing data sources available, Climate Watch used resources that have been widely employed, with a wealth of available documentation explaining the associated methodologies, and followed recognized guidelines such as those from the IPCC.

International Energy Agency

The International Energy Agency (IEA) annually publishes GHG emissions data from fossil fuel combustion by country (IEA 2021), and is the main source used in Climate Watch. We used the IEA dataset as the highest priority source for CO_2 and non-CO_2 emissions related to the burning of fossil fuels. We also used it for energy subsector emissions estimates for the countries that have data available. The IEA emissions data are based on IEA's own energy balances and the default methods and emission factors given in the 2006 IPCC guidelines, applying Tier 1 (the simplest) methodology.

When including IEA data in the Climate Watch dataset, we often combined (summed up) several flows of data to create one Climate Watch category.

Table 1 | **Overview of Climate Watch dataset: Sectors, contents, gases, and sources**

CLIMATE WATCH SECTOR		CLIMATE WATCH SECTOR CONTENTS	IPCC SOURCE/SINK CATEGORY	GREENHOUSE GASES COVERED	DATA SOURCE
Energy	Electricity/heat	Electricity and heat plants (fossil fuels)[a] ▪ Public plants (electricity, heat, combined heat and power [CHP]) ▪ Autoproducers[b] (electricity, heat, CHP)	1 A 1 a	CO_2, CH_4, N_2O	IEA 2021
		Other energy industries (fossil fuels)	1 A 1 b,c	CO_2, CH_4, N_2O	IEA 2021
	Manufacturing/ construction	Manufacturing and construction (fossil fuels)	1 A 2	CO_2, CH_4, N_2O	IEA 2021
	Transportation	Transportation (fossil fuels)	1 A 3	CO_2, CH_4, N_2O	IEA 2021
	Building	Residential, commercial, and public services	1 A 4 a,b	CO_2, CH_4, N_2O	IEA 2021
	Other fuel combustion	Agriculture, fishing, and other fuel use	1 A 4 c, 1 A 5	CO_2, CH_4, N_2O	IEA 2021
	Fugitive emissions[c]	Coal mining	1 B 1	CH_4	IEA 2021; EPA 2019
		Natural gas and oil systems	1 B 2	CO_2, CH_4	IEA 2021
		Other energy sources	1 B 1,2, 4 C	N_2O	EPA 2019
Industrial processes		Cement production	2 A 1	CO_2	Andrew 2021
		Adipic and nitric acid production	2 B 2,3	N_2O	EPA 2019
		Electronics manufacturing	2 E 1,2,3	Aggregated fluorinated gases	EPA 2019
		Electric power systems	2 G 1	SF_6	EPA 2019
		Metals (aluminum production, magnesium manufacturing)	2 C 3,4	PFCs, SF_6	EPA 2019
		Use of substitutes for ozone-depleting substances	2 F 1,2,3,4,5,6	HFCs	EPA 2019
		HCFC-22 production	2 B 9 a	HFCs	EPA 2019
		Other industrial process sources	2 A,B,C	CH_4, N_2O	EPA 2019
Agriculture		Enteric fermentation	3 A 1	CH_4	FAO 2022b
		Manure management	3 B 2	CH_4, N_2O	FAO 2022b
		Rice cultivation	3 C 7	CH_4	FAO 2022b
		Agricultural soils	3 C 4	N_2O	FAO 2022b
		Other agricultural sources	3 C	CH_4, N_2O	FAO 2022b
Waste		Landfills (solid waste)	4 A	CH_4	EPA 2019
		Wastewater treatment	4 D	CH_4, N_2O	EPA 2019
		Other nonagricultural sources (waste and other)	4 E	CH_4, N_2O	EPA 2019
Land use, land-use change and forestry		Land use total (forestland, net forest conversion, drained organic soils, and fires)	3 B 1, 3 B 2 b i 3 B 3 b I, 3 C 1	CO_2, CH_4, N_2O	FAO 2022b

Table 1 | **Overview of Climate Watch dataset: Sectors, contents, gases, and sources (cont.)**

CLIMATE WATCH SECTOR	CLIMATE WATCH SECTOR CONTENTS	IPCC SOURCE/SINK CATEGORY	GREENHOUSE GASES COVERED	DATA SOURCE
Bunker fuels	Aviation bunkers	1 A 3 a i	CO_2, CH_4, N_2O	IEA 2021
	Marine bunkers	1 A 3 d i	CO_2, CH_4, N_2O	IEA 2021

Notes: [a] Fossil fuels only, not including biofuels. [b] Autoproducers are "defined as undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity" (IEA 2021). [c] Fugitive emissions refer to intentional or unintentional releases of greenhouse gases that might occur during extraction, processing, and transmission or distribution of fossil fuels.

When presented on the Climate Watch data platform, emissions are reported under major sector (energy; industrial processes; agriculture; waste; land use, land-use change, and forestry) and energy subsector (electricity/heat, building, manufacturing, transportation, other fuel combustion, fugitive emissions). International bunker fuels are reported as an energy subsector, but excluded from national-level total energy emissions and total greenhouse gas emissions. More detailed disaggregates are available from the underlying data sources. We also used Global Carbon Project data (GCP 2021) for the energy sector to fill gaps where IEA data were not available.

The energy sector emissions cover all emissions from fuel combustion. Some of those emissions might occur in the industrial processes and product use (IPPU) process where fuels are obtained from feedstock, and could be reallocated to and reported under the IPPU category under the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; PFCs = perfluorocarbons; SF_6 = sulfur hexafluoride; HFCs = hydrofluorocarbons; GHG = greenhouse gas; IPCC = Intergovernmental Panel on Climate Change; HCFC-22 = hydrochlorofluorocarbons.

Sources: Authors compiled based on IEA 2021; EPA 2019; FAO 2022b; and Andrew 2021. IPCC categories are based on IPCC 2006.

