Global Greenhouse Gas Emissions

Identification

1. Indicator Description

This indicator describes emissions of greenhouse gases (GHGs) worldwide since 1990. It is highly relevant to climate change because greenhouse gases from human activities are the primary driver of observed climate change since the mid-20th century (IPCC, 2013). Tracking GHG emissions worldwide provides a context for understanding the United States' role in addressing climate change.

Components of this indicator include:

- Global GHG emissions by gas (Figure 1)
- Global GHG emissions by sector (Figure 2)
- Global carbon dioxide emissions by region (Figure 3)

2. Revision History

April 2010:	Indicator published.
December 2012:	Updated Figure 3 with data through 2008.
May 2014:	Updated Figures 1 and 2 with data through 2010, updated Figure 3 with data through 2011, and added land-use change and forestry data.
August 2016:	Updated Figure 3 with data through 2012.
April 2021:	Updated Figures 1 and 2 with data through 2015; updated Figure 3 with data through 2018.

Data Sources

3. Data Sources

This indicator is based on data from the World Resources Institute's (WRI's) Climate Analysis Indicators Tool (CAIT), a database of anthropogenic sources and sinks of GHGs worldwide. CAIT has compiled data from a variety of GHG emissions inventories. In general, a GHG emissions inventory consists of estimates derived from direct measurements, aggregated national statistics, and validated models.

CAIT compiles data from a variety of other databases and inventories, including:

- International Energy Agency (IEA) data on carbon dioxide (CO_2) emissions from combustion.
- EPA's estimates of global emissions of non-CO_2 gases.
- Estimates of CO_2 emissions from land-use change and forestry (LUCF), as compiled by the Food and Agriculture Organization of the United Nations (FAO).
- Additional data from the U.S. Carbon Dioxide Information Analysis Center (CDIAC) and U.S. Energy Information Administration (EIA) to fill gaps.

Other global emissions estimates—such as the estimates published by the Intergovernmental Panel on Climate Change (e.g., IPCC, 2013)—are based on many of the same sources. Note that as a condition to EPA's presentation of FAO data in non-United Nations contexts, FAO asserts that it does not endorse any views, products, or services associated with the presentation of its data.

EPA uses CAIT as the primary data source of this indicator for several reasons, including:

- WRI compiles data sets exclusively from peer-reviewed and authoritative sources, which are easily accessible through CAIT.
- CAIT allows for consistent and routine updates of this indicator, whereas data compiled from other sources (e.g., periodic assessment reports from the Intergovernmental Panel on Climate Change [IPCC]) may be superseded as soon as CAIT's underlying data sources have published newer numbers.
- CAIT relies exclusively on EPA's global estimates for non-CO_2 gases.
- Global estimates from CAIT (excluding LUCF) are comparable with other sources of global GHG data (e.g., the European Commission's Emission Database for Global Atmospheric Research [EDGAR]).

4. Data Availability

EPA obtained CAIT data through the collaborative Climate Watch data portal at: www.climatewatchdata.org/ghg-emissions. Many of the underlying data sources are also publicly available. For information on all the sources used to populate the CAIT database by country, by gas, and by source or sink category, see WRI (2015). Data for this particular indicator were compiled by WRI largely from the following sources:

- Boden et al. (2015)
- EIA (2020)
- FAO (2020)
- IEA (2020)
- U.S. EPA (2019)

To see a list of which countries are assigned to each region in Figure 3, see the "Countries/Regions" dropdown menu at: www.climatewatchdata.org/ghg-emissions.

Methodology

5. Data Collection

This indicator focuses on emissions of the six compounds or groups of compounds currently covered by agreements under the United Nations Framework Convention on Climate Change (UNFCCC). These compounds are CO_2, methane (CH_4), nitrous oxide (N_2O), selected hydrofluorocarbons (HFCs), selected perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). This indicator presents emissions data in units of million metric tons of CO_2 equivalents, the conventional unit used in GHG inventories prepared worldwide, because it adjusts for the various global warming potentials (GWPs) of different gases.

