

# Unit 4: Climate Change and Global Warming

## Environmental Sustainability — DI02000051

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## Unit 4 Topics

- 4.1 Greenhouse Effect and Greenhouse Gases
- 4.2 Global Warming — Causes, Evidence, Consequences
- 4.3 Climate Change Impacts (sea level, extreme weather, biodiversity)
- 4.4 Carbon Footprint, Carbon Credits and Carbon Trading
- 4.5 Mitigation Strategies (renewables, carbon capture, afforestation)
- 4.6 Adaptation Strategies (disaster management, resilient agriculture)
- 4.7 International Climate Agreements (Kyoto, Paris, COP)

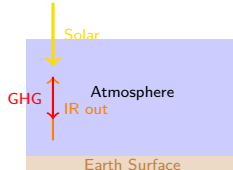
**20% marks | 6 lecture hours | PYQ topics: GHG, Paris Agreement, Carbon footprint, Mitigation vs Adaptation**

## Section 4.1

### Greenhouse Effect and Greenhouse Gases

## Solar radiation budget:

- Sun emits shortwave radiation (UV + visible)
- Earth absorbs  $\approx 70\%$ ; reflects 30% (albedo)
- Earth emits longwave (infrared) radiation to space
- **Without greenhouse effect:** Earth's avg temp =  $-18^{\circ}\text{C}$
- **With natural GHE:** actual avg temp =  $+15^{\circ}\text{C}$
- GHE raises temperature by  $33^{\circ}\text{C}$  — essential for life!



**Problem:** Industrial era has **enhanced** the greenhouse effect, causing **global warming**.

| GHG             | Formula                          | GWP (100yr)   | Main Sources                                   |
|-----------------|----------------------------------|---------------|------------------------------------------------|
| Carbon dioxide  | CO <sub>2</sub>                  | 1 (reference) | Fossil fuels, deforestation                    |
| Methane         | CH <sub>4</sub>                  | 25            | Livestock, rice fields, landfills, natural gas |
| Nitrous oxide   | N <sub>2</sub> O                 | 298           | Fertilisers, sewage, combustion                |
| CFC-12          | CCl <sub>2</sub> F <sub>2</sub>  | 10,900        | Refrigerants, aerosols (banned – Montreal)     |
| HFC-134a        | CH <sub>2</sub> FCF <sub>3</sub> | 1,430         | AC refrigerants (replacing CFCs)               |
| SF <sub>6</sub> | SF <sub>6</sub>                  | 22,800        | Electrical switchgear equipment                |
| Water vapour    | H <sub>2</sub> O                 | –             | Natural; feedback amplifier                    |

**GWP** = Global Warming Potential relative to CO<sub>2</sub> over 100 years.

**Current CO<sub>2</sub> level:** ≈421 ppm (2024) vs pre-industrial 280 ppm (+50%!)

## Global GHG share by sector:

| Sector                          | Share |
|---------------------------------|-------|
| Energy (electricity, heat)      | 25%   |
| Agriculture, forestry, land use | 24%   |
| Industry (cement, steel)        | 21%   |
| Transport                       | 14%   |
| Buildings                       | 6%    |
| Others                          | 10%   |

## India GHG Profile

- India: 3rd largest emitter (after China, USA)
- India emits  $\approx 3.3$  Gt CO<sub>2</sub>eq / year
- Per capita: 2.4 t/yr (world avg: 7 t/yr)
- India contributes  $\approx 7\%$  to global GHG
- India energy sector = 75% of India GHG
- India's NDC: reduce emission intensity 45% by 2030 (vs 2005)

## Section 4.2

### Global Warming — Causes, Evidence, Consequences

## Anthropogenic Causes

1. **Burning fossil fuels:** coal, oil, gas  $\rightarrow$   $\text{CO}_2$ ,  $\text{N}_2\text{O}$
2. **Deforestation:** releases stored C; reduces C sink
3. **Agriculture:** livestock  $\text{CH}_4$ ; rice fields; N fertilisers
4. **Industry:** cement ( $\text{CaCO}_3 \rightarrow \text{CO}_2$ ); steel, chemicals
5. **Waste:** landfills emit  $\text{CH}_4$ ; sewage emits  $\text{N}_2\text{O}$
6. **Refrigerants/CFCs:** high GWP; HFCs replacing CFCs

## Natural Causes

1. **Volcanic eruptions:**  $\text{CO}_2$ ,  $\text{SO}_2$  (short-term cooling)
2. **Solar variability:** sunspot cycles ( $\pm 0.1\%$  irradiance)
3. **Milankovitch cycles:** orbital changes (very slow, 10,000–100,000 yr)
4. **Ocean circulation:** ENSO, thermohaline circulation

**Note:** Natural causes **cannot explain** the rapid warming since 1950 — IPCC: **human activities are the dominant cause.**

| Indicator                     | Observed Change                   | Period                           |
|-------------------------------|-----------------------------------|----------------------------------|
| Global mean temperature       | +1.1°C                            | Since pre-industrial (1850-2019) |
| Sea level rise                | +20 cm                            | Since 1900; rate accelerating    |
| Arctic sea ice extent         | −40% in summer                    | Since 1980s                      |
| Greenland ice loss            | 280 Gt/year                       | Last decade                      |
| Ocean heat content            | Increased at all depths           | Measured since 1950s             |
| Glacier retreat               | 90%+ glaciers retreating          | Global (NASA data)               |
| Coral bleaching               | Great Barrier Reef; 4 mass events | Since 1998                       |
| CO <sub>2</sub> concentration | 421 ppm (2024) vs 280 ppm         | Pre-industrial baseline          |
| Extreme weather               | Frequency + intensity increased   | IPCC AR6 2021                    |