Emissions data reported by IEA cover all emissions from the combustion of fossil fuels. These data, however, might include emissions from fuels obtained from feedstock in industrial processes. Under the 2006 IPCC guidelines, those emissions could be reallocated to the industrial processes and product use (IPPU) sector where the process occurs. Furthermore, emissions from fossil fuels used for non-energy purposes (e.g., petrochemical feedstocks, lubricants) are no longer included in the IEA dataset, which creates a gap in coverage in the final Climate Watch GHG inventory.

The data fall under the IEA Terms and Conditions, and all uses of IEA data (as described and clarified in Table 1) shall be attributed to IEA following the Terms and Conditions outlined on its website: https://www.iea.org/t&c/termsandconditions.

Food and Agriculture Organization of the United Nations

The Statistics Division of the Food and Agriculture Organization of the United Nations (FAOSTAT) publishes emissions estimates for agriculture and land sectors by country through its FAOSTAT online database (FAO 2022b). GHG estimates reported by FAOSTAT are based on standard methodology and emissions factors following Tier 1 methodology from the 2006 IPCC guidelines. Input data include Forest Assessment Reports and activity data from official statistics collected by FAOSTAT.

FAO data cover carbon dioxide, methane, and nitrous oxide emissions. For the Climate Watch dataset, we converted the non-CO_2 gases into CO_2 equivalent using 100-year global warming potential values from the Fourth Assessment Report of the IPCC (IPCC 2007). When presented on the Climate Watch data platform, the subsector breakdown for agriculture and land-use emissions is not included, mostly limited by site functionality.

It is worth noting that forestry emissions from FAO are based on Forest Resource Assessments that are collected every five years, which resulted in sudden jumps or unsmooth trendlines in forestry emissions for certain countries.

Any use of the land use, land-use change, and forestry or agriculture data should be attributed to FAO following its Terms of Use: https://www.fao.org/contact-us/terms/db-terms-of-use/en/.

US Environmental Protection Agency

In 2019, the US Environmental Protection Agency (EPA) published a technical report on estimated and projected global anthropogenic non-CO_2 gases (EPA 2019). The EPA estimates combine Tier 1 calculated emissions following the 2006 IPCC guidelines, and country-reported emissions to the UNFCCC. For Annex I countries, EPA used reported emissions. For non-Annex I countries, especially those without a complete time series or those lacking data, EPA used a composite methodology to fill gaps in country-reported data, where applicable, using interpolations between reported years, or applying growth rates from Tier 1 calculations. We used the EPA dataset for non-CO_2 emissions from the industrial processes and waste sectors.

The Data annex accompanying the EPA report provides emissions estimates from 1990 to 2050 for 193 countries in five-year intervals with interpolations for years in between. Historical estimates are available from 1990 to 2015, and are projected through 2050. Emissions through 2020–50 are estimates under a "business-as-usual" scenario. Thus, emissions beyond 2015 have higher uncertainty and should be treated with caution.

Andrew 2021

The dataset published by Robbie M. Andrew reports global- and country-level CO_2 emissions from cement production, covering the period 1880–2020 (Andrew 2021). The data are assembled from a variety of available data sources, prioritizing official data including those submitted to the UNFCCC. The data build on the legacy work of the Carbon Dioxide Information Analysis Center, which we used in earlier iterations of the Climate Watch dataset.

Global Carbon Project

The Global Carbon Project publishes annual Global Carbon Budget reports estimating anthropogenic CO_2 emissions by country (GCP 2021). The fossil-related CO_2 emissions data are based on energy statistics, and we used them to fill gaps for a few countries (Andorra and Liechtenstein) that are not covered by the IEA database.

EMISSIONS BY SECTOR

GHG emissions originate from various sources. Providing sectoral information on where emissions come from is crucial at the country level to identify the major emissions sources, and thus prioritize emissions reduction actions. This section describes the framework for examining sector-level GHG emissions in Climate Watch.

To the extent possible, when presenting the Climate Watch dataset at the sectoral level, we followed the 2006 IPCC guidelines (IPCC 2006). The sectors included in Climate Watch are energy (including international bunkers); industrial processes; agriculture; land use, land-use change and forestry; and waste. The energy sector also includes six subsectors (e.g., electricity/heat). Agriculture and LULUCF, while grouped as agriculture, forestry, and other land use in the IPCC guidelines, are reported separately on Climate Watch so that total GHG emissions can be calculated and reported both with and without LULUCF.

International bunkers (emissions from international marine and aviation) are reported as a sector, but not included in the country-level estimates of energy sector or total emissions, in accordance with the 2006 IPCC guidelines (IPCC 2006). International bunkers are included in world total emissions. Therefore, global total emissions are slightly higher than the sum of all national total emissions.

This technical note briefly describes the main sectors. For a full explanation of methodology, further discussion of the estimates made, and detailed emissions breakdowns by fuel source and category, please refer to the original sources used.

Energy

The energy sector contains emissions generated from fuel combustion, as well as fugitive emissions.[3] For countries with data available, the sector is also broken down into the following subsectors: electricity/heat, building, manufacturing/construction, transportation, other fuel combustion, and fugitive emissions.

It is worth noting that emissions from fuels combusted should be allocated to the category where the process occurs, which could be either in the energy or IPPU sector under the 2006 IPCC guidelines. To fully account for all fuel combustion emissions, the underlying data source of energy sector emissions (IEA) reports all fuel combustion emissions regardless of where the combustion occurs. All fuel combustion emissions are included as the energy sector emissions for Climate Watch. Thus, certain energy subsectors could include emissions from fuel combustion that might be reallocated to IPCC's source/sink category IPPU under the 2006 IPCC guidelines.

IEA also provides estimates of CO_2 emissions reallocated to the IPPU sector, but those estimates are not included in the Climate Watch dataset. No double counting should be expected with this approach as the IEA dataset is the sole source of emissions from fossil fuel combustions.

