**Chapter Three**

**global warming and Greenhouse Effect**

**What is global warming?**

A: Since the Industrial Revolution, the global annual temperature has increased in total by a little more than 1 degree Celsius, or about 2 degrees Fahrenheit. Between 1880—the year that accurate recordkeeping began—and 1980, it rose on average by 0.07 degrees Celsius (0.13 degrees Fahrenheit) every 10 years. Since 1981, however, the rate of increase has more than doubled: For the last 40 years, we’ve seen the global annual temperature rise by 0.18 degrees Celsius, or 0.32 degrees Fahrenheit, per decade.

**What causes global warming?**

A: Global warming occurs when carbon dioxide (CO2) and other air pollutants collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth’s surface. Normally this radiation would escape into space, but these pollutants, which can last for years to centuries in the atmosphere, trap the heat and cause the planet to get hotter. These heat-trapping pollutants—specifically carbon dioxide, methane, nitrous oxide, water vapor, and synthetic fluorinated gases—are known as greenhouse gases, and their impact is called the greenhouse effect.

**The Greenhouse Effect**

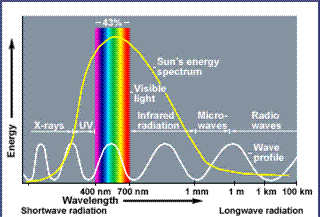
Human activities contribute to global warming by increasing the greenhouse effect. The greenhouse effect happens when certain gases—known as greenhouse gases—collect in Earth’s atmosphere. These gases, which occur naturally in the atmosphere, include carbon dioxide, methane, nitrogen oxide, and fluorinated gases sometimes known as chlorofluorocarbons (CFCs).

**Effects of Global Warming**

Even slight rises in average global temperatures can have huge effects. Perhaps the biggest, most obvious effect is that glaciers and ice caps melt faster than usual. The meltwater drains into the oceans, causing sea levels to rise and oceans to become less salty.

**What is the greenhouse effect?**

The greenhouse effect is an important part of the Earth’s climate without which the planet would be a far colder place. The effect is natural and not new. When sunlight hits the surface of the earth it is absorbed and the visible light (short wave radiation) is converted to heat (infrared or long wave radiation) (Fig. 1) which is radiated back into the atmosphere towards space.



**Figure 1**. A schematic of the electromagnetic spectrum, showing the Sun’s energy output in relation to wavelength.

Some gases in the atmosphere (the so called greenhouse gases: such as carbon dioxide, water vapour, methane, etc.) absorb the infra red radiation (heat) which is converted into kinetic and potential energy. Eventually these molecules then emit heat back into the atmosphere as infrared radiation. Some of this infrared radiation is absorbed by other greenhouse gases and some is absorbed at the earth’s surface and the cycles of absorption, conversion and emission are repeated (Fig. 2). Essentially this process slows the loss of heat to space, keeping the earth’s surface warmer than it would be without the greenhouse gases. Without this “greenhouse” the Earth’s atmosphere would be an average of about 30-35 oC cooler and life as we know it would not exist.

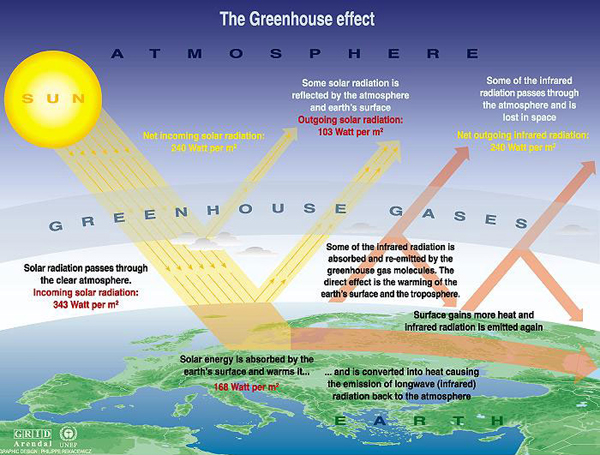


Figure 2. An overview of the Greenhouse Effect. From IPPC Working Group 1 contribution, Science of Climate Change, Second Assessment Report 19961

The enhanced greenhouse effect, sometimes referred to as climate change or global warming, is the impact on the climate from the additional heat retained due to the increased amounts of carbon dioxide and other greenhouse gases that humans have released into the earths atmosphere since the industrial revolution.

