1. Introduction to Global Warming, Climate Change and Greenhouse Effect

Global Warming

- Global warming is the **rise in temperature** of the Earth's atmosphere and oceans over time.
- It is the **long-term heating** of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere.
- This term is not interchangeable with the term "climate change."
- **2011-2020** was the **warmest decade** recorded, with global average temperature reaching 1.1°C above pre-industrial levels in 2019.
- Human-induced global warming is presently increasing at a rate of 0.2°C per decade.

Climate Change

- Climate change in Intergovernmental Panel on Climate Change (IPCC) usage refers to any change in climate over time, whether due to natural variability or as a result of human activity.
- This usage differs from that in the UN Framework Convention on Climate Change (UNFCCC), where climate change refers to a **change of climate that is attributed directly or indirectly to human activity** that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Greenhouse Effect

- The greenhouse effect is a process that occurs when **gases in Earth's atmosphere trap the Sun's heat.** This process makes Earth much warmer than it would be without an atmosphere.
- The atmosphere is **largely transparent to incoming solar radiation,** because it largely comprises **rays of shorter wavelengths.** Much of this incoming radiation is absorbed by the Earth’s surface.
- The hot surface of the earth then re-emits heat energy at long-wave infrared rays.
- While some of the infrared radiation passes through the atmosphere, a large part of it is **absorbed and redistributed back by gases** such as carbon dioxide, methane, nitrous oxide, etc. in the atmosphere. This heating effect is called the greenhouse effect and it causes global warming.

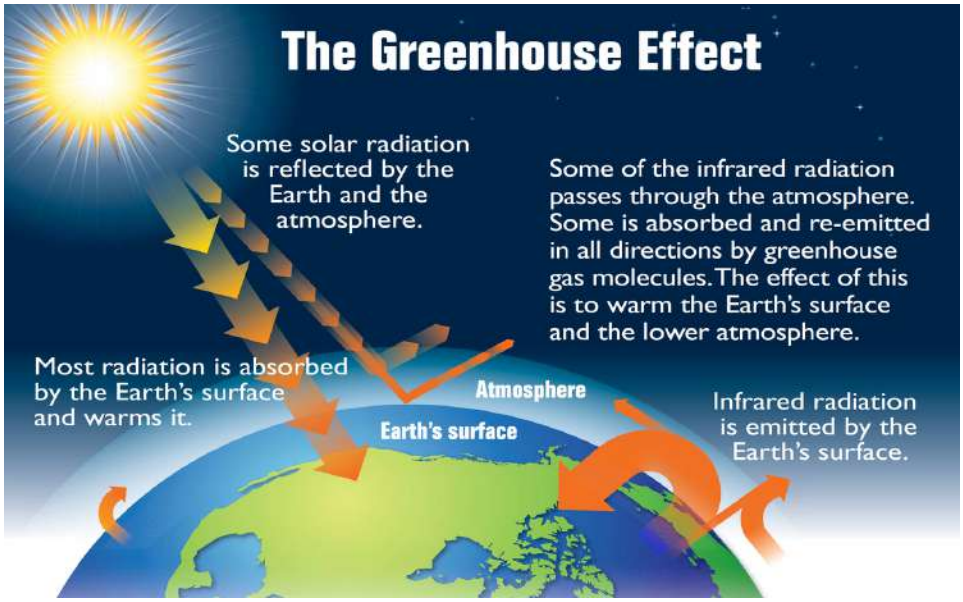

Figure.1. Process of Greenhouse Effect

The greenhouse effect has two types:

Natural Greenhouse Effect

- The natural greenhouse effect, refers to the greenhouse effect which occurs naturally on earth and is **essential to maintain normal global temperature patterns.**
- Without it, temperatures would drop by approximately 30°C, the oceans would freeze and life as we know it would be impossible.

Anthropogenic Greenhouse Effect

- The enhanced (anthropogenic) greenhouse effect results from human activities.
- It is this green house effect that is a cause of serious concern for the global environment.

