DP IB Environmental Systems & Societies (ESS): HL

Your notes

6.2 Climate Change Causes & Impacts

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Atmospheric Processes Affecting Climate

- Climate describes the typical conditions resulting from various **physical processes** in the atmosphere

Atmospheric Processes Affecting Climate

Process	Explanation
Solar radiation	Energy from sun reaches Earth's surface, varying in intensity due to Earth's tilt and rotation Heats equator more intensely than poles, creating temperature gradients Initiates atmospheric processes such as atmospheric circulation and convection currents
Atmospheric circulation	Movement of air driven by solar heating and Earth's rotation, creating global wind patterns (Hadley, Ferrel and Polar cells), which transport heat and moisture
Convection currents	Vertical movement of air due to temperature differences, creating weather phenomena (e.g. thunderstorms and tropical cyclones)
Condensation and cloud formation	Atmospheric water vapour cools and condenses into liquid droplets or ice crystals Forms clouds that affect weather by reflecting sunlight and trapping infrared radiation
Precipitation	Water droplets or ice crystals fall from clouds as rain, snow, sleet, or hail, depending on temperature and atmospheric conditions
Evaporation	Conversion of water from liquid to vapour phase due to heat, which then rises into the atmosphere
Greenhouse effect	Natural process where atmospheric gases in trap heat from sun, making Earth's temperature suitable for life Anthropogenic activities increase concentration of greenhouse gases

	Enhances greenhouse effect, increases average annual temperatures and impacts many of the atmospheric processes outlined above

- The main factors influencing climate are seasonal variations in **temperature** and **precipitation**
- These variations shape the long-term climate patterns of a region

Examiner Tips and Tricks

Don't get confused between **weather** and **climate**! Weather is the **short-term atmospheric conditions** (days to weeks) and is influenced by daily variations in temperature, humidity and air pressure.

Climate is the **long-term average** of weather conditions (typically over 30 years) and determines regional characteristics like vegetation and biodiversity.

A good way to remember this is: climate is what you **expect** (long-term patterns); weather is what you **get** (short-term conditions).

Causes of Climate Change

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Anthropogenic Influence on Climate

- Human activities have significantly increased atmospheric concentrations of **greenhouse gases** since the Industrial Revolution
  - Particularly **carbon dioxide** emissions from **burning fossil fuels**
- This has led to:
  - **Global warming:** average global temperatures have risen due to enhanced greenhouse effect
  - **Climate change:** altered weather patterns, sea level rise and impacts on ecosystems and human societies

Global rate of emissions

- Since **1950**, the rate of anthropogenic carbon dioxide emissions has **significantly accelerated**
  - This acceleration is due to several factors, including:
- **Industrial Revolution:**
  - It began in the late 18th century in Europe
  - Marked a turning point with the widespread use of fossil fuels such as coal and later oil
- **Technological advancements:**
  - The 20th century saw rapid industrialisation, transportation development and urbanisation
  - These all contributed to increased emissions
- **Population growth:**
  - The global population has increased exponentially
  - This has increased demand for energy and resources, further accelerating emissions

Analysis of ice cores, tree rings and sediments

- Ice cores, tree rings and sediment deposits provide important data for understanding:
  - **Historical climate patterns**
  - The relationship between **carbon dioxide levels** and **global temperatures**
- **Ice cores:**

- Layers of ice in glaciers trap air bubbles containing the gases from **ancient atmospheres**
- Analysis of these bubbles shows historical carbon dioxide levels
  - Ice is deposited as water freezes over time, so the deeper into the ice you go, the older it is

An ice core is being stored in a freezer warehouse for later chemical analysis—ice cores drilled from the Antarctic can reveal data about the composition of the atmosphere over thousands of years

- **Tree rings:**
  - Trees form annual rings with varying **widths** based on **climate conditions**
    - Thicker rings indicate favourable (warmer) conditions, potentially linked to higher carbon dioxide levels
  - Analysis of the width of tree rings can provide a measure of climate during each year of growth
  - Taking cores from the trunks of older trees can provide samples that go back over hundreds of years

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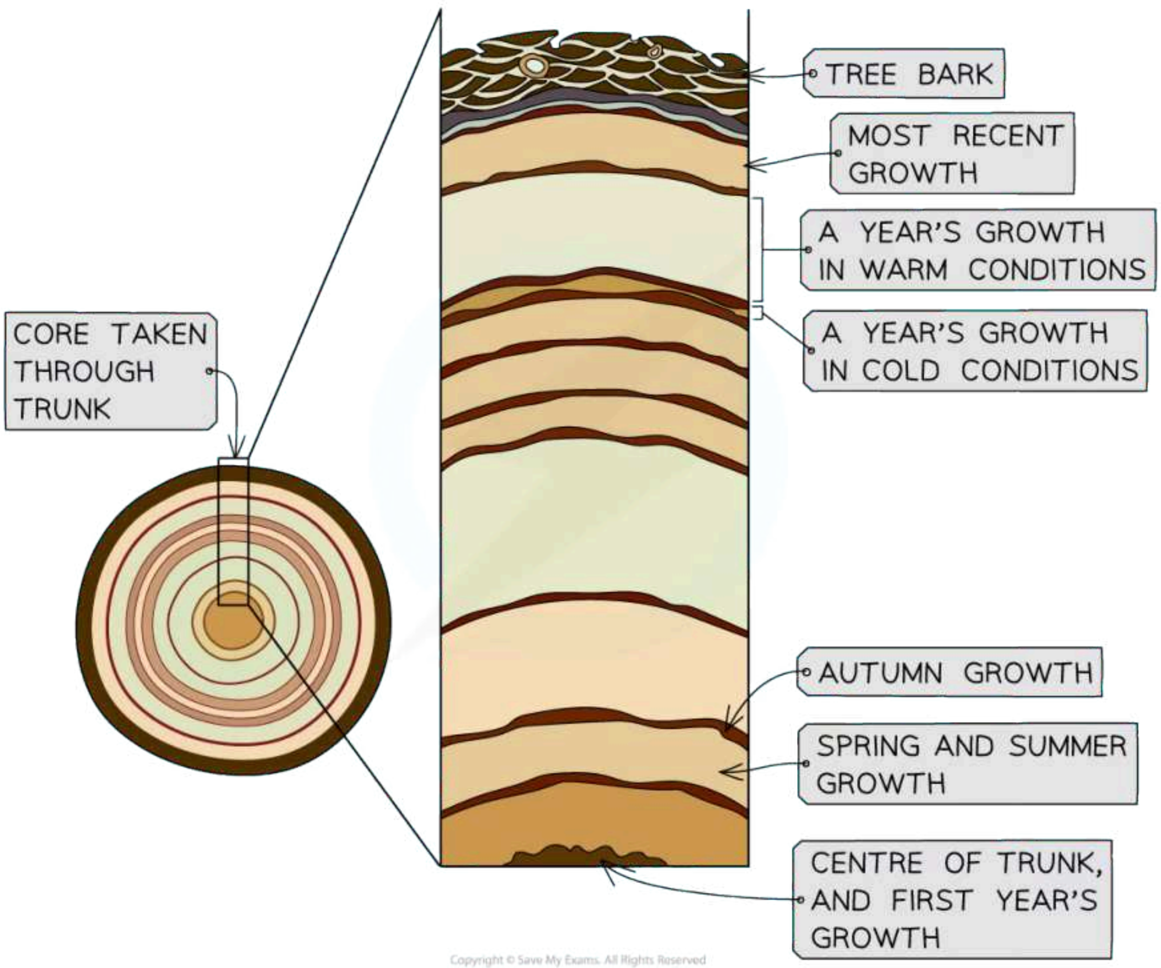


Dendrochronology uses the growth in a tree trunk each year as a measure of climate

