Lecture 10
The Science of Climate Change (III): Human Activities and Contemporary Climate Change

KEY QUESTION:

How significant is the influence of human activities on Earth's climate compared to natural factors?

With the completion of this lecture, attached readings and tutorial, you should be able to understand that:

- The consensus with the scientific community, represented by the IPCC, is that climate change in the last two centuries is unequivocal, and it is very likely contributed by human activities
- Human activities influence the global carbon cycle by increasing carbon emissions and reducing carbon sinks
- The enhanced greenhouse effect is due to the increased concentration of greenhouse gases by human activities
- Human activities have a role in accelerating warming through positive feedback and suppressing warming through negative feedback

Lecture Outline

10.1 Contemporary Climate Change: Global Warming

- **Climate variability** refers to **variations in the mean state and other statistics such as standard deviations and the occurrence of extremes of the climate on all spatial and temporal scales beyond that of individual weather events**. Climate variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.
- We have learnt that climate variability is not a new phenomenon. In fact, the climate of the Earth has been varying over a long period of time. We have studied the patterns of climate variability from the past (that is, during the Pleistocene and the Holocene) till the present. This knowledge is important to help us understand the **current** or **contemporary** phase of climate variability, and to examine the role of human activities in this change.
- The terms – *climate change* and *contemporary climate change* (*global warming)* – are sometimes used interchangeably, although technically they are not the same. Climate change is more accurately described as 'climate variability'. The term *contemporary climate change* (*global warming)* refers to **the changes in the state of the climate that persists for an extended period, typically decades or longer in more recent times.** The IPCC uses the **pre-industrial period** – the period prior to the onset of large-scale industrial activity around 1750 – as a reference. The **reference period 1850–1900** is used to approximate **pre-industrial global mean surface temperature**. (see **Fig. 1**).

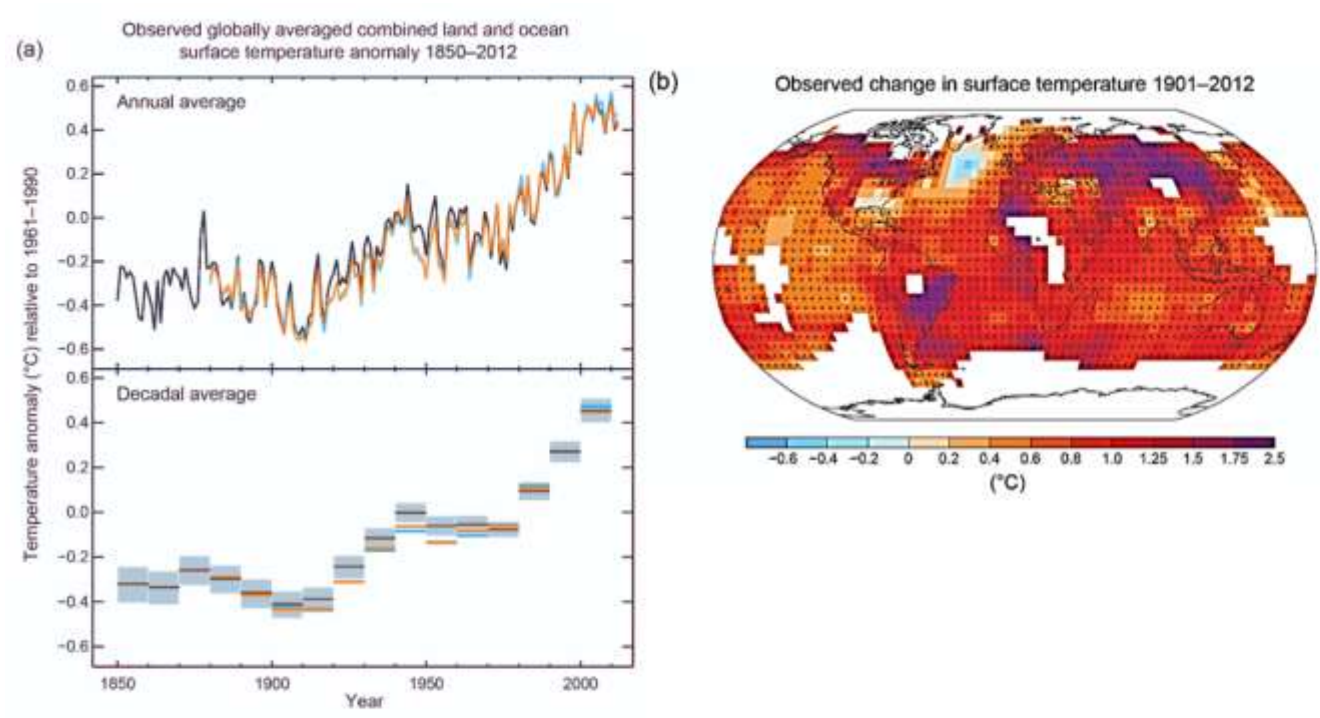


Fig. 1

10.2 Greenhouse Effect versus Enhanced Greenhouse Effect

- What is the science behind contemporary climate change?
  - The fundamental source of heat for the Earth's atmosphere is the sun.
  - While the Earth absorbs heat from the sun, it also loses heat to space.
  - The difference between what it receives and what it loses will determine the Earth's climate.
- The concerns for global warming arise because it is perceived that the Earth is not losing enough heat to space in comparison to what it receives.
  - While the Sun's output has increased only very slightly, about 0.007% over the last one million year or so, it does not seem to account for the reported trends in temperature increase.
  - Most scientists attribute this warming to the ***enhanced*** **greenhouse effect**. To understand this, we first need to be familiar with the **greenhouse effect**.

(a) How the Earth is heated up: The Greenhouse Effect

- The sun is the only source of energy on earth. Atmospheric temperature is determined by the balance between **insolation received** by the earth and **terrestrial radiation released** by the earth into the atmosphere.
  - The term **"insolation"** refers to **incoming solar radiation**. This input of **shortwave** solar radiation heats up only the earth's surface.
  - The earth's surface releases the heat in the form of **longwave terrestrial radiation**. Terrestrial radiation heats up the atmosphere as **greenhouse gases** like water vapour, carbon dioxide, methane, nitrous oxides **absorb the heat** (greenhouse effect; see **Fig. 3**). This increases the temperature of the atmosphere. **Table 1** shows the location and sources of major greenhouse gases, and their influence on global warming.

<u>Note</u>: In our syllabus, we focus on carbon emissions as carbon dioxide has contributed the most to contemporary climate change.

