<u>22CIV64C – Sustainable Development Goals</u>
Module 3: Curbing Climate Change

The Basic Science of Climate Change

Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the term.

Changes observed in Earth's climate since the mid-20th century are driven by human activities, particularly fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere, raising Earth's average surface temperature. Natural processes, which have been overwhelmed by human activities, can also contribute to climate change, including internal variability (e.g., cyclical ocean patterns like El Niño, La Niña and the Pacific Decadal Oscillation) and external forcings (e.g., volcanic activity, changes in the Sun's energy output, variations in Earth's orbit).

Engineers play a key role in designing solutions to reduce emissions and adapt infrastructure to changing conditions. For example, climate models help predict future risks, guiding resilient designs.

The earth's climate is changing; the following are the symptoms of climate change:

- **Weather & climate**:
  - *Rising Temperatures*: U.S. and global average temperatures have significantly increased since 1901, especially since the 1970s. Winters are warming faster than other seasons.
  - *Extreme Heat*: Heatwaves are now 3× more frequent than in the 1960s, with longer durations and more intense nighttime temperatures.
  - *Changing Precipitation*: Total precipitation has increased, but more comes from single intense events. Some regions like the Southwest are getting drier.
  - *Storms & Cyclones*: Atlantic tropical storms are stronger and more frequent, partly due to warmer seas.
  - *Floods & Droughts*: River flooding is increasing in some regions (Northeast, Midwest), decreasing in others (Southwest). Drought patterns vary but the West is especially vulnerable.
  - Melting of glaciers and sea ice
  - Changes in the frequency, intensity, and duration of extreme weather events
  - Shifts in ecosystem characteristics, like the length of the growing season, timing of flower blooms, and migration of birds.

- **Impact on Oceans**:
    - *Ocean Heat & Surface Temperature*: Ocean heat content has increased since the 1950s; sea surface temperatures are at record highs, with 2023 being the warmest on record.
    - *Marine Heat Waves*: More frequent and intense, harming marine ecosystems—especially along the northeastern U.S. and Alaskan coasts.
    - *Sea Level Rise*: Global sea level has risen ~0.6 inches per decade since 1880, accelerating in recent years; U.S. coasts (Mid-Atlantic, Gulf) have seen notable increases, with land loss documented.
    - *Coastal Flooding*: Increasing flood frequency since the 1950s, particularly in Hawaiʻi, and along East and Gulf Coasts.
    - *Ocean Acidity*: Oceans are more acidic due to absorbed CO_2, threatening coral, shellfish, and marine biodiversity.
    - *Long-Term Effects*: Oceanic changes unfold slowly over decades to centuries, meaning today's impacts will persist even if emissions are halted.

- **Melting of snow & Ice**:
    - *Arctic Sea Ice*: Shrinking in extent and thickness, with longer melt seasons.
    - *Greenland & Antarctica*: Losing billions of tons of ice annually, contributing significantly to sea level rise.
    - *Glaciers & Snowpack*: Shrinking worldwide, melting earlier, and reducing water storage.
    - *Lake & River Ice*: Freezing later and thawing earlier, especially in Alaska and northern U.S.
    - *Permafrost*: Warming across Alaska, threatening structures and ecosystems.
    - *Snowfall & Snow Cover*: Decreasing in many regions; more winter rain is replacing snow.

NOTE:

Snowpack:

Snowpack refers to the accumulation of snow on the ground, particularly in mountainous or cold regions, that builds up over winter. It acts like a natural reservoir—storing water in frozen form and gradually releasing it during spring and summer as it melts. This is crucial for water supply in many regions, especially for rivers and agriculture.

Permafrost:

Permafrost is ground (soil or rock) that remains frozen for two or more consecutive years. It's mostly found in polar regions like Alaska, Siberia, and northern Canada. When permafrost thaws due to warming, it can destabilize buildings and roads and release greenhouse gases like methane and carbon dioxide.

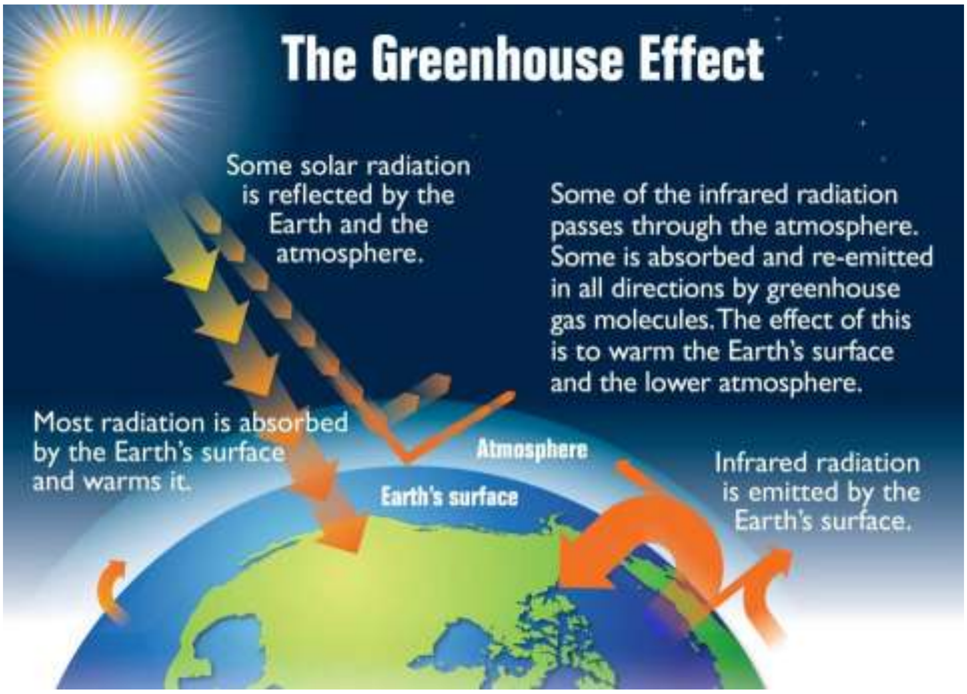
The Greenhouse Effect: Mechanism and Importance

