



GREENHOUSE GASES



Greenhouse gases from human activities are the most significant driver of observed climate change since the mid-20th century.¹ The indicators in this chapter characterize emissions of the major greenhouse gases resulting from human activities, the concentrations of these gases in the atmosphere, and how emissions and concentrations have changed over time. When comparing emissions of different gases, these indicators use a concept called “global warming potential” to convert amounts of other gases into carbon dioxide equivalents.

WHY DOES IT MATTER?

As greenhouse gas emissions from human activities increase, they build up in the atmosphere and warm the climate, leading to many other changes around the world—in the atmosphere, on land, and in the oceans. The indicators in other chapters of this report illustrate many of these changes. These changes have both positive and negative effects on people, society, and the environment—including plants and animals. Because many of the major greenhouse gases stay in the atmosphere for tens to hundreds of years after being released, their warming effects on the climate persist over a long time and can therefore affect both present and future generations.

Summary of Key Points



U.S. Greenhouse Gas Emissions. In the United States, greenhouse gas emissions caused by human activities increased by 5 percent from 1990 to 2012. However, since 2005, total U.S. greenhouse gas emissions have decreased by 10 percent. Carbon dioxide accounts for most of the nation's emissions and most of the increase since 1990. Electricity generation is the largest source of greenhouse gas emissions in the United States, followed by transportation. Emissions per person have decreased slightly in the last few years.



Sources of Data on U.S. Greenhouse Gas Emissions. EPA has two key programs that provide data on greenhouse gas emissions in the United States: the Inventory of U.S. Greenhouse Gas Emissions and Sinks and the Greenhouse Gas Reporting Program. The programs are complementary, providing both a higher-level perspective on the nation's total emissions and detailed information about the sources and types of emissions from individual facilities.



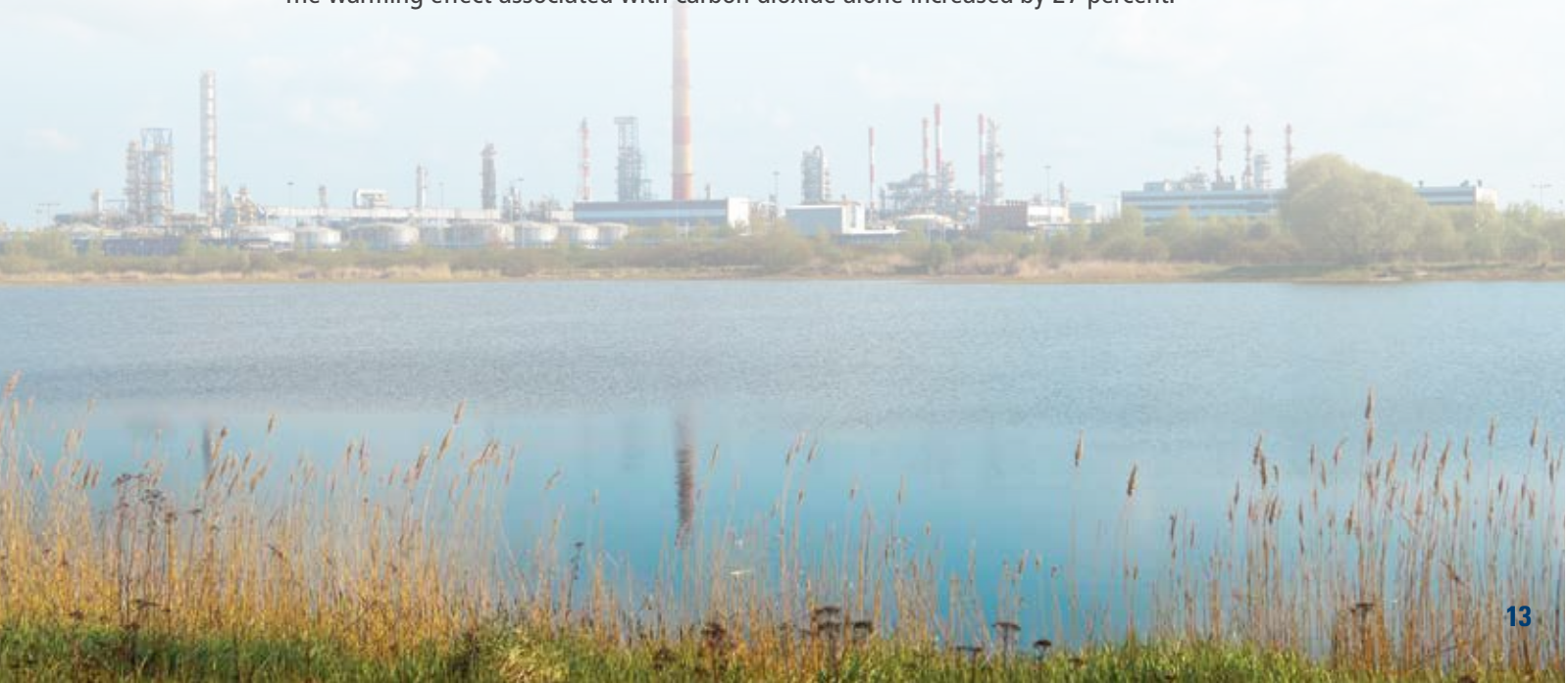
Global Greenhouse Gas Emissions. Worldwide, net emissions of greenhouse gases from human activities increased by 35 percent from 1990 to 2010. Emissions of carbon dioxide, which account for about three-fourths of total emissions, increased by 42 percent over this period. As with the United States, the majority of the world's emissions result from electricity generation, transportation, and other forms of energy production and use.



Atmospheric Concentrations of Greenhouse Gases. Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased since the beginning of the industrial era. Almost all of this increase is attributable to human activities.² Historical measurements show that current levels of many greenhouse gases are higher than any levels recorded for hundreds of thousands of years, even after accounting for natural fluctuations.



Climate Forcing. Climate forcing refers to a change in the Earth's energy balance, leading to either a warming or cooling effect. An increase in the atmospheric concentrations of greenhouse gases produces a positive climate forcing, or warming effect. From 1990 to 2013, the total warming effect from greenhouse gases added by humans to the Earth's atmosphere increased by 34 percent. The warming effect associated with carbon dioxide alone increased by 27 percent.





U.S. Greenhouse Gas Emissions

This indicator describes emissions of greenhouse gases in the United States.

KEY POINTS

- In 2012, U.S. greenhouse gas emissions totaled 6,526 million metric tons (14.4 trillion pounds) of carbon dioxide equivalents. This 2012 total represents a 5 percent increase since 1990 but a 10 percent decrease since 2005 (see Figure 1).
- For the United States, during the period from 1990 to 2012 (see Figure 1):
 - Emissions of carbon dioxide, the primary greenhouse gas emitted by human activities, increased by 5 percent.
 - Methane emissions decreased by 11 percent, as reduced emissions from landfills, coal mines, and natural gas systems were greater than increases in emissions from activities such as livestock production.³
 - Nitrous oxide emissions, predominantly from agricultural soil management practices such as the use of nitrogen as a fertilizer, increased by nearly 3 percent.
 - Emissions of fluorinated gases (hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride), released as a result of commercial, industrial, and household uses, increased by 83 percent.
- Electricity generation is the largest U.S. emissions source, accounting for 32 percent of total greenhouse gas emissions since 1990. Transportation is the second-largest source of greenhouse gas emissions, accounting for 27 percent of emissions since 1990 (see Figure 2).
- Emissions sinks, the opposite of emissions sources, absorb carbon dioxide from the atmosphere. In 2012, 15 percent of U.S. greenhouse gas emissions were offset by sinks resulting from land use and forestry practices (see Figure 2). One major sink is the net growth of forests, which remove

(Continued on p. 15)