The data originally come from a variety of GHG inventories. Some have been prepared by national governments; others by international agencies. Data collection techniques (e.g., survey design) vary depending on the source or parameter. For example, FAO is acknowledged as an authoritative source of land-use-related emissions data because they are able to estimate deforestation patterns with help from satellite imagery (Houghton et al., 2012). Although the CAIT database is intended to be comprehensive, the organizations that develop inventories are continually working to improve their understanding of emissions sources and how best to quantify them.

Inventories often use some degree of extrapolation and interpolation to develop comprehensive estimates of emissions in a few sectors and sink categories, but in most cases, observations and estimates from the year in question were sufficient to generate the necessary data.

GHG inventories are not based on any one specific sampling plan, but documents are available that describe how most inventories have been constructed. For example, U.S. EPA (2020) describes all the procedures used to estimate GHG emissions for EPA's annual U.S. inventory. See IPCC's GHG inventory guidelines (IPCC, 2006), 2019 refinements to those guidelines (IPCC, 2019), and *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000) for additional guidance that many countries and organizations follow when constructing GHG inventories.

6. Indicator Derivation

This indicator reports selected metrics from WRI's CAIT database, which compiles data from the most reputable GHG inventories around the world. WRI's website (http://cait.wri.org/faq.html) provides an overview of how the CAIT database was constructed, and WRI (2015) describes the data sources and methods used to populate the database. WRI's main role is to assemble data from other sources, all of which have been critically reviewed. As a result, the totals reported in CAIT are consistent with other compilations, such as a European tool called EDGAR (https://edgar.jrc.ec.europa.eu/index.php), which has been cited in reports by IPCC. EDGAR and CAIT use many of the same underlying data sources.

The most comprehensive estimates are available beginning in 1990. Global emissions estimates for CO_2 are available annually through 2018, while global estimates for gases other than CO_2 are available only at five-year intervals through 2015. (Technically, it is possible to find estimates of non-CO_2 gases for the intervening years, but the primary source data for many countries are only available at five-year intervals, so any published global estimates for intervening years would likely include interpolations. While such interpolations are feasible and often used when projecting future emissions of these GHGs data, EPA chose to use the five-year estimates for the purposes of this EPA indicator.) Thus, Figures 1 and 2 (which show all GHGs) plot values for 1990, 1995, 2000, 2005, 2010, and 2015.

All three figures in this indicator include emissions due to international transport (i.e., aviation and maritime bunker fuel). These emissions are not included in the U.S. Greenhouse Gas Emissions indicator because they are international by nature, and not necessarily reflected in individual countries' emissions inventories.

Figures 1 and 2 include estimates of emissions associated with LUCF. Figure 3 excludes LUCF because it focuses on gross emissions by region.

The indicator presents emissions data in units of million metric tons of CO_2 equivalents, which are conventionally used in GHG inventories prepared worldwide because they adjust for the various GWPs of different gases. This analysis uses the 100-year GWPs that are documented in the IPCC's Fourth Assessment Report (AR4) (IPCC, 2007). This choice arises because CAIT's data for non-CO_2 gases come from a global compilation that EPA assembles every five years, and EPA's most recent version of that compilation used AR4 GWPs because the Agency was required to do so to comply with international reporting standards under the UNFCCC.

Figure 1. Global Greenhouse Gas Emissions by Gas, 1990–2015

EPA plotted total emissions for each gas. EPA formatted the graph as a series of stacked columns instead of a continuous stacked area because complete estimates for all gases are available only every five years, and it would be misleading to suggest that information is known about trends in the interim years.

Figure 2. Global Greenhouse Gas Emissions by Sector, 1990–2015

EPA plotted total GHG emissions by IPCC sector. IPCC sectors are different from the sectors used in Figure 2 of the U.S. Greenhouse Gas Emissions indicator, which uses an economic sector breakdown that is not available on a global scale. EPA formatted the graph as a series of stacked columns instead of a continuous stacked area because complete estimates for all gases are available only every five years, and it would be misleading to suggest that information is known about trends in the interim years.