The greenhouse effect is a natural process where atmospheric gases trap heat from the sun, maintaining Earth's average temperature at approximately 15°C (habitable) instead of -18°C (uninhabitable without it). The Mechanism is as follows:

- Solar radiation (shortwave) passes through the atmosphere, with approximately 50% absorbed by Earth's surface (land, oceans).
- The surface emits infrared radiation (longwave), which is absorbed by greenhouse gases (GHGs) like CO_2, CH_4, and water vapor.
- GHGs re-emit some heat back to Earth, warming the atmosphere and surface.

A simple analogy - Compare the greenhouse effect to a car with closed windows on a sunny day: sunlight enters, heats the interior, but the glass (GHGs) traps the heat, making it warmer inside. Excessive GHGs are like adding tinted windows, trapping even more heat.

Though the greenhouse effect is essential for life, but human activities (e.g., burning fossil fuels) enhance the effect, causing global warming. Ex: Bengaluru feels warmer than rural Karnataka due to urban heat islands and GHG emissions, illustrating the greenhouse effect locally.



Greenhouse Gases (GHGs)

The Major GHGs that give rise to global warming is as follows:

- Carbon Dioxide (CO2): Contributes approximately 76% of global GHG emissions. Sources: Fossil fuel combustion (vehicles, power plants), deforestation, cement production (e.g., Karnataka's cement plants in Kalaburagi).
- Methane (CH4): Contributes approximately 16% of emissions, 25 times more potent than CO2 over 100 years. Sources: Agriculture (rice paddies in Mandya, livestock digestion), landfills, natural gas leaks.
- Nitrous Oxide (N2O): Contributes approximately 6% of emissions, 298 times more potent than CO2. Sources: Agricultural fertilizers (used in Karnataka's sugarcane fields), industrial processes.
- Fluorinated Gases: Synthetic gases (e.g., HFCs) used in refrigeration and air conditioning, highly potent but low in volume.

Global Warming Potential (GWP)

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime").

Starting in 1990, the Intergovernmental Panel on Climate Change (IPCC) has used the Global Warming Potential (GWP) to allow comparisons of the global warming impacts of different gases. Specifically, the GWP is a measure of how much energy the emission of 1 ton of a gas will absorb over a given period of time, relative to the emission of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years.

Thus GWP measures how much heat a gas traps compared to CO2 over 100 years. Example: 1 kg of CH4 has the same warming effect as 25 kg of CO2.

Ex: In the context of Karnataka, CO2 comes from Bengaluru's 10 million vehicles and industries, CH4 from rice fields in Mandya, and N2O from fertilizer use in agriculture.

A table showing the comparison of different GHGs:

Gas	**Sources**	**GWP**	**Gas released now will last for..**
CO2	Fossil fuels, cement	1	1000 years
CH4	Transportation	27 to 30	10 years
N2O	Fertilizer industry	273	100 years
CFCs/HFCs	Aerosols, refrigerants, ACs etc.	1000 or 10,000	More than 1000 years

In Bengaluru the major greenhouse gases (GHGs) released are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). CO_2 is the most significant, contributing around 65% of total GHG emissions. Other GHGs include chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Global Warming