Electricity/heat production

The electricity/heat subsector contains CO_2, CH_4, and N_2O emissions from fuel combustion occurring in the following activities:

- Main activity producer of electricity and heat (emissions from electricity plants, combined heat and power plants, heat plants)
- Unallocated autoproducers[4] (generation of electricity and/or heat by autoproducers)
- Other energy industry own use (fuel use in energy production such as oil refineries, manufacture of solid fuels, coal mining, oil and gas extraction)

Note that some of these emissions might be reallocated to the IPPU category under the 2006 IPCC guidelines.

Building

The building subsector contains CO_2, CH_4, and N_2O emissions from heating and other fuel combustion activities taking place in the following buildings:

- Residential
- Commercial and public services

Note that only on-site fuel combustion (e.g., cook stoves in households) is covered here. Emissions associated with the use of electricity are reported under electricity/heat.

Manufacturing/construction

The manufacturing/construction subsector contains CO_2, CH_4, and N_2O emissions from fuel combustion occurring in the following activities:

- Mining and quarrying
- Construction
- Manufacturing
  - Iron and steel
  - Chemical and petrochemical
  - Non-ferrous metals
  - Non-metallic minerals
  - Transport equipment
  - Machinery
  - Food and tobacco
  - Paper, pulp, and printing
  - Wood and wood products
  - Textile and leather
  - Non-specified industry

Note that part of the fuel combustion–related emissions might be reallocated to the IPPU category per the 2006 IPCC guidelines. Those are reported separately by IEA under "CO_2 sectoral approach (Energy)," which excludes the emissions "IPPU CO_2 fuel combustion—total reallocated" (IEA 2021).

Transportation

The transportation subsector contains CO_2, CH_4, and N_2O emissions from fuel combustion in the following activities:

- Road transport
- Rail transport
- Domestic aviation
- Pipeline transport
- Domestic navigation
- Non-specified transport (all emissions from transport not specified elsewhere)

Note that transport emissions for the world total include international marine bunkers and international aviation bunkers, which are not included in transportation emissions at the national or regional level.

Other fuel combustion

The "other fuel combustion" subsector contains emissions from the following activities:

- CO_2, CH_4, and N_2O emissions from fossil fuel usage in agriculture/forestry, fishing, and other fuel consumption

Other fuel consumption includes emissions from military fuel use.

Fugitive emissions

Fugitive emissions refer to intentional or unintentional releases of greenhouse gases that might occur during extraction, processing, and transmission or distribution of fossil fuels. This subsector contains fugitive CO_2 and CH_4 emissions from the following activities:

- CO_2 from flaring
- CH_4 from coal mining
- CH_4 from natural gas and oil systems
  - Production
  - Flaring and venting
  - Transmission and distribution
- CH_4 and N_2O from other energy sources (solid fuels, oil and natural gas, incineration, and open burning of waste)

Bunker fuels

Bunker fuels contain GHG (CO_2, CH_4, and N_2O) emissions from international marine and aviation bunkers. The split of domestic and international is determined by the departure and landing locations, and not by the nationality of the ship/airline.

Bunker fuels are shown as a sector, but excluded from national totals for energy (including the energy subsector transport) and national total GHG emissions, in accordance with IPCC reporting guidelines. In other words, except at the world level, total national GHG emissions (and accordingly energy sector and transport subsector emissions) do not include bunker fuel emissions.

Industrial processes

Industrial processes refer to emissions from the following activities:

- CO_2 emissions from cement manufacture
- N_2O emissions from adipic and nitric acid production
- Fluorinated gases (F-gases) from electronics manufacturing (semiconductor, flat panel display, and photovoltaic)
- SF_6 from electric power systems
- PFCs and SF_6 from metal production (PFCs as a by-product of aluminum production, SF_6 from magnesium production)
- HFCs from use of substitutes for ozone-depleting substances
- HFCs from HCFC-22 production
- N_2O and CH_4 emissions from other industrial activities (nonagricultural)

When presented on the Climate Watch online data platform, all fluorinated gases are reported as aggregated F-gas. For a detailed breakdown of F-gases, please refer to EPA (2019).

It is important to note that cement is not the only source of process CO_2 emissions. Other major sources of process emissions include steel and chemicals, which are estimated to contribute around 0.3 gigatonnes of carbon dioxide ($GtCO_2$) and 0.2 $GtCO_2$ per year, respectively (IEA 2020). We are carrying out research to fill this data gap. Until a suitable data source is identified for other industrial process CO_2 emissions, they will not be included in the Climate Watch dataset.

Agriculture

The agriculture sector contains emissions from the following activities:

- CH_4 emissions from enteric fermentation (livestock)
- CH_4 and N_2O emissions from manure management (livestock)
- CH_4 emissions from rice cultivation
- N_2O emissions (direct and indirect) from agriculture soils
  - Crop residues
  - Drained organic soils
  - Manure applied to soils
  - Manure left on pasture
  - Synthetic fertilizers
- CH_4 and N_2O emissions from other agricultural sources (e.g., burning of crop residues, savanna fires)

Please note that emissions associated with agriculture-related energy use are reported under the energy sector, and thus are not included here.

Land use, land-use change and forestry

The land use, land-use change, and forestry sector contains emissions (or sinks) from the following activities:

- CO_2 emissions (or sinks) from forestland and net forest conversion (forestland converted to cropland and grassland)
- CO_2 emissions from drained organic soils
- CO_2 and CH_4 emissions from fires[5] in organic soils
- CH_4 and N_2O emissions from forest fires

Please note that the forestland emissions data reflect emissions from changes in forestland area between reported years of Forest Resource Assessments (FAO 2022a) submitted by countries. The data are published every five years, and emissions values are estimated by interpolating data over those five-year periods.