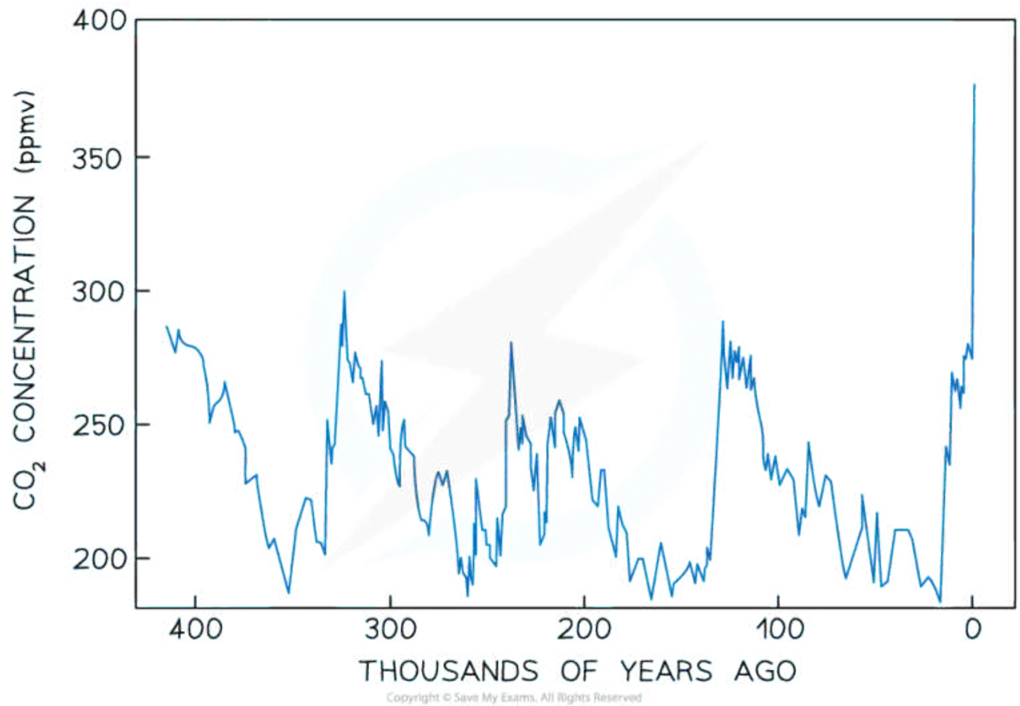
- **Sediments:**
  - Deposits in lakes and oceans contain remains of organisms sensitive to environmental changes
    - This provides indirect evidence of past climates

Positive correlation between carbon dioxide and global temperatures

- Research using data from these sources shows a clear positive correlation between atmospheric carbon dioxide concentrations and global temperatures
  - **Carbon dioxide levels:** as industrial activities have increased, so have atmospheric carbon dioxide levels

- **Temperature records:** proxy data from ice cores, tree rings and other sources indicates that periods with higher carbon dioxide concentrations correspond to warmer global temperatures
- **Modern instrumental records:** direct measurements since the mid-20th century confirm a sharp rise in temperatures, aligning with increased emissions

- Since the Industrial Revolution, atmospheric carbon dioxide levels have risen to their **highest in Earth's history**
  - Before, the highest atmospheric carbon dioxide concentration was around 300 parts per million (ppm)
  - It is currently **above 400 ppm**



Average global atmospheric carbon dioxide concentration over the last 400 000 years

- Data show a **correlation** between changing atmospheric carbon dioxide levels and temperature over thousands of years
  - **Correlation does not equal causation**
  - However, this is convincing evidence supporting the hypothesis that carbon dioxide emissions from **human activity** are driving up global temperatures

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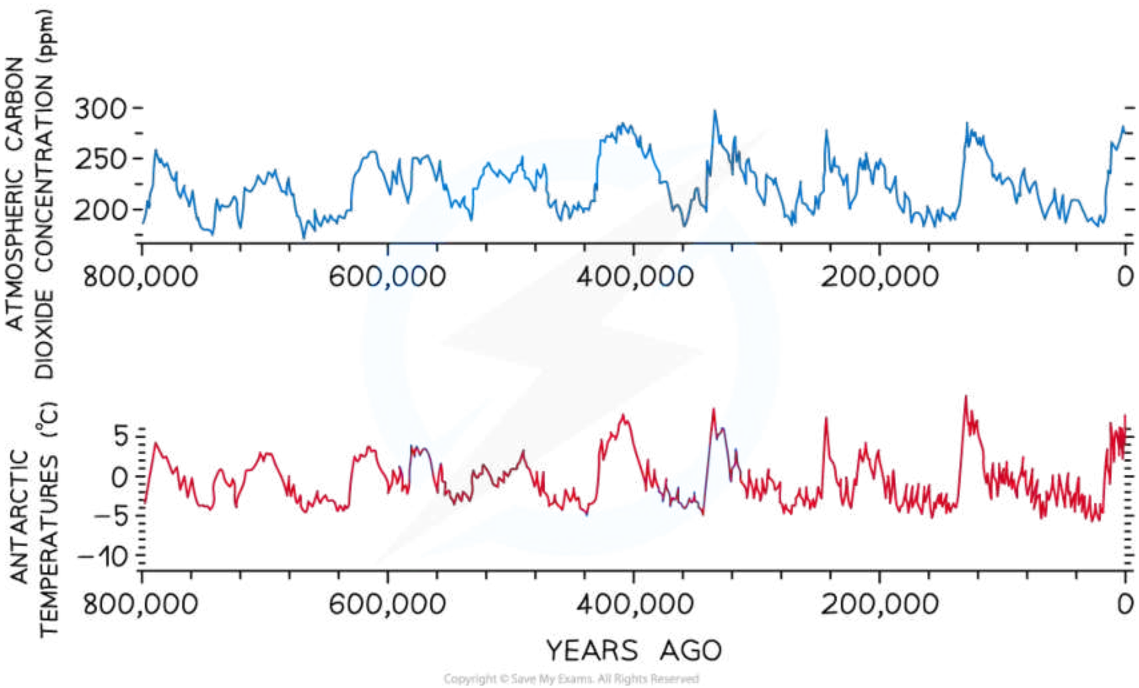
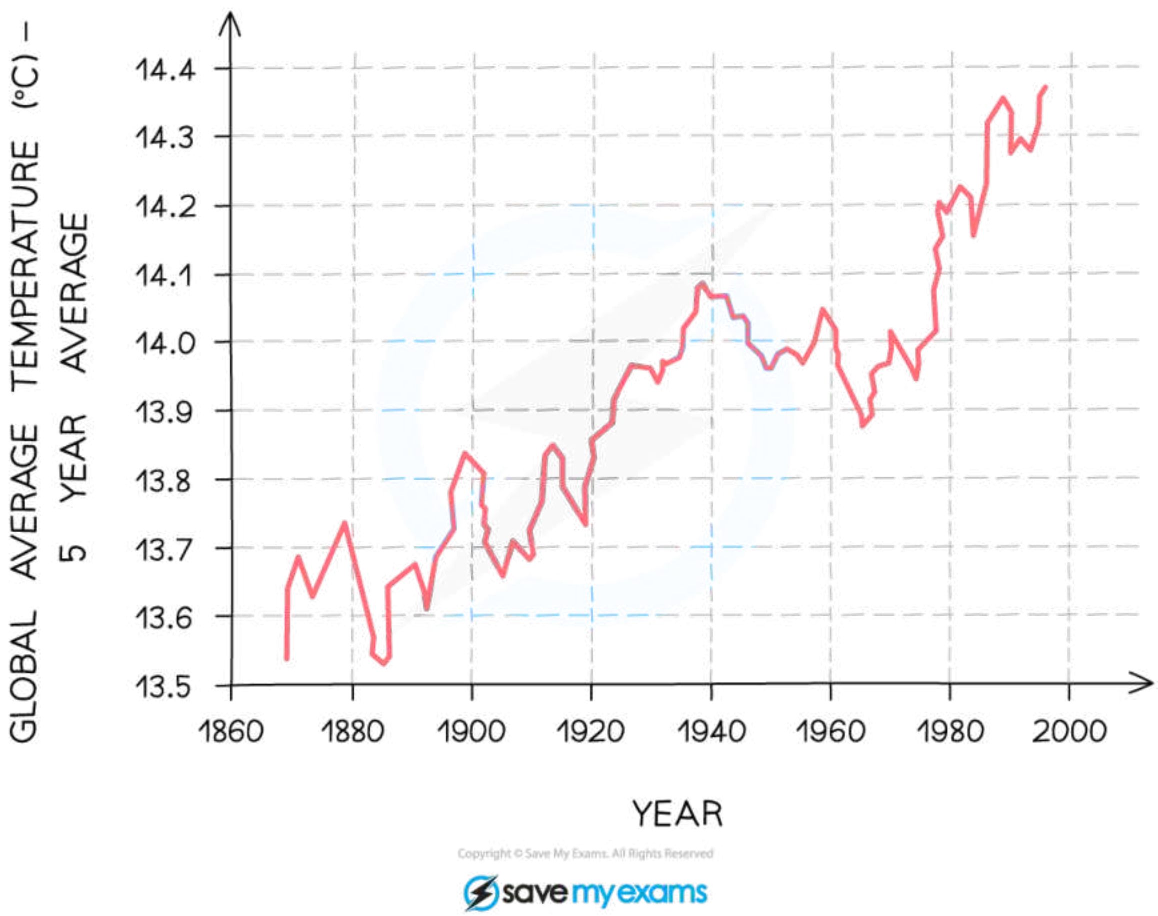


There is a correlation between atmospheric carbon dioxide concentrations and average Antarctic temperatures over time

Average global temperatures

- Thermometers can be used to measure air temperature
- Records from the mid-1800s show an **overall trend of increasing average global temperatures**
  - There are some short time periods within this window during which temperatures have declined, but the overall trend is **upward**
- The time period since the mid-1800s corresponds with the time during which humans have been **burning fossil fuels**



Average global temperature records show some temperature fluctuations but an overall trend of increasing temperatures over time