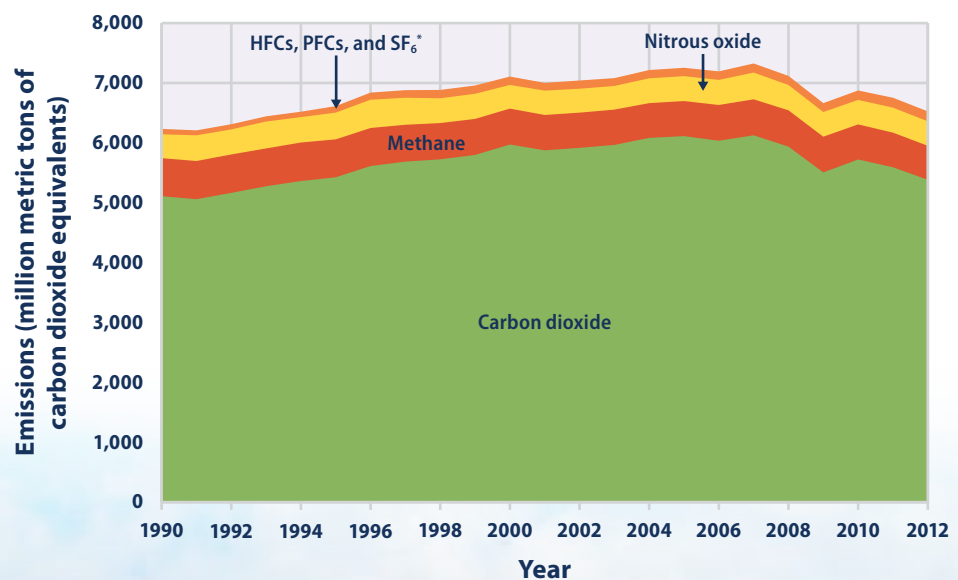
A number of factors influence the quantities of greenhouse gases released into the atmosphere, including economic activity, population, consumption patterns, energy prices, land use, and technology. There are several ways to track these emissions, such as by measuring emissions directly, calculating emissions based on the amount of fuel that people burn, and estimating other activities and their associated emissions. EPA has two key programs that provide data on greenhouse gas emissions in the United States: the Inventory of U.S. Greenhouse Gas Emissions and Sinks and the Greenhouse Gas Reporting Program. See “Sources of Data on U.S. Greenhouse Gas Emissions” (on p. 16) to learn more about these programs.

ABOUT THE INDICATOR

This indicator focuses on emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases—all important greenhouse gases that are influenced by human activities. These particular gases are covered under the United Nations Framework Convention on Climate Change, an international agreement that requires participating countries to develop and periodically submit an inventory of greenhouse gas emissions. Data and analysis for this indicator come from EPA’s annual inventory submission, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.⁴ This indicator is restricted to emissions associated with human activities.

Each greenhouse gas has a different lifetime (how long it stays in the atmosphere) and a different ability to trap heat in our atmosphere. To allow different gases to be compared and added together, emissions are converted into carbon dioxide equivalents. This step uses each gas’s 100-year global warming potential, which measures how much a given amount of the gas is estimated to contribute to global warming over a period of 100 years after being emitted. Carbon dioxide is assigned a global warming potential equal to 1. This analysis uses global warming potentials from the Intergovernmental Panel on Climate Change’s (IPCC’s) Second Assessment Report. In that report, methane has a global warming potential of 21, which means a ton of methane emissions contributes 21 times as much warming as a ton of carbon dioxide emissions over 100 years, and that ton of methane emissions is therefore equal to 21 tons of carbon dioxide equivalents. See the table on p. 7 for comparison with global warming potentials from IPCC’s Fifth Assessment Report. For additional perspective, this indicator also shows greenhouse gas emissions in relation to economic output and population.

Figure 1. U.S. Greenhouse Gas Emissions by Gas, 1990–2012

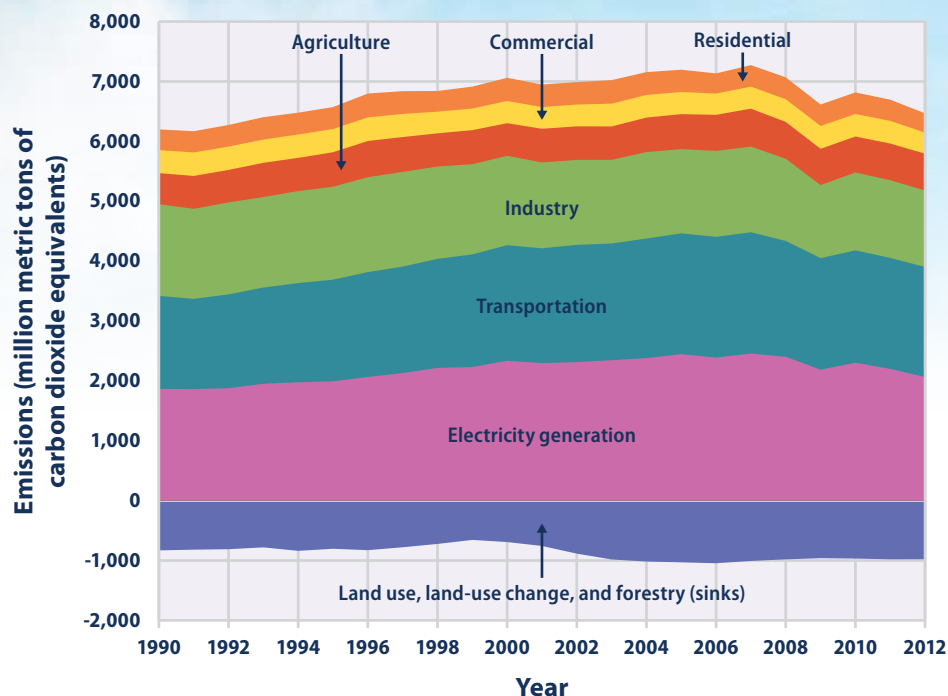


This figure shows emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases in the United States from 1990 to 2012. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents.

* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF₆ is sulfur hexafluoride.

Data source: U.S. EPA, 2014⁵

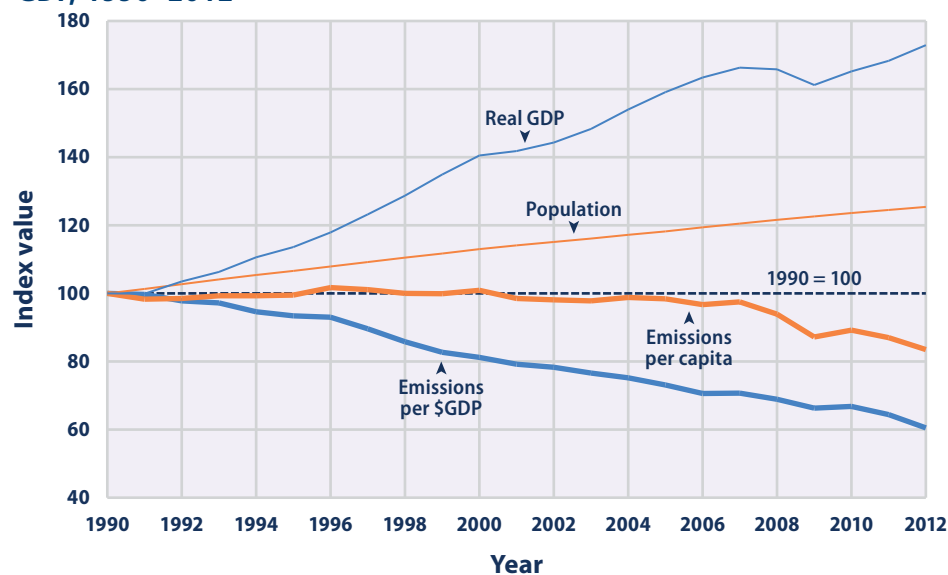
Figure 2. U.S. Greenhouse Gas Emissions and Sinks by Economic Sector, 1990–2012



This figure shows greenhouse gas emissions and sinks (negative values) by source in the United States from 1990 to 2012. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. All electric power emissions are grouped together in the “Electricity generation” sector, so other sectors such as “Residential” and “Commercial” are only showing non-electric sources, such as burning oil or gas for heating. Totals do not match Figure 1 exactly because the economic sectors shown here do not include emissions from U.S. territories outside the 50 states.

Data source: U.S. EPA, 2014⁶

Figure 3. U.S. Greenhouse Gas Emissions per Capita and per Dollar of GDP, 1990–2012



This figure shows trends in greenhouse gas emissions from 1990 to 2012 per capita (heavy orange line), based on the total U.S. population (thin orange line). It also shows trends in emissions per dollar of real GDP (heavy blue line). Real GDP (thin blue line) is the value of all goods and services produced in the country during a given year, adjusted for inflation. All data are indexed to 1990 as the base year, which is assigned a value of 100. For instance, a real GDP value of 173 in the year 2012 would represent a 73 percent increase since 1990.