The FAO recently changed its approach to reporting emissions from fires in organic soils: Now, values from only Southeast Asian countries are included in country, regional, and global aggregates.

Waste

The waste sector contains emissions from the following activities:

- CH_4 from landfills (including industrial and municipal solid waste)
- CH_4 and N_2O from wastewater treatment (rural and urban)
- CH_4 and N_2O from other waste sources

GREENHOUSE GASES

The Climate Watch dataset disaggregates greenhouse gases into carbon dioxide, methane, nitrous oxide, and fluorinated gases. F-gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Due to current site functionality constraints, all F-gases are reported as a group.

Non-CO_2 gases are reported in CO_2 equivalent using 100-year global warming potential (GWP) values from the Fourth Assessment Report (AR4) of the IPCC. The decision to continue to use AR4 GWP values (versus more recent values) stemmed from the data source for F-gases. F-gases are a group of fluorinated gases with huge variations in GWP values, ranging from below 10 to over 20,000, which makes the conversion of GWP values subject to assumptions, introducing further uncertainties. As AR4 GWP values are still widely used in inventory reports, we used those instead of converting to newer GWP values (see Box 1, Table B1-1).

We calculated emissions by greenhouse gas by aggregating each gas across the sectors covered in the Climate Watch dataset. Emissions by gas and by sector are available on the Climate Watch platform.

DISCUSSION

Uncertainties

The values published in this dataset are given as a best estimate without including ranges for uncertainties. Users of the data should be aware that the data underpinning this GHG dataset may have substantial uncertainties.

In general, for information about uncertainty, users should refer to documentation from the individual data sources described above (see Andrew 2021; EPA 2019; FAO 2020b; GCP 2021; IEA 2021). These documents provide much more detail and information than can be included in this note. However, a brief discussion here is warranted.

Box 1 | Global warming potential values

To allow for comparison across different greenhouse gases and aggregation of different GHGs to a total value, we converted non-CO_2 gases into CO_2 equivalent using GWP values. GWP is defined as "an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2)" (IPCC 2014).

Table B1-1 includes 100-year GWP values relative to CO_2 for CH_4 and N_2O, adapted from IPCC assessment reports. While Sixth Assessment Report values are the most recent, GWP values from the Second Assessment Report, Fourth Assessment Report, and Fifth Assessment Report are also listed since different GHG inventories use different GWP values.

TABLE B1-1 | Global warming potential values for a 100-year time horizon cited in Intergovernmental Panel on Climate Change assessment reports

GASES	SECOND ASSESSMENT REPORT	FOURTH ASSESSMENT REPORT	FIFTH ASSESSMENT REPORT	SIXTH ASSESSMENT REPORT
CO_2	1	1	1	1
CH_4	21	25	28	27.9
N_2O	310	298	265	273

Note: CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide.

Sources: GHGP 2016; IPCC 2021.

CO_2 emissions from fossil fuels generally have lower uncertainties compared with other sectors and gases. However, most data sources derive these estimates from national energy use data and default IPCC emission factors, which may contain inaccuracies. To consistently improve accuracy, annual revisions of national energy data are common, leading in some cases to significant revisions of recently reported emissions data.

According to the most recent IPCC report (IPCC 2022), estimated uncertainty for global CO_2 emissions from fossil fuels is relatively low, about 8 percent. For non-CO_2 GHG emissions, CH_4 and F-gases have "intermediate" uncertainties of around 30 percent, while N_2O has a higher uncertainty of around 60 percent. CO_2 emissions from land use, land-use change, and forestry have very large uncertainties of 70 percent. In total, when combining these uncertainties, estimates of global total GHG emissions have an uncertainty of around 11 percent.

World total GHG emissions

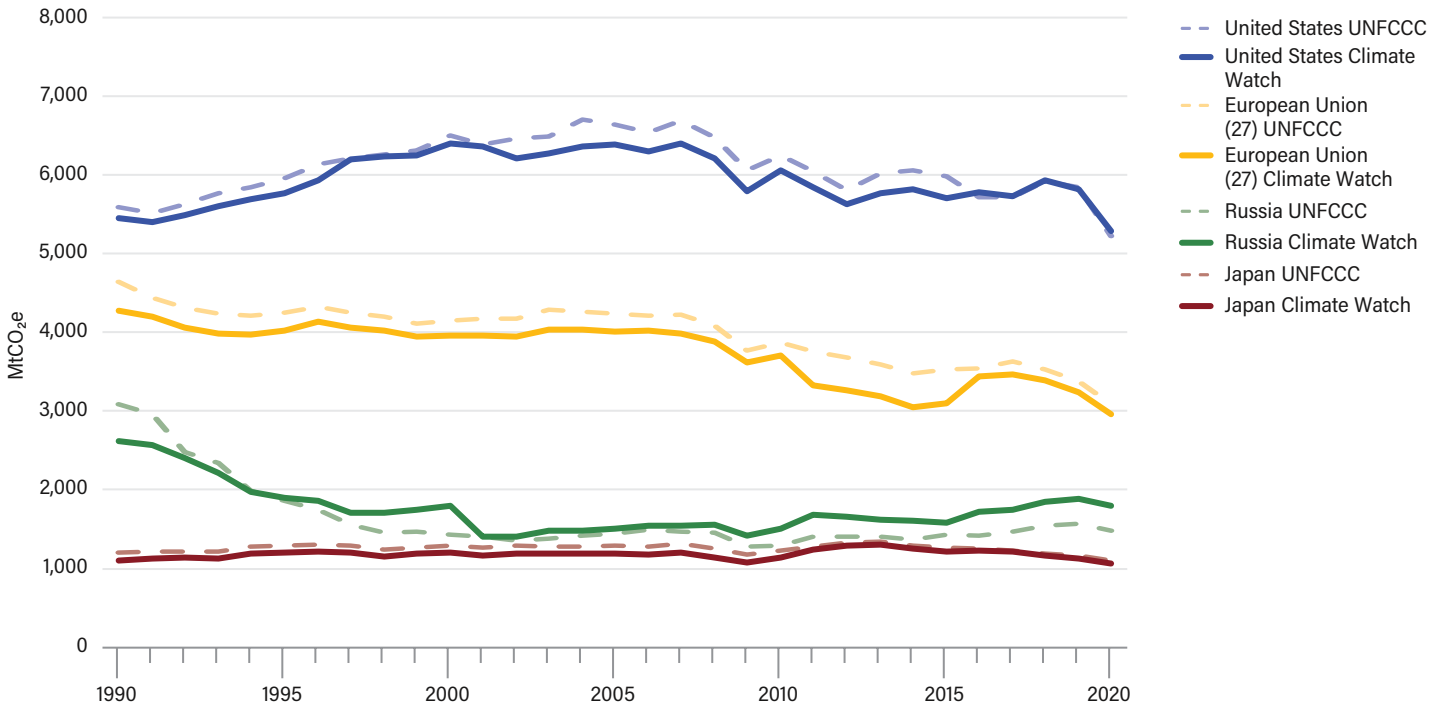
We compiled the world total emissions inventory using the same methodology and data sources as the country-level emissions inventory. However, it is important to note that the sum of all countries' emissions data available in the Climate Watch dataset will not be the same as total global emissions. This is due to two reasons:

1. As explained above, international bunker fuel–related emissions are not included in the country-level totals following the IPCC methodology. These emissions accounted for around 1.3 $GtCO_2e$ in 2019.
2. The Climate Watch dataset covers 194 parties to the UNFCCC, leaving out some territories whose anthropogenic emissions might be reported in world totals by the original data sources.

Differences between Climate Watch and official inventories

Due to the differences in data sources and methodologies used, the Climate Watch dataset's estimated country GHG emissions are inevitably different from official inventories reported by countries (Figure 1).

Figure 1 | **Comparison of Climate Watch and UNFCCC inventories for largest emitters**



Note: UNFCCC = United Nations Framework Convention on Climate Change; $MtCO_2e$ = million tonnes of carbon dioxide equivalent.

Sources: Climate Watch 2023; UNFCCC 2022.

Parties to the UNFCCC are required to "develop, updated periodically, publish and make available to the Conference of the Parties, their national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol" (United Nations 1992). Due to differences in capacity and resources available for Annex I parties to the Convention and non-Annex I parties, not all countries have full time-series GHG data available. Given the different reporting requirements and guidelines, not all inventories reported by parties to the UNFCCC are comparable to each other.

The Climate Watch dataset is provided to offer a comprehensive and comparable dataset across countries, and as a complement to the official inventories that are available.

Other GHG emissions datasets

Many other datasets report GHG emissions that are not used by the Climate Watch dataset or presented on the Climate Watch online data platform. Below we discuss some of those data sources. This is not intended to be comprehensive, but to provide some information on the other existing resources.

EDGAR (Emissions Database for Global Atmospheric Research) data are widely used in the academic field and scientific community and are cited by reputable data sources such as IPCC. The EDGAR database is compiled using international statistics, applying a globally consistent methodology and covering all IPCC sectors and gases. The EDGAR and Climate Watch datasets use different data sources. We see the value in offering another comprehensive dataset to complement the official and scientific datasets and making it available for public access.

The US Energy Information Administration (EIA) publishes CO_2 emissions data as part of its international energy statistics database. The emissions are available by fuel type, including coal, natural gas, and petroleum. The data are available for all countries annually from 1949 to 2021 (EIA n.d.).

BP publishes a statistical review of world energy in its annual report, which includes a dataset on energy CO_2 emissions. The data are usually more timely compared with other data sources. The most recent edition of the report (now published by the Energy Institute) includes emissions thorough 2022.

Other limitations

The Climate Watch dataset aggregates several existing datasets into one inventory. Thus, the methodologies and uncertainties associated with each underlying data source are reflected in our dataset. Several limitations arise due to this approach:

- The years for which Climate Watch data are available, which depend on the update schedule of the data sources
- The coverage in terms of sector, gas, and country is limited by the source coverage
- During annual updates, the data are usually revised for previous years with the underlying data sources; the changes are sometimes significant if the data source underwent major methodology changes
- Any other methodological limitations associated with the data sources, as discussed in the "Data sources" section, such as the allocation of emissions among sectors and unsmooth trendlines of emissions data.

While these limitations exist, when we update the data each year, we evaluate the data sources being used, and adjust our compilation method accordingly to strive for completeness and comparability in the Climate Watch dataset.

Future work

The Climate Watch dataset has evolved over the past decade to include changes in data sources, compilation methodologies, and global warming potential values. Future development of the Climate Watch dataset and data platform could include improving data granularity, such as by including subsectors for the agriculture and LULUCF sectors and breaking down the F-gas group to individual gases. Other future developments could include exploring data sources to fill the data gaps associated with process emissions. Another potential area of improvement is to provide data using more up-to-date GWP values. The Climate Watch dataset is intended to be updated annually, with both data updates and improvements to the methodologies. Continued effort will be made to further improve the Climate Watch dataset and data platform.

APPENDIX A. ESTIMATES MADE FOR HISTORICAL EMISSIONS

This appendix describes the methodology employed to produce more complete time-series data from the raw data sources. These estimates were needed both due to how the data are reported by the raw data sources and because certain country boundaries have changed, especially during the early 1990s.

For the years affected, a method was required to apportion historical carbon emissions in accordance with today's geographic boundaries. We estimated historical emissions for around 30 countries whose emissions are reported differently, often together with another country, or whose borders changed in the early 1990s. These include, for example, former Soviet Republics and former Yugoslav Republics. We employed the methodology described below separately for each gas and sector, where applicable.