- 90% of global carbon dioxide emissions come from industry and burning fossil fuels
  - As carbon dioxide, methane and water vapour are released, they act as **greenhouse gases** and **trap heat** within the Earth's atmosphere
  - Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years

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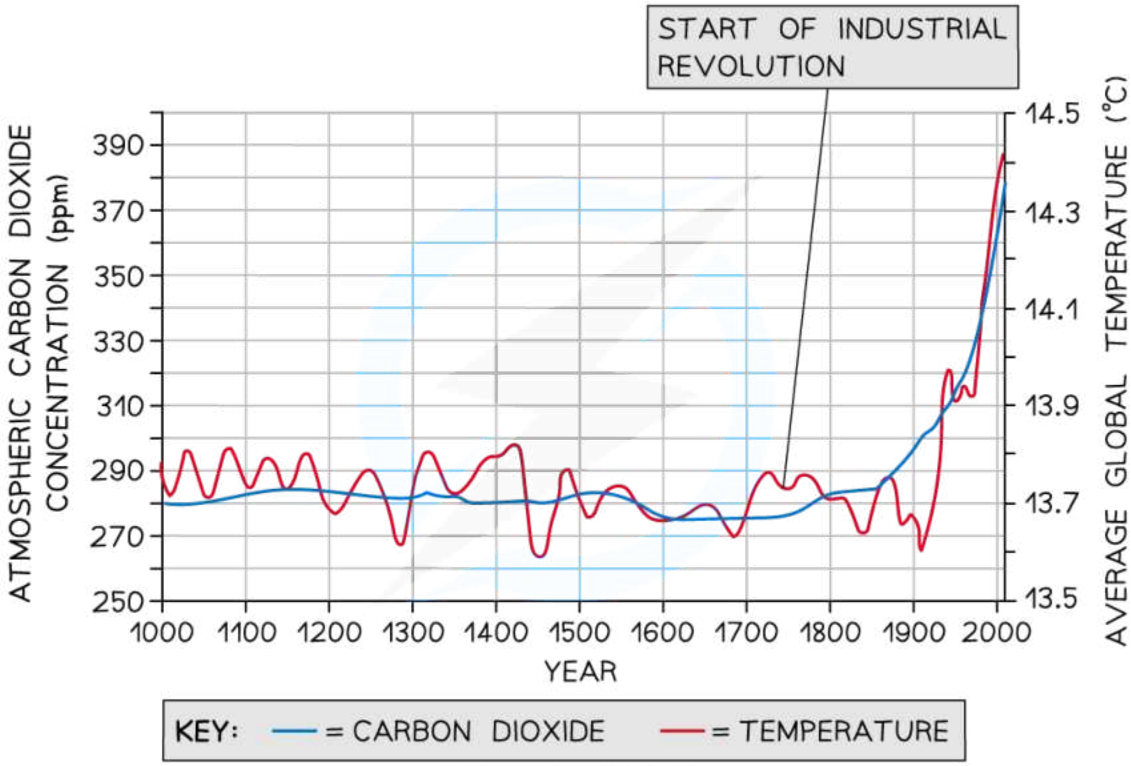

Since the 1960s, global concentrations of carbon dioxide have risen from 320 ppm to just over 425 ppm (2024)

The Enhanced Greenhouse Effect

- The enhanced greenhouse effect is **different** from the natural greenhouse effect
    - It is the result of human activities that release excessive greenhouse gases into the atmosphere
    - This leads to an intensified trapping of heat and results in **global warming**
- The **natural** greenhouse effect is a **necessary process**
    - It helps regulate the Earth's temperature by trapping some heat to maintain a **habitable climate**
- The enhanced greenhouse effect **disrupts** this balance as a result of greenhouse gas concentrations being **artificially increased beyond natural levels**

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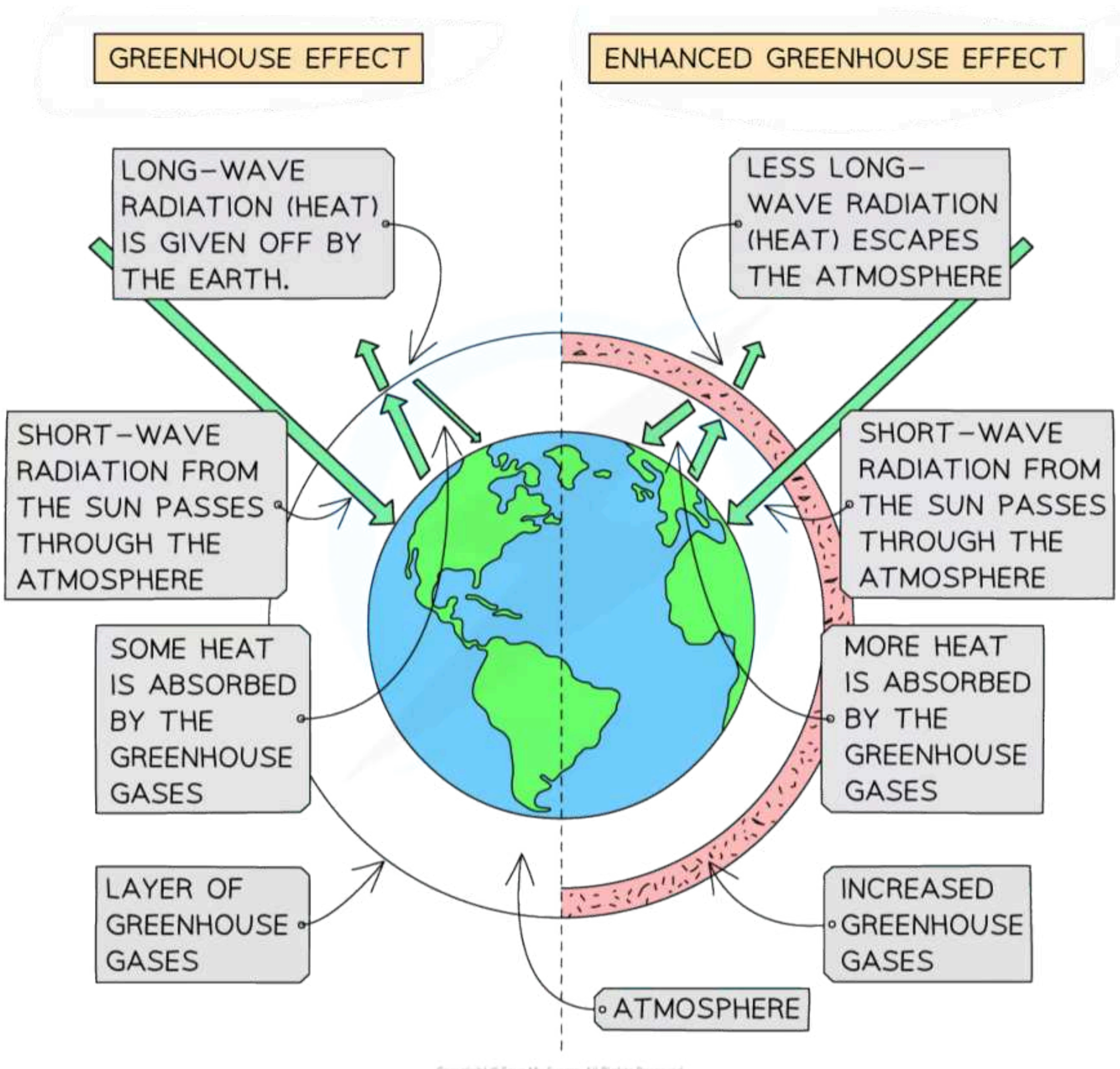

Human activities lead to the emission of greenhouse gases that enhance the greenhouse effect, contributing to global warming

Modelling Climate Change

Systems diagrams and models

- **Representing cause and effect:**
  - Systems diagrams and models are tools that can be used to visualise how different factors **interact** and cause climate change

- They help us understand **cause-and-effect** relationships and how changes in one part of the system affect others

Feedback loops

- **Feedback loops** are processes that can either amplify or dampen the effects of climate change
  - **Positive** feedback loops **amplify** changes
  - **Negative** feedback loops **reduce** or **counteract** changes
- **Global energy balance:**
  - The global energy balance is the balance between the energy Earth **receives** from the Sun and the energy it **radiates back** into space
  - **Changes** in this balance can significantly impact the climate

Changes in solar radiation and terrestrial albedo

- Solar radiation is the primary source of energy for Earth's climate system
- Variations in solar radiation can lead to changes in climate
  - For example, the Maunder Minimum (1645–1715), a period with very few sunspots, was associated with cooler global temperatures
- Changes in solar radiation can initiate **feedback loops**
  - **Decrease in solar radiation:** can cause cooling, leading to an increase in snow and ice cover
    - This increases the Earth's albedo, causing further cooling (negative feedback loop)
    - For example, during the Maunder Minimum, reduced solar radiation contributed to the Little Ice Age
  - **Increase in solar radiation:** can cause warming, reducing snow and ice cover
    - This decreases the Earth's albedo, causing further warming (positive feedback loop)