Table 1: Location and sources of major greenhouse gases, and their influence on global warming

Greenhouse gas	**Where it is found**	**Where it comes from**	**Function**
Water vapour	Concentrated in lowest 10 km of troposphere.	Surface water e.g. lakes, rivers, sea, oceans. Moisture loss from plants and other organisms. Largely constant in amount with spatial variations. Not significantly affected by human activities.	Water vapour only absorbs a small amount of outgoing radiation. Water droplets absorb wavelengths not absorbed by gases/vapour and radiate this heat back to the ground.
Carbon dioxide (CO_2)	Concentrated in lower troposphere.	Released by animals during respiration; burning of fossil fuels and vegetation e.g. rainforests. Annual fluctuations reflect seasonal vegetation growth, especially in northern hemisphere in summer huge amounts of CO_2 are absorbed, while in winter the process slows. The southern hemisphere does	Absorbs long-wave radiation from the earth.

		not feature strongly as there is less land area.	
Methane (CH_4)	Concentrated in lower atmosphere.	Released as bacteria break down organic matter: Marshes (also known as 'marsh gas'), swamps, tundra, wetlands (used for rice-growing), disposal of organic waste, waste from digestion in mammals. An increase in ruminating animals e.g. sheep, cows has caused levels to rise over the last 200 years.	Absorbs long-wave radiation from the earth.
Nitrous oxide (N_2O)	Concentrated in lower troposphere.	Combustion of fossil fuels in power stations and transport. Also, from denitrifying bacteria which break down nitrate and nitrites – increasing due to use of nitrate fertilisers.	Absorbs long-wave radiation from the earth. Concentration of N_2O is rising at approx. 0.3% per year.
CFCs	Ascends to the ozone layer: 15-50km above earth's surface.	Released from aerosol sprays, 1960s-1970s. Used in refrigeration.	
Ozone (O_3)	Largely concentrated 15-50km above earth's surface. About 10% in the troposphere.	Formed naturally from 3 oxygen atoms due to UV radiation. Tropospheric ozone is human made resulting from complex chemical reactions between pollutants and sunlight. Sources of these pollutants are nitrogen oxides from power stations and hydrocarbons from cars and other types of transport.	Ozone is vital to life on earth; it filters harmful short-wave UV radiation from the sun.

- These greenhouse gases occur naturally. Without them, the Earth's average temperature would be 33˚C lower than it is today and would not provide a suitable habitat for humans and other life-forms. Water vapour provides most of the natural greenhouse effect, with lesser contributions from carbon dioxide, methane, nitrous oxide and ozone. **Figs 2** and **3** (see below) both outline the natural greenhouse effect.

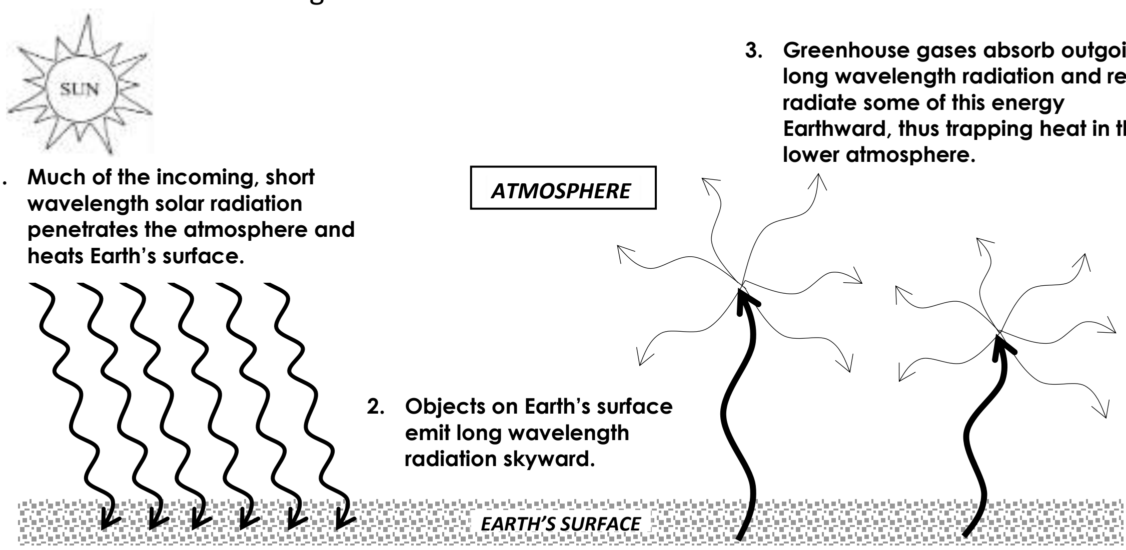


Fig. 2 Natural Greenhouse Effect

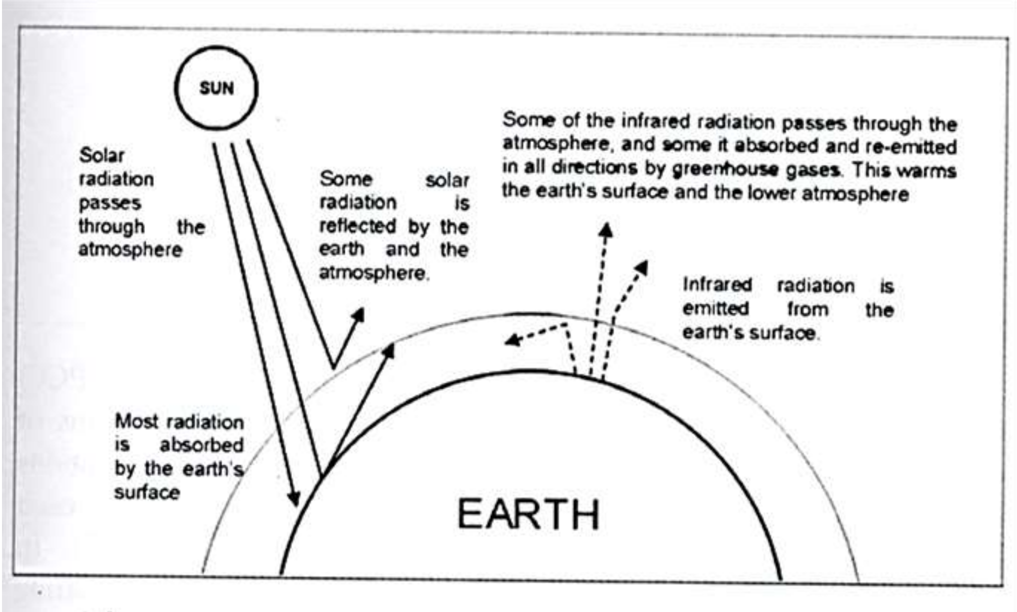


Fig. 3 Natural Greenhouse Effect

(b) Global Warming: The Enhanced Greenhouse Effect

- It is important to note that the greenhouse effect and contemporary climate change/global warming are not the same thing. Contemporary climate change or global warming, as we use the term today, is in fact the result of **enhanced greenhouse effect** which takes place due to the **increased** concentration of greenhouse gases in the atmosphere. More long-wave radiation is intercepted and absorbed by the excess greenhouse gases, resulting in higher global temperatures (compare **Fig. 3** with **Fig. 4**). This increase in concentration of greenhouse gases is definitely not natural and, in this lecture, we will examine the activities responsible for the enhanced greenhouse effect.