2. Greenhouse Gases

- The gases present in the earth's atmosphere which absorb and redistribute the infrared heat radiations are called the greenhouse gases.
- Concentrations of the key greenhouse gases have all increased since the Industrial Revolution due to human activities.
- These greenhouse gas emissions have **increased the greenhouse effect and caused the earth's surface temperature to rise.** Burning fossil fuels changes the climate more than any other human activity.
- The important greenhouse gases include:
    1. Water Vapour
    2. Carbon dioxide (CO2)
    3. Methane (CH4)
    4. Nitrous oxide (N2O)
    5. Fluorinated gases (F-gases)
        a. Hydrofluorocarbons (HFCs)
        b. Perfluorocarbons (PFCs)
        c. Sulphur hexafluoride (SF6)

Water Vapour

- Water vapour is the **most abundant greenhouse gas** on Earth and is responsible for about half of Earth's greenhouse effect.
- Humans are not directly responsible for emitting water vapour in quantities sufficient to change its concentration in the atmosphere.
- But, CO2 and other greenhouse gases are responsible for increasing the amount of water vapour in the air.
- As greenhouse gases increase, Earth's temperature rises in response. This increases evaporation from both water and land areas.
- Because warmer air holds more moisture, its concentration of water vapour increases. Specifically, this happens because water vapour does not condense and precipitate out of the atmosphere as easily at higher temperatures.
- The water vapour then absorbs heat radiated from Earth and prevents it from escaping out to space. This further warms the atmosphere, resulting in even more water vapor in the atmosphere.

Carbon dioxide (CO2)

- Human activities are altering the carbon cycle both by adding more CO2 to the atmosphere and by reducing the natural sinks, like deforestation.
- Carbon dioxide enters the atmosphere **through burning fossil fuels** (coal, natural gas, and oil), solid waste, trees and other biological materials, and also as a result of certain chemical reactions (e.g. cement production).
- Atmospheric CO2 concentrations have increased by more than 40 percent since pre-industrial times, from approximately 280 parts per million (ppm) in the 18th century to 421 ppm in 2022.
- Carbon dioxide is removed from the atmosphere (or "sequestered") when it is **absorbed by plants as part of the biological carbon cycle.**

Methane (CH4)

- Methane is the **second most abundant anthropogenic greenhouse gas** after CO2, accounting for about 20 percent of global emissions.
- Methane is **more than 25 times as potent as carbon dioxide** at trapping heat in the atmosphere.
- It is emitted from a variety of anthropogenic and natural sources. Anthropogenic emission sources include landfills, oil and natural gas systems, agricultural activities, coal mining, mobile combustion, wastewater treatment, etc.
- **Livestock emissions** from manure and gastroenteric releases alone account for roughly 32 percent of human-caused methane emissions.
- **Paddy rice cultivation** – in which flooded fields prevent oxygen from penetrating the soil, creating ideal conditions for methane-emitting bacteria – accounts for another 8 percent of human-linked emissions.
- Methane is also the **primary contributor to the formation of ground-level ozone,** a hazardous air pollutant and greenhouse gas, exposure to which causes 1 million premature deaths every year.
- Natural processes in soil and chemical reactions in the atmosphere help remove methane from the atmosphere.

Nitrous oxide (N2O)

- Nitrous oxide is naturally present in the atmosphere as part of the Earth's nitrogen cycle and has a variety of natural sources.
- However, human activities are increasing the amount of N2O in the atmosphere. Globally, **40% of total N2O emissions come from human activities.**
- It is emitted during agricultural, land use, and industrial activities; combustion of fossil fuels and solid waste; as well as during treatment of wastewater.
- One pound of the nitrous oxide gas **warms the atmosphere some 300 times more** than a pound of carbon does over a 100-year period.
- Nitrous oxide molecules **stay** in the atmosphere **for an average of 121 years** before being removed by a sink or destroyed through chemical reactions.
- N2O is **removed** from the atmosphere **when it is absorbed by certain types of bacteria** or destroyed by ultraviolet radiation or chemical reactions.