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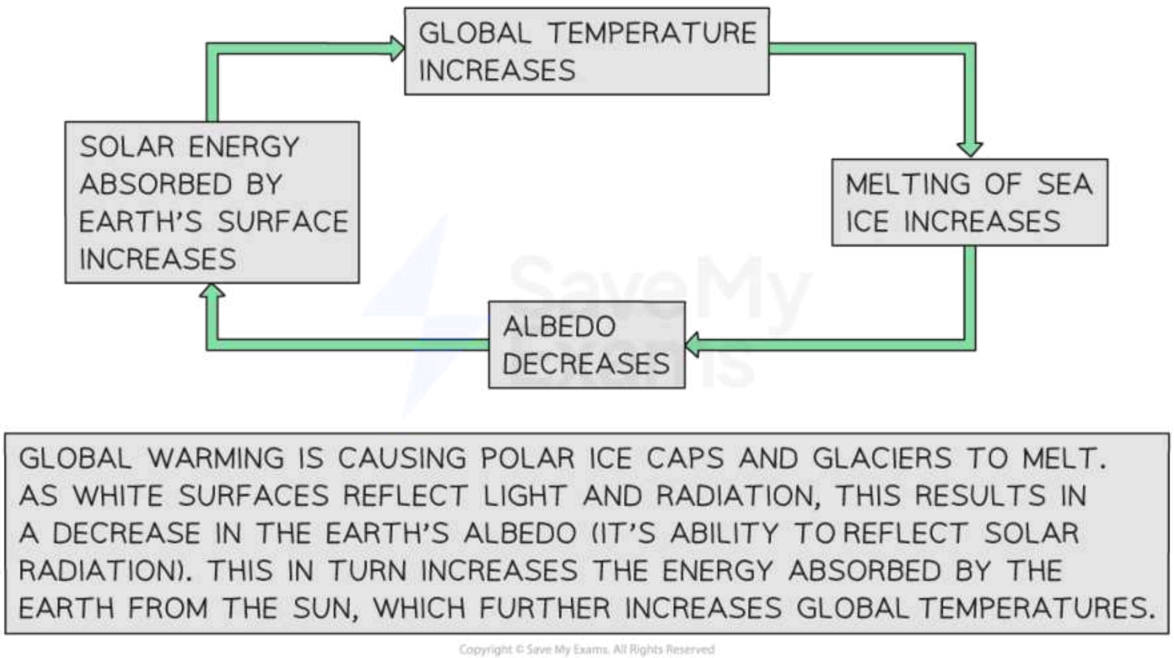
Your notes



Positive feedback loops triggered by global warming are increasing the rate at which the ice caps are melting

Carbon dioxide and methane release

- Carbon dioxide and methane are greenhouse gases
- Carbon dioxide and methane get **trapped** in **permafrost** as organic matter freezes before it can fully decompose
- **Positive feedback loop:**
  - When the permafrost thaws due to warming temperatures, these trapped gases are released into the atmosphere
  - These greenhouse gases then contribute to further global warming and climate change

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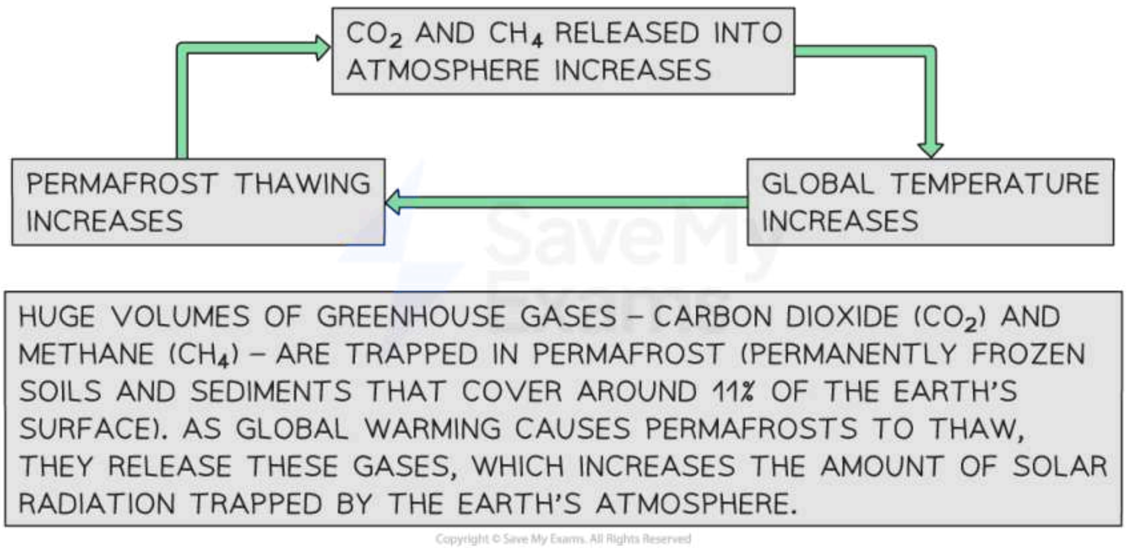

Positive feedback loops triggered by human-induced global warming are increasing the rate at which further greenhouse gases are released from permafrost

Crossing the planetary boundary for climate change

- Climate change is one of the nine planetary boundaries outlined by the planetary boundaries model
  - Planetary boundaries are **thresholds** that lead to significant environmental changes if they are crossed
- Evidence suggests Earth has **already crossed** the boundary for climate change
  - The **Intergovernmental Panel on Climate Change (IPCC)** is a leading authority on climate science
  - IPCC **reports** provide comprehensive assessments of climate change, based on the latest **scientific research**
  - These reports show:
    - **Significant increases in global temperatures:**
      - Over the past century, the average global temperature has risen by approximately 1.1 °C
      - The most rapid warming has occurred in recent decades
    - **Rising greenhouse gas concentrations:**
      - Levels of carbon dioxide and methane in the atmosphere have increased dramatically
      - Due to human activities like burning fossil fuels, deforestation and agriculture,

- **Current impacts:**
  - These changes contribute to more frequent and intense extreme weather events, such as heatwaves, storms and flooding
  - As well as long-term effects like rising sea levels and shifting ecosystems

Your notes

Examiner Tips and Tricks

Make sure you are clear on the difference between positive and negative feedback loops and how they impact the climate. It can be easy to get the two types of feedback confused!

It might help to remember it this way—when it comes to climate, it is often the **opposite** to how it sounds: positive feedback is often a negative thing, as it leads to extremes, whereas negative feedback is often a positive thing, as it counteracts changes and brings them back to equilibrium.

Impacts of Climate Change on Ecosystems

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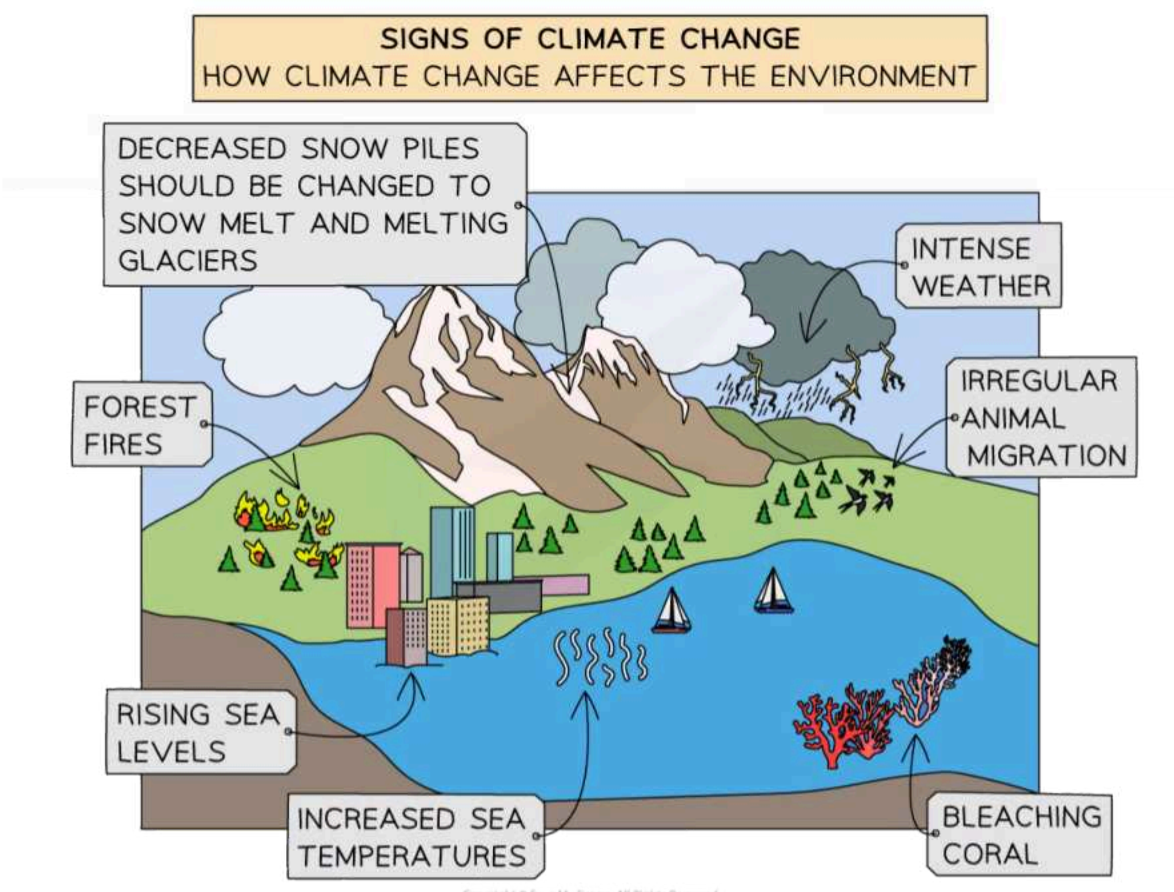
Impacts of Climate Change on Ecosystems