Data source: U.S. EPA, 2014⁷

INDICATOR NOTES

While this indicator includes the major greenhouse gases emitted by human activities, it does not include other greenhouse gases and substances that are not covered under the United Nations Framework Convention on Climate Change but that still affect the Earth’s energy balance and climate (see the Climate Forcing indicator on p. 24 for more details). For example, this indicator excludes ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which have high global warming potentials, as these gases have been or are currently being phased out under an international agreement called the Montreal Protocol. This indicator also excludes black carbon and aerosols, which most greenhouse gas emissions inventories do not cover. There are also many natural greenhouse gas emissions sources; however, this indicator includes only emissions that are associated with human activities—those that are most responsible for the observed buildup of these gases in our atmosphere.

KEY POINTS

(Continued from p. 14)

- carbon from the atmosphere. Other carbon sinks are associated with how people use the land, including the practice of depositing yard trimmings and food scraps in landfills.
- Emissions increased at about the same rate as the population from 1990 to 2007, which caused emissions per capita to remain fairly level (see Figure 3). Total emissions and emissions per capita declined from 2007 to 2009, due in part to a drop in U.S. economic production during this time. Emissions decreased again from 2010 to 2012, largely due to the growing use of natural gas to generate electricity in place of more carbon-intensive fuels.⁸
- From 1990 to 2012, greenhouse gas emissions per dollar of goods and services produced by the U.S. economy (the gross domestic product or GDP) declined by 39 percent (see Figure 3). This change may reflect a combination of increased energy efficiency and structural changes in the economy.

DATA SOURCES

Data for this indicator came from EPA’s *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*. This report is available online at: www.epa.gov/climatechange/ghgemissions/usinventoryreport.html. The calculations in Figure 3 are based on GDP and population data provided by the U.S. Bureau of Economic Analysis and the U.S. Census, respectively.



Sources of Data on U.S. Greenhouse Gas Emissions



EPA has two key programs that provide data on greenhouse gas emissions in the United States: the Inventory of U.S. Greenhouse Gas Emissions and Sinks and the Greenhouse Gas Reporting Program.

EPA'S INVENTORY OF GREENHOUSE GAS EMISSIONS AND SINKS

EPA develops an annual report called the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (or the Greenhouse Gas Inventory). This report tracks trends in total annual U.S. emissions by source (or sink), economic sector, and greenhouse gas going back to 1990. EPA uses national energy data, data on national agricultural activities, and other national statistics to provide a comprehensive accounting of total greenhouse gas emissions for all man-made sources in the United States. This inventory fulfills the nation's obligation to provide an annual emissions report under the United Nations Framework Convention on Climate Change.

EPA'S GREENHOUSE GAS REPORTING PROGRAM

EPA's Greenhouse Gas Reporting Program collects annual emissions data from industrial sources that directly emit large amounts of greenhouse gases. Generally, facilities that emit more than 25,000 metric tons of carbon dioxide equivalents per year are required to report. The program also collects data from entities known as "suppliers" that supply certain fossil fuels and industrial gases that will emit greenhouse gases into the atmosphere if burned or released—for example, refineries that supply petroleum products such as gasoline. The Greenhouse Gas Reporting Program only requires reporting; it is not an emissions control program. This program helps EPA and the public understand where greenhouse gas emissions are coming from, and will improve our ability to make informed policy, business, and regulatory decisions. This program:

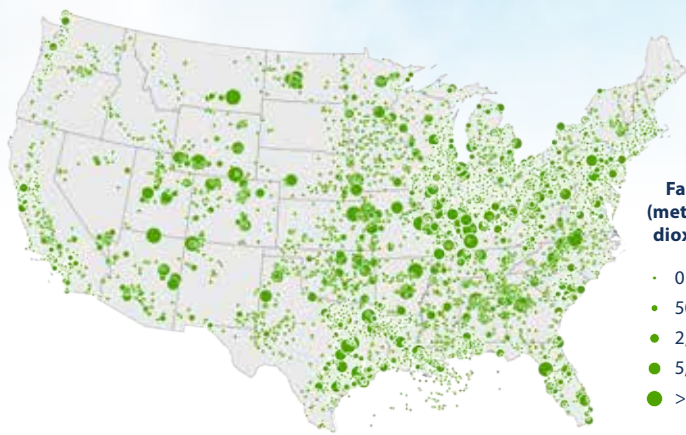
- Covers carbon dioxide, methane, nitrous oxide, and fluorinated gases.
- Represents 85 to 90 percent of U.S. greenhouse gas emissions.
- Covers 41 industrial categories (for example, power plants, oil and gas producers, landfills, and other industrial facilities).
- Collects greenhouse gas data from more than 8,000 entities.

Visit: www.epa.gov/ghgreporting to learn more about the sources that report data.

EPA's Greenhouse Gas Reporting Program provides facility-level information and allows people to track changes in greenhouse gas emissions in various industries, geographic areas, and industrial facilities. EPA has now verified three years of data and made them publicly available.

Data from the Greenhouse Gas Reporting Program are easily accessible from EPA's website at: www.epa.gov/ghgreporting/ghgdata/index.html. Visitors can explore data by facility, industry, location, or gas using a data visualization and mapping tool called FLIGHT.

Facilities That Directly Emit Greenhouse Gases and Report to EPA's Greenhouse Gas Reporting Program (2012)



- Facility emissions (metric tons of carbon dioxide equivalents)**
- 0–500,000
 - 500,000–2,000,000
 - 2,000,000–5,000,000
 - 5,000,000–10,000,000
 - >10,000,000



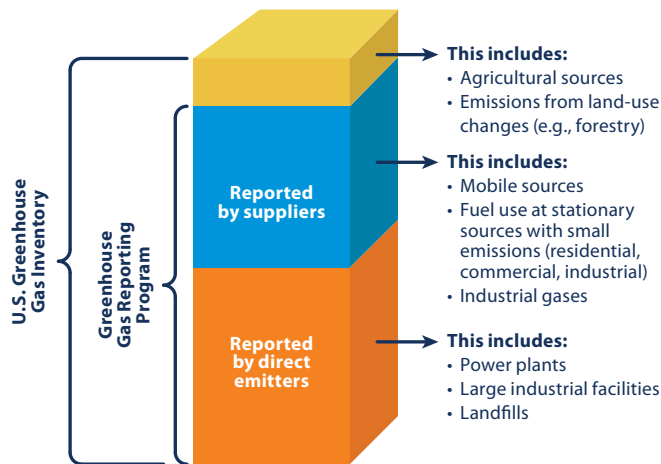
COMPARING THE SOURCES

EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks presents annual national-level greenhouse gas emissions estimates from 1990 to the present. It estimates the total greenhouse gas emissions across all sectors of the economy using national-level data. This inventory and its 20+ years of data serve as the basis for this report's U.S. Greenhouse Gas Emissions indicator (p. 14).

In contrast, the Greenhouse Gas Reporting Program is a relatively new program that began collecting data in 2010. The reporting program collects detailed emissions data from the largest greenhouse gas emitting facilities in the United States.

While the inventory provides high-level perspective needed to understand the United States' total emissions or "carbon footprint," the Greenhouse Gas Reporting Program provides detailed information that helps us better understand the sources and types of greenhouse gas emissions at individual facilities. The inventory provides a more complete estimate of total U.S. emissions because it accounts for some sources that the reporting program does not cover (see diagram at right). Thus, the inventory and the reporting program are complementary tools.