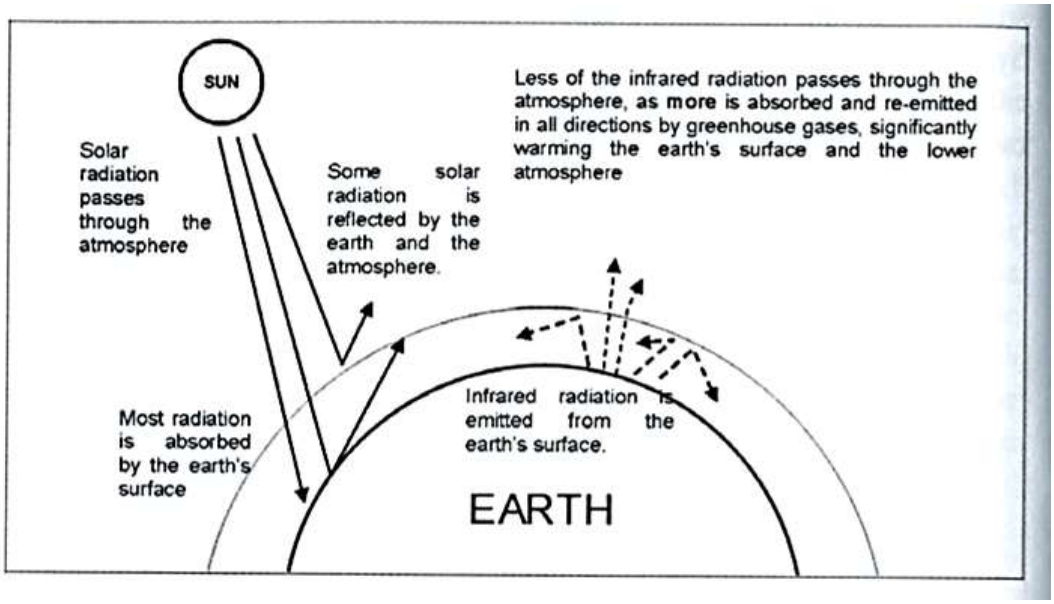
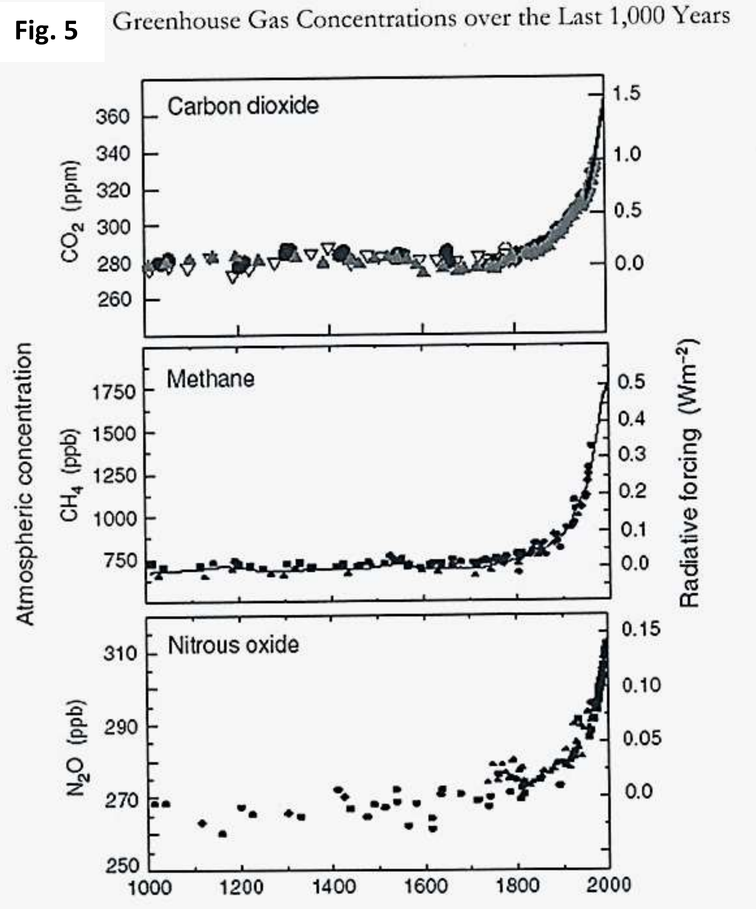


Fig. 4 Enhanced Greenhouse Effect

- World temperatures have risen by 1˚C in the last 150 years or so (see **Fig. 5**). During this period, there has been a rise in greenhouse concentrations (with the exception of water vapour which remains a constant in the system).
- Scientific consensus has identified **carbon dioxide** as the **dominant** greenhouse gas providing the main warming in the atmosphere. Methane and nitrous oxide are also major contributors to the enhanced greenhouse effect (see **Fig. 5**). Since the beginning of Industrial Revolution, atmospheric concentrations of **CO_2 have increased nearly 30%**, **methane concentrations have more than doubled**, and **nitrous oxide concentrations have risen by about 15%**.

Fig. 5



10.2.1 Per Capita GHG Emissions by Sector

- The **energy sector** (see **Fig.6**) produces the most greenhouse gas emissions by far, accounting for a whopping 75.7% worldwide. The energy sector includes emissions from electricity and heat (29.7% of all emissions), transportation (13.7%), manufacturing and construction (12.7%) and buildings (6.6%).
- It also includes **fugitive emissions** (greenhouse gases released during fossil fuel production or transmission) and emissions from other fuel combustion.
- We can also look at which specific activities (or end-uses) drive the most emissions within each sector. For example, **residential buildings** account for the largest share of energy sector emissions and 12.5% of all emissions globally. This includes emissions from generating the electricity used in homes as well as from direct fossil fuel use, such as cooking with gas.

- Another major GHG source in the energy sector is **road transportation**, which accounts for 12.2% of global emissions.
- Non-energy sectors contribute just one-quarter of global emissions. **Agriculture** is the second highest emitting sector after energy, accounting for 11.7% of global emissions. Major emitters in this sector include livestock farming and agricultural soils, such as methane from manure. Agriculture can also drive emissions through land-use change and energy use.
- **Industrial processes** make up 6.5% of global emissions. This includes emissions from chemical and cement production, among other things (but excludes energy use).
- **Waste emissions**, such as methane and nitrous oxide from landfills, make up 3.4% of the global total.
- **Land use, land-use change, and forestry** make up another 2.7%. This net total includes both emissions released by lands and forests such as when trees are cut down or when organic matter breaks down in soil as well as carbon removed from the atmosphere as forests grow. Gross emissions from the sector (not including removals) are therefore higher than what's shown here.