- Climate change:
  - Impacts ecosystems on various scales, from **local** to **global**
  - Affects the **resilience** of ecosystems
  - Leads to **biome shifts**



How climate change affects the environment

Local impacts

Coral bleaching

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- **Cause**:
  - Increased sea temperatures cause corals to expel the algae (zooxanthellae) living in their tissues
  - Without these algae, corals **lose their colour** (giving them a white appearance)
  - They also **lose their main food source** (the algae perform photosynthesis, producing organic compounds that the corals use as a primary energy source)
  - This leads to **bleaching** and eventually coral **death**
- **Effects**:
  - Loss of biodiversity as fish and other marine species lose their habitat
  - Decline in fish populations in reef ecosystems
- **Example**:
  - The Great Barrier Reef in Australia has experienced significant coral bleaching events

Desertification

- **Cause**:
  - Prolonged **droughts** and **higher temperatures**
  - Unsustainable land practices like **deforestation** and **overgrazing**
- **Effects**:
  - Loss of arable land and vegetation, leading to **soil erosion**
  - Reduced agricultural productivity
  - Displacement of communities
- **Example**:
  - The Sahel region in Africa is facing severe desertification, affecting local livelihoods that rely on agriculture

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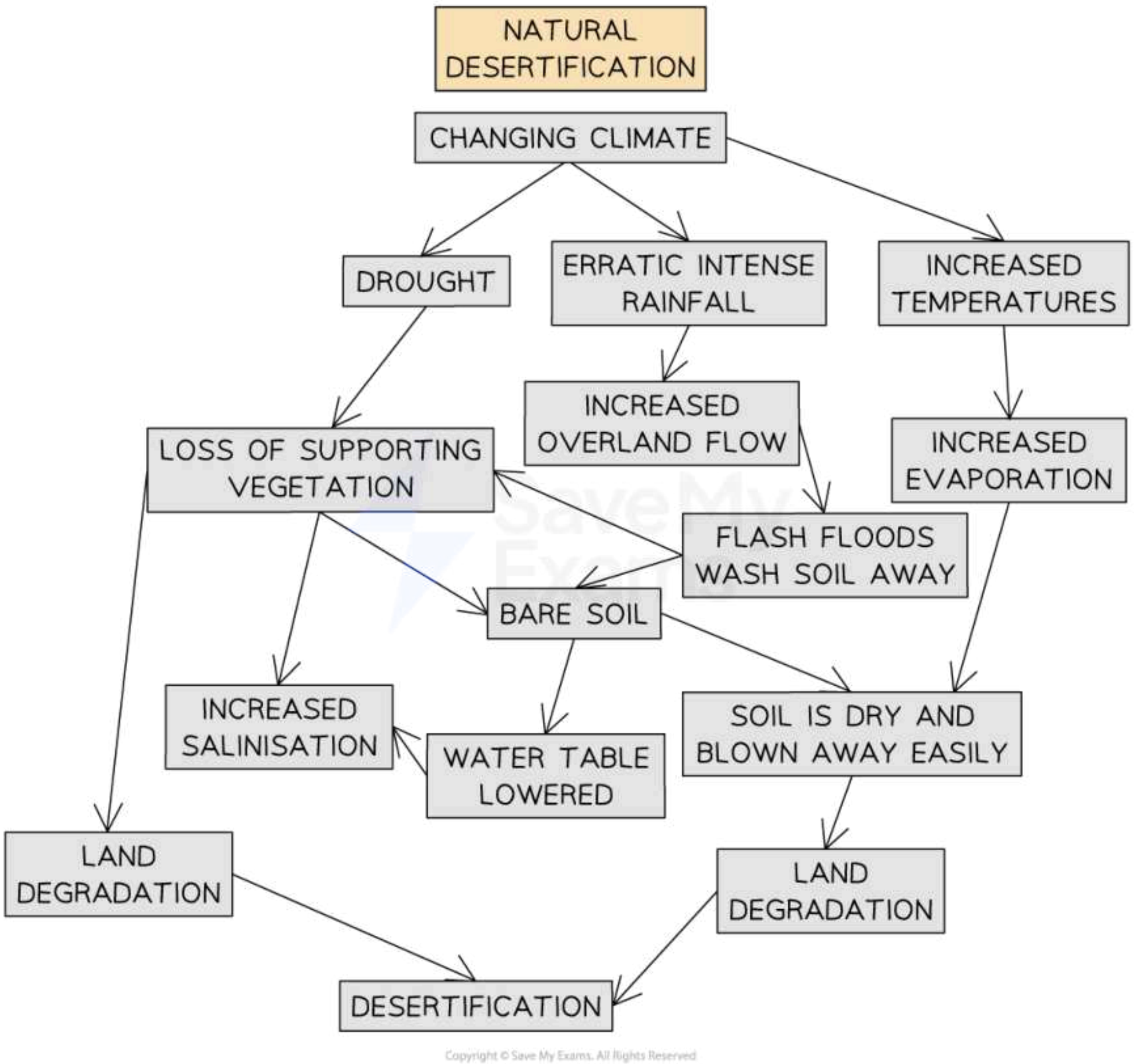

Climate change is causing increased desertification

Global impacts

Changes to ocean circulation

- **Cause**:
  - Melting ice caps and glaciers increase the freshwater input into oceans
  - This disrupts normal currents and circulation patterns
- **Effects**:

- Altered weather patterns
- Changes in marine and coastal ecosystems
- Changes in fish migration and distribution affecting fisheries
- **Example**:
  - Slowing down of Atlantic Meridional Overturning Circulation (AMOC), which includes the Gulf Stream
  - This is leading to colder winters in Europe and warmer temperatures in the Arctic

Sea-level rise

- **Cause**:
  - Melting ice caps and glaciers
  - **Thermal expansion of seawater** due to higher temperatures
- **Effects**:
  - Coastal flooding and erosion, impacting ecosystems like mangroves and salt marshes
  - Loss of habitats for species in these biodiverse ecosystems
- **Example**:
  - The Maldives is at risk of becoming uninhabitable due to rising sea levels

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Coastal flooding is becoming increasingly common as a consequence of the rising sea levels caused by climate change (Photo by Nguyen Kiet on Unsplash)

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Regional impacts on natural productivity

Increased productivity

- **Northern regions**:
  - Warmer temperatures can **extend the growing season** and increase vegetation
  - Expansion of suitable areas for agriculture and forestry
  - For example, in parts of Canada and Russia, agriculture is expanding northward and growing seasons are longer due to warmer conditions

Decreased productivity

- **Tropical regions**:
  - Higher temperatures and unpredictable rainfall can **harm crops**
  - For instance, shifting monsoon patterns in Southeast Asia are threatening rice yields

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Factors affecting ecosystem resilience

Biodiversity

- Climate change can reduce resilience by decreasing biodiversity
- **High biodiversity**:
  - Increases resilience by providing a variety of species that can **adapt to changes**
  - For example, tropical rainforests have high biodiversity, helping them **recover from disturbances**
- **Low biodiversity**:
  - Decreases resilience, making ecosystems **more vulnerable**
  - For example, monoculture farms are less resilient to pests and diseases
- **Impact of climate change**:
  - Climate change can lead to habitat loss, altered food webs and extreme weather events
  - All of these can reduce biodiversity
    - For example, coral bleaching due to increased sea temperatures reduces the variety of species in coral reefs
    - This can reduce the resilience of coral reefs to other stressors, like ocean acidification or increased tropical storms

Habitat fragmentation

- Climate change can also reduce resilience by causing habitat fragmentation
- **Connected habitats**:
  - Enable species to migrate and adapt to changes
- **Fragmented habitats**:
  - Isolate species and split populations, reducing their ability to adapt
- **Impact of climate change**:
  - Rising temperatures and changing precipitation patterns can shift habitats, leading to fragmented landscapes
  - Climate change can fragment habitats in various ways:
    - **Increased desertification**: expanding deserts can divide ecosystems, making it harder for species to find resources and migrate