Comparing EPA's Two Sources of Data on Greenhouse Gas Emissions

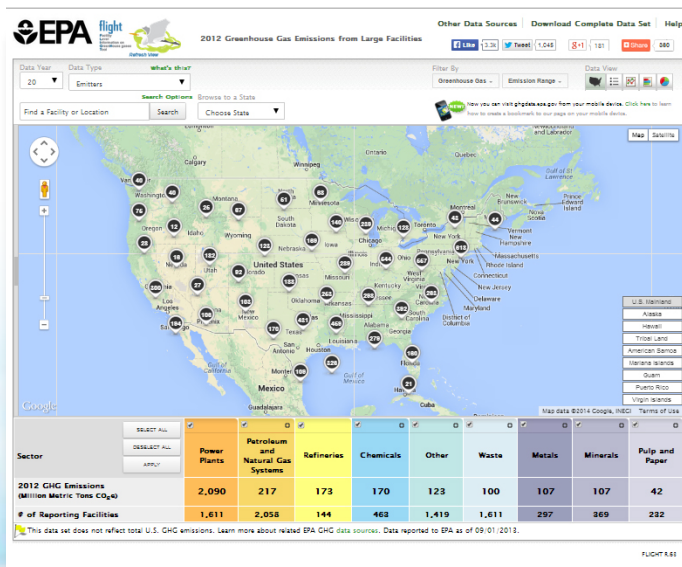


flight

Facility Level Information on Greenhouse gases Tool

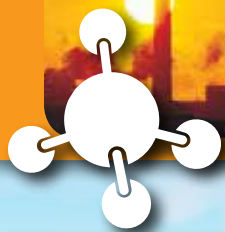


A snapshot of FLIGHT: EPA's Greenhouse Gas Reporting Program data visualization and mapping tool: <http://ghgdata.epa.gov>.



Global Greenhouse Gas Emissions

This indicator describes emissions of greenhouse gases worldwide.



KEY POINTS

- In 2010, estimated worldwide emissions from human activities totaled nearly 46 billion metric tons of greenhouse gases, expressed as carbon dioxide equivalents. This represents a 35 percent increase from 1990 (see Figures 1 and 2). These numbers represent net emissions, which include the effects of land use and forestry.
- Between 1990 and 2010, global emissions of all major greenhouse gases increased (see Figure 1). Net emissions of carbon dioxide increased by 42 percent, which is particularly important because carbon dioxide accounts for about three-fourths of total global emissions. Nitrous oxide emissions increased the least—9 percent—while emissions of methane increased by 15 percent. Emissions of fluorinated gases more than doubled.
- Energy production and use (including fuels used by vehicles) represent the largest source of greenhouse gas emissions worldwide (about 71 percent of the total in 2010), followed by agriculture (13 percent in 2010) (see Figure 2). While land-use change and forestry represent a net sink for emissions in the United States, absorbing carbon dioxide and offsetting emissions from other sources (see the U.S. Greenhouse Gas Emissions indicator on p. 14), these activities are a net source of emissions on a global scale, largely because of deforestation.⁹
- Carbon dioxide emissions are increasing faster in some parts of the world (for example, Asia) than in others (see Figure 3). The majority of emissions come from three regions: Asia, Europe, and the United States, which together accounted for 82 percent of total global emissions in 2011.

Increasing emissions of greenhouse gases due to human activities worldwide have led to a substantial increase in atmospheric concentrations of long-lived and other greenhouse gases (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 20). Every country around the world emits greenhouse gases into the atmosphere, meaning the root cause of climate change is truly global in scope. Some countries produce far more greenhouse gases than others, and several factors—such as economic activity, population, income level, land use, and climatic conditions—can influence a country's emissions levels. Tracking greenhouse gas emissions worldwide provides a global context for understanding the United States' and other nations' roles in climate change.

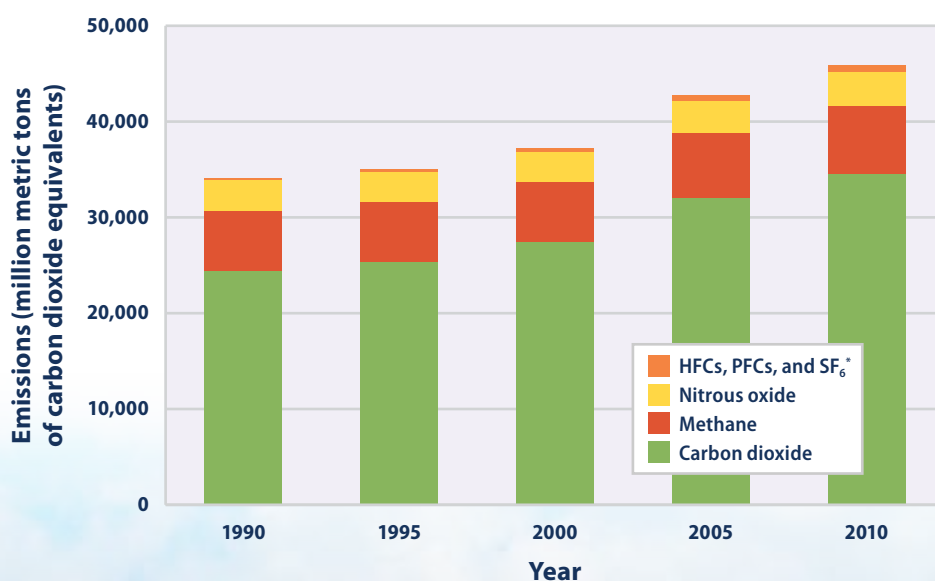
ABOUT THE INDICATOR

Like the U.S. Greenhouse Gas Emissions indicator (on p. 14), this indicator focuses on emissions of gases covered under the United Nations Framework Convention on Climate Change: carbon dioxide, methane, nitrous oxide, and several fluorinated gases. These are all important greenhouse gases that are influenced by human activities, and the Convention requires participating countries to develop and periodically submit an inventory of these emissions.

Data and analysis for this indicator come from the World Resources Institute's Climate Analysis Indicators Tool (CAIT), which compiles data from peer-reviewed and internationally recognized greenhouse gas inventories developed by EPA and other government agencies worldwide. Global estimates for carbon dioxide are published annually, but estimates for other gases, such as methane and nitrous oxide, are available only every fifth year. CAIT includes estimates of emissions and sinks associated with land use and forestry activities, which come from global estimates compiled by the Food and Agriculture Organization of the United Nations.

Each greenhouse gas has a different lifetime (how long it stays in the atmosphere) and a different ability to trap heat in our atmosphere. To allow different gases to be compared and added together, emissions are converted into carbon dioxide equivalents. This step uses each gas's 100-year global warming potential, which measures how much a given amount of the gas is estimated to contribute to global warming over a period of 100 years after being emitted. Carbon dioxide is assigned a global warming potential equal to 1.

Figure 1. Global Greenhouse Gas Emissions by Gas, 1990–2010

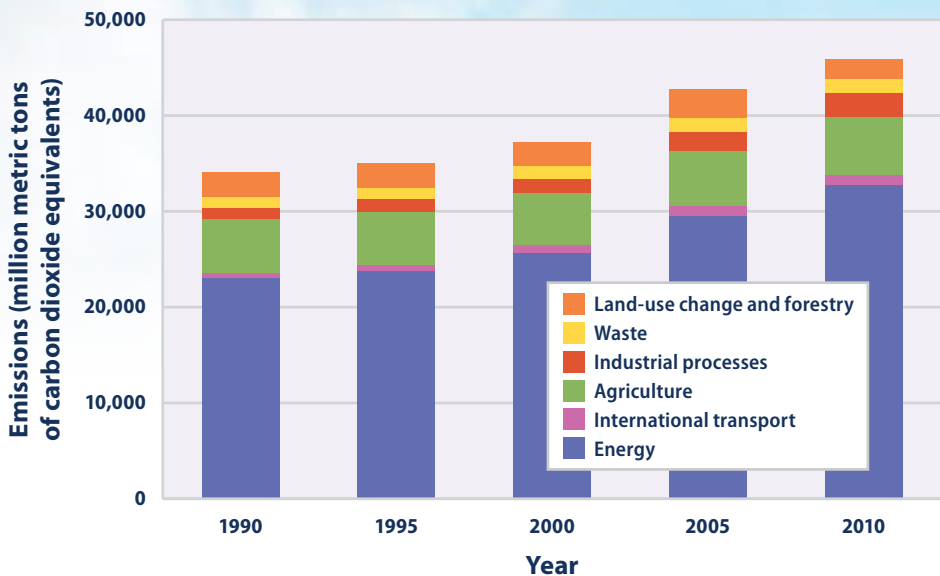


This figure shows worldwide emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases from 1990 to 2010. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. These totals include emissions and sinks due to land-use change and forestry.

* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF₆ is sulfur hexafluoride.