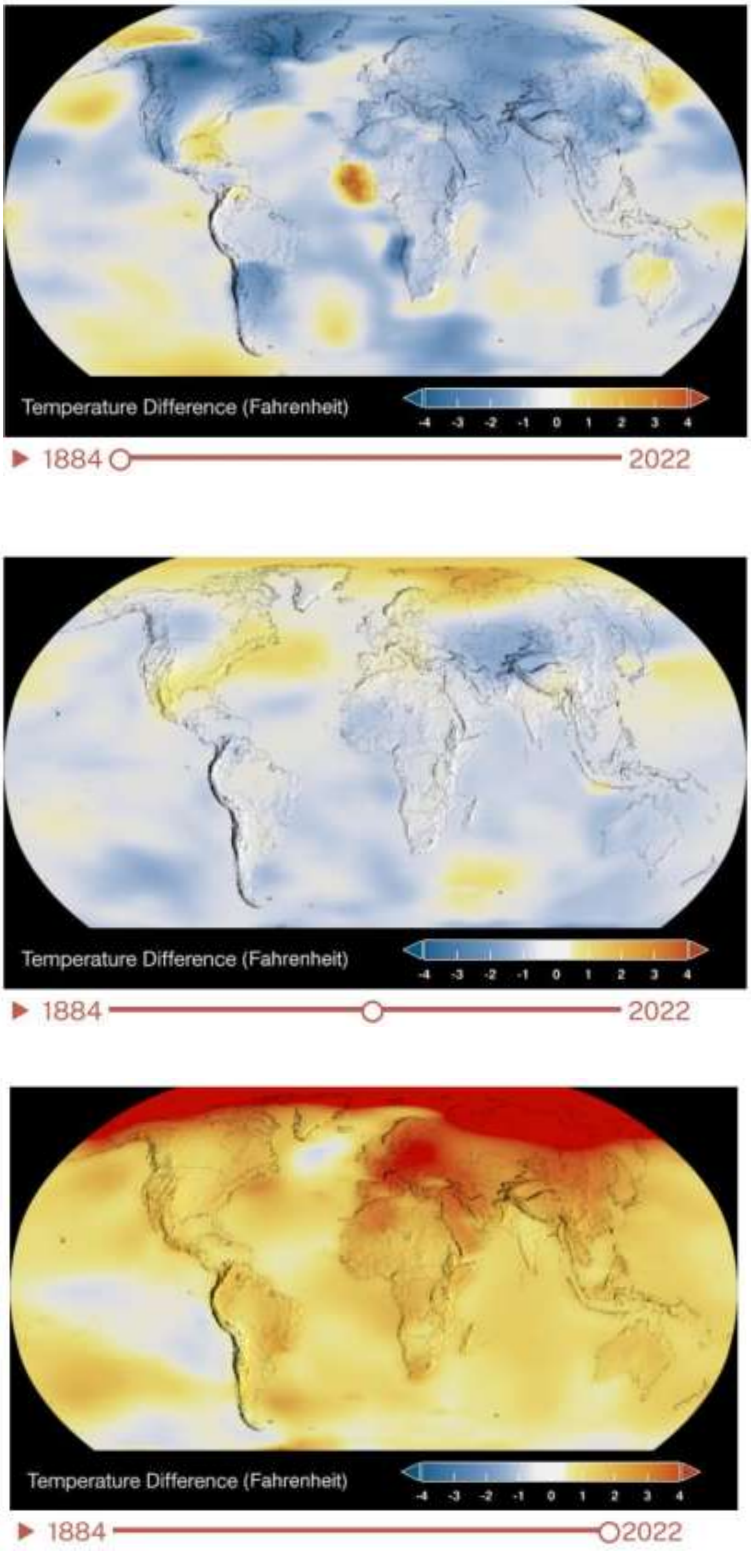
The causes of global warming are as follows:

- Anthropogenic: Burning fossil fuels (coal, oil, gas), deforestation (reducing CO_2 absorption), industrial processes (e.g., cement production), agriculture (methane from livestock).
- Natural: Volcanic eruptions (release CO_2), solar variability (minor impact compared to human activities).

Mechanism

Increased GHG concentrations enhance the greenhouse effect, trapping more infrared radiation. This raises Earth's average temperature (1.1°C increase since pre-industrial times, per IPCC). The Scientific Evidence for this phenomenon of Global warming is as follows:

- *Temperature Records*: NOAA data shows global temperatures rising by approximately 0.08°C per decade since 1880.
- *Ice Core Data*: Antarctic ice cores show CO_2 levels at 420 ppm today (vs. 280 ppm in 1850).
- *Glacier Retreat*: Himalayan glaciers (e.g., Gangotri) retreating at 10–20 meters/year, affecting India's rivers.
- *Sea Level Rise*: Global rise of 3.7 mm/year due to melting ice and thermal expansion.
- Bengaluru's average temperature has risen by approximately 1°C in 50 years due to urbanization and emissions, leading to hotter summers and altered rainfall patterns.



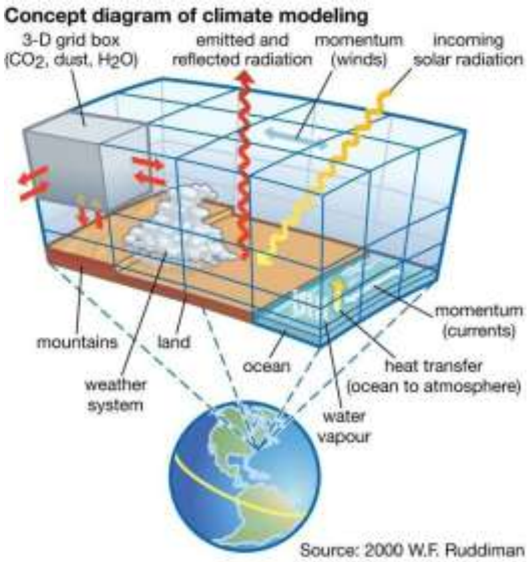
Plots showing global temperature difference from 1884 to 2022

(Source: NASA - https://climate.nasa.gov/vital-signs/global-temperature/?intent=121)

Climate Models: Predictions and Their Role

Climate models are computer based tools that simulate Earth's climate system to understand past, present, and future climate conditions. They use mathematical equations based on physical, chemical, and biological processes to represent interactions among the atmosphere, oceans, land, and ice. These models are critical for studying climate change, informing policy, and guiding adaptation strategies.

Models range from simple to complex, depending on the processes included and the resolution of the grid. They are tested via "hind-casting" (simulating past climates) and compared with observations to validate accuracy.