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    - **Increased rates of forest fires**: more frequent and intense fires can break up forest ecosystems, isolating populations and reducing biodiversity
    - **Melting polar ice caps**: loss of ice habitats can fragment the habitats of polar species like polar bears and penguins, affecting their ability to hunt and reproduce
    - Species in mountainous regions might be forced to move to **higher altitudes**, creating isolated populations
- These changes reduce the resilience of ecosystems by isolating species and limiting their ability to adapt to new conditions

Biome shifts

- Climate change can result in biome shifts
  - This is where ecosystems change in location or type due to altered climatic conditions
- **Cause**:
  - Changes in temperature, precipitation and extreme weather events
- **Effects**:
  - **Movement of biomes**:
    - Biomes, such as forests, grasslands and tundra, may shift towards the poles or higher altitudes as species (including plants) shift ranges to find suitable climates
    - For example, in North America, temperate forests are moving northward, slowly replacing boreal forests
    - As species move to new areas or experience changes in their habitats, they may face new competition, predation, or disease
  - **Transformation of existing biomes**:
    - Current biomes may change in structure and composition
    - For example, the Arctic tundra is transforming into shrubland as warmer temperatures allow shrubs to grow
  - **Loss of unique biomes**:
    - Some biomes may disappear if conditions become unsuitable for the species that inhabit them
    - For example, alpine regions may lose their unique flora and fauna as temperatures rise and snow cover decreases
    - This can lead to declines in population numbers and even **extinction** in some cases

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Examiner Tips and Tricks

Remember that climate change has mixed effects. While it poses significant challenges, it can also bring advantages, such as extended growing seasons and the ability to cultivate crops further north. Higher temperatures can make some crops more productive, benefiting certain regions and societies. Keep this balanced perspective in mind during your exams!

Impacts of Climate Change on Societies

Your notes

Impacts of Climate Change on Societies

- Climate change impacts human societies at **various scales** and **socio-economic conditions**
  - This means that the impacts of climate change affect societies differently based on their:
    - Economic status
    - Resources
    - Social conditions
  - Socio-economic conditions include factors like:
    - Income levels
    - Access to resources
    - Quality of infrastructure
    - Education
    - Healthcare availability
- Impacts of climate change also affect the **resilience** of societies

Key impacts of climate change

- Key areas of societies that are impacted include health, water supply, agriculture and infrastructure

Health impacts

- **Heatwaves**:
  - Increased frequency and intensity
  - These can be especially dangerous for the young and elderly
  - E.g. the North American Heatwave 2021:
    - A severe and prolonged heatwave hit the Pacific Northwest region of the United States and Western Canada in June 2021
    - The extreme heatwave led to:
      - Hundreds of deaths across the region
      - Overwhelmed hospitals with cases of heat-related illnesses

        - Caused power outages as electrical grids struggled to cope with increased demand for air conditioning
- **Diseases**:
    - Warmer temperatures expand habitats for disease-carrying insects
    - Leads to spread of vector-borne diseases like malaria and dengue to new areas
- **Air quality**:
    - Poor air quality due to higher temperatures and pollutants:
        - Higher temperatures can enhance the formation of ground-level ozone, a harmful air pollutant
        - More frequent and severe wildfires release large amounts of smoke and particulate matter into the air
        - Climate change can lead to more frequent stagnant air conditions, which prevent pollutants from dispersing

Water supply impacts

- **Droughts**:
    - Longer and more severe droughts reduce water availability
    - E.g. Cape Town's **Day Zero** water crisis in 2018
- **Melting glaciers**:
    - Reduces freshwater availability for downstream communities
    - E.g. glaciers in the Andes are melting, threatening water supplies in South America
- **Flooding**:
    - More intense rainfall leads to flooding
    - Flooding can contaminate drinking water sources with pollutants, sewage and hazardous chemicals, making the water unsafe to drink
- **Water Quality**:
    - Combined with nutrient pollution (e.g. from agricultural runoff), warmer water temperatures promotes the growth of harmful algal blooms
    - These blooms produce toxins that can contaminate drinking water
    - E.g. algal blooms in Lake Erie in North America have repeatedly made the water unsafe for consumption

Agriculture impacts

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- **Crop yields**:
  - Changes in temperature and rainfall affect crop production
  - E.g. reduced wheat yields in Australia and India due to heat stress
- **Pest outbreaks**:
  - Warmer climates increase the prevalence of agricultural pests
- **Food security**:
  - Less reliable food supply and higher prices
- **Livestock**:
  - Heat stress affects livestock health and productivity
  - E.g. heat stress in dairy cows decreases their milk yield

Infrastructure impacts

- **Extreme weather**:
  - More frequent hurricanes, floods and storms damage infrastructure
- **Transportation**:
  - Roads and railways damaged by extreme weather
  - E.g. UK railways have been disrupted by flooding and heat in recent years
- **Buildings**:
  - Increased costs for cooling
  - Increased cost of repairs from storm damage
  - Coastal erosion damages properties on seafronts
- **Energy supply**:
  - Power outages from extreme weather affecting grids

Resilience of societies

- Resilience refers to a society's ability to withstand, adapt to and recover from climate change impacts
  - Different factors contribute to the resilience of societies, including economic stability, social equity and adaptive capacity
- **Economic stability**:

- Economic resources are crucial for repairing and rebuilding after climate-related disasters
    - E.g. the cost of rebuilding after hurricanes can strain local economies, but wealthier regions have more resources to recover quickly
- **Social equity**:
    - Vulnerable communities, such as low-income or marginalised groups, are often more severely affected by climate change
- **Adaptive capacity**:
    - The ability to adapt to climate change varies significantly between regions and countries
    - E.g. the Netherlands has advanced flood defences, while Bangladesh remains highly vulnerable to flooding due to limited resources

Examiner Tips and Tricks

Remember that climate change impacts societies differently based on their socio-economic conditions. Wealthy and developed regions can better adapt and mitigate impacts, while poorer and developing areas are more vulnerable. Urban areas face challenges like pollution and heat, whereas rural areas are more affected by changes in agriculture and water availability. Communities with strong social networks can better cope with climate impacts, whereas communities with less cohesion and support may find it more challenging to adapt and recover.

Perspectives on Climate Change

- **Individual** experiences, societal values, and policies all influence perspectives on climate change
    - These perspectives shape how people and societies **respond** to climate challenges

Individual perspectives

- People's **own experiences** with climate change shape their awareness and concern
    - For example, farmers noticing changes in growing seasons may be more aware of climate impacts than urban residents
- Individuals can take personal steps to mitigate their contributions to climate change
    - E.g. by reducing their carbon footprint, such as using public transport or reducing energy consumption
- Personal health concerns may influence perspectives on climate action
    - E.g. parents in polluted urban areas may be concerned about children's asthma

Societal perspectives

- **Government policies** play an important role in mitigating and adapting to climate change
  - E.g. UK's commitment to net-zero carbon emissions by 2050
- Local communities often take **initiatives** to enhance resilience and reduce climate impacts
  - E.g. urban community gardens may help to improve food security and reduce heat island effects
- **Cultural values** and **traditions** influence how societies perceive and respond to climate change
  - For example, indigenous communities may incorporate traditional ecological knowledge into their adaptation strategies
  - This might include adjusting agricultural practices based on seasonal changes observed over many generations

Your notes

Climate Monitoring & Data Collection (HL)

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Climate Monitoring & Data Collection

- Collecting climate data is essential for understanding climate change
- Data is gathered from diverse sources, including:
  - **Weather stations**, e.g. can measure local temperature, humidity, and wind
  - **Observatories,** e.g. can monitor gases like CO_2 to track atmospheric changes
  - **Radar,** e.g. can track precipitation and storms, helpful in predicting weather patterns
  - **Satellites,** e.g. orbiting sensors that monitor large-scale climate data, such as sea surface temperatures and cloud cover, across the globe

Types of climate data collected

Direct measurements

- Direct measurements are gathered through instruments that physically capture data on-site or in real-time
- Examples include:
  - **Temperature:** recorded by thermometers at weather stations worldwide to monitor warming trends
  - **Greenhouse gas (GHG) concentrations:** measured by spectrometers and gas sensors in observatories to track gases like carbon dioxide and methane
  - **Sea level changes:** useful for studying impacts of melting ice and thermal expansion of seawater
  - **Precipitation patterns:** rain gauges measure rainfall to monitor droughts, floods, and changes in precipitation patterns

Indirect measurements (proxies)

- Indirect data (proxies) provide climate information by examining natural recorders of environmental conditions
  - Proxies are useful when direct measurements are not available
  - This is especially important for collecting **historical climate data**
- Common proxies include:
  - **Ice cores:**