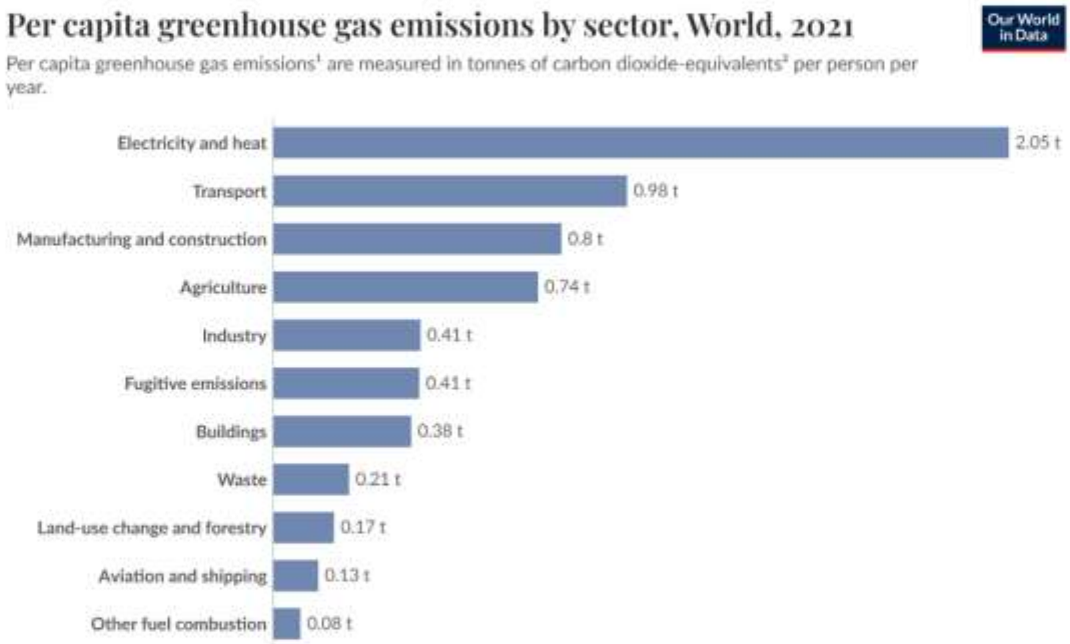


Fig. 6

10.2.2 Relative Contribution of Countries to GHG Emissions

- There are different ways to present countries' GHG emissions, and each one can tell a different story. These GHG emissions are measured in millions of metric tons of CO_2 equivalent (MMTCO_2e).
- To account for all greenhouse gases, emissions are measured in carbon dioxide equivalents (CO_2eq), which reflect the warming impact of each gas relative to CO_2. This is done by multiplying the amount of each gas by its global warming potential (GWP), typically over a 100-year timescale (GWP100). The total CO_2eq is then calculated by summing these values for all greenhouse gases.
- The different ways to present countries' GHG emissions are as follows.

(a) Annual GHG emissions by selected countries

- This method focuses on identifying which countries are **currently producing the most greenhouse gases** (see **Fig. 7**). Right now, some countries are emitting much more than others. For instance, China is the largest emitter of greenhouse gases today, even though that wasn't always the case. Historically, countries like the United States and many in Europe had higher emissions, but they have reduced their greenhouse gases in recent years due to stricter environmental regulations. Meanwhile, China's emissions have increased because of its rapid economic growth. Measuring today's emissions illuminates which countries are worsening climate change the most right now.
- Electricity and heat production are the largest contributors to global emissions. This is followed by transport, manufacturing, construction (largely cement and similar materials), and agriculture.
- But this is not the same everywhere. If we look at the United States, for example, transport is a much larger contributor than the global average. In Brazil, most emissions come from agriculture and land use change.

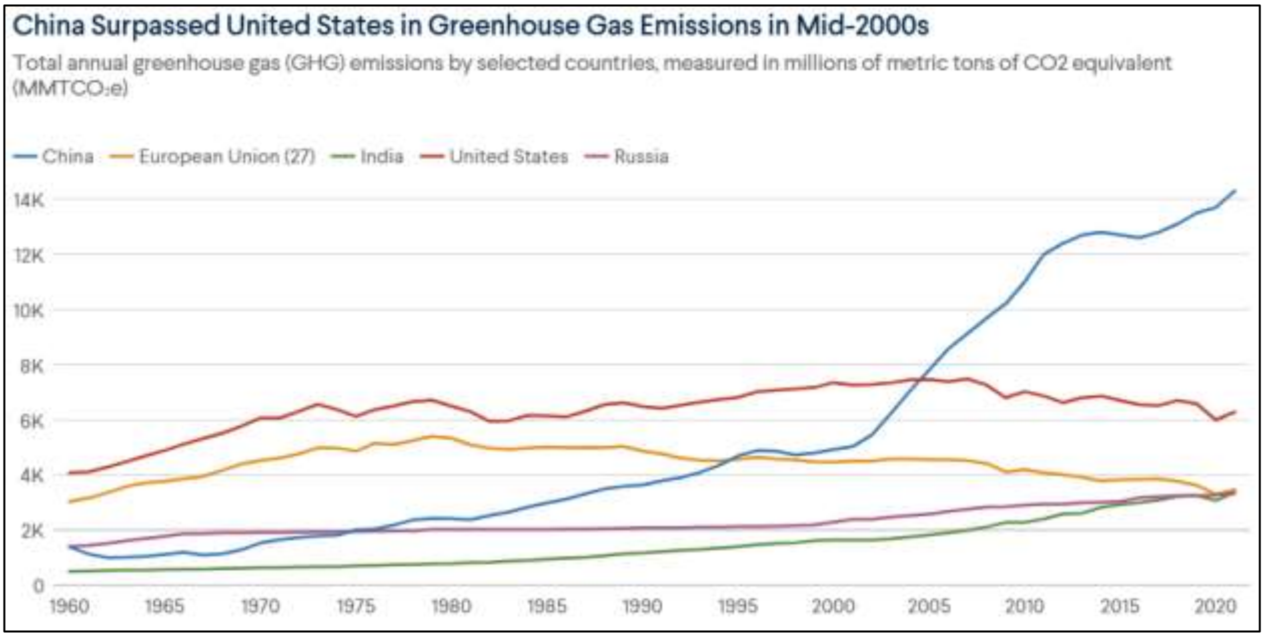


Fig. 7

(b) Cumulative GHG emission (from 1850 to 2021)

- The measurement of "cumulative emissions" looks at emissions over time (see **Fig. 8**), adding up all the emissions a country has ever released since records began around 1850. By that measure, countries like the United States and other wealthy, industrialised nations are the biggest historical polluters. They have been burning fossil fuels for a long time, way before countries like China and India were industrialised.