## Physical Consequences

- Sea level rise (thermal expansion + ice melt)
- More frequent extreme heat waves
- Intense hurricanes, cyclones, floods
- Droughts and desertification
- Permafrost thawing → CH<sub>4</sub> feedback loop
- Glacier retreat → freshwater crisis

## Human/Eco consequences

## Conse- quences

- Crop failure: food insecurity for billions
- Coral bleaching → fishery collapse
- Species extinction (6th mass extinction)
- Climate refugees (coastal, small islands)
- Spread of vector-borne diseases (malaria, dengue)
- Economic losses: trillions/year by 2100

**IPCC AR6 (2021):** +1.5°C is the "safe" limit; currently on track for +2.5–3.0°C by 2100 unless drastic action.

## Section 4.3

### Climate Change Impacts

## Two causes of sea level rise:

### 1. Thermal expansion (steric):

Water expands as it warms. Oceans absorb >90% of excess heat. Contributes  $\approx$ 50% of observed SLR.

### 2. Ice melt (eustatic):

Greenland ice sheet, Antarctic ice sheets, mountain glaciers. Contributes other  $\approx$ 50%.

**Observed:** +3.6 mm/year (recent decade)

**Projected:** 0.28–1.01 m by 2100 (IPCC AR6)

### Impacts:

- Flooding of coastal cities (Mumbai, Kolkata)
- Loss of small island nations (Maldives, Tuvalu)
- Salinisation of freshwater aquifers
- Displacement of 1 billion coastal people

## Vulnerable Countries

- Bangladesh: 17% of land below 1m
- Maldives: avg elevation 1.5 m
- Netherlands: 27% below sea level
- Egypt: Nile delta at risk
- India: Mumbai, Kolkata, Chennai
- USA: Miami, New Orleans, NYC

## How does warming intensify extreme weather?

Every  $1^{\circ}\text{C}$  rise  $\rightarrow$  atmosphere holds 7% more water vapour (Clausius-Clapeyron). This fuels:

| Event                 | Change with Warming                                | Recent Example                                   |
|-----------------------|----------------------------------------------------|--------------------------------------------------|
| Heat waves            | More frequent, longer, hotter                      | Europe 2022 ( $48^{\circ}\text{C}$ ); India 2024 |
| Cyclones/Hurricanes   | More intense (Cat 4–5); more rapid intensification | Cyclone Biparjoy, 2023                           |
| Heavy rainfall/floods | More intense precipitation                         | Pakistan floods 2022 (33M displaced)             |
| Droughts              | Longer, more severe                                | Horn of Africa 2022; SW USA 2023                 |
| Wildfires             | Longer fire season, larger area                    | Australia 2019-20; Canada 2023                   |
| Cold spells           | Paradoxically, polar vortex disruption             | Texas freeze 2021                                |

## Impacts on Species & Ecosystems

### **Range shifts:**

Species moving poleward or to higher altitudes ( $\approx 6$  km/decade). Alpine species face "extinction on mountain tops".

### **Phenological mismatch:**

Flowers bloom earlier; pollinators not yet active  $\rightarrow$  reproduction failure.

### **Coral bleaching:**

Corals expel zooxanthellae when ocean temp rises  $>1^{\circ}\text{C}$ . 14% of global corals lost in 2009–2018 (GCRMN 2020).

### **Mass extinctions:**

Current extinction rate  $100\text{--}1000\times$  background rate. 1 million species threatened (IPBES 2019).

### **Ocean acidification:**

$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow$  lowers ocean pH. Dissolves shells of molluscs, echinoderms.

## Physical Impacts

- **Monsoon changes:** erratic timing; dry spells + floods
- **Himalayan glaciers:** Gangotri retreating 22 m/year
- **Sea level:** Mumbai, Kolkata at risk
- More intense cyclones (Bay of Bengal warmer)
- Heat waves: Delhi 2024 (52.9°C, all-time record)
- Extreme rainfall: Kerala 2018, Uttarakhand 2021

## Socio-Economic Impacts

- **Agriculture:** wheat yield -6% per 1°C rise
- 600M people depend on monsoon for water
- **Fisheries:** warming ocean disrupts patterns
- **Health:** dengue, malaria spreading north
- **Labour productivity** loss in outdoor work
- **GDP loss:** 2.8% by 2050 (World Bank est.)

## Section 4.4

### Carbon Footprint, Carbon Credits and Carbon Trading

## Definition

Total greenhouse gas emissions (expressed as CO<sub>2</sub> equivalent — CO<sub>2</sub>eq) caused directly and indirectly by an individual, organisation, event, or product over its lifecycle.

## Types

**Direct (Scope 1):** Own fuel combustion (furnace, fleet)

**Indirect (Scope 2):** Purchased electricity/heat

**Value chain (Scope 3):** Supply chain, product use, disposal

## Per Capita Comparison

USA:  $\approx 15$  t CO<sub>2</sub>eq/year  
EU average:  $\approx 8$  t  
China:  $\approx 8$  t  
India:  $\approx 2.4$  t (much lower!)  
World average:  $\approx 7$  t  
Sustainable target:  $< 2$  t by 2050

**How to reduce?** Switch to RE, use EVs, eat less meat, fly less, plant trees, buy local.

## Definition

A **carbon credit** is a tradeable permit that represents the right to emit **1 tonne of CO<sub>2</sub>eq**. Organisations that reduce emissions earn credits; those that exceed their limit must buy credits.