Data source: WRI, 2014;¹⁰ FAO, 2014¹¹

Figure 2. Global Greenhouse Gas Emissions by Sector, 1990–2010

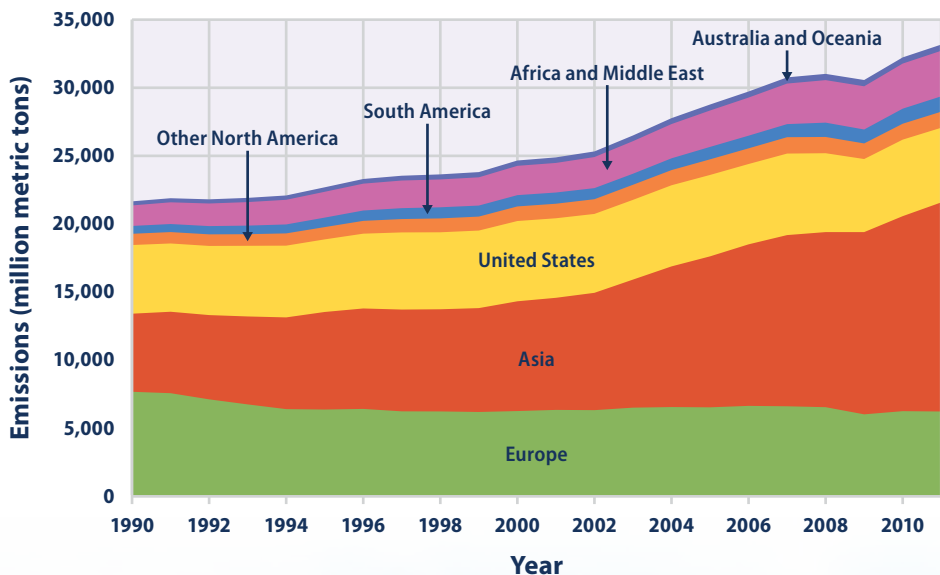


This figure shows worldwide greenhouse gas emissions by sector from 1990 to 2010. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. These totals include emissions and sinks due to land-use change and forestry.

Note that the sectors shown here are different from the economic sectors used in U.S. emissions accounting (see the U.S. Greenhouse Gas Emissions indicator on p. 14). Emissions from international transport (aviation and marine) are separate from the energy sector because they are not part of individual countries' emissions inventories. The energy sector includes all other transportation activities.

Data source: WRI, 2014;¹² FAO, 2014¹³

Figure 3. Global Carbon Dioxide Emissions by Region, 1990–2011



This figure shows carbon dioxide emissions from 1990 to 2011 for different regions of the world. These totals do not include emissions or sinks related to land-use change or forestry. Inclusion of land-use change and forestry would increase the apparent emissions from some regions while decreasing the emissions from others.

Data source: WRI, 2014¹⁴

This analysis uses global warming potentials from the Intergovernmental Panel on Climate Change's (IPCC's) Second Assessment Report. In that report, methane has a global warming potential of 21, which means a ton of methane emissions contributes 21 times as much warming as a ton of carbon dioxide emissions over 100 years, and that ton of methane emissions is therefore equal to 21 tons of carbon dioxide equivalents. See the table on p. 7 for comparison with global warming potentials from IPCC's Fifth Assessment Report.

INDICATOR NOTES

Like the U.S. Greenhouse Gas Emissions indicator (on p. 14), this indicator does not include emissions of gases that affect climate but are not covered under the United Nations Framework Convention on Climate Change. For example, this indicator excludes ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which have high global warming potentials, because these gases have been or are currently being phased out under an international agreement called the Montreal Protocol. This indicator also excludes black carbon and aerosols, which most emissions inventories do not cover. There are also various emissions of greenhouse gases of natural origin, which this indicator does not cover.

Global emissions inventories for gases other than carbon dioxide are limited to five-year intervals. The United Nations Framework Convention on Climate Change database has more comprehensive data; however, these data are available mainly for a group of mostly developed countries that account for only about half of global greenhouse gas emissions. Thus, to provide a more representative measure of global greenhouse gas emissions, this indicator uses the broader CAIT database.

DATA SOURCES

Data for this indicator came from the World Resources Institute's CAIT database, which is accessible online at: <http://cait.wri.org>. CAIT compiles data that were originally collected by organizations including the International Energy Agency, EPA, the U.S. Carbon Dioxide Information Analysis Center, and the Food and Agriculture Organization of the United Nations. Other global emissions estimates—such as the estimates published by the Intergovernmental Panel on Climate Change¹⁵—are based on many of the same sources.



Atmospheric Concentrations of Greenhouse Gases

This indicator describes how the levels of major greenhouse gases in the atmosphere have changed over time.

KEY POINTS

- Global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and certain manufactured greenhouse gases have all risen significantly over the last few hundred years (see Figures 1, 2, 3, and 4).
- Historical measurements show that the current global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide are unprecedented compared with the past 800,000 years (see Figures 1, 2, and 3).



WATER VAPOR AS A GREENHOUSE GAS

Water vapor is the most abundant greenhouse gas in the atmosphere. Human activities have only a small direct influence on atmospheric concentrations of water vapor, primarily through irrigation and deforestation, so it is not included in this indicator.¹⁶ However, the surface warming caused by human production of other greenhouse gases leads to an increase in atmospheric water vapor, because warmer temperatures make it easier for water to evaporate and stay in the air in vapor form. This creates a positive “feedback loop” in which warming leads to more warming.

Since the Industrial Revolution began in the 1700s, people have added a substantial amount of greenhouse gases into the atmosphere by burning fossil fuels, cutting down forests, and conducting other activities (see the U.S. and Global Greenhouse Gas Emissions indicators on pp. 14 and 18). When greenhouse gases are emitted into the atmosphere, many remain there for long time periods ranging from a decade to many millennia. Over time, these gases are removed from the atmosphere by chemical reactions or by emissions sinks, such as the oceans and vegetation, which absorb greenhouse gases from the atmosphere. However, as a result of human activities, these gases are entering the atmosphere more quickly than they are being removed, and thus their concentrations are increasing.

Carbon dioxide, methane, nitrous oxide, and certain manufactured gases called halogenated gases (gases that contain chlorine, fluorine, or bromine) become well mixed throughout the global atmosphere because of their relatively long lifetimes and because of transport by winds. Concentrations of these greenhouse gases are measured in parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt) by volume. In other words, a concentration of 1 ppb for a given gas means there is one molecule of that gas in every 1 billion molecules of air. Some halogenated gases are considered major greenhouse gases due to their very high global warming potentials and long atmospheric lifetimes even if they only exist at a few ppt (see table on p. 7).

Ozone is also a greenhouse gas, but it differs from other greenhouse gases in several ways. The effects of ozone depend on its altitude, or where the gas is located vertically in the atmosphere. Most ozone naturally exists in the layer of the atmosphere called the stratosphere, which ranges from approximately 6 to 30 miles above the Earth’s surface. Ozone in the stratosphere has a slight net warming effect on the planet, but it is good for life on Earth because it absorbs harmful ultraviolet radiation from the sun, preventing it from reaching the Earth’s surface. In the troposphere—the layer of the atmosphere near ground level—ozone is an air pollutant that is harmful to breathe, a main ingredient of urban smog, and an important greenhouse gas that contributes to climate change (see the Climate Forcing indicator on p. 24). Unlike the other major greenhouse gases, tropospheric ozone only lasts for days to weeks, so levels often vary by location and by season.

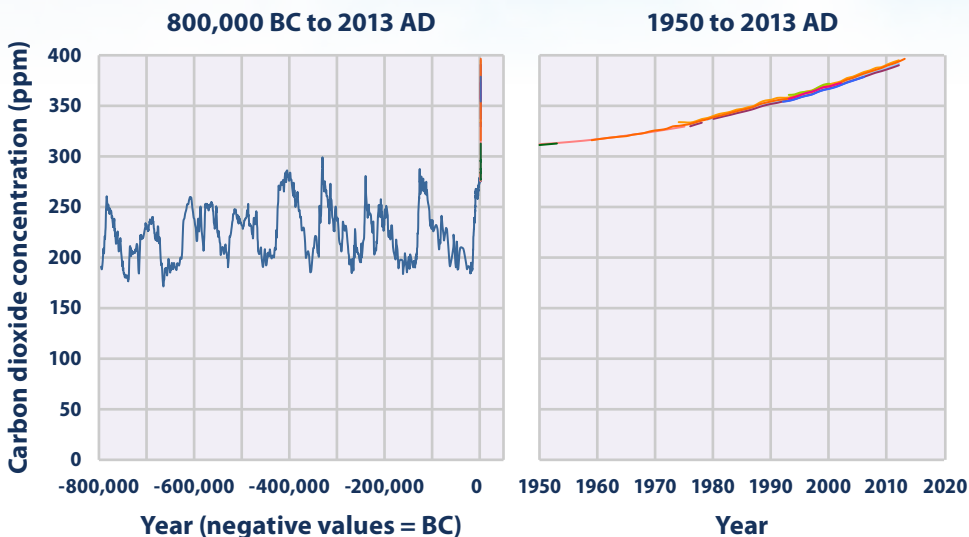
ABOUT THE INDICATOR

This indicator describes concentrations of greenhouse gases in the atmosphere. It focuses on the major greenhouse gases that result from human activities.