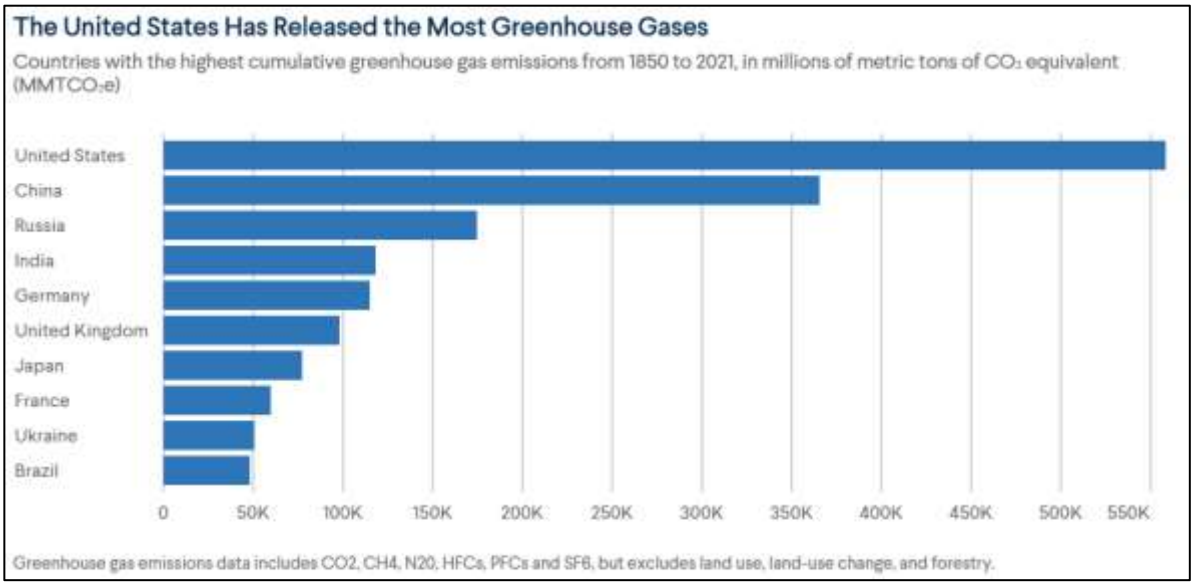


Fig. 8

(c) Per capita GHG emissions (as of 2020) (How much does each person pollute?)

- "Per capita GHG emissions" looks at how much each person in a country is responsible for producing GHGs (see **Fig. 9**). Some developing countries like to use emissions per capita because it shows that, despite high overall emissions, their emissions per person are lower than those of richer countries. Many countries with small populations but energy-hungry industries have high emissions per capita. In contrast, large countries like China and India don't show up as high per-capita emitters because their huge populations spread out the total emissions.

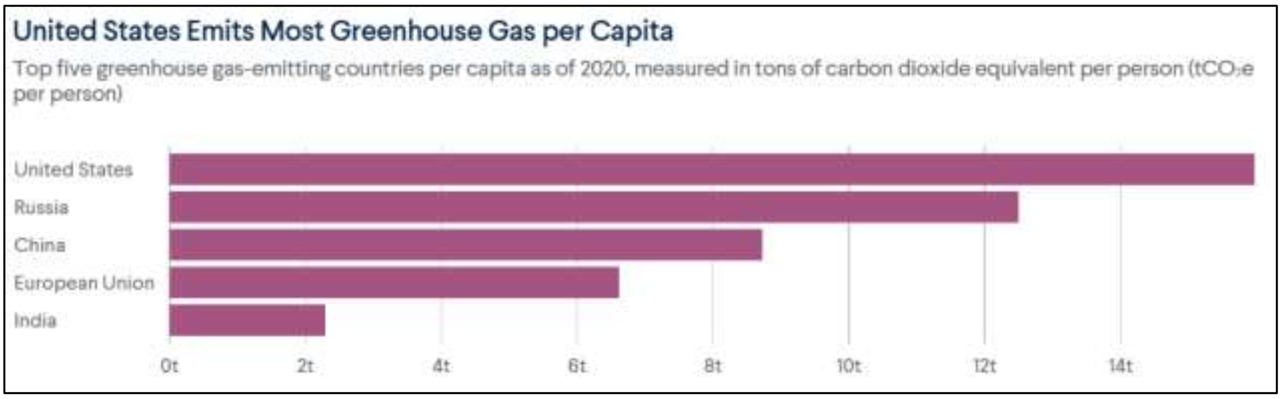


Fig. 9

- To decide who's responsible for greenhouse gas emissions, policymakers consider various factors, such as total emissions, per capita emissions, and historical emissions. While the debate continues, countries broadly agree on the principle of "common but differentiated responsibilities," meaning all nations must act, but those with greater contributions to the problem or more resources should do more.

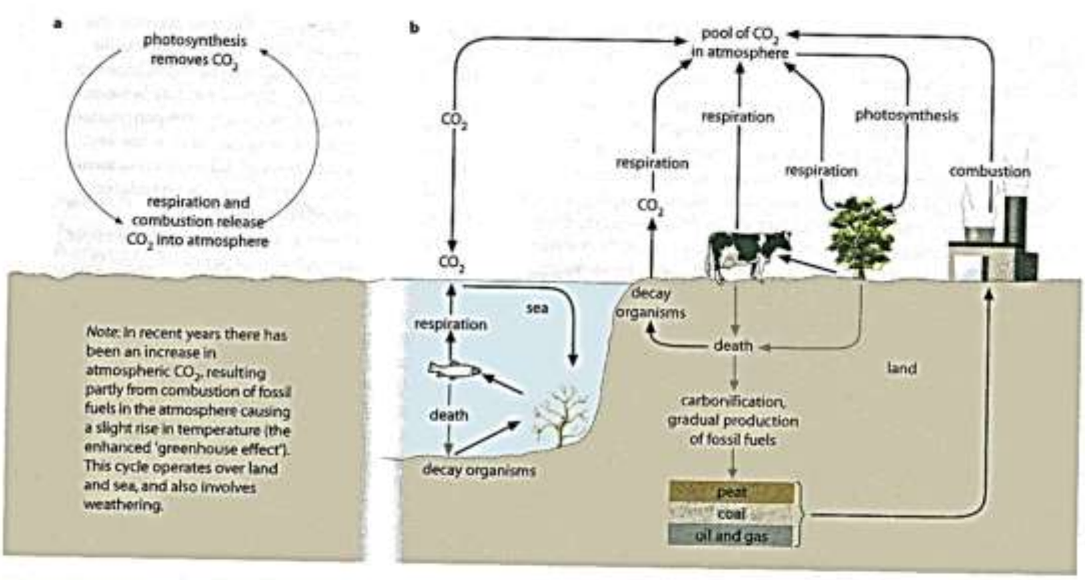
10.3 Role of the Carbon Cycle and Carbon Sinks in Contemporary Climate Change

- The **global carbon cycle** is the flow of carbon in various forms, e.g. through the earth's atmosphere, hydrosphere, terrestrial and marine biosphere and lithosphere (**Fig. 10**). The global carbon cycle is very complex and many areas where carbon moves from one part of the cycle to another are still not fully understood.
- There are huge amounts of carbon in the atmosphere, in the oceans and on land that are exchanged naturally between these systems. For centuries, this cycle was broadly in balance, but there is strong evidence that suggest human activities have disrupted this balance (see **Section 12.4**).