### **Clean Development Mechanism (CDM) — Kyoto Protocol:**

Developed countries can fund emission-reduction projects in developing countries and earn **Certified Emission Reductions (CERs)** = carbon credits.

**Example:** A cement plant in India installs waste heat recovery → earns CERs → sells to EU company that is over its quota.

**Voluntary carbon market:** Companies voluntarily offset emissions (e.g., airline lets you offset your flight).

**Types of carbon offset projects:** Renewable energy, reforestation, methane capture, cookstove programs

## How Cap-and-Trade Works

- Step 1:** Government sets a **CAP** (total allowed emissions) for a sector.
- Step 2:** Companies get **allowances** (permits) for their share.
- Step 3:** Companies that emit less than their allowance can **sell surplus**.
- Step 4:** Companies over limit must **buy allowances** or face penalty.
- Step 5:** Cap reduced over time → total emissions fall.

| System                                    | Feature                               |
|-------------------------------------------|---------------------------------------|
| EU ETS (Emissions Trading Scheme)         | World's largest, 11,000 installations |
| California Cap-and-Trade                  | Links with Quebec (Canada)            |
| China ETS (since 2021)                    | World's largest by volume             |
| India Carbon Credit Trading Scheme (CCTS) | Launched 2023 (India's first)         |

**Carbon neutral:**  $\text{CO}_2$  emitted =  $\text{CO}_2$  removed/offset (net zero  $\text{CO}_2$  only).

**Net zero:** All GHG emissions reduced to near-zero; remaining offset by carbon sinks (forests, DACCS).

**Carbon negative/Climate positive:** Removes more  $\text{CO}_2$  than it emits (e.g., Bhutan is carbon negative!).

**DACCS:** Direct Air Carbon Capture and Storage — machines pull  $\text{CO}_2$  from air; expensive but promising.

**BECCS:** Bioenergy with Carbon Capture and Storage — burn biomass (carbon-neutral) + capture emissions = **negative emissions**.

**India's target:** Net zero by **2070** (announced at COP26, Glasgow).

## Section 4.5

### Mitigation Strategies

## Mitigation (Reduce the Cause)

Actions that reduce or prevent GHG emission or enhance carbon sinks.

**Goal:** Stop further climate change from happening.

**Examples:** Switch to renewable energy; improve fuel efficiency; plant forests; carbon capture.

## Adaptation (Live with the Effect)

Actions that help humans and ecosystems cope with the impacts of climate change that cannot be avoided.

**Goal:** Reduce vulnerability to existing and future changes.

**Examples:** Build sea walls; drought-resistant crops; early warning systems; disease surveillance.

**We need BOTH — mitigation reduces long-term risk; adaptation handles locked-in changes.**

## **1. Transition to renewable energy:**

Solar, wind, hydro, geothermal replace coal/oil. Eliminates Scope 1 and 2 emissions from power sector.

## **2. Energy efficiency:**

LED lighting; 5-star appliances; EV/hybrid vehicles; building insulation. Reduces demand.

## **3. Carbon capture & storage (CCS):**

Capture CO<sub>2</sub> at source (power plant or cement factory), compress, and inject into deep geological formations. Cost: \$50–100/tonne.

## **4. Nuclear power:**

Low lifecycle GHG (12 g CO<sub>2</sub>eq/kWh vs coal 820 g). IPCC includes nuclear as mitigation option. Controversial (waste, safety).

## **5. Green hydrogen:**

Electrolysis of water using RE. Zero-emission fuel for heavy industry and transport.

## Forests

- Forests store  $\approx 660$  Gt C ( $2\times$  atmosphere)
- **Afforestation:** plant trees on previously treeless land
- **Reforestation:** replant already-cleared forest
- India planted 1.5 billion trees (2016–2020)
- REDD+: UN program pays developing countries to **not** deforest
- Agroforestry: trees + crops together

## Blue Carbon

- Mangroves, seagrasses, salt marshes store carbon at  $5\text{--}10\times$  rate of tropical forests
- Called “blue carbon” ecosystems
- Degradation  $\rightarrow$  fast  $\text{CO}_2$  release
- India: 4,992  $\text{km}^2$  mangroves (4th largest worldwide)
- Protection = low-cost mitigation

Agriculture causes  $\approx 10\text{--}12\%$  of global GHG emissions. Mitigation options:

| Source               | Emission                             | Mitigation                             |
|----------------------|--------------------------------------|----------------------------------------|
| Livestock            | CH <sub>4</sub> (ruminant digestion) | Feed additives (3-NOP), fewer ca       |
| Paddy fields         | CH <sub>4</sub> (anaerobic flooding) | Alternate wetting and drying; SR       |
| Nitrogen fertiliser  | N <sub>2</sub> O                     | Precision fertilisation, nitrification |
| Crop residue burning | CO <sub>2</sub> , black carbon       | Mechanised incorporation, biocha       |
| Land clearing        | CO <sub>2</sub>                      | Forest protection, agroforestry        |

**Biochar:** Charred crop residue buried in soil  $\rightarrow$  stable carbon for 1000+ years.

## Section 4.6

### Adaptation Strategies

## **Infrastructure-based adaptation:**

- Sea walls, surge barriers, levees for coastal flooding
- Elevated roads and buildings in flood-prone areas
- Green roofs and urban heat island mitigation