Figure 3. Global Carbon Dioxide Emissions by Region, 1990–2018

In order to show data at more than six points in time, EPA elected to display emissions by region for CO_2 only, as CO_2 emissions estimates are available with annual resolution. EPA used CAIT's existing regional groupings and confirmed that no emissions were double-counted. EPA isolated U.S. totals from CAIT's "North America" region, leaving Canada as a separate category. Mexico is included in "Latin America and Caribbean." In the graph, regions are ordered from lowest to highest 2018 emissions.

Indicator Development

In the course of developing and revising this indicator, EPA considered data from a variety of sources, including WRI's CAIT (www.climatewatchdata.org/ghg-emissions) and EDGAR (http://edgar.jrc.ec.europa.eu/index.php). EPA compared data obtained from CAIT and EDGAR for global carbon dioxide emissions, and found the two data sources were highly comparable for global estimates of non-LUCF data, with differences of less than 2 percent for all years.

For the purposes of CAIT, WRI essentially serves as a secondary compiler of global emissions data, drawing on internationally recognized inventories from government agencies and using extensively peer-reviewed data sets. EPA has determined that WRI does not perform additional interpolations on the data, but rather makes certain basic decisions in order to allocate emissions to certain countries (e.g., in the case of historical emissions from Soviet republics). These methods are described in CAIT's supporting documentation, which EPA carefully reviewed to assure the credibility of the source.

Previous versions of EPA's indicator excluded LUCF because of its relatively large uncertainty and because of a time lag at the original source that caused LUCF estimates to be up to five years behind the other source categories in this indicator. The scientific community has developed a better understanding of LUCF uncertainties (see Section 10), however, and FAO now provides timely global LUCF estimates based on improved methods. As Houghton et al. (2012) note, "Better reporting of deforestation rates by the FAO [due to the inclusion of satellite data] has narrowed the range of estimates cited by Houghton (2005) and the IPCC (2007) and is likely to reduce the uncertainty still more in the future." Thus, EPA added LUCF to this indicator in 2014.

Additionally, FAO activity data are the default data to which the UNFCCC expert review teams compare country-specific data when performing GHG inventory reviews under the Convention. If the data a country uses to perform its calculations differ significantly from FAO data, the country needs to explain the discrepancy.

7. Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) documentation is not explicitly provided with the full CAIT database, but many of the contributing sources have documented their QA/QC procedures. For example, EPA and its partner agencies have implemented a systematic approach to QA/QC for the annual U.S. GHG inventory, following procedures that has been formalized in accordance with a QA/QC plan and the UNFCCC reporting guidelines. Those interested in documentation of the various QA/QC procedures for the U.S. inventory should send such queries to EPA's Climate Change Division (www.epa.gov/ghgemissions/forms/contact-us-about-greenhouse-gas-emissions). QA/QC procedures for other sources can generally be found in the documentation that accompanies the sources cited in Section 4.

Analysis

8. Comparability Over Time and Space

Some inventories have been prepared by national governments; others by international agencies. Data collection techniques (e.g., survey design) vary depending on the source or parameter. To the extent possible, inventories follow a consistent set of best practice guidelines described in IPCC (2000, 2006, 2019).

9. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. This indicator does not yet include emissions of GHGs or other radiatively important substances that are not explicitly covered by the UNFCCC and its subsidiary protocol. Thus, it excludes gases such as those controlled by the Montreal Protocol and its Amendments, including chlorofluorocarbons and hydrochlorofluorocarbons. Although some countries report emissions of these substances, the origin of the estimates is fundamentally different from those of other GHGs, and therefore these emissions cannot be compared directly with the other emissions discussed in this indicator.

2. This indicator does not include aerosols and other emissions that affect radiative forcing and that are not well-mixed in the atmosphere, such as sulfate, ammonia, black carbon, and organic carbon. Emissions of these compounds are highly uncertain and have qualitatively different effects from the six types of emissions in this indicator.

3. This indicator does not include emissions of other compounds—such as carbon monoxide, nitrogen oxides, nonmethane volatile organic compounds, and substances that deplete the stratospheric ozone layer—which indirectly affect the Earth's radiative balance (for example, by altering GHG concentrations, changing the reflectivity of clouds, or changing the distribution of heat fluxes).

