Greenhouse Gases

The Greenhouse Effect

The greenhouse effect is a natural phenomenon that insulates the Earth from the cold of space. As solar radiation reaches the Earth's surface, it is absorbed and re-emitted as infrared energy. Greenhouse gases (GHGs) in the atmosphere prevent some of this heat from escaping into space, instead absorbing and re-radiating the energy back to further warm the surface.[1] The greenhouse effect was first described in the 1820s. By the late 1800s, scientists had identified specific GHGs and human activities, such as burning coal, that intensify this.[2] Anthropogenic (human-caused) GHG emissions are changing the Earth's energy balance between incoming solar radiation and outgoing heat, amplifying the greenhouse effect and resulting in global warming.[1]

Greenhouse Gases

- Of the primary GHGs, water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) occur naturally. F-gases—hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—arise from industrial processes.[1]
- Water vapor is the most abundant GHG in the atmosphere. Its concentration is regulated by temperature and other meteorological factors, rather than direct human activities.[1]
- Global Warming Potentials (GWPs) measure the relative effectiveness of GHGs in trapping heat in the atmosphere over a given period. CO_2, the dominant anthropogenic GHG, serves as the reference with a GWP of 1. N_2O has a 100-year GWP of 273, meaning it traps 273 times more heat than the same mass of CO_2 over the same time period.[1]
- GHG emissions are reported as carbon dioxide equivalents (CO_2e) by multiplying the mass of each gas by its GWP.[5]
- In addition to trapping heat, ozone-depleting GHGs such as CFCs deplete O_3 in the stratosphere, reducing its ability to block ultraviolet radiation.[1]

The Main Greenhouse Gases[1,3]

Compound	Chemical Abbreviation	Pre-industrial Concentration	Concentration in 2019	Atmospheric Lifetime (years)	Main Human Activity Source	GWP**
Carbon dioxide	CO_2	278 ppm	420 ppm*	Variable	Fossil fuels, cement production, land use change	1
Methane	CH_4	729 ppb	1,934 ppb*	12	Fossil fuels, rice paddies, waste dumps, livestock	30 (fossil fuel) 27 (non fossil fuel)
Nitrous oxide	N_2O	270 ppb	336.9 ppb*	109	Fertilizers, combustion industrial processes	273
HFC-32	CH_2FH_2	0 ppt	20 ppt	5	Refrigerant	771
HFC-134a	CF_3CHF_2	0 ppt	108 ppt	14	Refrigerant	1,526
CFC-11	CCl_3F	0 ppt	226 ppt	52	Refrigerant	6,226
PFC-14	CF_4	34 ppt	86 ppt	50,000	Aluminum production	7,380
Sulfur hexafluoride	SF_6	0 ppt	9.95 ppt	1,000	Electrical insulation	24,300

*Concentration in 2023; 1 ppm = 1,000 ppb = 1,000,000 ppt, ** GWP = 100-year global warming potential

Atmospheric Concentrations

- Since 1750, atmospheric concentrations of CO_2, CH_4, and N_2O have risen by 51%, 165%, and 25%, respectively,[3] to levels unprecedented in the past 800,000 years.[1]
- Before the Industrial Revolution, CO_2 levels were about 290 parts per million (ppm).[1] By February 2025, the global monthly average concentration had increased to 426 ppm.[6]

Sources of Greenhouse Gas Emissions

- Fossil fuel combustion is the primary anthropogenic source of CO_2, which is also released through land-use changes such as deforestation, land clearing, and soil degradation.[26]
- CH_4 arises from agricultural activities, waste management, energy production and use, and biomass burning.[26]
- Anthropogenic N_2O emissions mostly come from agricultural activities, like fertilizer use, as well as chemical production and fossil fuel combustion. [26]
- Industrial processes, refrigeration, and consumer products lead to emissions of HFCs (substitutes for O_3-depleting CFCs), PFCs, and SF_6.[7,26]

Emissions and Trends

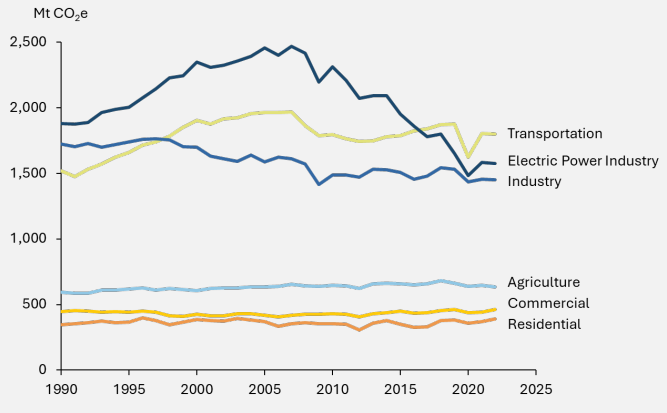
Global

- In 2023, global anthropogenic GHG emissions totaled 52.9 Gt CO_2e, a 62% increase since 1990.[8]
- Average annual GHG emissions were 56 Gt CO_2e from 2010–2019—a record high, and 10 Gt CO_2e more than 2000–2009.[4]
- CO_2 from fossil fuel combustion accounts for 64% of global anthropogenic GHG emissions.[4] In 2024, global energy-related CO_2 emissions reached a record high of 37.8 Gt—up 54% since 2000.[11, 27] Global energy-related CO_2 emissions are projected to increase by 15% from 2022–2050.[15]
- F-gases are the fastest-growing GHGs. In 2023, global F-gas emissions increased by 4.2%, CH_4 by 1.3%, N_2O by 1.1%.[10]
- The U.S. has emitted the most cumulative CO_2, followed by the EU and China. India and the African Union have produced a minor share despite large populations.[10]
- Since 2005, China has surpassed the U.S. as the largest source of CO_2 emissions.[14] In 2023, China's per capita GHG emissions were twice the global average, while the U.S. was three times the global average.[8]
- Globally, the top 10% of income earners were responsible for 48% of emissions—two-thirds of whom live in developed countries. The bottom 50% contributed just 12%.[12] See the Environmental Justice Factsheet.
- CO_2 emissions in the Americas are expected to fall 0.2% annually; a 0.7% decline in the U.S. and 0.5–1.4% increases everywhere else. Total emissions in Africa are projected to increase 1.2% yearly, but will remain the lowest globally.[15]