What is causing the enhanced greenhouse effect?

Since the mid 1800’s the average concentration of CO2 in the earth’s atmosphere has risen from about 280 parts per million (ppm) to just over 383 ppm in 2007, and methane from about 800 part per billion (ppb) to around 1790 ppb in 2008 (Fig. 3).

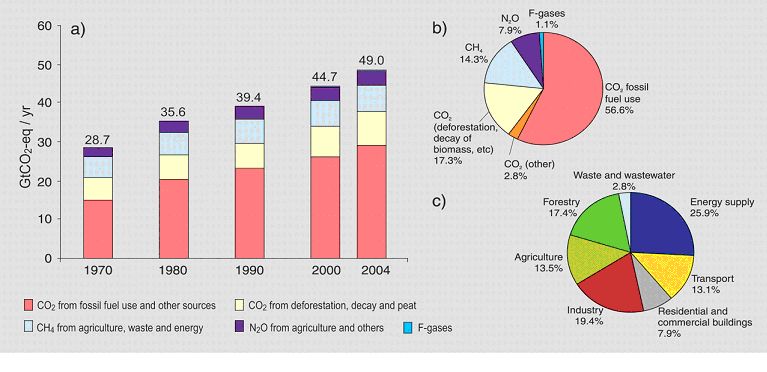


Figure 3. Global atmospheric concentrations of four greenhouse gases. From the IPCC 2007 4th Assessment Report2.

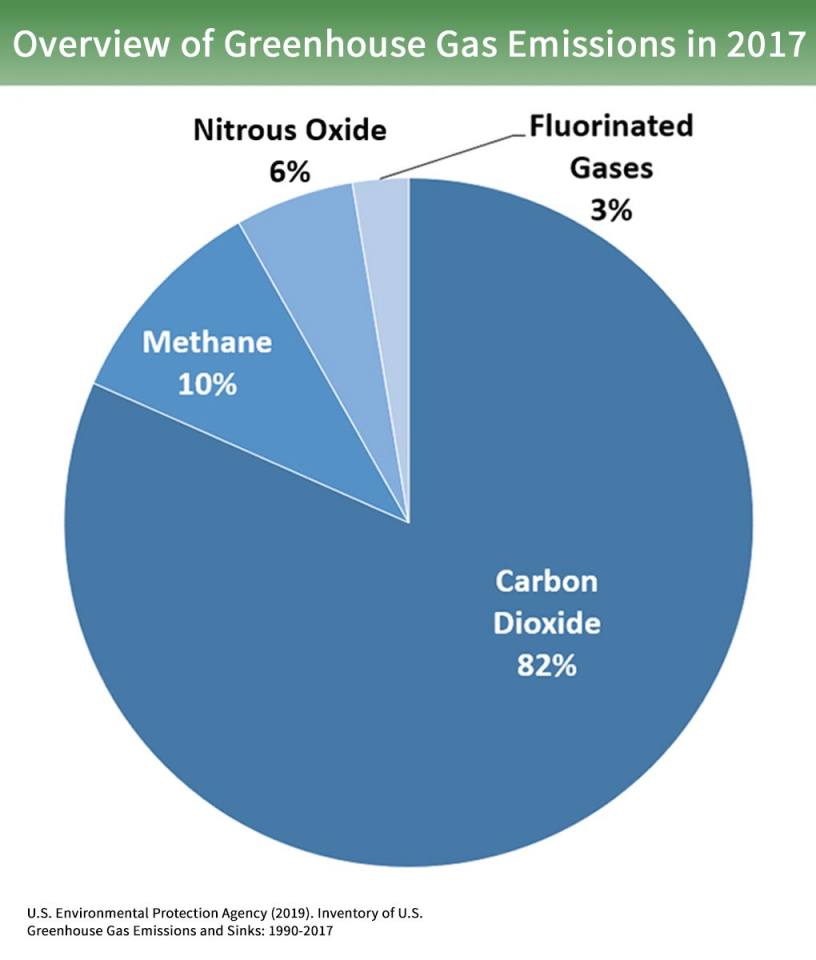
While these changes represent only a very small change to the overall composition of the earth’s atmosphere, it is a significant change to its capacity to absorb and emit heat. The main contributors are changes to the carbon cycle that have led to increased levels of carbon dioxide in the earth’s atmosphere in the last 200 years. These include reduced CO2 removal and storage through deforestation; direct CO2 production from the burning of fossil fuels and CO2 released from cement production.