## **Agricultural adaptation:**

- Drought-resistant/heat-tolerant crop varieties (GM crops, traditional varieties)
- Crop diversification; change cropping calendar
- Rainwater harvesting, drip irrigation

## **Health adaptation:**

- Early warning systems for heat waves
- Vector-borne disease surveillance (dengue, malaria)
- Cool shelters and emergency response plans

## **Ecosystem-based adaptation (EbA):**

- Restore mangroves (protect coasts naturally)
- Watershed protection; wetland restoration

## Disaster Risk Reduction (DRR)

**Sendai Framework 2015–2030:** Global disaster risk reduction plan (UNDRR)

### Priority Actions:

1. Understand disaster risk (hazard mapping, exposure data)
2. Strengthen disaster risk governance (NDMA, SDMA)
3. Invest in resilience (early warning, infrastructure)
4. Enhance preparedness (response, recovery)

## India's Institutions

- **NDMA:** National Disaster Management Authority (Disaster Management Act 2005)
- **NDRF:** National Disaster Response Force (16 battalions)
- **IMD:** Indian Meteorological Department (weather forecasting)
- **INCCA:** India Network for Climate Change Assessment

**Climate-Smart Agriculture (CSA):** FAO concept; 3 pillars: Productivity + Adaptation + Mitigation

**Key practices:**

1. **Drought-resistant varieties:** millet, sorghum over rice/wheat in dry areas
2. **Traditional crops:** native landraces often more resilient than modern HYVs
3. **Water-efficient irrigation:** drip irrigates 40–60% less water
4. **Weather-based crop insurance:** Pradhan Mantri Fasal Bima Yojana (PMFBY)
5. **Agroforestry:** trees provide buffer against temperature extremes
6. **Integrated pest management (IPM):** climate change shifts pest ranges
7. **Crop diversification:** reduces risk of complete crop failure

**India's initiative:** NICRA (National Innovations in Climate Resilient Agriculture)

### Urban Heat Island

Cities are 2–5°C warmer than surrounding rural areas.

**Solutions:**

- Green roofs and vertical gardens
- Cool/white/reflective roofs
- Urban tree canopy (>25% cover)
- Permeable pavement (reduce runoff)
- Water bodies (lakes, ponds)

### Flood Resilience

- Sponge city concept (China): urban design that absorbs water
- Early flood warning systems (24–48 hr alert)
- Flood plains left free of construction
- Wetland restoration in urban fringe
- Elevated evacuation corridors

## Section 4.7

### International Climate Agreements

**UNFCCC:** United Nations Framework Convention on Climate Change

**Adopted:** Rio Earth Summit, 1992

**In force:** March 21, 1994

**Signatories:** 197 parties (near-universal)

**Objective:** “Stabilize GHG concentrations at a level that would prevent dangerous human interference with the climate system.”

**Principles:**

- **Common but Differentiated Responsibilities (CBDR):** Developed countries must act first (historical emitters)
- Precautionary principle (act even with scientific uncertainty)
- Technology transfer and financial support to developing nations

**COP:** Conference of Parties — annual meeting. COP1 (Berlin 1995) → COP28 (Dubai 2023).

**Adopted:** Kyoto, Japan, 1997    **In force:** Feb 2005

**First binding treaty** to reduce GHG emissions.

**Target:** Annex I (developed) countries reduce emissions by 5.2% below 1990 levels (2008–2012).

**Three flexible mechanisms:**

1. **Emissions Trading (ET):** countries trade unused quota
2. **Joint Implementation (JI):** Annex I invests in emission reduction in other Annex I countries
3. **Clean Development Mechanism (CDM):** Annex I funds projects in developing countries → earns CER credits

**Limitation:** USA never ratified; China, India (developing) had no binding targets.

**Doha Amendment (2012):** Extended to 2020 with new targets (most countries committed).

## Key Features of Paris Agreement

**Adopted:** COP21, Paris, December 12, 2015

**Parties:** 196 (nearly all nations including USA, China, India)

**Goal:** Keep global warming **well below 2°C** above pre-industrial (aim for 1.5°C).

**Mechanism:** **NDCs (Nationally Determined Contributions)** — each country sets own target, reviewed every 5 years.

### **Key provisions:**

- \$100 billion/year green climate fund (developed → developing)
- Transparency and accountability (global stocktake)
- Loss and damage mechanism for vulnerable nations

**India's NDC:** 45% emission intensity reduction by 2030; 500 GW RE capacity; Net Zero by 2070.

**USA:** withdrew 2017 (Trump); rejoined 2021 (Biden); withdrew again 2025 (Trump).

| COP   | Location/Year         | Key Outcome                                             |
|-------|-----------------------|---------------------------------------------------------|
| COP1  | Berlin, 1995          | Berlin Mandate: developed countries to take lead        |
| COP3  | Kyoto, 1997           | <b>Kyoto Protocol</b> — first binding emission targets  |
| COP13 | Bali, 2007            | Bali Roadmap; developing countries included             |
| COP15 | Copenhagen, 2009      | Copenhagen Accord (non-binding; major disappointment)   |
| COP17 | Durban, 2011          | Durban Platform; agreed to new universal agreement      |
| COP21 | Paris, 2015           | <b>Paris Agreement</b> — NDCs; 2°C / 1.5°C goal         |
| COP26 | Glasgow, 2021         | "Coal phase-down"; India Net Zero 2070; \$100B fund     |
| COP27 | Sharm el-Sheikh, 2022 | Loss and Damage Fund agreed for first time              |
| COP28 | Dubai, 2023           | First global stocktake; fossil fuel transition language |