For newly formed countries, such as the independent republics of the former Soviet Union, we estimated the share of emissions for the years prior to country formation based on each country's emissions in the five years immediately following its formation (or the first five years for which data are available). Specifically, we used the following four-step methodology to make historical emissions estimates for newly formed countries:

1. Add the emissions together for the first five years *after* independence or for which data are available (e.g., 1992–96 for agricultural emissions data for Kazakhstan, a former Soviet Republic).
2. Add these five-year totals together for all newly formed countries (e.g., sum *all* former Soviet Republics' emissions from 1992 to 1996).
3. Divide the figure obtained in step 1 by the figure obtained in step 2. This yields a percentage "share" of emissions for each newly created country.
4. Apply the share of emissions obtained in step 3 to all pre-independence emissions data.

For example, Kazakhstan's total agricultural emissions in 1992–96 were about 160.7 million tonnes of carbon dioxide equivalent ($MtCO_2e$) (step 1). Emissions for all former Soviet Republics in 1992–96 were about 1,792.1 $MtCO_2e$ (step 2). Thus, Kazakhstan's share of Soviet emissions is calculated to be 8.97% (step 3). To estimate Kazakhstan's emissions prior to 1992, 8.97% is multiplied by the Soviet Union's emissions for any given year.

In step 1 above, we used five years rather than a single year to get a smoother average—a single year of data may not be representative because of the economic and social disruption that often accompanies border changes. We did not use a longer period since data many years after independence may poorly reflect that country's relative emissions share prior to independence (of course, this might also be the case even for the five-year period used). Generally, there is no precise way to attribute historical emissions to countries when they did not exist. Accordingly, the estimates made should be considered rough approximations.

We used this allocation approach for the agriculture and LULUCF sectors, and performed calculations at the gas and sectoral levels. Table A-1 is an example of agriculture's total emissions with a list of countries affected, and corresponding estimates for each of the newly formed countries.

Table A-1 | **Allocation of agriculture's total emissions to historical years**

FORMER AREA	CURRENT AREA	YEARS ESTIMATES MADE	YEARS USED TO ESTIMATE SHARE	ESTIMATED SHARE OF FORMER COUNTRY'S EMISSIONS
Belgium-Luxembourg	Belgium	1990–99	2000–04	94.44%
	Luxembourg	1990–99	2000–04	5.56%
Czechoslovakia	Czechia	1990–92	1993–97	68.23%
	Slovakia	1990–92	1993–97	31.77%
People's Democratic Republic of Ethiopia	Eritrea	1990–92	1993–97	5.63%
	Ethiopia	199–992	1993–97	94.37%

Table A-1 | **Allocation of agriculture's total emissions to historical years (cont.)**

FORMER AREA	CURRENT AREA	YEARS ESTIMATES MADE	YEARS USED TO ESTIMATE SHARE	ESTIMATED SHARE OF FORMER COUNTRY'S EMISSIONS
Sudan (former)	South Sudan	1990–2011	2012–16	39.36%
	Sudan	1990–2011	2012–16	60.64%
Serbia and Montenegro	Montenegro	1990–2005	2006–10	6.20%
	Serbia	1990–2005	2006–10	93.80%
Union of Soviet Socialist Republics	Armenia	1990–91	1992–96	0.33%
	Azerbaijan	1990–91	1992–96	1.19%
	Belarus	1990–91	1992–96	6.68%
	Estonia	1990–91	1992–96	0.71%
	Georgia	1990–91	1992–96	0.64%
	Kazakhstan	1990–91	1992–96	8.97%
	Kyrgyzstan	1990–91	1992–96	1.17%
	Latvia	1990–91	1992–96	1.09%
	Lithuania	1990–91	1992–96	1.97%
	Republic of Moldova	1990–91	1992–96	0.97%
	Russian Federation	1990–91	1992–96	49.68%
	Tajikistan	1990–91	1992–96	1.00%
	Turkmenistan	1990–91	1992–96	1.13%
	Ukraine	1990–91	1992–96	19.89%
	Uzbekistan	1990–91	1992–96	4.57%
Socialist Federal Republic of Yugoslav	Bosnia and Herzegovina	1990–91	1992–96	11.08%
	Croatia	1990–91	1992–96	17.25%
	Serbia and Montenegro	1990–91	1992–96	51.59%
	Slovenia	1990–91	1992–96	10.39%
	North Macedonia	1990–91	1992–96	9.69%

Source: Author calculations based on FAO 2022b.

APPENDIX B. COUNTRIES AND REGIONS IN CLIMATE WATCH

The Climate Watch dataset includes country-level GHG emissions data for 194 parties to the UNFCCC.[6] This covers all UNFCCC parties except the Holy See (Vatican City), Monaco (combined with France), San Marino (combined with Italy), and Palestine. The European Union is also included as a "country" in Climate Watch because the European Union (a unit of the EU) is a party to the Convention.

APPENDIX C. EMISSIONS BY END USE/ACTIVITY

Table C-1 and Figure C-1 break down the sources of emissions by sector (as covered in Climate Watch in the "Sector" column) and greenhouse gas, as well as the content of end use/activities.