For carbon dioxide, methane, nitrous oxide, and halogenated gases, recent measurements come from monitoring stations around the world, while measurements of older air come from air bubbles trapped in layers of ice from Antarctica and Greenland. By determining the age of the ice layers and the concentrations of gases trapped inside, scientists can learn what the atmosphere was like thousands of years ago.

This indicator also shows data from satellite instruments that measure ozone density in the troposphere, the stratosphere, and the “total column,” or all layers of the atmosphere. These satellite data are routinely compared with ground-based instruments to confirm their accuracy. Ozone data have been averaged worldwide for each year to smooth out the regional and seasonal variations.

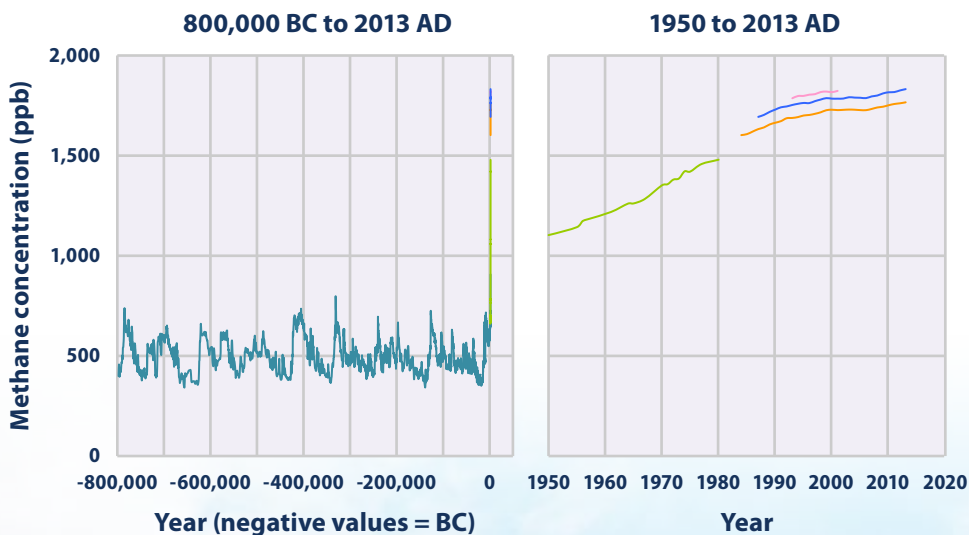
Figure 1. Global Atmospheric Concentrations of Carbon Dioxide Over Time



This figure shows concentrations of carbon dioxide in the atmosphere from hundreds of thousands of years ago through 2013, measured in parts per million (ppm). The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

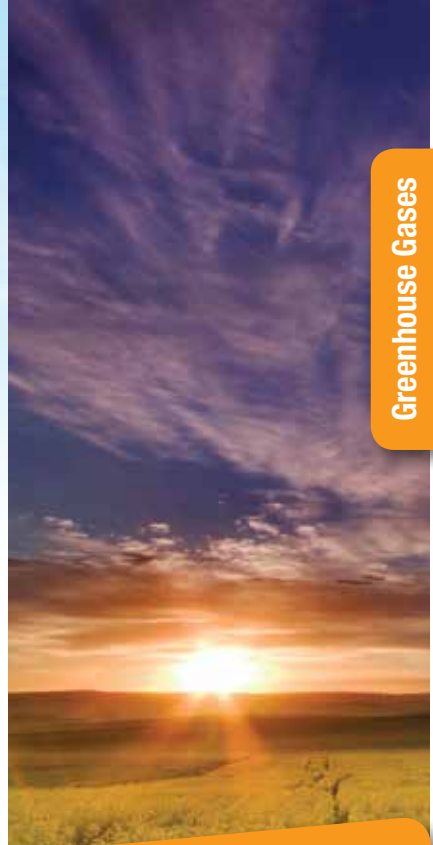
Data source: Compilation of 10 underlying datasets¹⁷

Figure 2. Global Atmospheric Concentrations of Methane Over Time



This figure shows concentrations of methane in the atmosphere from hundreds of thousands of years ago through 2013, measured in parts per billion (ppb). The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

Data source: Compilation of five underlying datasets¹⁸



KEY POINTS

- Carbon dioxide concentrations have increased steadily since the beginning of the industrial era, rising from an annual average of 280 ppm in the late 1700s to 396 ppm at Mauna Loa in 2013—a 41 percent increase (see Figure 1). Almost all of this increase is due to human activities.¹⁹
- The concentration of methane in the atmosphere has more than doubled since preindustrial times, reaching approximately 1,800 ppb in 2013 (see the range of measurements in Figure 2). This increase is predominantly due to agriculture and fossil fuel use.²⁰

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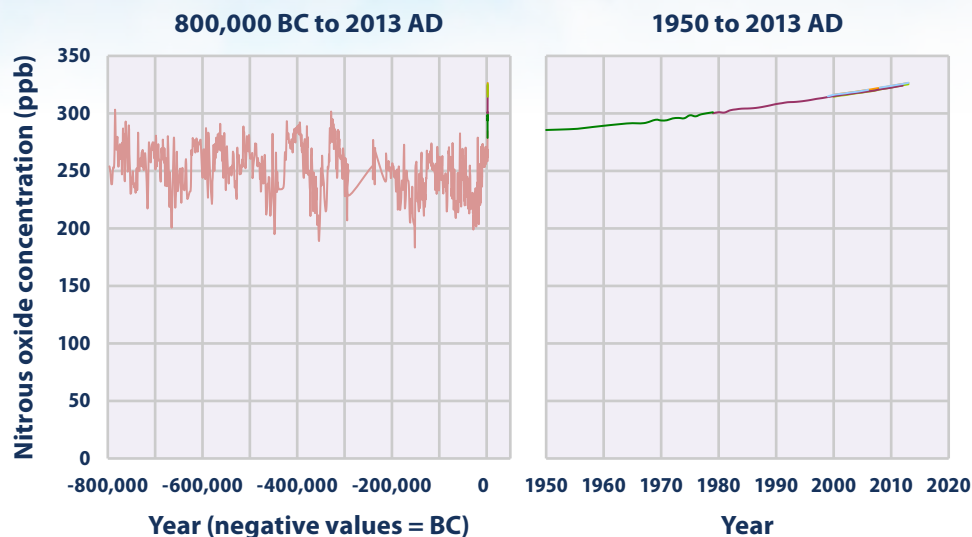
Atmospheric Concentrations of Greenhouse Gases

Continued

KEY POINTS

- Over the past 800,000 years, concentrations of nitrous oxide in the atmosphere rarely exceeded 280 ppb. Levels have risen since the 1920s, however, reaching a new high of 326 ppb in 2013 (average of three sites in Figure 3). This increase is primarily due to agriculture.²¹
- Concentrations of many of the halogenated gases shown in Figure 4 were essentially zero a few decades ago but have increased rapidly as they have been incorporated into industrial products and processes. Some of these chemicals have been or are currently being phased out of use because they are ozone-depleting substances, meaning they also cause harm to the Earth's protective ozone layer. As a result, concentrations of many major ozone-depleting gases have begun to stabilize or decline (see Figure 4, left panel). Concentrations of other halogenated gases have continued to rise, however, especially where the gases have emerged as substitutes for ozone-depleting chemicals (see Figure 4, right panel).