Fluorinated gases (F-gases)

- Unlike other greenhouse gases, they have no significant natural sources and come almost entirely from human-related activities.
- They are used in a multitude of applications including commercial and industrial refrigeration, air-conditioning systems, heat pump equipment, and as blowing agents for foams, fire extinguishants, aerosol propellants, and solvents.
- F-gases are often **used as substitutes for ozone-depleting substances** because they do not damage the atmospheric ozone layer.
- However, F-gases are powerful greenhouse gases, with an even higher warming potential than CO2, and **some are nearly inert to removal** by chemical processes.
- If released, **HFCs stay** in the atmosphere **for decades** and both **PFCs and SF6 can stay** in the atmosphere **for millennia.**
- Many fluorinated gases are **removed** from the atmosphere **only when they are destroyed by sunlight** in the upper atmosphere.
- In general, they are the **most potent and longest lasting** type of greenhouse gases emitted by human activities.

3. Factors Leading to Climate Change

Transportation

- Most cars, trucks, ships, and planes run on fossil fuels. That makes transportation a major contributor of greenhouse gases, especially carbon-dioxide emissions.
- **Road vehicles account for the largest part**, due to the combustion of petroleum-based products, like gasoline, in internal combustion engines.

Electricity and Heat

- Generating electricity and heat by burning fossil fuels causes a large chunk of global emissions.
- Most electricity is still generated by burning coal, oil, or gas, which produces carbon dioxide and nitrous oxide.

Manufacturing goods

- The manufacturing industry is one of the largest contributors to greenhouse gas emissions worldwide.

- Manufacturing and industry produce emissions, mostly from burning fossil fuels to produce energy for making things like cement, iron, steel, electronics, and other goods.

Deforestation

- Cutting down forests to create farms or pastures, or for other reasons, causes emissions, since trees, when they are cut, **release the carbon they have been storing.**
- Since forests absorb carbon dioxide, destroying them also **limits nature's ability** to keep emissions out of the atmosphere.

Food Production

- Production of food causes emissions of carbon dioxide, methane, and other greenhouse gases in various ways, including
    - **through deforestation and clearing of land** for agriculture and grazing,
    - **digestion** by cows and sheep,
    - **production and use of fertilizers** and manure for growing crops, and
    - use of energy to run farm equipment or fishing boats, usually with fossil fuels.
- Greenhouse gas emissions also come from packaging and distributing food.

Energy demands

- Globally, residential and commercial buildings consume over half of all electricity.
- As they continue to draw on coal, oil, and natural gas for heating and cooling, they emit significant quantities of greenhouse gas emissions.
- Growing energy demand for heating and cooling, with rising air-conditioner ownership, as well as increased electricity consumption, has contributed to a rise in energy-related carbon-dioxide emissions from buildings in recent years.

4. Impact of Climate Change

Hotter temperatures

- As greenhouse gas concentrations rise, so does the global surface temperature.
- Since the 1980s, each decade has been warmer than the previous one.

More severe storms

- As temperatures rise, more moisture evaporates, which exacerbates extreme rainfall and flooding, causing more destructive storms.
- Warmer air also holds more moisture, making tropical cyclones wetter, stronger, and more capable of rapidly intensifying.

Melting sea ice

- The Arctic is **heating up twice** as fast as anywhere else on earth, leading to the rapid melting of glaciers and polar ice sheets.
- As sea ice melts, darker ocean waters that **absorb more sunlight** become exposed, creating a positive feedback loop that speeds up the melting process.

A warming, rising ocean

- The ocean soaks up most of the heat from global warming. The rate at which the ocean is warming strongly increased over the past two decades, across all depths of the ocean.
- Temperature-sensitive fish and other marine life are already changing migration patterns toward cooler and deeper waters to survive, sending food webs and important commercial fisheries into disarray.

- The elevated absorption of carbon dioxide by the ocean **leads to its gradual acidification**, which alters the fundamental chemical makeup of the water.
- Animals like corals, oysters, and mussels will likely feel these effects first, as acidification disrupts the calcification process required to build their shells.