4. The LUCF component of this indicator is limited to the CO_2 estimates available from FAO, which cover emissions and sinks associated with forest land, grassland, cropland, and biomass burning. FAO excludes wetlands, settlements, and "other" categories, but these sources/sinks are relatively small on a global scale, and FAO's four categories constitute a large majority of LUCF emissions and sinks. This indicator also does not include non-CO_2 LUCF emissions and sinks, which are estimated to be much smaller than CO_2 totals.

5. This indicator does not account for "natural" emissions of GHGs, such as from wetlands, tundra soils, termites, and volcanoes.

6. Discrete global emissions estimates for non-CO_2 GHGs are only available at five-year intervals. Thus, Figures 1 and 2 show data for just six points in time: 1990, 1995, 2000, 2005, 2010, and 2015.

10. Sources of Uncertainty

In general, all emissions estimates will have some inherent uncertainty. Estimates of CO_2 emissions from energy-related activities and cement processing are often considered to have the lowest uncertainties, but even these data can have errors as a result of uncertainties in the numbers from which they are derived, such as national energy use data. In contrast, estimates of emissions associated with land-use change and forestry may have particularly large uncertainties. As Ito et al. (2008) explain, "Because there are different sources of errors at the country level, there is no easy reconciliation of different estimates of carbon fluxes at the global level. Clearly, further work is required to develop data sets for historical land cover change areas and models of biogeochemical changes for an accurate representation of carbon uptake or emissions due to [land-use change]." Houghton et al. (2012) reviewed 13 different estimates of global emissions from land use, land-use change, and forestry. They estimated an overall error of ±500 million metric tons of carbon per year. This estimate represents an improvement in understanding LUCF, but still results in a larger uncertainty than can be found in other sectors.

The Modeling and Assessment of Contributions of Climate Change (MATCH) group has thoroughly reviewed a variety of global emissions estimates to characterize their uncertainty. A summary report and detailed articles are available on the MATCH website at: www.match-info.net.

For specific information about uncertainty, users should refer to documentation from the individual data sources cited in Section 4. Uncertainty estimates are available from the underlying national inventories in some cases, in part because the UNFCCC reporting guidelines follow the recommendations of IPCC

(2000) and require countries to provide single point uncertainty estimates for many sources and sink categories. For example, the U.S. GHG emissions inventory (U.S. EPA, 2020) provides a qualitative discussion of uncertainty for all sources and sink categories, including specific factors affecting the uncertainty of the estimates. Most sources also have a quantitative uncertainty assessment, in accordance with the new UNFCCC reporting guidelines. Thorough discussion of these points can be found in U.S. EPA (2020). Annex 7 of EPA's inventory publication is devoted entirely to uncertainty in the inventory estimates. Uncertainties are expected to be greater in estimates from developing countries, due in some cases to varying quality of underlying activity data and uncertain emissions factors. Uncertainties are generally greater for non-CO_2 gases than for CO_2.

Uncertainty is not expected to have a considerable impact on this indicator's conclusions. Uncertainty is indeed present in all emissions estimates, in some cases to a great degree—especially for LUCF and for non-CO_2 gases in developing countries. At an aggregate global scale, however, this indicator accurately depicts the overall direction and magnitude of GHG emissions trends over time, and hence the overall conclusions inferred from the data are reasonable.

The FAO data set has certain limitations that result from the application of Tier 1 methods and from uncertainties in the underlying data. Specific estimates of the uncertainty are not readily available from FAO, and it would be complicated and speculative to provide uncertainty bounds around these data.

11. Sources of Variability

On a national or global scale, year-to-year variability in GHG emissions can arise from a variety of factors, such as economic conditions, fuel prices, and government actions. Overall, variability is not expected to have a considerable impact on this indicator's conclusions.

12. Statistical/Trend Analysis

This indicator does not report on the slope of the apparent trends in global GHG emissions, nor does it calculate the statistical significance of these trends. The "Key Points" describe percentage change between 1990 and the most recent year of data—an endpoint-to-endpoint comparison, not a trend line of best fit.

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