Table C-1 | **Contents of end-use/activity emissions by gas and sector**

END USE/ACTIVITY	CONTENTS	GAS	SECTOR
Road	Direct fuel combustion	CO_2, CH_4, N_2O	Energy: Transportation
Air	Domestic aviation (direct fuel combustion) International aviation bunkers (direct fuel combustion)	CO_2, CH_4, N_2O	Energy: Transportation, including bunkers
Ship	Domestic navigation (direct fuel combustion) International marine bunkers (direct fuel combustion)	CO_2, CH_4, N_2O	Energy: Transportation, including bunkers
Rail	Rail (direct fuel combustion) Rail (electricity)	CO_2	Energy: Transportation, electricity and heat
Pipeline	Pipeline transport (direct fuel combustion) Pipeline transport (electricity)	CO_2	Energy: Transportation, electricity and heat
Other transportation	Non-specified transport (direct fuel combustion) Non-specified transport (electricity)	CO_2	Energy: Transportation, electricity and heat
Residential buildings	On-site energy use (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2, CH_4, N_2O	Energy: Buildings, electricity and heat
Commercial buildings	Commercial and public services on-site energy use (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2, CH_4, N_2O	Energy: Buildings, electricity and heat
Agriculture and fishing energy use	Agriculture/forestry	CO_2, CH_4, N_2O	Energy: Electricity and heat, other fuel combustion
	Fishing	CO_2, CH_4, N_2O	Energy: Electricity and heat, other fuel combustion
Unallocated fuel combustion	Final consumption not specified elsewhere	CO_2, CH_4, N_2O	Energy: Electricity and heat, other fuel combustion, fugitive emissions
	Other energy industry own use	CO_2, CH_4, N_2O	Energy: Electricity and heat
	Electricity and heat production	CH_4, N_2O	Energy: Electricity and heat
	Waste incineration	CH_4, N_2O	Energy: Fugitive emissions

Table C-1 | **Contents of end-use/activity emissions by gas and sector (cont.)**

END USE/ACTIVITY	CONTENTS	GAS	SECTOR
Iron and steel	Iron and steel (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Mining and quarrying	Mining and quarrying (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Construction	Construction (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Non-ferrous metals	Non-ferrous metals (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
	Aluminum	F-gases	Industrial processes
	Magnesium	F-gases	Industrial processes
Non-metallic minerals	Non-metallic minerals (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Transport equipment	Transport equipment (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Machinery	Machinery (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Food and tobacco	Food and tobacco (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Paper, pulp, and printing	Paper, pulp, and printing (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Wood and wood products	Wood and wood products (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Textile and leather	Textile and leather (direct fuel combustion) Electricity and heat consumption (indirect)	CO_2	Energy: Electricity and heat, manufacturing and construction
Transmission and distribution	Distribution losses (deliberate)	CH_4	Energy: Fugitive emissions
	Transmission and distribution (accidental)	CH_4	Energy: Fugitive emissions
Flared	Flared	CO_2, CH_4	Energy: Fugitive emissions
Production	Production	CH_4	Energy: Fugitive emissions
Vented	Vented	CH_4	Energy: Fugitive emissions
Cement	Cement	CO_2	Industrial processes

Table C-1 | **Contents of end-use/activity emissions by gas and sector (cont.)**

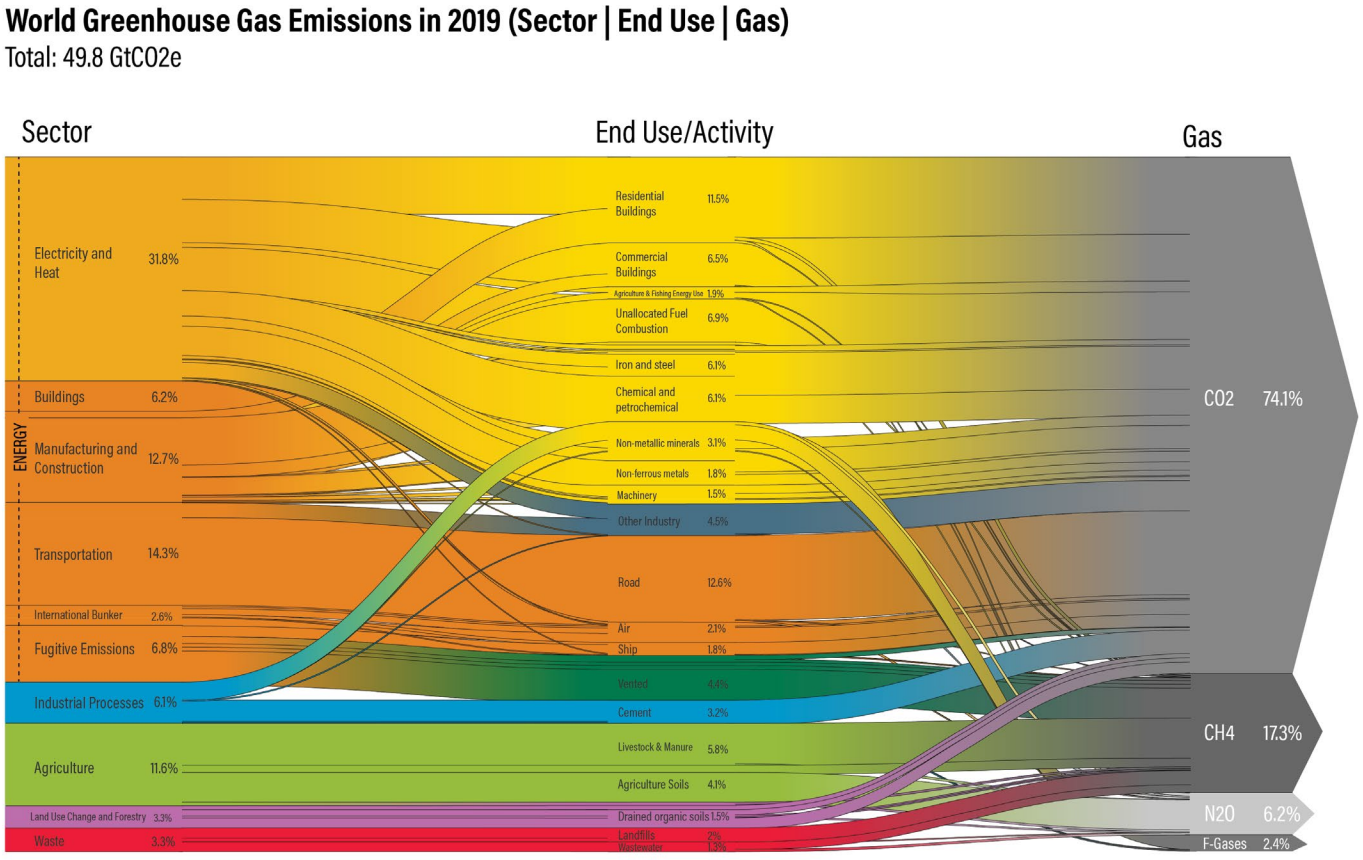
END USE/ACTIVITY	CONTENTS	GAS	SECTOR
Chemical and petrochemical	Chemical and petrochemical	CO_2	Energy: Electricity and heat, manufacturing and construction
	Ozone-depleting substance (ODS) substitute (subs): Aerosols	F-gases	Industrial processes
	ODS subs: Fire extinguishing	F-gases	Industrial processes
	ODS subs: Foams	F-gases	Industrial processes
	ODS subs: Refrigeration/air conditioning	F-gases	Industrial processes
	ODS subs: Solvents	F-gases	Industrial processes
	HCFC-22	F-gases	Industrial processes
	Adipic	N_2O	Industrial processes
	Nitric	N_2O	Industrial processes
Electronics	Semi	F-gases	Industrial processes
	Flat panel display	F-gases	Industrial processes
	Photovoltaic	F-gases	Industrial processes
Other industry	Non-specified industry	CO_2	Energy: Electricity and heat
	Non-specified industry	CO_2, CH_4, N_2O	Energy: Manufacturing and construction
	Other industrial processes sources	CH_4, N_2O	Industrial processes
Electric power systems	Electric power systems	F-gases	Industrial processes
Livestock and manure	Enteric fermentation	CH_4	Agriculture
	Manure management	CH_4, N_2O	Agriculture
Rice cultivation	Rice cultivation	CH_4	Agriculture
Agriculture soils	Synthetic fertilizers	N_2O	Agriculture
	Manure applied to soils	N_2O	Agriculture
	Manure left on pasture	N_2O	Agriculture
	Crop residues	N_2O	Agriculture
	Cultivation of organic soils	N_2O	Agriculture
Burning	Burning—savanna	CH_4, N_2O	Agriculture
	Burning—crop residues	CH_4, N_2O	Agriculture
Forestland	Forestland	CO_2	Land use, land-use change and forestry
	Net forest conversion	CO_2	Land use, land-use change and forestry
Fires in organic soils	Fires in organic soils	CO_2, CH_4	Land use, land-use change and forestry