Types of Climate Models

Climate models are categorized by complexity and scope. The main types of climate models are:

1. Energy Balance Models (EBMs):

    - They are the simplest models, focusing on Earth's energy budget (incoming solar radiation vs. outgoing heat). They use equations to balance energy inputs and outputs, accounting for factors like albedo (reflectivity) and greenhouse gas effects.
    - They require low computational demand, often applied to large scales (regional or global).
    - Ex: Estimating global temperature changes due to CO_2 increases.

2. Intermediate Complexity Models (EMICs):

    - They are more detailed than EBMs, incorporating simplified representations of geographical features (land, oceans, ice) and some climate feedbacks (e.g., cloud effects).

- They balance computational efficiency with added complexity, suitable for long-term simulations (centuries to millennia).
- Ex: Studying paleoclimate i.e., a climate prevalent at a particular time in the geological past.

3. General Circulation Models (GCMs):

    - They are most comprehensive models, simulating global atmosphere and ocean circulation using detailed physics (thermodynamics, fluid dynamics). Include coupled land, ocean, and ice components.
    - They require high computational demand, coarse resolution (100s of km)
    - Ex: Projecting global temperature and precipitation under IPCC emissions scenarios (e.g., RCP8.5)
    - NOTE: Representative Concentration Pathways (RCPs) are scenarios developed by scientists to project future greenhouse gas concentrations in the atmosphere, which are used to model potential future climate change scenarios.

4. Regional Climate Models (RCMs):

- They are high-resolution models (10s of km) focused on specific areas, driven by GCM outputs. Include detailed topography, vegetation, and land cover.
- They capture local climate phenomena (e.g., mountain effects, coastal storms) but rely on GCM boundary conditions.
- Ex: Predicting regional impacts, like flooding in Europe or drought in the Western U.S

5. Earth System Models (ESMs):

- They are advanced GCMs that include biogeochemical cycles (e.g., carbon, nitrogen) and interactions with ecosystems, ice sheets, and atmospheric chemistry.
- They are the most complex climate models, integrating human and natural systems. Used for long-term projections and feedback studies.
- Ex: Assessing carbon cycle feedbacks under high-emission scenarios.

Significance of Climate Models

Climate models are essential for advancing scientific understanding and informing decision-making. Their significance includes:

- **Understanding Complex Systems**: Models simulate interactions among atmosphere, oceans, and land, revealing how factors like CO_2 emissions drive warming. They help test hypotheses about climate drivers (e.g., greenhouse gases vs. solar variability).
- **Predicting Future Climate**: Models project temperature, precipitation, and sea level changes under scenarios like RCP4.5 or RCP8.5, guiding mitigation and adaptation strategies. For example, IPCC reports rely on models to estimate 2–4°C warming by 2100 without emissions cuts.

- **Attributing Climate Change**: Detection and attribution studies use models to confirm that recent warming is primarily due to human activities (e.g., greenhouse gas emissions), not natural variability.
- **Informing Policy and Adaptation**: Models provide data for policymakers to assess risks (e.g., sea level rise, drought) and plan infrastructure, agriculture, and health responses. For instance, NOAA uses models to predict hurricane frequency.
- **Supporting Global Assessments**: Models underpin IPCC and National Climate Assessments, synthesizing data for global and regional climate strategies.

Applications of Climate Models

Climate models have diverse applications across science, policy, and society, as evidenced by authoritative sources:

1. **Climate Change Projections**:
    - Models predict global and regional changes in temperature, precipitation, and extreme events under emissions scenarios. Example: Projecting 8–20 cm sea level rise by 2050
    - <u>Application</u>: Informing coastal planning (e.g., Miami Beach raising roads).
2. **Extreme Weather Analysis**:
    - Models assess whether events like hurricanes or heatwaves are linked to climate change. Example: NOAA (National Oceanic & Atmospheric Administration) uses models to predict tropical cyclone frequency.
    - <u>Application</u>: Improving disaster preparedness and insurance risk models.
3. **Paleoclimate Studies**:
    - Models simulate past climates to validate accuracy against proxy data (ice cores, tree rings). Example: USGS uses models to study Holocene climate cycles.
    - <u>Application</u>: Understanding long-term climate variability.
4. **Hydrological Assessments**:
    - Models project water availability, drought, and flooding. Example: Nature study uses GCMs to assess multi-year hydrologic droughts, showing 37% of land at risk of drier futures.
    - Application: Planning water resource management in agriculture and urban areas.
5. **Health and Economic Impacts**:
    - Models estimate climate impacts on health (e.g., heat-related deaths) and economies (e.g., agricultural losses). Example: WHO projects 250,000 additional deaths annually by 2030s due to climate-related diseases.
    - Application: Guiding public health policies and economic resilience plans.
6. **Policy and Adaptation Planning**:
    - Models support adaptation strategies, like Louisiana’s Coastal Master Plan for sea level rise protection.
    - Application: Designing infrastructure (e.g., flood-resistant bridges) and managed retreat from coastlines.