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    - Extracted from glaciers and polar ice sheets
    - Cores contain trapped **gas bubbles** that reveal past **greenhouse gas concentrations** and temperatures
- **Dendrochronology (tree rings):**
    - Width and density of tree rings reflect yearly climate conditions
    - Wider rings often indicate wetter, warmer years
- **Pollen analysis from peat cores:**
    - Pollen is preserved in sediment layers of bogs and peatlands
    - Certain plants grow best in **specific climate conditions**, such as warmer or wetter periods
    - By analysing preserved pollen from layers of peat or bog sediment, scientists can **identify which plants were growing at different times**
    - From this information, they can infer past climate conditions based on the types of plants that **thrived**
    - This can provide insights into temperature, rainfall, and other environmental factors

Role of data in climate modelling

- Both **direct** and **indirect** measurements are essential for creating accurate climate models
- Climate models **simulate atmospheric processes** and help **predict future climate trends**
- Long-term data, such as GHG concentrations and temperature trends, inform these models and allow for better predictions of global warming impacts

Global Climate Models (HL)

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Climate Models

- Climate models are highly complex mathematical tools used to understand and predict Earth's climate
  - They simulate climate processes by using complex equations to represent the interactions within Earth's atmosphere, oceans, land, and ice
  - Climate models predict possible outcomes by **manipulating different inputs** and **observing potential changes**

Inputs to climate models

- There can be a very large number of different inputs to climate models
  - This depends on the specific model being used
- Some **common inputs** include:
  - Greenhouse gas concentrations
  - Solar radiation levels
  - Volcanic activity
  - Land surface changes
- Some inputs are known accurately, while others, like past GHG levels, may use **proxy data** (e.g. ice cores)

How climate models work

- Climate models **create predictions** based on equations that represent key processes, such as:
  - **Atmospheric circulation**, which includes wind and heat flow
  - **Ocean currents**, which distribute heat across the planet
  - **Water cycle processes**, such as evaporation, precipitation, and condensation
- Models can be highly complex, integrating **thousands of variables** to simulate climate changes over time

Testing climate models: hindcasting

- Hindcasting is a technique used to test the **accuracy** of climate models
  - Models are run **backwards in time** from the present

- By comparing modelled past climate data with actual recorded data, scientists can test the reliability of the model
- Hindcasting helps identify inaccuracies and improves model reliability for future predictions

Limitations and uncertainty in climate models

- There is some **uncertainty** in models due to:
  - Limited or imperfect input data, especially from **ancient proxies**
  - Simplified representations of complex natural processes
- These limitations mean that models predict a **range of outcomes** rather than a single precise forecast
- Models are **updated** as more accurate data and advanced computing methods become available

Climate Model Predictions

- Climate models provide **future climate scenarios** based on different **inputs** and **assumptions**
- They predict future impacts of climate change in several key areas, including:
  - temperature
  - sea levels
  - precipitation

Temperature change predictions

- Climate models predict global temperature changes under different greenhouse gas emission scenarios:
  - Higher emissions scenarios predict greater temperature increases
  - Predictions often give a range of possible temperature rises by the end of the century
    - For example, some models predict a temperature rise between 1.5°C and 4°C by 2100, depending on emissions

Sea-level rise predictions

- Climate models show possible scenarios for sea-level rise due to:
  - Melting polar ice and glaciers
  - Thermal expansion, where warmer water expands
    - For example, some models suggest that sea levels could rise by 0.5 to 1 metre by 2100 under high-emission scenarios

Your notes

Your notes

Precipitation pattern predictions

- Climate models predict changes in rainfall patterns:
  - Some regions may experience more frequent and intense rainfall
  - Other regions may become drier, leading to drought conditions
    - For example, some models predict increased rainfall in the northern hemisphere but drier conditions in parts of Africa

Uncertainty in predictions

- Different models may produce slightly different outcomes for the same scenario
- This range helps scientists understand **possible outcomes** and **prepare for various future conditions**

Examiner Tips and Tricks

Make sure you can recognise the **limitations** of climate models but also be able to explain their importance in planning for future climate impacts.

Critical Climate Thresholds & Tipping Points (HL)

Your notes

Critical Climate Thresholds & Tipping Points

- Climate thresholds are points at which **small changes in climate conditions** can lead to **significant shifts** in the **Earth's systems**
- Once a threshold is crossed, a **new climate equilibrium** may be established
- These shifts can be **rapid** and **difficult to reverse**
- Critical thresholds are often referred to as 'tipping points'

Global tipping points

- Global tipping points occur when climate changes reach critical levels on a global scale
  - Reaching a global tipping point can lead to unpredictable and potentially catastrophic impacts
  - **Positive feedback loops** are key in tipping points
    - These loops can amplify changes
    - This can push the climate towards a new, often more extreme state

Examples of global tipping points

- **Antarctic ice sheet melting**:
  - Melting ice reduces the albedo (reflectivity) of the Earth's surface
  - This causes more heat absorption
  - This leads to further melting, creating a positive feedback loop
  - Antarctic ice loss contributes to rising sea levels worldwide
  - Sea level rise endangers many coastal ecosystems and human populations
- **Atlantic thermohaline circulation (AMOC) slowing**:
  - AMOC is a major ocean current that regulates global climate
  - Melting Greenland ice releases fresh water into the North Atlantic
  - This reduces ocean salinity
  - This decreases water density, which weakens the sinking motion that drives the AMOC
  - This slowing disrupts the global flow of heat and nutrients

- This affects climate patterns, especially in Europe and North America, potentially leading to harsher winters
- **Amazon Rainforest-Cerrado transition (CAT)**:
  - Deforestation and warming threaten the stability of the Amazon rainforest
  - Loss of forest cover is shifting the ecosystem from rainforest to a drier, more savannah-like ecosystem similar to the Cerrado
  - This is reducing carbon storage
  - This is contributing to more greenhouse gases in the atmosphere, accelerating global climate change

Local tipping points

- Local systems, like specific ecosystems or regions, also have their own climate-related thresholds
  - If these thresholds are crossed, significant and rapid changes can occur within the local environment

Example of local tipping point

- **Coral reef bleaching**:
  - Increased ocean temperatures can cause coral bleaching
  - Without their symbiotic algae, corals struggle to survive
  - This leads to widespread reef death if temperatures do not stabilise
  - Coral reefs support diverse marine life, so their loss can significantly reduce local marine biodiversity

Tipping cascades

- Individual tipping points within the climate system can interact
  - This can create 'tipping cascades'
  - When one tipping point is crossed, it can make other tipping points more likely to be reached
  - These interactions increase the uncertainty in predicting the pace and scale of climate change

Example of a tipping cascade

1. **Increased temperatures**:
   - Rising temperatures melt Arctic ice, reducing sunlight reflection and causing further warming and ice loss

- This leads to...?

2. **Permafrost thawing**:
    - Warmer Arctic temperatures thaw permafrost, releasing greenhouse gases like methane and carbon dioxide, which further accelerates warming
    - This leads to...?
3. **Greenland ice sheet melting**:
    - Warming leads to melting of Greenland's ice, adding freshwater to the North Atlantic and disrupting the Atlantic thermohaline circulation
    - This leads to...?
4. **Global climate impact**:
    - These combined tipping points—Arctic ice melt, permafrost thaw, and AMOC disruption—create a tipping cascade that results in:
        - Increased global temperatures
        - Raised sea levels
        - Disrupted global weather patterns

Biotic and abiotic tipping points

- Individual tipping points can be biotic, abiotic or a combination of biotic and abiotic factors
- **Biotic tipping points**:
    - Involve living organisms, such as forests, reefs, and biodiversity loss
    - E.g. widespread tree loss in rainforests can change local climate and disrupt water cycles
- **Abiotic tipping points**:
    - Involve non-living components of the Earth, like ice sheets, oceans, and atmosphere
    - E.g. melting of permafrost releases greenhouse gases (methane and CO_2) into the atmosphere, increasing global warming

Examiner Tips and Tricks

Be prepared to discuss how individual tipping points can trigger additional tipping points, leading to **trophic cascades**.