Key terms to help understand the carbon cycle:

- What are **carbon emissions**?
  - Carbon emissions refer to the release of carbon into the atmosphere, ocean and soil by activities like burning of fossil fuels (coal, petroleum and natural gas) to produce electricity needed to run industries, automobiles, household utilities etc. Burning of vegetation like trees, during the process of deforestation, emits carbon. Decaying of plants and organisms emits carbon. Organism respiration emits carbon.
- What are **carbon sinks**?
  - Outputs from processes such as combustion, respiration and the weathering of carbonate rocks were compensated for by processes like photosynthesis that absorb CO_2 in natural **sinks** (stores).
  - A **carbon sink** is a natural reservoir of carbon. It always takes in more carbon than it releases both in the short and the long run. Carbon sinks can be in the form of geological formations (such as carbonate rocks), forests, oceans – anything that takes more carbon out of the atmosphere than it releases. Most of the carbon on the earth is stored in forests, oceans, soils, sediments, rocks and fossil fuels.

Fig. 10 Carbon Cycle and Carbon Sinks



10.4 Influence of Human Activities on the Global Carbon Cycle

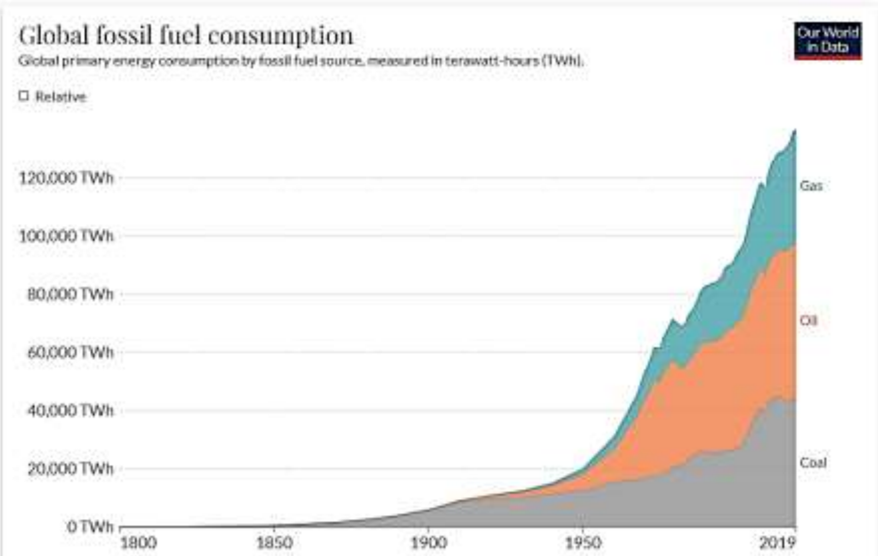
- Contemporary climate change is attributed to the enhanced greenhouse effect caused by human activities, which disrupt the carbon cycle, by **increasing carbon emissions** (see **Section 10.4.1**) and **reducing the carbon sinks** (see **Section 10.4.2**) available.

10.4.1 Increasing Carbon Emissions:

(a) Burning of Fossil Fuels

- Most carbon emissions come from burning fossil fuels for energy, transportation, and industry, as well as land-use changes like deforestation.
- Today, fossil fuels supply 87% of the world's energy. Although coal is no longer the leading fossil fuel, coal production in the early 21st century reached record levels (see **Fig. 11**).
- Unfortunately, coal is also the dirtiest fossil fuel: it emits twice as much as CO_2 as natural gas and 20% more than oil.
- Expansion of the global economy between 1990 and 2012, stimulated by globalisation and the growth of emerging economies (especially China), increased the consumption of fossil fuels, especially among developed countries and emerging economies, and according to the International Energy Agency led to a 51% increase in CO_2 emissions. At present, two of the world's largest economies, China and India, are powered largely by coal.

Fig. 11



- **Fossil fuel burning is releasing carbon dioxide into the atmosphere**. When we mine coal and extract oil from the Earth's crust, and then burn these fossil fuels for transportation, heating, cooking, electricity, and manufacturing, we are effectively moving carbon more rapidly into the atmosphere than is being removed naturally through sedimentation of carbon. This will ultimately cause atmospheric carbon dioxide concentrations to increase.
- The observed increase of CO_2 in the atmosphere from about 280 ppm in the preindustrial era to about 364 ppm in 1997 has come largely from fossil fuel combustion and cement production. By the early 1980s, an estimated 20 thousand million tonnes of CO_2 was added to the atmosphere annually from the burning of fossil fuel.

- **Fig. 20 (p. 20)** shows that 87% all human-produced carbon dioxide emissions come from the burning of fossil fuels like coal, natural gas and oil.

(b) Deforestation

- **Burning or Decomposing Trees Releases Stored Carbon**
  - Trees store carbon dioxide (CO_2) they absorb from the atmosphere during photosynthesis. When trees are cut down and burned (as in slash-and-burn agriculture) (dry wood is about 50% carbon) or left to rot or decompose, that stored carbon is released back into the atmosphere as CO_2.
- **Loss of Future Carbon Absorption**
  - Living forests act as carbon sinks, meaning they absorb more CO_2 than they release. When forests are removed, they no longer take in CO_2 from the air, reducing Earth's ability to naturally balance emissions. Thus, CO_2 increases due to deforestation. For example, a rainforest that once absorbed tons of CO_2 per year will stop doing so if it's converted into farmland or urban land thus increasing CO_2 in the atmosphere.
- **Loss of Soil Carbon**
  - Forest soils store a lot of carbon. When trees are removed, soil can degrade, and some of that carbon is released into the atmosphere too.