Drawbacks of Climate Models

Despite their utility, climate models have limitations, critically examined below based on authoritative sources and inherent challenges:

1. **Simplification of Reality**:
   - Models simplify complex processes (e.g., clouds, precipitation). This introduces errors.
   - **Impact**: Predictions of rainfall and regional effects may be less reliable.
2. **Model Uncertainty**:
   - Different models use varied algorithms, parameterizations, and initial conditions, leading to divergent projections. Example: ProQuest study shows GCMs differ in rainfall projections over Ethiopia's Nile basin.
   - **Impact**: Ensemble approaches (combining multiple models) are needed to reduce uncertainty, but no single model is perfect.
3. **Coarse Resolution**:
   - GCMs have resolutions of 100s of km, missing local phenomena (e.g., orographic effects). RCMs improve this but rely on GCM inputs, inheriting their biases.
   - **Impact**: Limited accuracy for small-scale impacts, like urban flooding.
4. **Bias and Validation Challenges**:
   - Models exhibit biases (differences from observations) due to incomplete physics or data. Example: Copernicus notes biases grow with time in seasonal predictions.
   - **Impact**: Future projections assume past biases persist, reducing confidence in long-term forecasts.
5. **Internal Variability**:
   - Natural fluctuations (e.g., El Niño) add uncertainty, as models struggle to predict decade-scale variability. Example: CMIP5 models cannot fully replicate 1951–2010 warming trends without anthropogenic forcing.
   - **Impact**: Short-term predictions are less certain than long-term trends.
6. **Tuning and Subjectivity**:
   - Models are "tuned" to match historical data, introducing subjective adjustments. Example: Hoover Institution critiques tuning for clouds, which may bias results.
   - **Impact**: Questions arise about whether models reflect physics or fitted assumptions.
7. **Computational Limits**:
   - High-resolution models require supercomputers, limiting accessibility and run frequency. Smaller time steps or grids increase detail but demand more resources.
   - **Impact**: Trade-offs between resolution and feasibility constrain model scope.
8. **Scenario Uncertainty**:
   - Projections depend on emissions scenarios (e.g., RCP4.5 vs. RCP8.5), which are uncertain due to unpredictable human behavior. Example: IPCC notes CO_2 emission paths vary with economic and policy choices.
   - **Impact**: Projections are conditional, not definitive forecasts.

Consequences of Climate Change

- **Hotter temperatures**
    - As greenhouse gas concentrations rise, so does the global surface temperature. The last decade, 2011-2020, is the warmest on record. Since the 1980s, each decade has been warmer than the previous one. Nearly all land areas are seeing more hot days and heat waves.
    - Higher temperatures increase heat-related illnesses and make working outdoors more difficult.
    - Wildfires start more easily and spread more rapidly when conditions are hotter. Temperatures in the Arctic have warmed at least twice as fast as the global average.
- **More severe storms**
    - Destructive storms have become more intense and more frequent in many regions. As temperatures rise, more moisture evaporates, which exacerbates extreme rainfall and flooding, causing more destructive storms.
    - The frequency and extent of tropical storms is also affected by the warming ocean. Cyclones, hurricanes, and typhoons feed on warm waters at the ocean surface. Such storms often destroy homes and communities, causing deaths and huge economic losses.
- **Increased drought**
    - Climate change is changing water availability, making it scarcer in more regions. Global warming exacerbates water shortages in already water-stressed regions and is leading to an increased risk of agricultural droughts affecting crops, and ecological droughts increasing the vulnerability of ecosystems.
    - Droughts can also stir destructive sand and dust storms that can move billions of tons of sand across continents. Deserts are expanding, reducing land for growing food. Many people now face the threat of not having enough water on a regular basis.
- **Global warming and rising sea levels**
    - 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. As the ocean warms, its volume increases since water expands as it gets warmer.
    - Melting ice sheets also cause sea levels to rise, threatening coastal and island communities. In addition, the ocean absorbs carbon dioxide, keeping it from the atmosphere. But more carbon dioxide makes the ocean more acidic, which endangers marine life and coral reefs.
- **Loss of species**
    - Climate change poses risks to the survival of species on land and in the ocean. These risks increase as temperatures climb. Exacerbated by climate change, the world is losing species at a rate 1,000 times greater than at any other time in recorded human history.
    - One million species are at risk of becoming extinct within the next few decades. Forest fires, extreme weather, and invasive pests and diseases are among many threats related to climate change. Some species will be able to relocate and survive, but others will not.

- **Scarcity of food**
    - Changes in the climate and increases in extreme weather events are among the reasons behind a global rise in hunger and poor nutrition. 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.
    - Changes in snow and ice cover in many Arctic regions have disrupted food supplies from herding, hunting, and fishing. Heat stress can diminish water and grasslands for grazing, causing declining crop yields and affecting livestock.
- **Increased health risks**
    - Climate change is the single biggest health threat facing humanity. 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.
    - Every year, environmental factors take the lives of around 13 million people. Changing weather patterns are expanding diseases, and extreme weather events increase deaths and make it difficult for health care systems to keep up.
- **Poverty and displacement**
    - Climate change increases the factors that put and keep people in poverty. Floods may sweep away urban slums, destroying homes and livelihoods. Heat can make it difficult to work in outdoor jobs.
    - Water scarcity may affect crops. Over the past decade (2010–2019), weather-related events displaced an estimated 23.1 million people on average each year, leaving many more vulnerable to poverty. Most refugees come from countries that are most vulnerable and least ready to adapt to the impacts of climate change.

Mitigation Strategies

Nature-Based Solutions

- **Protection of Natural Carbon Sinks**: Forests, wetlands, and oceans absorb atmospheric CO_2. Preserving these ecosystems prevents further emissions from deforestation and degradation.