Table C-1 | **Contents of end-use/activity emissions by gas and sector (cont.)**

END USE/ACTIVITY	CONTENTS	GAS	SECTOR
Forest fires	Forest fires	CH_4, N_2O	Land use, land-use change and forestry
Drained organic soils	Drained organic soils	CO_2	Land use, land-use change and forestry
Landfills	Industrial solid waste	CH_4	Waste
	Municipal solid waste	CH_4	Waste
Wastewater	Rural	CH_4, N_2O	Waste
	Urban	CH_4, N_2O	Waste
Other waste	Other	CH_4, N_2O	Waste

Source: Authors compiled based on IEA 2021; EPA 2019; and FAO 2022b.

Figure C-1 | **World greenhouse gas emissions in 2019**



Note: This figure uses 2019 data as 2020 emissions were affected by the COVID-19 global pandemic.

Source: Reproduced from "World Greenhouse Gas Emissions: 2019," Climate Watch, World Resources Institute, Data Visualization, June 23, 2022, https://www.wri.org/data/world-greenhouse-gas-emissions-2019. Based on raw data from "GHG Emissions from Fuel Combustion," International Energy Agency, 2021, www.iea.org/statistics; modified by WRI.

ENDNOTES

1. Climate Watch Country Greenhouse Gas Emissions Data was previously called CAIT (Climate Analysis Indicators Tool).

2. The UNFCCC divides countries into groups. Annex I parties include the industrialized countries that were members of the Organisation for Economic Co-operation and Development in 1992, plus countries with economies in transition; Non-Annex I parties are mostly developing countries.

3. Fugitive emissions refer to intentional or unintentional releases of greenhouse gases that might occur during extraction, processing, and transmission or distribution of fossil fuels.

4. Autoproducers are "defined as undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity" (IEA 2021).

5. FAOSTAT estimates of emissions from fires in organic soils rely on remote sensing data and have very high uncertainties. In Southeast Asian countries, existing literature supports the association of the burning of the organic layer with deforestation fires and drainage. However, for countries outside of Southeast Asia, insufficient information exists to determine whether fires in organic soils are human-induced or wild. Thus, FAOSTAT reports burned areas and emissions as 0 for countries that are not in Southeast Asia.

6. See UNFCCC, "Parties to the Convention and Observer States," n.d., https://unfccc.int/parties_and_observers/parties/items/2352.php, accessed February 1, 2024.

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ACKNOWLEDGMENTS

We are pleased to acknowledge our institutional strategic partners that provide core funding to WRI: the Netherlands Ministry of Foreign Affairs, Royal Danish Ministry of Foreign Affairs, and Swedish International Development Cooperation Agency.

The authors would like to thank the following people for providing input and feedback during the drafting of this note: Dominique Blain, Francesco Tubiello, Gregory Taff, Kevin Kennedy, Leandro Vigna, Muhamad Rizki, Taryn Fransen, and Zhe Liu.

This technical note builds on the previous Climate Watch documentation, which reflects decades of work that resulted in the initial Climate Watch dataset.

ABOUT THE AUTHORS

Mengpin Ge is an associate II in the Global Climate Program at WRI.

Contact: mge@wri.org

Johannes Friedrich is the Director of Climate Data in the Global Climate Program at WRI.

Contact: jfriedrich@wri.org

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Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.