(c) Land Use Change

- Land use change or conversion of land from forested to agricultural land can have a wide range of negative effects as far as greenhouse gas emission is concerned. **Soil disturbance and increased rates of decomposition** lead to enhanced emissions of carbon to the atmosphere.
  - Man's conversion of soils from natural to agricultural use has led to substantial losses in the soil carbon sink. Greater soil disturbance, such as that caused by ploughing, causes soil detritus that was originally below the soil surface to be brought up to the surface.
  - This exposes the soil detritus to moisture and warmth at the surface, conditions that promote the action of decomposing organisms. This then helps to accelerate soil respiration, releasing large amounts of soil carbon which would otherwise decompose more slowly.

10.4.2 Reducing Carbon Sinks:

(a) Deforestation

- **While 66% of CO_2 emissions over the last 150 years have resulted from burning fossil fuels by human activities, 33% have resulted from changes in land use, primarily deforestation**. Deforestation is the permanent removal of forests.
- Forests naturally absorb and store carbon dioxide (CO_2) from the atmosphere. Trees absorb CO_2 during photosynthesis, storing the carbon in their trunks, branches, leaves, and roots. Thus, forests are known as **carbon sinks** or storehouse of carbon. When trees are cut down (deforestation) there is direct reduction in carbon sinks. Furthermore, as the trees are cut, the absorption of CO_2 stops. There is then a consequent decline in photosynthesis, so CO_2 that would otherwise be absorbed remains in the atmosphere. For example, the Amazon rainforest, often called the "lungs of the Earth," has been heavily deforested for **soybean farming** and **cattle ranching**, reducing its ability to act as a carbon sink.

- Today, forests cover only 31% of the land surface. Deforestation is particularly pronounced in the tropics, where vast tracts are cleared for ranching and agriculture or subjected to inefficient logging operations. According to estimates, the destruction of tropical rainforests averages 15.4 million hectares per year between 1981 and 1990 alone, while between 2000 and 2010, deforestation continues apace with 5.2 million hectares.

(b) Agriculture

- Unsustainable farming practices deplete organic matter in soil, which lowers its carbon-holding capacity. For example, over-ploughing and excessive use of chemical fertilizers in large-scale agriculture in the U.S. Midwest reduce soil health, releasing stored carbon and decreasing future absorption.
- Today 40% of the Earth's surface is used for agriculture compared with just 7% in 1700, and the proportion is growing.
- **Agriculture in particular also releases significant amounts of methane and nitrous oxide**, two potent greenhouse gases. Methane is produced by livestock during digestion and released via belches. It can also escape from stored manure and organic waste from livestock. Nitrous oxide is emitted by denitrifying bacteria which break down the increasing amount of nitrate and nitrites due to the use of nitrate fertilisers.

(c) Ocean Pollution and Warming

- Oceans are Earth's largest carbon sink. Warming and pollution reduce their ability to absorb CO_2. For example, coral reef bleaching and acidification caused by excess CO_2 harm marine ecosystems that support plankton and algae, which help absorb carbon.

(d) Urbanisation

- Cities replace natural carbon sinks like forests, wetlands, and grasslands with concrete and asphalt, which do not absorb carbon. For example, expanding cities like **Shanghai or Lagos** involve large-scale clearing of green spaces, cutting off those areas from contributing to carbon absorption.

10.4.3 Relative Contribution of Countries to Carbon Emissions

The History of Carbon Dioxide Emissions

- Carbon dioxide (CO_2) emissions from human activities are now higher than at any point in our history. In fact, recent data reveals that global CO_2 emissions were 182 times higher in 2022 than they were in 1850 (see **Fig. 12**), around the time the Industrial Revolution was underway. The major drivers of increasing emissions were rise in population growth, economic development and energy use. For context, the United Kingdom was the world's largest CO_2 emitter in 1850, the first year of available data. Its emissions were nearly six times those of the United States, the second-ranked country at the time. According to the latest data available in 2022, China ranked as the world's largest CO_2 emitter, followed by the United States, India, Russia and Japan. However, among the top 10 CO_2 emitters, the United States has the highest emission per person. Per capita emissions in the U.S. are double those of China and 8 times those of India.