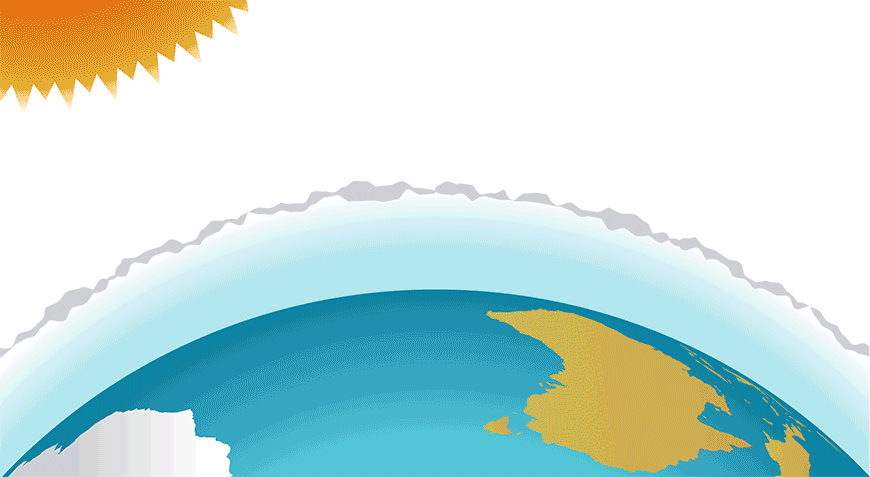
**Which gases cause the greenhouse effect?**

The contribution that a greenhouse gas makes to the greenhouse effect depends on how much heat it absorbs, how much it re-radiates and how much of it is in the atmosphere.

In descending order, the gases that contribute most to the Earth’s greenhouse effect are:

1. water vapour (H2O)
2. carbon dioxide (CO2)
3. nitrous oxide(N2O)
4. methane (CH4)





Greenhouse effect

Step 1: Solar radiation reaches the Earth's atmosphere - some of this is reflected back into space.

Step 2: The rest of the sun's energy is absorbed by the land and the oceans, heating the Earth.

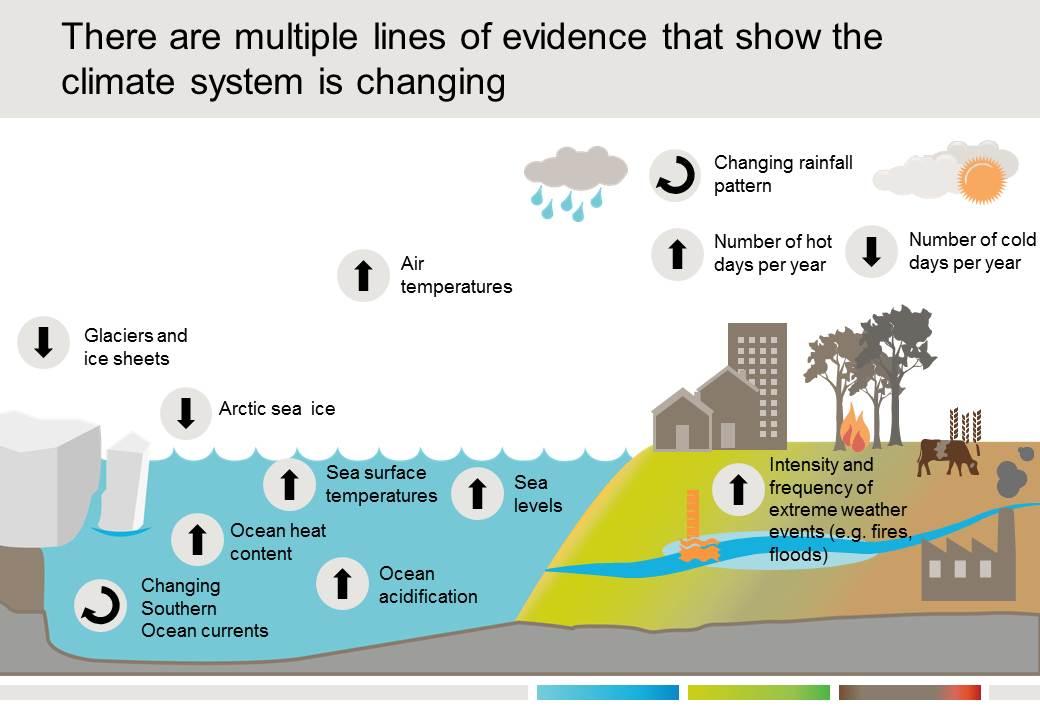
Step 3: Heat radiates from Earth towards space.