- **Restoration of Ecosystems**: Reforestation and wetland restoration enhance carbon sequestration. Agricultural improvements like yield optimization and carbon return also contribute.
- **Organic Soils**: Despite covering only 3% of land, organic soils hold ~20% of terrestrial organic carbon. Restoration via rewetting could sequester 0.1–1.3 Pg C/year.
- **Global Potential**: Current net terrestrial carbon flux is ~3.1 Pg/year (~30% of emissions from fossil fuels), showing significant but insufficient mitigation capacity on its own.

- **Afforestation & Reforestation**: Could mitigate up to 7 Pg CO_2e annually by 2030. However, socio-ecological complexities must be considered to avoid negative impacts.
- **Broader Restoration Scope**: Beyond forests, restoring grasslands and wetlands is also critical.

- **Strategic Planning Needed**: Restoration must consider biodiversity, feasibility, and long-term monitoring to avoid overstating benefits and shifting focus from emission reduction.

- **Organic Matter Addition**: Using crop residues, green mulching, and biochar can significantly increase soil organic carbon (SOC). Biochar is particularly effective due to its stability.
- **Reduced/No-Tillage**: Conserves SOC in upper soil layers, although initial carbon losses in subsoils may occur before long-term gains are realized.
- **Crop Management**:
    - Crop rotation and deep-rooting varieties improve carbon storage and reduce emissions.
    - Intensified rotations increase SOC and reduce greenhouse gas emissions without sacrificing yield.
- **Fertilizer Optimization:** Lowering nitrogen input and using precision agriculture can reduce emissions.

- **Nitrification Inhibitors**: Compounds like NBPT and DMPSA (types of fertilizers) are effective without harming yield.
- **Microbial Enhancement**: Promoting N_2O-reducing microbes (bioaugmentation, biostimulation) and use of mycorrhizal fungi can significantly lower emissions.

- **Paddy Fields**:
    - Mid-season drainage and reduced flooding inhibit CH_4 production.
    - Improved rice varieties and biochar application reduce emissions by improving aeration.
- **Organic Residue Management**: Composting or removing straw and using sulfate fertilizers lowers CH_4 emissions.
- **Microbial Inhibitors and Fertilization**: Enhance anaerobic oxidation of CH_4.

- **Climate-Friendly Practices**:
    - Crop rotation, herbaceous cover, minimal tillage, and organic fertilizers.
    - Reduces reliance on synthetic inputs.
- **GHG Reduction Potential**:
    - Organic farming improves SOC and reduces N_2O emissions in certain contexts.
    - Integrated crop-livestock systems enhance carbon benefits.
- **Energy Efficiency**:
    - Organic farming often has lower energy inputs per unit of yield.
    - Can approach a neutral or even positive carbon balance compared to conventional systems.
- **Biodiversity and Resilience**:
    - Supports insectivorous species, improves resilience to climate stress, and promotes ecological balance.

Technology-Based Solutions for Climate Change Mitigation

1. Renewable and Clean Energy Technologies

- **Fossil Fuels and Their Impacts**:
  - Fossil fuels (coal, oil, natural gas) are formed from ancient organic matter and are heavily used for industrialization and lifestyle demands.
  - Their lifecycle—from extraction to consumption—emits GHGs and causes air/water pollution and ecological degradation.
  - Transport leaks and combustion release toxic chemicals, contributing to climate change and public health issues.
- **Transition to Renewable Energy**:
  - Clean alternatives include **biomass**, **geothermal**, **solar**, **hydropower**, and **wind**.
  - Renewables are expected to become the **largest source of electricity by 2027**.
  - Solar PV is projected to surpass coal in installed power capacity by 2027.
  - Hydropower dominates grid-scale renewable capacity, though limited by geography and high capital costs.
- **Energy Storage Technologies**:
  - Crucial for integrating intermittent sources (solar, wind) into the grid.
  - Includes **Li-ion batteries**, **flow batteries**, **supercapacitors**, **flywheels**, **compressed air**, and **pumped hydro**.

2. Carbon Capture, Utilization, and Storage (CCUS)

- **Definition and Function**:
  - CCUS involves capturing CO_2 from industrial sources or the atmosphere, utilizing it, and storing it underground or converting it into products.
  - Considered essential for achieving climate goals, especially where emissions are hard to eliminate.
- **Emission Reduction Potential**:
  - Can reduce **3.0–6.8 billion tons of CO_2 annually by 2050**.
  - IEA projects CCUS contributing **15% of total CO_2 reductions** needed for net zero by 2070.
  - Critical for near-zero emissions in **coal-fired power**, **steel**, and **cement** industries.
- **Direct Air Capture (DAC) and BECCS**:
  - **DAC** captures CO_2 directly from the air; still in R&D phase but promising.
  - **BECCS (Bioenergy with Carbon Capture and Storage)** combines energy production with carbon storage.
  - Offers negative emissions but raises concerns over land use, biodiversity, soil degradation, water pressure, and increased fertilizer demand.

3. Smart Management of Agri-Food Systems

- **Importance**:
  - The agri-food system contributes nearly **one-third of global anthropogenic GHG emissions**.
  - Optimizing practices here can deliver rapid climate benefits.
- **Key Strategies**:

- **Rice Cultivation**: Improved irrigation can reduce methane emissions.
- **Livestock Management**: Better feeding practices reduce CH_4 from ruminants.
- **Crop Choice**: Shift towards low-emission, high-yield crops to improve sustainability.
- **Spatial Crop Redistribution**: Grow crops in regions with high productivity and water availability.
- **Biotechnology**: Use of **genotyping**, **marker-assisted selection**, and **genome editing** to boost crop yields and free land for bioenergy or forests.