Figure 3. Global Atmospheric Concentrations of Nitrous Oxide Over Time



This figure shows concentrations of nitrous oxide from hundreds of thousands of years ago through 2013, measured in parts per billion (ppb). The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

Data source: Compilation of six underlying datasets²²

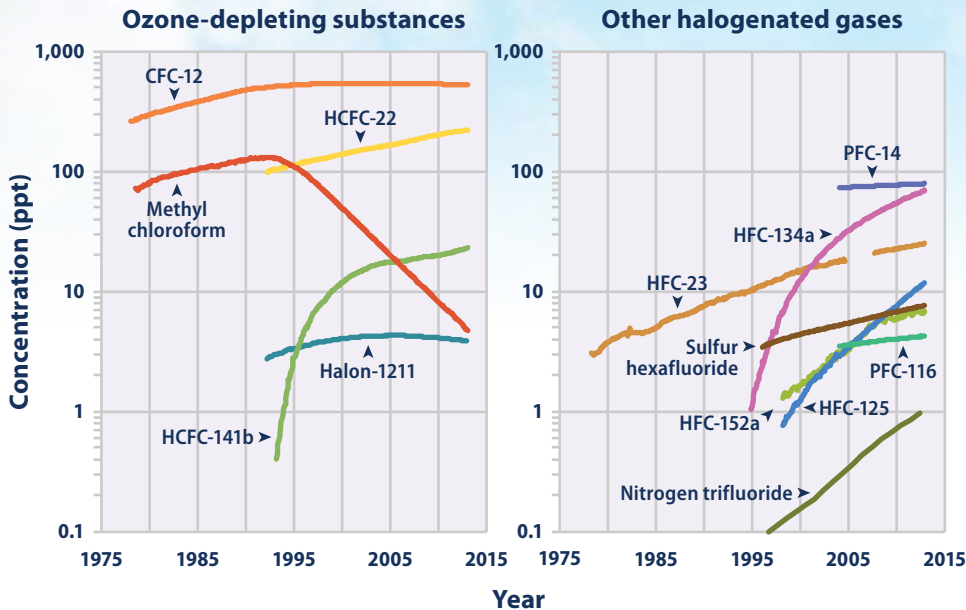
INDICATOR NOTES

This indicator includes several of the most important halogenated gases, but some others are not shown. Many other halogenated gases are also greenhouse gases, but Figure 4 is limited to a set of common examples that represent most of the major types of these gases. The indicator also does not address certain other pollutants that can affect climate by either reflecting or absorbing energy. For example, sulfate particles can reflect sunlight away from the Earth, while black carbon aerosols (soot) absorb energy. Data for nitrogen trifluoride (Figure 4) reflect modeled averages based on measurements made in the Northern Hemisphere and some locations in the Southern Hemisphere, to represent global average concentrations over time. The global averages for ozone only cover the area between 50°N and 50°S latitude (77 percent of the Earth's surface), because at higher latitudes the lack of sunlight in winter creates data gaps and the angle of incoming sunlight during the rest of the year reduces the accuracy of the satellite measuring technique.

DATA SOURCES

Global atmospheric concentration measurements for carbon dioxide (Figure 1), methane (Figure 2), and nitrous oxide (Figure 3) come from a variety of monitoring programs and studies published in peer-reviewed literature. Global atmospheric concentration data for selected halogenated gases (Figure 4) were compiled by the Advanced Global Atmospheric Gases Experiment, the National Oceanic and Atmospheric Administration, and a peer-reviewed study on nitrogen trifluoride. A similar figure with many of these gases appears in the Intergovernmental Panel on Climate Change's Fifth Assessment Report.²³ Satellite measurements of ozone were processed by the National Aeronautics and Space Administration and validated using ground-based measurements collected by the National Oceanic and Atmospheric Administration.

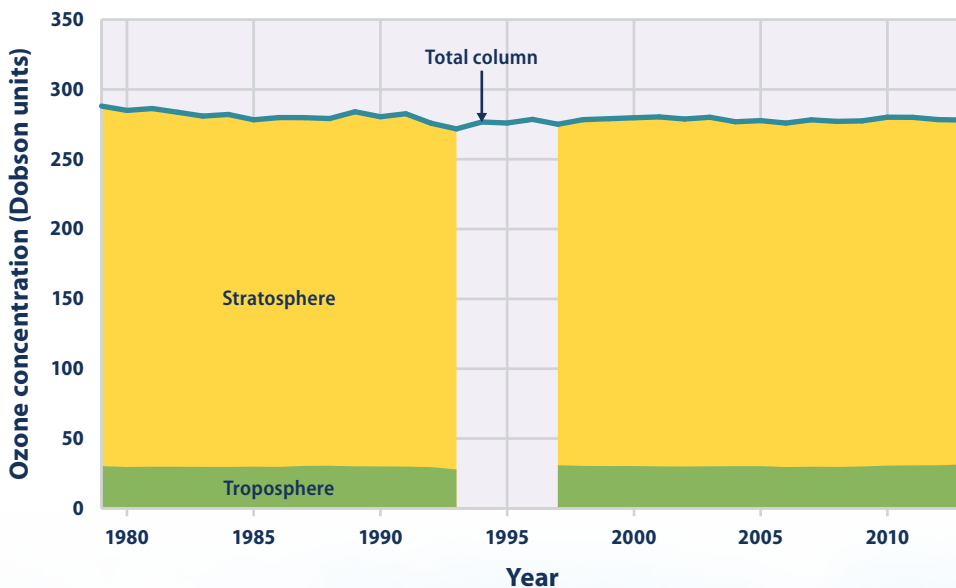
Figure 4. Global Atmospheric Concentrations of Selected Halogenated Gases, 1978–2012



This figure shows concentrations of several halogenated gases (which contain fluorine, chlorine, or bromine) in the atmosphere, measured in parts per trillion (ppt). The data come from monitoring sites around the world. Note that the scale increases by factors of 10. This is because the concentrations of different halogenated gases can vary by a few orders of magnitude. The numbers following the name of each gas (e.g., HCFC-22) are used to denote specific types of those particular gases.

Data sources: AGAGE, 2014;²⁴ Arnold, 2013;²⁵ NOAA, 2013²⁶

Figure 5. Global Atmospheric Concentrations of Ozone, 1979–2013

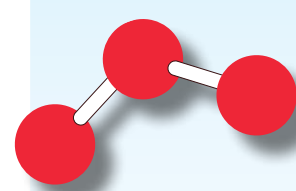


This figure shows the average amount of ozone in the Earth's atmosphere each year, based on satellite measurements. The total represents the "thickness" or density of ozone throughout all layers of the Earth's atmosphere, which is called total column ozone and measured in Dobson units. Higher numbers indicate more ozone. For most years, Figure 5 shows how this ozone is divided between the troposphere (the part of the atmosphere closest to the ground) and the stratosphere. From 1994 to 1996, only the total is available, due to limited satellite coverage.

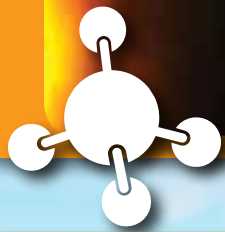
Data sources: NASA, 2013,²⁷ 2014^{28,29}

KEY POINTS

- Overall, the total amount of ozone in the atmosphere decreased by about 3 percent between 1979 and 2013 (see Figure 5). All of the decrease happened in the stratosphere, with most of the decrease occurring between 1979 and 1994. Changes in stratospheric ozone reflect the effect of ozone-depleting substances. These chemicals have been released into the air for many years, but recently, international efforts have reduced emissions and phased out their use.
- Globally, the amount of ozone in the troposphere increased by about 4 percent between 1979 and 2013 (see Figure 5).



This indicator looks at global average levels of ozone in both the stratosphere and troposphere. For trends in ground-level ozone concentrations within the United States, see EPA's National Air Quality Trends Report at: www.epa.gov/airtrends.



Climate Forcing

This indicator measures the “radiative forcing” or heating effect caused by greenhouse gases in the atmosphere.

KEY POINTS

- In 2013, the Annual Greenhouse Gas Index was 1.34, which represents a 34 percent increase in radiative forcing (a net warming influence) since 1990 (see Figure 1).
- Of the greenhouse gases shown in Figure 1, carbon dioxide accounts for by far the largest share of radiative forcing since 1990, and its contribution continues to grow at a steady rate. Carbon dioxide alone would account for a 27 percent increase in radiative forcing since 1990.
- Although the overall Annual Greenhouse Gas Index continues to rise, the rate of increase has slowed somewhat over time. This change has occurred in large part because methane concentrations have increased at a slower rate in recent years and because chlorofluorocarbon (CFC) concentrations have been declining, as production of CFCs has been phased out globally due to the harm they cause to the ozone layer (see Figure 1).
- Greenhouse gases produced by human activities have caused an overall warming influence on the Earth’s climate since 1750. The largest contributor to warming has been carbon dioxide, followed by methane, and black carbon. Although aerosol pollution and certain other activities have caused cooling, the net result is that human activities on the whole have warmed the Earth (see Figure 2).