| Feature              | Kyoto Protocol (1997)            | Paris Agreement (2015)               |
|----------------------|----------------------------------|--------------------------------------|
| Approach             | Top-down: targets set by treaty  | Bottom-up: self-determined NDCs      |
| Binding targets      | Yes for Annex I (developed) only | No binding emission targets          |
| Developing countries | Exempt from targets              | All must contribute (CBDR preserved) |
| USA                  | Never ratified                   | Signed, withdrew, rejoined           |
| Mechanism            | CDM, JI, ET                      | Green Climate Fund, NDCs             |
| Goal                 | 5.2% below 1990                  | Well below 2°C / 1.5°C               |
| Review cycle         | Fixed commitment periods         | NDCs reviewed every 5 years          |
| Status               | Succeeded by Paris 2020          | In force; current framework          |

## IPCC

**IPCC:** Intergovernmental Panel on Climate Change

**Est:** 1988 (WMO + UNEP)

**Role:** Assess scientific literature on climate change (NOT a research body).

**Reports:** Assessment Reports every 5–7 years.

**AR6 (2021):** “Human influence warmed the climate at unprecedented rate.”

**Nobel Peace Prize 2007** (shared with Al Gore)

## India's NDC (Updated 2022)

- Reduce emission intensity of GDP by 45% by 2030 (vs 2005)
- Achieve 50% cumulative electric power from non-fossil sources by 2030
- Create carbon sink of 2.5–3 Gt CO<sub>2</sub>eq through forests by 2030
- Net Zero by 2070
- 500 GW renewable energy by 2030

# Other Key Environmental Agreements (Quick Reference)

| Agreement                             | Year         | Focus                                           |
|---------------------------------------|--------------|-------------------------------------------------|
| Vienna Convention                     | 1985         | Framework for ozone layer protection            |
| Montreal Protocol                     | 1987         | Phase-out of ozone-depleting substances (CFCs); |
| Brundtland Commission                 | 1987         | Defined sustainable development                 |
| Rio Earth Summit (UNCED)              | 1992         | UNFCCC + Convention on Biodiversity + Agenda    |
| Kyoto Protocol                        | 1997         | Binding GHG emission targets (Annex I)          |
| Doha Development Agenda               | 2001         | Trade and environment linkages (WTO)            |
| Paris Agreement                       | 2015         | NDCs; 1.5°C goal                                |
| Glasgow Climate Pact                  | 2021 (COP26) | Coal phase-down; 1.5°C reaffirmed               |
| Kigali Amendment                      | 2016         | Phase-down of HFCs (high GWP refrigerants)      |
| Kunming-Montreal (COP15 biodiversity) | 2022         | 30×30 goal: protect 30% land/sea by 2030        |

## 1. Post-combustion CCS:

Capture  $\text{CO}_2$  from flue gas using amine scrubbing; compress; inject underground. Proven but expensive (\$60–100/t). Best for cement, steel.

## 2. Pre-combustion (IGCC):

Convert fuel to syngas ( $\text{CO} + \text{H}_2$ ); separate  $\text{CO}_2$  before burning. Used in Integrated Gasification Combined Cycle power plants.

## 3. Oxy-fuel combustion:

Burn fuel in pure oxygen → flue gas is nearly pure  $\text{CO}_2$  (easy capture). High energy penalty.

## 4. Direct Air Capture (DAC):

Pull  $\text{CO}_2$  directly from atmosphere using chemical sorbents. Cost: \$300–600/t (falling). Climeworks (Iceland) operational.

## 5. Enhanced weathering:

Spread crushed silicate rock on croplands → rock weathers, absorbs  $\text{CO}_2$ . Also fertilises soil.

| Energy Source      | GHG (g CO <sub>2</sub> eq/kWh) | vs Coal (820) | Role in Mitigation                  |
|--------------------|--------------------------------|---------------|-------------------------------------|
| Solar PV           | 20–50                          | –97%          | Rooftop + utility scale replacement |
| Wind               | 7–15                           | –98%          | Grid-scale electricity; no fuel     |
| Nuclear            | 12                             | –98%          | Baseload; no GHG at operation       |
| Hydro              | 4–30                           | –97%          | Peaking power + storage             |
| Natural gas (CCGT) | 490                            | –40%          | Transition fuel (still emits!)      |
| Coal with CCS      | 100–200                        | –75%          | Bridge if CCS scales up             |
| Coal               | 820                            | (reference)   | Highest emitter — phase out         |

**Key message:** Replacing coal with solar + wind alone can eliminate  $\approx 35\%$  of global GHG. Fastest, cheapest mitigation.