Step 4: Some of this radiative heat is trapped by greenhouse gases in the atmosphere, keeping the Earth warm enough to sustain life.

Step 5: Human activities such as burning fossil fuels, agriculture and land clearing are increasing the amount of greenhouse gases released into the atmosphere.

Step 6: This is trapping extra heat, and causing the Earth's temperature to rise, along with other effects like ocean acidification noted in the figure below.

Observed changes



**What Are Greenhouse Gases?**

Earth’s greenhouse gases trap heat in the atmosphere and warm the planet. The main gases responsible for the greenhouse effect include carbon dioxide, methane, nitrous oxide, and water vapor. In addition to these natural compounds, synthetic fluorinated gases also function as greenhouse gases. Different greenhouse gases have different chemical properties and are removed from the atmosphere, over time, by various processes. Carbon dioxide, for example, is absorbed by “carbon sinks” such as forests, soil, and the ocean. Fluorinated gases are only destroyed by sunlight in the far upper atmosphere.

What Are Greenhouse Gas Emissions?

The release of greenhouse gases associated with human activities and climate change is referred to as greenhouse gas emissions, or climate pollution. And since the start of the Industrial Revolution and the advent of coal-powered steam engines, human activities have supersized the volume of greenhouse gases emitted into the atmosphere. It is estimated that between 1750 and 2019, atmospheric concentrations of carbon dioxide increased by 47 percent, methane by 156 percent, and nitrous oxide by 23 percent. In the late 1920s, we started adding man-made fluorinated gases like chlorofluorocarbons to the mix.

**Five Major Greenhouse Gases**

The most significant gases that cause global warming via the greenhouse effect are the following:

**1-Carbon dioxide**

Accounting for almost 80 percent of global human-caused emissions, carbon dioxide sticks around for quite a while. Once it’s emitted into the atmosphere, 40 percent still remains after 100 years, 20 percent after 1,000 years, and 10 percent as long as 10,000 years later. (Carbon dioxide’s lifetime cannot be represented with a single value because the gas is not destroyed over time, but instead moves among different parts of the ocean, atmosphere, and land. Some carbon dioxide isabsorbed quickly, but some will remain in the atmosphere for thousands of years.)

**2-Methane**

Methane (CH4) persists in the atmosphere for around 12 years, which is less time than carbon dioxide, but it is much more potent in terms of the greenhouse effect. In fact, pound for pound, its global warming impact is almost 30 times greater than that of carbon dioxide over a 100-year period. In the United States, according to the U.S. Environmental Protection Agency (EPA), methane accounted for more than 12 percent of human-generated greenhouse gas emissions in 2021. While methane can come from natural sources like wetlands, more than half of all global methane emissions come from human activities like natural gas production and livestock-based agriculture. Nitrous oxide

**3-Nitrous oxide (N2O)** is a powerful greenhouse gas: According to the EPA, it has a GWP that is around 270 times that of carbon dioxide on a 100-year time scale, and it remains in the atmosphere, on average, a little more than a century. The EPA estimates that it accounts for about 6 percent of human-caused greenhouse gas emissions in the United States, from sources like the fertilizers used in agriculture.