- **Smart Fertilizer Use**:
  - Utilize biodegradable coatings and smart-release mechanisms.
  - Reduce nitrogen losses and emissions during fertilization.

4. Smart Livestock Production Systems

- **Structural Adjustments**:
  - Adjust animal production structures to enhance food waste recycling and reduce feed intensity.
  - Balance between monogastric and ruminant livestock to optimize resource use.
- **Spatial Planning**:
  - In large countries, redistribute livestock to regions where nutrient cycles can be closed and synthetic fertilizer use reduced.
- **Food System Adjustments**:
  - **Livestock vs. Crops**: Livestock emissions are double those from crops.
  - Adoption of **EAT-Lancet diet** (more plant-based foods) can significantly cut emissions.
- **Emerging Technologies**:
  - **Insect farming** using food waste for feed or human food.
  - **Microbial protein** production using natural gas.
  - **Cultured meat**: Low land and water demand with high mitigation potential.

3.2 Adaptation: Adjusting to Climate Impacts

- Climate-Resilient Agriculture:
- Drought-resistant crops (e.g., millets in Karnataka), drip irrigation to conserve water.
  - Example: Karnataka’s micro-irrigation schemes cover 1.5 million hectares, saving 30% water.
- Flood Defenses:
  - Embankments, early warning systems, permeable pavements to reduce urban flooding.
  - Example: Odisha’s cyclone shelters saved thousands during Cyclone Phailin (2013).
- Water Management:
  - Rainwater harvesting, watershed management to combat water scarcity.
  - Example: Bengaluru’s lake rejuvenation (e.g., Bellandur Lake) improves water storage.

Adaptation Strategies:

1. **Infrastructure Adaptation:**
    - Build climate-resilient infrastructure (e.g., flood defenses, seawalls, elevated roads).
    - Upgrade stormwater systems to handle increased rainfall.
2. **Agricultural Adaptation:**
    - Develop drought-resistant crops.
    - Change planting dates and crop varieties based on climate projections.
3. **Water Management:**
    - Improve irrigation efficiency.
    - Invest in water recycling and desalination.
4. **Urban Planning:**
    - Green infrastructure (e.g., urban forests, green roofs) to reduce urban heat.
    - Zoning regulations to avoid construction in flood-prone areas.
5. **Health Adaptation:**
    - Strengthen healthcare systems to manage heatwaves, disease spread (like dengue, malaria).
    - Improve early warning systems.
6. **Ecosystem-Based Adaptation:**
    - Restore wetlands and mangroves to buffer storm surges and sequester carbon.

Examples of Adaptation Measures:

Sector	**Key Actions**
Infrastructure	Build **flood defenses**, **seawalls**, and **storm drains**. - Reinforce buildings against extreme weather.
Agriculture	Use **climate-resilient crops**. - Develop **early warning systems** for droughts and pests.
Water Resources	Implement **efficient irrigation** systems. - Build **rainwater harvesting** structures.
Health	Monitor and respond to **heatwaves and vector-borne diseases**. - Improve healthcare access and infrastructure.
Urban Design	Create **green spaces**, plant **urban forests**. - Design **cool roofs** and **heat-reflective surfaces**.

3.3 Technologies and Innovations

Mitigation:

- Carbon capture and storage (CCS) for industries (e.g., capturing CO_2 from power plants).
- IoT-based energy monitoring for buildings to optimise energy use.
- Example: India's pilot CCS project at NTPC's power plant.

Adaptation: **Adaptation** involves making **adjustments in natural or human systems** in response to actual or expected climate impacts. It is **reactive and proactive resilience-building**.

- AI-driven weather forecasting for farmers to predict rainfall.
- Floating solar panels for water-scarce regions to save land and water.
- Example: Floating solar plant in Kerala's Banasura Sagar reservoir.

3.4 Differences Between Mitigation and Adaptation

- Mitigation: Addresses the cause of climate change by reducing GHG emissions.
  Example: Installing solar panels reduces CO_2 emissions.
- Adaptation: Addresses the effects by adjusting to impacts.
  Example: Building flood barriers protects against rising sea levels.

Synergy: Both are complementary (e.g., afforestation mitigates emissions by sequestering CO_2 and adapts to soil erosion).

Types of Mitigation Policies:

Instrument	**Description**
Carbon Pricing	**Carbon Tax**: Direct fee on fossil fuels. - **Cap-and-Trade**: Set emissions cap and allow permit trading.
Regulations	Emission standards for vehicles and industries. - Energy codes for buildings.
Incentives & Subsidies	Rebates for **solar panels**, **EVs**, and **energy-efficient upgrades**.
Public Investment	R&D in **clean energy**. - Public transport and low-emission infrastructure.
International Treaties	**Paris Agreement (2015)**: Global GHG reduction goals. - **Nationally Determined Contributions (NDCs)** guide country-level action.