**Global forests store 660 Gt of C** — 2× what's in the atmosphere.

**Deforestation emits 4–6 Gt CO<sub>2</sub>/year** — equivalent to all of EU and India combined!

**Why forests matter for climate:**

- Absorb ≈30% of human CO<sub>2</sub> emissions every year (2.6 Gt C/yr)
- Regulate water cycle — forests drive local + regional rainfall
- Cooling effect via evapotranspiration (not just carbon storage)

**India's forest cover:** 21.7% of land (target: 33% under Forest Policy 1988)

**Programs:** Green India Mission; CAMPA fund; Van Dhan Vikas Kendra

**REDD+:** Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN program under UNFCCC)

**Linear economy:** Take → Make → Dispose (high GHG)

**Circular economy:** Reduce → Reuse → Recycle → Recover

## Why it helps climate?

- Recycling aluminium: 95% less energy vs making new
- Recycled steel: 72% less energy; recycled paper: 60% less
- Extending product life → fewer factories running → fewer emissions
- Organic waste composting avoids landfill CH<sub>4</sub>

## Examples:

- Rent-not-buy models (cars, tools, clothes)
- Industrial symbiosis (Kalundborg, Denmark): waste from one factory = input for another
- EPR (Extended Producer Responsibility): producer responsible for product end-of-life

### Why climate finance matters:

Climate change is a market failure — fossil fuels don't pay for environmental damages. Public finance must bridge the gap.

### Key funds:

- **Green Climate Fund (GCF):** largest dedicated climate fund; \$100B/yr pledge (Paris); channels money to developing countries
- **Adaptation Fund:** focus on adaptation in most vulnerable developing countries (COP13, Bali 2007)
- **Global Environment Facility (GEF):** 1991; funds projects in environment/climate

### India's access:

- India approved for GCF projects (solar, metro rail, wetland)
- ISA: International Solar Alliance (India-France initiative, 120 countries)

## What makes Paris different from Kyoto?

- **Universal:** all 196 parties (rich + poor) have targets
- **Flexible:** NDCs are self-determined (not top-down)
- **Ratchet mechanism:** Every 5 years, NDCs must be revised upward (no back-sliding)
- **Long-term goal:** Net zero emissions in second half of 21st century
- **Transparency:** all countries report progress; global stocktake every 5 years

## Key Articles:

Art 2: Temperature goal ( $2^{\circ}\text{C}$  /  $1.5^{\circ}\text{C}$ )

Art 4: NDCs every 5 years; CBDR

Art 6: Carbon market mechanisms

Art 9: Finance (\$100B/yr; from 2025: \$300B/yr – COP29 2024)

Art 12: Climate education and public awareness

**Weakness:** NDCs currently track for  $+2.5^{\circ}\text{C}$  — insufficient!

# Individual & Corporate Climate Action (You Can Help!)

## Individual Actions

- Switch to LED (saves 80% electricity)
- Use EV or public transport
- Eat less red meat (cow = 70 kg CO<sub>2</sub>/kg beef)
- Fly less; or offset flights
- Reduce AC use; better insulation
- Plant trees, protect local forests
- Compost food waste (no landfill CH<sub>4</sub>)
- Buy energy-efficient (5-star BEE) appliances

## Corporate Actions

- Science-based targets (SBTi)
- 100% renewable energy (RE100 initiative)
- Carbon disclosure (CDP reporting)
- Scope 3 supply chain sustainability
- ESG reporting; green bonds
- Circular design of products
- CSR in afforestation, community RE

## Worked PYQs

### Unit 4 — Climate Change Past Year Question Practice

Q: Explain greenhouse effect and list main greenhouse gases (4M)

**Greenhouse Effect:**

Shortwave solar radiation passes through Earth's atmosphere and warms the surface. The warmed Earth emits longwave (infrared) radiation. Greenhouse gases (GHGs) in the atmosphere absorb this infrared and re-radiate it in all directions — including back to Earth. This traps heat, raising surface temperature.

**Natural GHE:** raises Earth temp from  $-18^{\circ}\text{C}$  to  $+15^{\circ}\text{C}$  — essential for life.

**Enhanced GHE:** excess GHGs from human activity → global warming.

**Main GHGs (with GWP):**

1.  $\text{CO}_2$  (GWP=1) — fossil fuels, deforestation
2.  $\text{CH}_4$  (GWP=25) — livestock, landfills
3.  $\text{N}_2\text{O}$  (GWP=298) — fertilisers, combustion
4. CFCs/HFCs (GWP up to 10,000+) — refrigerants
5. Water vapour — amplifies other GHGs

Q: Describe the Paris Agreement and India's commitments (4M)

**Paris Agreement (COP21, 2015):**

- Adopted Dec 12, 2015; in force Nov 2016
- Goal: Limit warming to **well below 2°C** above pre-industrial; pursue 1.5°C
- Each country submits NDC (Nationally Determined Contribution) – revised every 5 years
- \$100 billion/year climate finance from developed to developing countries
- Transparency and global stocktake mechanism
- Loss and damage provisions for vulnerable nations

**India's NDC commitments:**

- Reduce GDP emission intensity by 45% below 2005 levels by 2030
- 50% of electricity from non-fossil fuel sources by 2030
- Create additional carbon sink of 2.5–3 Gt CO<sub>2</sub>eq via forests by 2030
- Net zero emissions by **2070**

## Q: Define carbon footprint. How can it be reduced? (4M)

### Definition:

Carbon footprint = total GHG emissions (expressed as CO<sub>2</sub> equivalent) caused directly and indirectly by an individual/organisation/product/event.