**4-Fluorinated gases** Emitted from a variety of manufacturing and industrial processes, fluorinated gases are man-made. There are four main categories: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). Although fluorinated gases are emitted in smaller quantities than other greenhouse gases (they account for 3 percent of U.S. emissions, per the EPA), they trap substantially more heat. Indeed, the GWP for these gases can be in the thousands to tens of thousands, and they have long atmospheric lifetimes, in some cases lasting tens of thousands of years.

**5-Water vapor** The most abundant greenhouse gas overall, water vapor differs from other greenhouse gases in that changes in its atmospheric concentrations are linked not to human activities directly, but rather to the warming that results from the other greenhouse gases we emit. Warmer air holds more water. And since water vapor is a greenhouse gas, more water absorbs more heat, inducing even greater warming and perpetuating a positive feedback loop. (It’s worth noting, however, that the net impact of this feedback loop is still uncertain, as increased water vapor also increases cloud cover that reflects the sun’s energy away from the earth but holds heat in at night.)

1. Greenhouse Gases
2. Greenhouse Gases
3. Greenhouse Gases

You have already learned that Earth's atmosphere is composed primarily of nitrogen and oxygen. These gases are transparent to incoming solar radiation. They are also transparent to outgoing infrared radiation, which means that they do not absorb or emit solar or infrared radiation. However, there are other gases in Earth's atmosphere that do absorb infrared radiation. These gases are known as greenhouse gases. Below are the most important greenhouse gases that influence Earth's climate system.

**1-Water vapor (H2O)**

Water vapor (H2O) is the strongest greenhouse gas, and the concentration of this gas is largely controlled by the temperature of the atmosphere. As air becomes warmer, it can hold more moisture or water vapor. When the air becomes saturated (or holds as much moisture as the air can at that temperature), the excess moisture will condense into cloud droplets. And if these droplets are large enough, they will fall as precipitation.

**2-Carbon dioxide (CO2)** Carbon dioxide (CO2) is also an important greenhouse gas. It has a long lifetime in Earth's atmosphere. Carbon dioxide strongly absorbs energy with a wavelength of 15 μm (micrometers). This makes carbon dioxide a good absorber of wavelengths falling in the infrared radiation region of the spectrum.

Carbon dioxide constantly moves into and out of the atmosphere through four major processes: photosynthesis, respiration, organic decomposition or decay, and combustion or the burning of organic material. You will learn more about carbon dioxide and the carbon cycle in Module 4.

**4-Methane (CH4)**

Methane (CH4) is 30 times stronger than carbon dioxide as an absorber of infrared radiation. Methane, however, is present in smaller concentrations than carbon dioxide, so its net contribution to the greenhouse effect is not as large. Methane is also relatively short-lived (lasting approximately 8 years) in the atmosphere. Methane is produced when bacteria decompose organic plant and animal matter in such places as wetlands (e.g., marshes, mudflats, flooded rice fields), sewage treatment plants, landfills, and the guts of cattle and termites. Scientists are concerned about the concentration of methane increasing in regions where the Arctic and alpine permafrost is thawing and releasing methane as it warms.

**Nitrous oxide (N2O)** Nitrous oxide (N2O), a relatively long-lived gas, has increased in atmospheric concentration due mainly to agriculture. Nitrate (NO3-) and ammonia (NH4+) are used as fertilizers. Bacteria convert a small amount of this nitrate and ammonia into the form of nitrous oxide. Internal combustion engines also produce nitrous oxide.

**Ozone (O3)** Ozone (O3) is also a relatively minor greenhouse gas because it is found in relatively low concentrations in the troposphere (the lowest layer of the atmosphere). In the troposphere, it is produced by a combination of pollutants — mostly hydrocarbons and nitrogen oxide compounds.