Loss of species

- Half of all animal species in the world's most biodiverse places, like the Amazon rainforest and the Galapagos Islands, are at risk of extinction from climate change.
- Climate change is especially harmful for species' habitats that are currently under threat from other causes. Ice-dependent mammals like walruses and penguins, for example, won't fare well as ice sheets shrink.

Ecosystem stressors

- Climate change is likely to increase outbreaks of pests, invasive species, and pathogen infections in forests.
- It's changing the kinds of vegetation that can thrive in a given region and disrupting the life cycles of wildlife, all of which is changing the composition of ecosystems and making them less resilient to stressors.
- The ecosystem destabilization may be **most apparent when it comes to keystone species** that have an outsize- role in holding up an ecosystem's structure.

Not enough food

- Fisheries, crops, and livestock may be destroyed or become less productive. With the ocean becoming more acidic, marine resources that feed billions of people are at risk.
- Heat stress can diminish water and grasslands for grazing, causing declining crop yields and affecting livestock.

Less predictable growing seasons

- In a warming world, farming crops is more unpredictable—and livestock, which are sensitive to extreme weather, become harder to raise.
- Climate change shifts precipitation patterns, causing unpredictable floods and longer-lasting droughts. More frequent and severe hurricanes can devastate an entire season's worth of crops.

More health risks

- Climate impacts are already harming health, through air pollution, disease, extreme weather events, forced displacement, pressures on mental health, and increased hunger and poor nutrition in places where people cannot grow or find sufficient food.

5. Trends in Global Warming

- The year **2022 was the sixth warmest year** since global records began in 1880 at 0.86°C (1.55°F) above the 20th century average of 13.9°C (57.0°F).
    - This value is 0.13°C (0.23°F) less than the record set in 2016 and it is only 0.02°C (0.04°F) higher than the 2021 value, which ranks as the seventh highest.
- The 10 warmest years in the 143-year record have all occurred since 2010, with the last nine years (2014–2022) ranking as the nine warmest years on record.

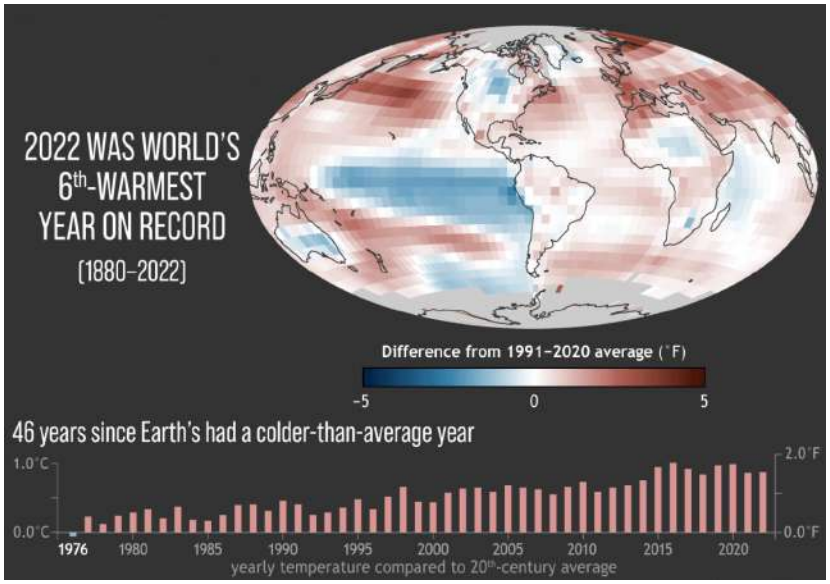

Figure.2. Trends in Global Warming

Regional Temperatures

- The year 2022 was characterized by much-warmer-than-average temperatures across much of the globe, with record-high annual temperatures across parts of Europe, southern Asia, the North and southwestern Pacific Ocean, the Atlantic, and southeastern Pacific oceans.
- Meanwhile, cooler-than-average temperatures were limited to the central and eastern tropical Pacific Ocean, consistent with an episode of La Niña that persisted throughout the year.