### Categories:

- **Direct:** personal combustion (car, gas stove)
- **Indirect:** electricity consumed, flights, food production

### How to reduce:

1. Use renewable energy (solar, wind) for electricity
2. Use EVs or public transport (reduce transport GHG 14%)
3. Eat plant-based diet (less meat = less CH<sub>4</sub> from livestock)
4. Improve building insulation (reduce heating/cooling energy)
5. Buy energy-efficient (BEE 5-star) appliances (LED, AC, fridge)
6. Reduce, reuse, recycle (less industrial production needed)
7. Plant trees (forest = carbon sink)

Q: Differentiate between mitigation and adaptation to climate change (4M)

| Aspect       | Mitigation                                          | Adaptation                                                 |
|--------------|-----------------------------------------------------|------------------------------------------------------------|
| Definition   | Reduce/prevent GHG emission or enhance carbon sinks | Adjust to cope with actual/expected climate change impacts |
| Focus        | Addressing the <b>cause</b> of climate change       | Addressing the <b>effects</b> of climate change            |
| Goal         | Slow down climate change; reduce future risks       | Reduce current/future vulnerability                        |
| Timeframe    | Long-term impact                                    | Short + long-term benefit                                  |
| Examples     | Switch to solar; plant forests; EVs; CCS            | Sea walls; drought-resistant crops; early warning          |
| Who benefits | Everyone globally (public good)                     | Local communities (private+public b                        |

**India needs both:** mitigation (via RE targets) and adaptation (via NICRA, NDMA, sea walls, climate-resilient crops).

## Q: Write notes on Kyoto Protocol (4M)

### Kyoto Protocol (1997):

- Adopted at COP3, Kyoto, Japan (Dec 1997); in force Feb 2005
- First legally **binding international treaty** on GHG reduction
- Operated under UNFCCC framework

### Key features:

- **Annex I (developed) countries** must reduce emissions 5.2% below 1990 levels in 2008–2012
- Developing countries (India, China) had **no binding** targets (CBDR)
- USA didn't ratify (world's largest emitter at that time)

### Three mechanisms:

1. Emissions Trading: trade surplus allowances
2. Joint Implementation: Annex I countries earn credits via projects in other Annex I
3. CDM: fund emission-reduction projects in developing countries, earn CERs

**Significance:** Established carbon market; paved way for Paris Agreement.

1. The Paris Agreement aims to limit warming to:  
(A) 1°C                      **(B) 1.5–2°C**                      (C) 3°C                      (D) 0.5°C
2. GWP of methane ( $\text{CH}_4$ ) over 100 years is:  
(A) 1                      **(B) 25**                      (C) 298                      (D) 100
3. India's net zero target year under Paris Agreement is:  
(A) 2050                      (B) 2030                      **(C) 2070**                      (D) 2060
4. CDM stands for:  
(A) Carbon Dioxide Management                      **(B) Clean Development Mechanism**
5. IPCC stands for:  
**(A) Intergovernmental Panel on Climate Change**    (B) International Protocol on Climate Control
6. Pre-industrial  $\text{CO}_2$  level was:  
(A) 315 ppm                      (B) 350 ppm                      **(C) 280 ppm**                      (D) 180 ppm

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**Wrong**

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Greenhouse effect is harmful

Paris Agreement was in 1997

Kyoto Protocol binds all countries

COP is a law-making body

Mitigation = living with climate change

Global warming = same as climate change

India has no climate targets

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**Correct**

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**Natural GHE is essential** for life; enhanced GHE is harmful

1997 = **Kyoto Protocol**; Paris = **2015**

Only **Annex I** (developed) countries had binding targets

COP is a **negotiating conference**; it agrees on treaties

Mitigation = **reducing causes**; Adaptation = living with effects

GW = rising avg temp; CC = broader pattern changes

India's NDC: 45% intensity cut, 500 GW RE, Net Zero 2070

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# Flash Revision 1 — GHE & Global Warming (Quick Recall)

## Greenhouse Effect

- Solar input = shortwave radiation (UV + visible)
- Earth emits longwave (IR) radiation
- GHGs absorb and re-radiate IR → warming
- Natural GHE:  $-18^{\circ}\text{C} \rightarrow +15^{\circ}\text{C}$  ( $33^{\circ}\text{C}$  warming)
- $\text{CO}_2$ : GWP 1 |  $\text{CH}_4$ : 25 |  $\text{N}_2\text{O}$ : 298 | CFCs: up to 10,900
- $\text{CO}_2$  now: 421 ppm (vs 280 pre-industrial)
- Evidence:  $1.1^{\circ}\text{C}$  warming; SLR 20 cm; ice melt

## Global Warming Impacts

- SLR: 20 cm since 1900;  $+3.6 \text{ mm/yr}$  now
- 0.28–1.01 m rise by 2100 (IPCC AR6)
- More intense cyclones, floods, droughts
- Coral bleaching (temp  $>1^{\circ}\text{C}$  above normal)
- 1 million species threatened (IPBES 2019)
- India: glacier retreat, erratic monsoon, heat waves
- Heat wave record: Delhi  $52.9^{\circ}\text{C}$  (2024)

# Flash Revision 2 — Carbon Markets & Mitigation

## (Quick Recall)

### Carbon Markets

- 1 carbon credit = right to emit 1 t CO<sub>2</sub>eq
- Cap-and-trade: government sets cap; companies buy/sell
- CDM: fund RE/efficiency projects in developing countries → earn CERs
- EU ETS: world's largest; 11,000 installations
- India CCTS: launched 2023
- Voluntary offset: airlines, companies
- Net zero ≠ carbon neutral (net zero = all GHGs)

### Mitigation Actions

- Renewable energy replaces fossil fuels
- Energy efficiency (LED = 80% less energy)
- CCS: capture CO<sub>2</sub> at source; store underground
- DAC: pull CO<sub>2</sub> from air (\$300–600/t)
- Afforestation + REDD+
- Circular economy: recycled Al = 95% less energy
- EV: 3–4× more efficient than IC engine