Your notes

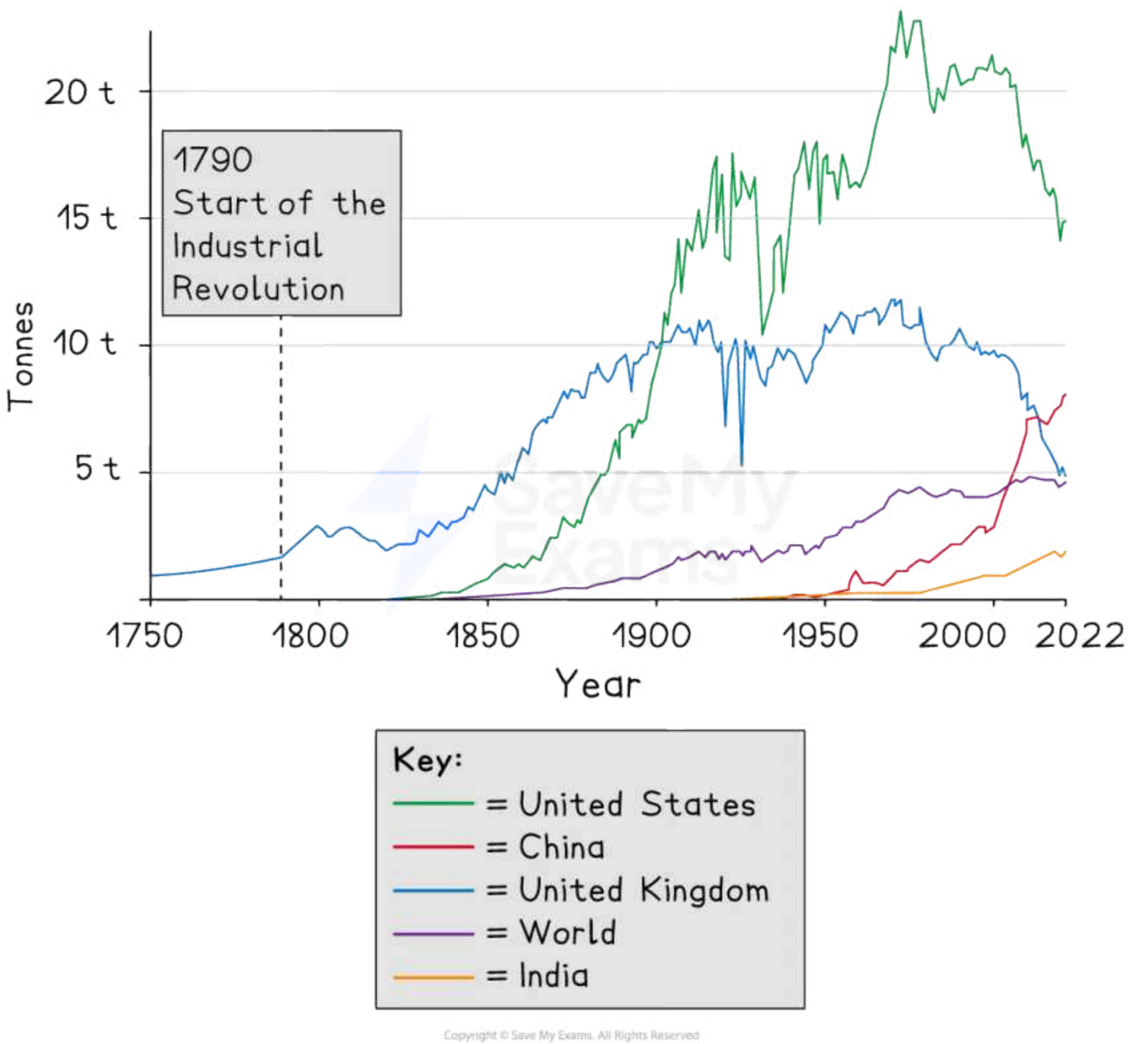
Climate Change Responsibility & Vulnerability (HL)

Your notes

Climate Change Responsibility & Vulnerability

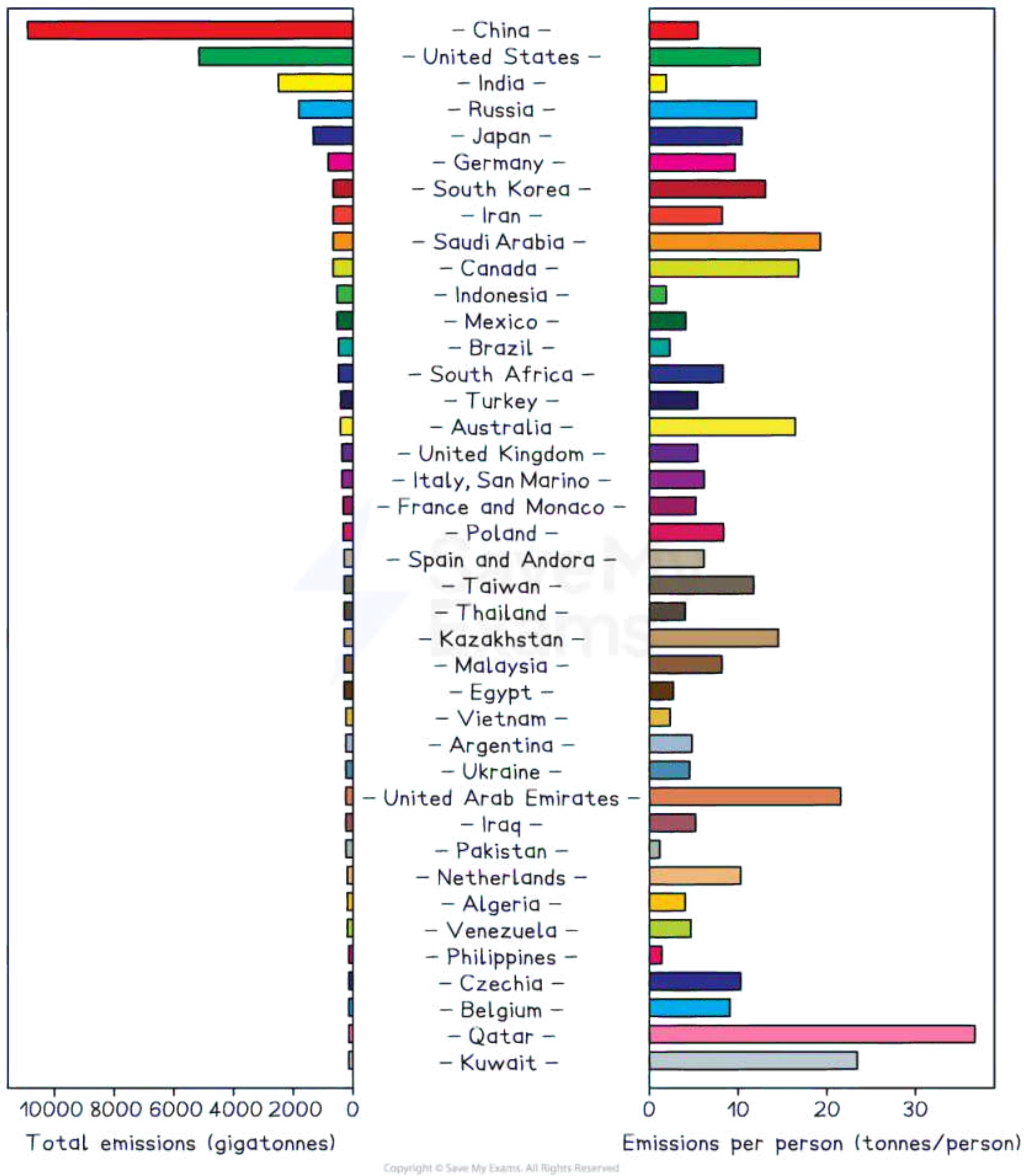
Climate change responsibility

- Responsibility for climate change is difficult to identify
- Determined by:
  - **Current greenhouse gas emission rates**
  - As well as **historical cumulative greenhouse gas emissions**
- **Current emissions**:
  - The biggest current emitters are countries like **China**, **India**, and the **USA**
- **Historical emissions**:
  - Developed nations, particularly industrialised countries, have been emitting greenhouse gases since the start of the Industrial Revolution
- **Cumulative emissions**:
  - The **USA** and **European Union** are historically the largest contributors to the overall build-up of greenhouse gases



Per capita carbon dioxide emissions for USA, China, UK and India, compared to the average for the rest of the global population

- **Emissions per capita**:
  - Higher per capita emissions are generally seen in developed nations
  - Developing countries generally have lower emissions per person



Total vs per capita carbon dioxide emissions—countries with low per capita emissions can still have the biggest total emissions due to their large populations

Climate change vulnerability

- Vulnerability refers to how much countries or regions are affected by the impacts of climate change, e.g.

Your notes

    - Rising sea levels
    - Extreme weather events
    - Food security threats
- The **least responsible countries** are often the most vulnerable to climate change
    - E.g. small island nations like the **Maldives** and **Kiribati** are highly vulnerable to rising sea levels despite contributing very little to global emissions
    - Vulnerable countries typically include:
        - **Low-income nations**
        - Nations with **limited infrastructure** to cope with climate impacts
    - Vulnerability is mainly influenced by:
        - **Geographical location,** e.g. coastal nations or those in tropical areas, are more vulnerable to flooding, storms, and temperature extremes
        - **Economic capacity** to adapt to changes e.g. wealthier countries can invest in climate adaptation; poorer countries may struggle

Climate justice and equity

- **Climate justice** addresses the ethical issues related to who should take responsibility for addressing climate change
    - **Developed countries** often have greater responsibility due to their historical emissions and economic resources
    - **Developing countries** are more vulnerable and have contributed less to the problem
- **Equity** calls for **fair distribution** of the costs and benefits of climate change mitigation and adaptation efforts
- Many believe wealthier nations should provide **financial climate reparations** to help developing nations adapt and mitigate the impacts they did not cause