United States

- The U.S. had 4.2% of the world's total population,[16] and 11% of annual anthropogenic GHG emissions in 2023.[8]
- CO_2 accounts for 80% of U.S. GHG emissions. The largest source of CO_2 in the U.S. is fossil fuel combustion (74%), primarily from transportation and power generation.[5]
- In 2022, CO_2 emissions were 1.5% lower than in 1990 and 18% lower than in 2005. GHG emissions were 3% below 1990 levels; an average annual decline of 0.1%.[5]
- Since 2005, GHG and fossil fuel emissions fell by 15% and 18% respectively, while GDP grew 36%.[5]
- Livestock, natural gas systems, and landfills are the primary anthropogenic sources of CH_4.[5] CH_4 emissions from the oil and gas industry were 12 Mt (2.3% of gross production)-60% higher than EPA estimates. The climate imapct rivals CO_2 from combustion.[17]

U.S. GHG Emissions by Sector (Mt CO_2e)[5]

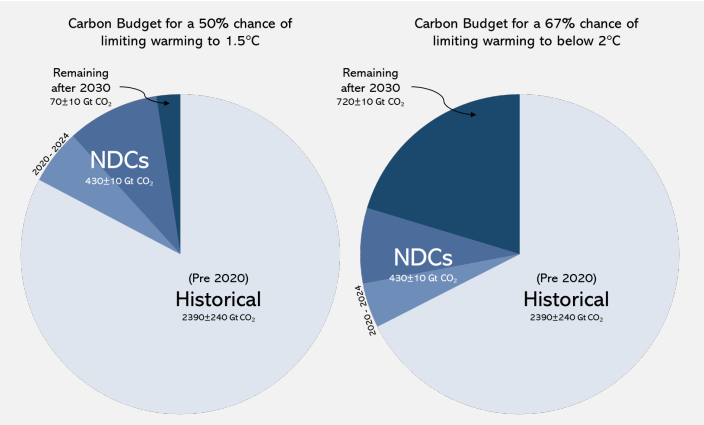


- HFC and PFC emissions increased since 1990, driven by the phase-out of O_3-depleting CFCs, making up 90% of F-gas emissions in 2022.[5]
- Transportation has been the largest source of U.S. GHG emissions since 2017, accounting for 28% in 2022. Emissions were 6% below 2005 levels but 18% above 1990.[5]
- Passenger cars and light-duty trucks emitted 370 and 660 Mt CO_2e, respectively, accounting for 57% of U.S. transportation emissions and 16% of total U.S. emissions.[5]
- The electric power sector accounts for 25% of total U.S. GHG emissions. This is the only sector showing major declines; down 16% since 1990 and 36% since 2005.[5]
- The residential sector accounts for 15% of U.S. emissions, driven by electricity use and consumption of natural gas and petroleum.[5]
- Emissions have risen since 1990 due to population growth, migration to warmer regions, and larger houses. Recent trends reflect a shift toward energy-efficiency.[5]
- The land use and forestry sector offsets 14% of U.S. emissions, absorbing CO_2 through plant and tree growth.[5]

Solutions

- Stabilizing global temperatures and limiting climate change impacts require net-zero or net-negative emissions.[20]
- Any rise in global warming harms human health, with greater mortality, economic, and security risks above 1.5 °C. Limiting warming to 1.5 °C is projected to reduce ecosystem loss and species extinction compared to 2 °C.[20]
- GHG emissions can be reduced by transitioning from fossil fuels, improving energy efficiency, adopting sustainable agriculture and forest management, and conserving critical ecosystems.[22]
- International cooperation to mitigate climate change is established through the 1992 UN Framework Convention on Climate Change (UNFCCC) and its legal instruments—the 1997 Kyoto Protocol and the 2015 Paris Agreement.[9] See the Climate Change: Policy and Mitigation Factsheet.
- Nationally Determined Contributions (NDCs) are countries' self-defined climate pledges under the Paris Agreement, outlining their commitments to limit global warming to 1.5 °C.[23] As of September 2024, the 168 latest NDCs cover 95% of total global emissions in 2019.[24]
- Global GHG emissions must fall 43% from 2019 levels by 2030 and reach net-zero by 2050 to limit warming to 1.5 °C.[21]
- Full implementation of latest NDCs cuts emissions by just 5.9%; this requires financial and technology transfer. Without transfers, emissions could rise 0.8%.[24]
- Current NDCs would use 86% of the carbon budget—for a 50% chance of limiting warming to 1.5°C—by 2030, leaving only two years' worth of emissions after 2030, and requiring even steeper post-2030 reductions to stay on track for 1.5 °C or well below 2 °C warming.[24]
- Under current assumptions, 21st century warming is projected to reach 2.1 °C – 2.8 °C.[24]
- As of September 2024, 60% of the world's largest companies have set net-zero emissions targets, covering $31T or 67% of aggregate annual revenue.[25]

Global CO_2 Emissions Budget[24]



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