Mitigation vs Adaptation – Key Differences

Dimension	**Mitigation**	**Adaptation**
Focus	Preventing climate change	Managing impacts of climate change
Approach	Global, long-term	Local/regional, short-to-medium term
Benefits	Climate stabilization, global	Resilience, disaster risk reduction, local
Urgency	Critical for future	Critical for now

Relationship Between Mitigation and Adaptation:

Feature	**Mitigation**	**Adaptation**
Goal	Reduce climate change itself	Manage the impacts of climate change
Feature	**Mitigation**	**Adaptation**
Time Frame	Long-term benefits	Immediate to long-term benefits
Examples	Renewable energy, reforestation	Flood barriers, heat-resistant crops
Cost-Benefit	Costs now, benefits later (global)	Costs now, benefits soon (local/regional)
Responsibility	Global cooperation needed	Primarily local/national action

Case Study: India's National Solar Mission

- Objective: Achieve 100 GW of solar power by 2022 (achieved approximately 60 GW, now targeting 500 GW by 2030).
- Achievements: Reduced solar costs from ₹15/kWh (2010) to ₹2.5/kWh (2023); 10% reduction in India's CO_2 emissions from energy sector by 2022.
- Challenges: Land acquisition, grid integration, high upfront costs.

4. Mitigation and Adaptation Policies

Mitigation policies are governmental actions, regulations, and incentives designed to support mitigation efforts and reduce emissions.

1. **Carbon Pricing:**
   - **Carbon Tax:** Direct tax on the carbon content of fossil fuels.
   - **Cap-and-Trade (ETS):** Limits total emissions and allows trading of emission permits.
2. **Subsidies & Incentives:**
   - Financial support for renewable energy (solar panels, wind farms).
   - Tax credits for EVs and energy-efficient appliances.
3. **Regulations & Standards:**
   - Emission limits for vehicles, factories, and power plants.
   - Mandatory energy efficiency standards (e.g., LED lighting, insulation).
4. **Research & Development:**
   - Funding for clean technology innovation and deployment.

5. **Land Use Policies:**
   - Support for sustainable agriculture and forest conservation.
   - Urban zoning laws to encourage density and reduce sprawl.
6. **International Agreements:**
   - **Paris Agreement (2015):** Countries commit to emission reduction targets (NDCs).
   - **Kyoto Protocol (1997):** Set binding emission reduction targets for developed nations.

4.1 Global Policies

- Paris Agreement (2015):
  - Goal: Limit global warming to below 2°C, ideally 1.5°C, via Nationally Determined Contributions (NDCs).
  - Key Feature: Voluntary commitments by countries, reviewed every 5 years.
  - Example: India's NDC targets (see below).
- Kyoto Protocol (1997):
  - Set binding emission reduction targets for developed countries.
  - Impact: Reduced global emissions by approximately 5% (1990–2012) but limited by non-participation of major emitters (e.g., USA).
- IPCC Reports:
  - Provide scientific basis for climate action (e.g., 2021 report: Net-zero emissions needed by 2050 to limit warming to 1.5°C).
  - Example: IPCC's warning of irreversible impacts (e.g., glacier loss) if emissions aren't cut.

4.2 National Policies: India's NDCs and NAPCC

- India's NDCs (Paris Agreement):
  - Reduce emissions intensity by 45% by 2030 (from 2005 levels).
  - Achieve 50% non-fossil fuel energy by 2030.
  - Create a carbon sink of 2.5–3 billion tonnes through afforestation.
- National Action Plan on Climate Change (NAPCC, 2008):
  - Eight missions: Solar, Energy Efficiency, Sustainable Habitat, Water, Green India, Agriculture, Himalayan Ecosystem, Strategic Knowledge.
  - Example: Solar Mission scaled India's solar capacity from 0 GW (2008) to 60 GW (2023).

    - Impact: India reduced emissions intensity by 24% (2005–2019), on track for NDC goals.
    - NAPCC's eight missions, their objectives, and examples (e.g., Solar Mission: 500 GW by 2030, Pavagada Solar Park). Discuss Karnataka's role in each to make it relevant.

4.3 Local Policies: Karnataka's Climate Action

- Karnataka Renewable Energy Policy (2022–2027):
    - Targets 10 GW of renewable energy, including 7 GW solar.
    - Example: Pavagada Solar Park (2 GW) is one of Asia's largest.
- Lake Rejuvenation: Restoring lakes like Bellandur and Varthur to combat water scarcity and flooding.
- Urban Planning: Bengaluru's green building incentives under NAPCC's Sustainable Habitat Mission.

4.4 Role of Engineers in Policy Implementation

- Design and Implementation:
    - Green buildings (e.g., GRIHA/LEED-certified structures in Bengaluru).
    - Renewable energy systems (e.g., solar panels, wind turbines).
    - Climate-resilient infrastructure (e.g., flood-resistant roads).
- Innovation:
    - Develop IoT-based flood monitoring systems or low-cost water purifiers.
    - Example: IIT Madras's IoT flood sensors deployed in Chennai.
- Policy Support:
    - Conduct feasibility studies for renewable energy projects.
    - Retrofit buildings for energy efficiency (e.g., ECBC compliance).

Case Study: NAPCC's Mission on Sustainable Habitat

- Objective: Promote energy-efficient buildings, sustainable urban planning, and waste management.
- Implementation: Green building certifications (e.g., GRIHA in Bengaluru's IT parks).
- Impact: Reduced energy consumption by 20–30% in certified buildings.
- Challenges: High initial costs, lack of awareness among developers.