When energy from the sun reaches the Earth, the planet absorbs some of this energy and radiates the rest back to space as heat. The Earth’s surface temperature depends on this balance between incoming and outgoing energy. Average conditions tend to remain stable unless the Earth experiences a force that shifts the energy balance. A shift in the energy balance causes the Earth’s average temperature to become warmer or cooler, leading to a variety of other changes in the lower atmosphere, on land, and in the oceans.

A variety of physical and chemical changes can affect the global energy balance and force changes in the Earth’s climate. Some of these changes are natural, while others are influenced by humans. These changes are measured by the amount of warming or cooling they can produce, which is called “radiative forcing.” Changes that have a warming effect are called “positive” forcing, while changes that have a cooling effect are called “negative” forcing. When positive and negative forces are out of balance, the result is a change in the Earth’s average surface temperature.

Changes in greenhouse gas concentrations in the atmosphere affect radiative forcing (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 20). Greenhouse gases absorb energy that radiates upward from the Earth’s surface, re-emitting heat to the lower atmosphere and warming the Earth’s surface. Human activities have led to increased concentrations of greenhouse gases that can remain in the atmosphere for decades, centuries, or longer, so the corresponding warming effects will last for a long time.

ABOUT THE INDICATOR

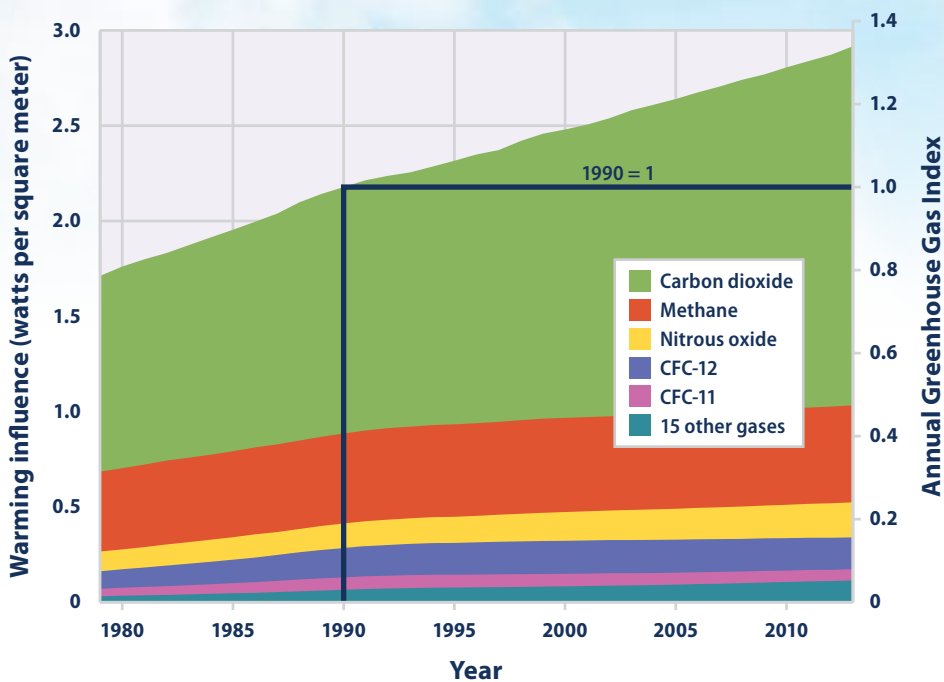
Figure 1 of this indicator measures the average total radiative forcing of 20 long-lived greenhouse gases, including carbon dioxide, methane, and nitrous oxide. The results were calculated by the National Oceanic and Atmospheric Administration based on measured concentrations of the gases in the atmosphere, compared with the concentrations that were present around 1750, before the Industrial Revolution began. Because each gas has a different ability to absorb and emit energy, this indicator converts the changes in greenhouse gas concentrations into a measure of the total radiative forcing (warming effect) caused by each gas. Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere.

The National Oceanic and Atmospheric Administration also translates the total radiative forcing of these measured gases into an index value called the Annual Greenhouse Gas Index (right side of Figure 1). This number compares the radiative forcing for a particular year with the radiative forcing in 1990, which is a common baseline year for global agreements to track and reduce greenhouse gas emissions.

For reference, this indicator also presents an estimate of the total radiative forcing associated with a variety of human activities from 1750 to the present. Figure 2 shows the influence of:

- Tropospheric ozone, a short-lived greenhouse gas.
- Emissions that indirectly lead to greenhouse gases through chemical reactions in the atmosphere. For example, methane emissions also lead to an increase in tropospheric ozone.
- Aerosol pollution, which consists of solid and liquid particles suspended in the air that can reflect incoming sunlight.
- Black carbon (soot), which can make the Earth’s surface darker and less reflective when it is deposited on snow and ice.
- Several other factors, like land use change, that affect radiative forcing.

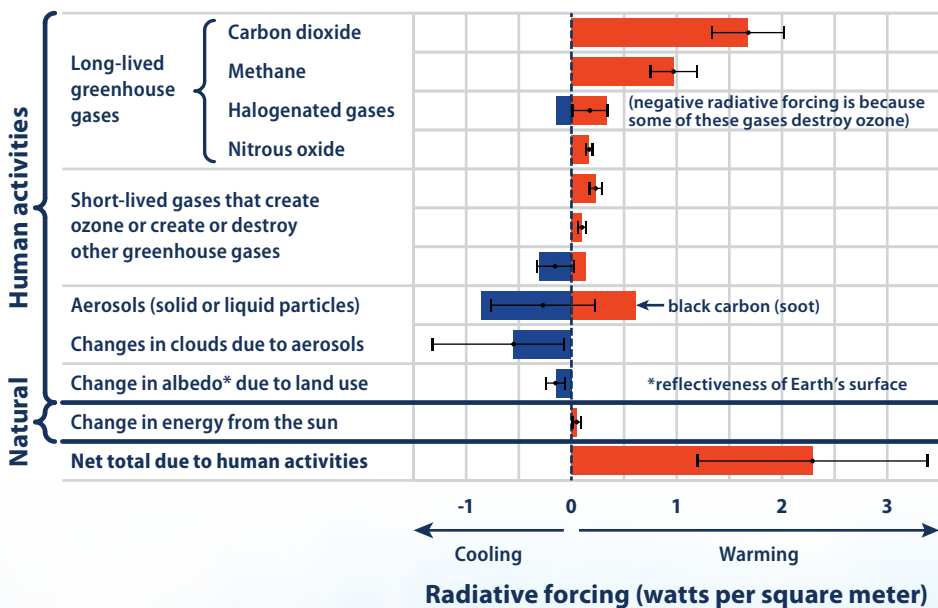
Figure 1. Radiative Forcing Caused by Major Long-Lived Greenhouse Gases, 1979–2013



This figure shows the amount of radiative forcing caused by various greenhouse gases, based on the change in concentration of these gases in the Earth's atmosphere since 1750. Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere. On the right side of the graph, radiative forcing has been converted to the Annual Greenhouse Gas Index, which is set to a value of 1.0 for 1990.

Data source: NOAA, 2014³⁰

Figure 2. Radiative Forcing Caused by Human Activities Since 1750



This figure shows the total amount of radiative forcing caused by human activities—including indirect effects—between 1750 and 2011. Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere. Each colored bar represents scientists' best estimate, while the thin black bars indicate the likely range of possibilities. The natural change in the energy received from the sun over this time period is provided for reference.

Data source: IPCC, 2013³¹

INDICATOR NOTES

The index in Figure 1 does not include short-lived greenhouse gases like tropospheric ozone, reflective aerosol particles, black carbon (soot), or the indirect influence of methane through its effects on water vapor and ozone formation. Figure 2 includes these and other indirect influences.

DATA SOURCES

Data for Figure 1 were provided by the National Oceanic and Atmospheric Administration. This figure and other information are available at: www.esrl.noaa.gov/gmd/aggi. Data for Figure 2 came from the Intergovernmental Panel on Climate Change (www.ipcc.ch), which publishes assessment reports based on the best available climate science data.