# Flash Revision 3 — International Agreements (Quick Recall)

## Key Treaties

- UNFCCC 1992 (Rio): foundation treaty; 197 parties
- Kyoto Protocol 1997: binding targets for Annex I; CDM/JI/ET
- Paris Agreement 2015 (COP21): NDCs; 2°C/1.5°C goal; all countries
- Glasgow Pact 2021 (COP26): coal phase-down; India Net Zero 2070
- Montreal Protocol 1987: CFC phase-out; most successful
- Kigali 2016: phase-down HFCs

## Adaptation

- Adaptation = living with effects (vs mitigation = reduce cause)
- Sea walls, drought-resistant crops, early warning
- NDMA: National Disaster Management Authority (India)
- Sendai Framework 2015: global DRR
- CSA: Climate-Smart Agriculture (FAO)
- NICRA: India's climate-resilient agriculture program
- EbA: Ecosystem-based Adaptation (mangroves, wetlands)

# Important Definitions Recap — Unit 4 (Exam Guide)

| Term             | Definition                                                                                            |
|------------------|-------------------------------------------------------------------------------------------------------|
| Greenhouse gas   | Gas that absorbs and re-emits infrared radiation, trapping heat in atmosphere                         |
| GWP              | Global Warming Potential — warming effect of 1 kg GHG relative to 1 kg CO <sub>2</sub> over 100 years |
| Carbon footprint | Total GHG emissions (CO <sub>2</sub> eq) of an individual, org, product or event                      |
| Carbon credit    | Permit to emit 1 tonne CO <sub>2</sub> eq; tradeable in carbon markets                                |
| CDM              | Clean Development Mechanism: Annex I countries earn credits funding RE projects in developing nations |
| NDC              | Nationally Determined Contribution: each country's Paris Agreement climate action plan                |
| Mitigation       | Reducing GHG emissions or enhancing carbon sinks to limit climate change                              |
| Adaptation       | Adjusting human/natural systems to cope with actual or expected climate impacts                       |
| Net zero         | Reducing all GHG to near-zero; remaining offset by carbon sinks/CCS                                   |
| IPCC             | Intergovernmental Panel on Climate Change (1988); synthesizes climate science                         |

| Fact                                       | Value                        |
|--------------------------------------------|------------------------------|
| Current global warming (vs pre-industrial) | +1.1°C (IPCC AR6, 2021)      |
| Paris target                               | Well below 2°C; pursue 1.5°C |
| Current CO <sub>2</sub> concentration      | ≈421 ppm (2024)              |
| Pre-industrial CO <sub>2</sub>             | 280 ppm                      |
| GWP of CH <sub>4</sub>                     | 25 (100-year)                |
| GWP of N <sub>2</sub> O                    | 298 (100-year)               |
| India net zero year                        | 2070                         |
| India emission intensity reduction target  | 45% below 2005 by 2030       |
| India RE target                            | 500 GW by 2030               |
| Sea level rise observed                    | +20 cm since 1900            |

**Q.** What is ocean acidification? (3M)

**Ans:** As  $\text{CO}_2$  levels in atmosphere rise, more  $\text{CO}_2$  dissolves in oceans.  $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$  (carbonic acid), lowering ocean pH from 8.2 to 8.1 (30% more acidic on logarithmic scale). Threatens marine organisms with calcium carbonate shells (oysters, corals, plankton) and disrupts food chains.

**Q.** What is the Kyoto CDM? (3M)

**Ans:** Clean Development Mechanism under Kyoto Protocol. Allows Annex I (developed) countries to fund emission-reduction projects in non-Annex I (developing) countries and earn Certified Emission Reductions (CERs). Acts as carbon credit they can use to meet their own Kyoto targets. Win-win: developing countries get clean technology investment; developed countries get credits.

**Q.** What is permafrost thawing? (2M)

**Ans:** Frozen soil in Arctic regions thaws as Earth warms. Releases stored  $\text{CH}_4$  (trapped organic matter decays) creating a vicious positive feedback loop: more warming  $\rightarrow$  more thaw  $\rightarrow$  more  $\text{CH}_4 \rightarrow$  more warming.

## GHE & Warming

- Natural GHE warms Earth by  $33^{\circ}\text{C}$  (essential!)
- Enhanced GHE  $\rightarrow$  global warming ( $+1.1^{\circ}\text{C}$  so far)
- Top GHGs:  $\text{CO}_2$  (GWP 1),  $\text{CH}_4$  (25),  $\text{N}_2\text{O}$  (298), CFCs
- Impacts: SLR, extreme weather, coral bleaching, extinction

## International Agreements

- UNFCCC 1992: foundation framework
- Kyoto 1997: binding for Annex 1; CDM/JI/ET
- Paris 2015: NDCs;  $2^{\circ}\text{C}/1.5^{\circ}\text{C}$ ; all countries
- India NDC: 45% intensity cut; 500 GW RE; Net Zero 2070

## Carbon Markets

- 1 carbon credit = right to emit 1 t  $\text{CO}_2\text{eq}$
- CDM: developed countries fund RE in developing
- Cap-and-trade: EU ETS (largest); India CCTS (2023)
- Net zero: reduce all GHG + offset remaining

## Key Actions

- Mitigation: RE, EV, forests, CCS, circular economy
- Adaptation: sea walls, drought crops, early warning

**Weightage: 20% | Hours: 6 | Top PYQs:**  
**GHE/GWP, Paris Agreement, Carbon foot-**