Precipitation

- Below-average annual precipitation occurred across parts of the southwestern and south-central contiguous United States, southern Chile, parts of southern and western Europe, and north-central China.
- Above-average annual precipitation occurred across parts of southern Alaska, the north-central contiguous United States, northern and eastern Asia, and eastern Australia.

Ocean Heat Content

- The annual global ocean heat content (OHC) for 2022 for the upper 2000 meters was record high, surpassing the previous record set in 2021.
- The four highest OHC have all occurred in the last four years (2019–2022).

6. Sixth Assessment Report (AR6) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC)

- IPCC released its Synthesis Report for the Sixth Assessment Cycle on March 20, 2023 in Interlaken, Switzerland.
- Comprehensive scientific assessment reports are published every 6 to 7 years. The First Assessment Report of the IPCC was completed in 1990.

- The Synthesis Report is a compilation of the main findings of the IPCC's Sixth Assessment Report, based on **results from three Working Groups** (WGs):
    - WG I evaluated the physical science basis of climate change
    - WG II evaluated the impacts, adaptation, and vulnerability
    - WG III evaluated the mitigation
- The Synthesis Report also drew from Special Reports based on Global Warming of 1.5°C (October 2018), Climate Change and Land (August 2019), and the Ocean and Cryosphere in a Changing Climate (September 2019).

6.1. Major Findings of the AR6

- The report emphasised the need to reduce greenhouse gas emissions and adapt to human-caused climate change through "mainstream effective and equitable action" for a "liveable sustainable future for all."
- It highlights the urgency of drastically reducing the emission of greenhouse gasses and so limit rising global temperatures by 1.5°C from pre-industrial levels, set by the Paris Agreement.
- Despite the IPCC's warnings in 2018, the increase in greenhouse gas emissions continued so much so that the **global surface temperature has already warmed by 1.1°C over pre-industrial levels,** leading to extreme and/or unpredictable weather events that are risking human health, fortunes, and ecosystems.
- Noting the impact of the rise in temperature, the report states that such events have made people much more susceptible to food insecurity, water shortages with vulnerable populations disproportionately facing the brunt of climate change.
- The report also highlighted the economic loss and damages incurred due to climate change and stressed on the need for financial resolution for a more equitable world.

6.2. Recommendations

- The report suggests climate resilient development that will not only mitigate the effects of climate change but also provide wider benefits.
- Access to clean energy, improving air quality to increase employment opportunities, boosting healthcare through technology, and delivering equity are among the report's recommended goals to help adapt to climate change.
- The report also foregrounded the role of financial investments to achieve climate goals and encouraged public funding through central banks, government and financial regulators to reduce emissions, scale up climate resilience, and protect low-income and marginalised communities.

7. Intergovernmental Panel on Climate Change (IPCC)

7.1. What is IPCC?

- The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change.
- It reviews and **assesses the most recent scientific, technical and socio-economic information** produced worldwide relevant to the understanding of climate change. It does **not conduct any research nor does it monitor climate related data** or parameters.

7.2. Establishment

- IPCC was established **by the United Nations Environment Programme** (UNEP) **and the World Meteorological Organization** (WMO) **in 1988** to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

7.3. Members

- It is open to all member countries of the United Nations (UN) and WMO. Currently **195 countries** are members of the IPCC.

7.4. Objective

- The objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations.

7.5. Work of IPCC

- The IPCC prepares comprehensive Assessment Reports about knowledge on climate change, its causes, potential impacts and response options.
- Thousands of people from all over the world contribute to the work of the IPCC.
- For the assessment reports, experts volunteer their time as IPCC authors to assess the thousands of scientific papers published each year to provide a comprehensive summary of what is known about the drivers of climate change, its impacts and future risks, and how adaptation and mitigation can reduce those risks.
- **Note:** The 2007 Nobel Peace Prize was shared, in two equal parts, between the IPCC and Al Gore.