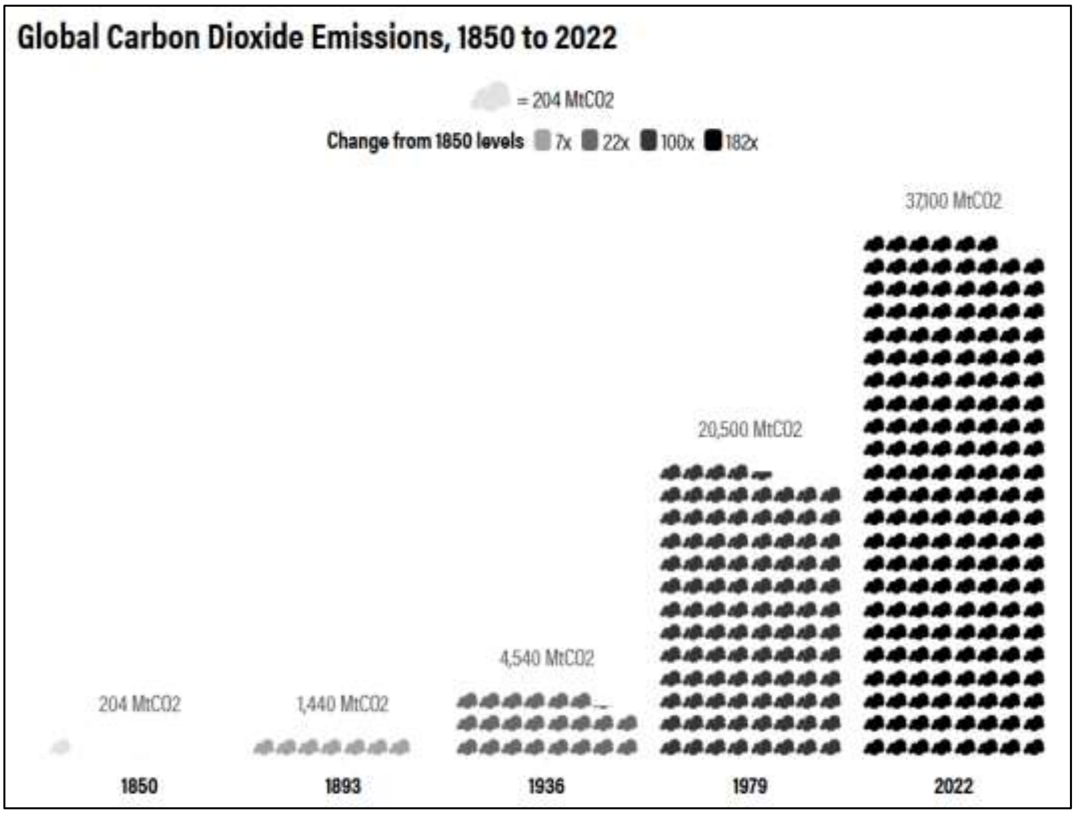


Fig. 12

- From 1850 to the mid-20th century, the world experienced near-constant growth in emissions. This was due largely to industrialisation and population growth in the United States and Europe. The U.S. became the top CO_2 emitter in 1887 and saw the greatest acceleration in emissions over the next nine decades, followed by the United Kingdom and Germany.
- This trend was occasionally interrupted by historic events, like the Great Depression in the 1930s and the end of World War II in 1945. But the resulting emission reductions were only temporary. Countries in North America and Europe continued to dominate global emissions through the first half of the century. As a result, the U.S. and EU remain the largest cumulative emitters to date, bearing responsibility for most CO_2 in the atmosphere.
- From the 1950s to 1980s, Russia also experienced rapid emissions growth. However, its emissions dropped off significantly with the dissolution of the Soviet Union.
- For comparison, the U.K., once the world's highest emitter, stabilized its total CO_2 emissions around 1970.
- While the United States kept its place as the top CO_2 emitter throughout the 20th century, Asian countries began to emerge onto the scene, led by China.
- Since then, China's economy has continued to expand rapidly — along with its consumption of fossil fuels. China surpassed the U.S. as the world's top CO_2 emitter in 2005.

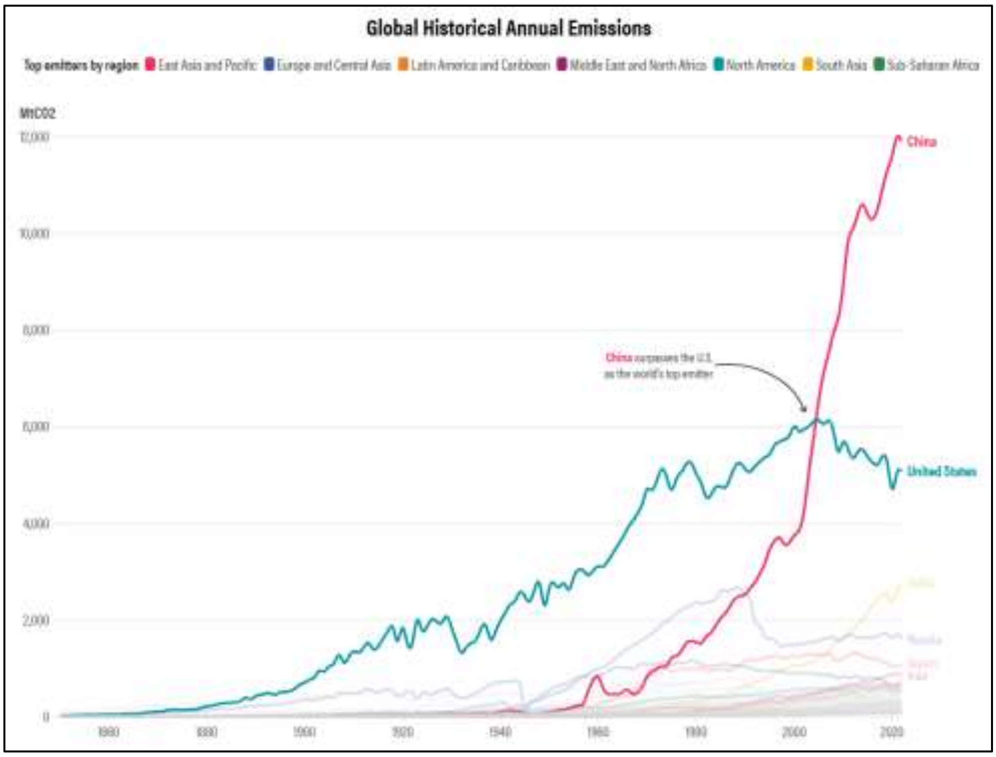


Fig. 13

- A similar picture emerges when looking at emissions by region. East Asia and the Pacific became the top regional emitter in 2004. By 2022, it was contributing 44% of global CO2 emissions. Europe and Central Asia and North America, the next-highest emitting regions, accounted for 17% and 15% respectively. However, this only represents total annual emissions.

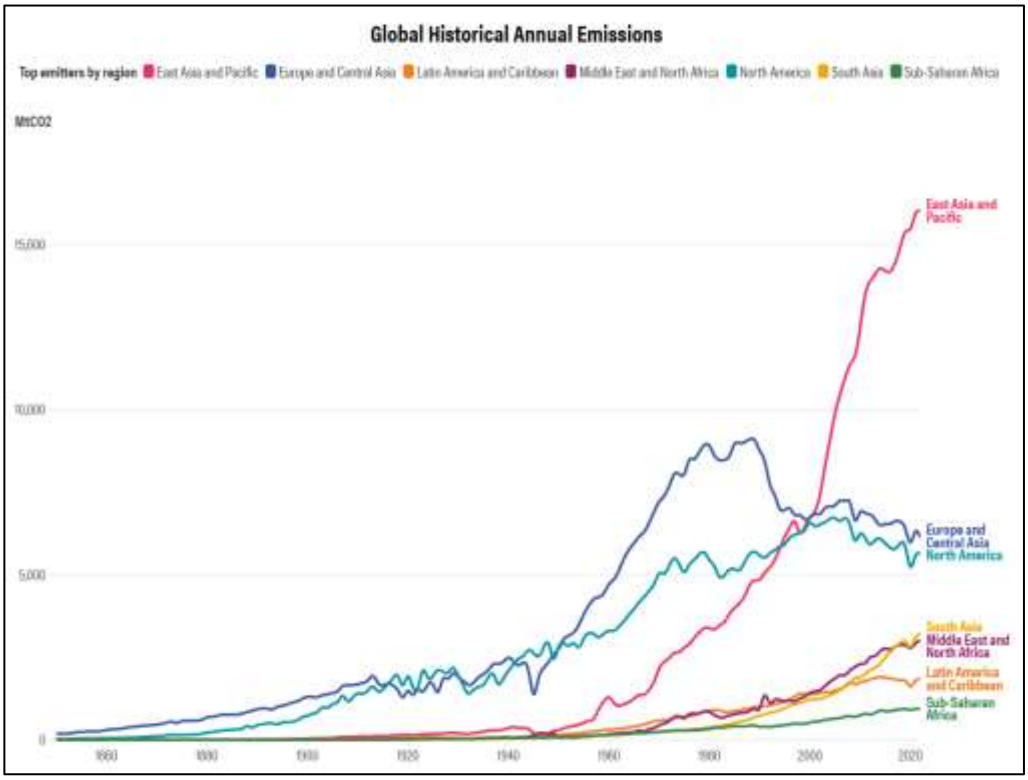


Fig. 14

- When it comes to per capita emissions, North America, remains the highest by far, followed by Europe and Central Asia. However, East Asia and the Pacific is very close to becoming the second largest per-person emitter.

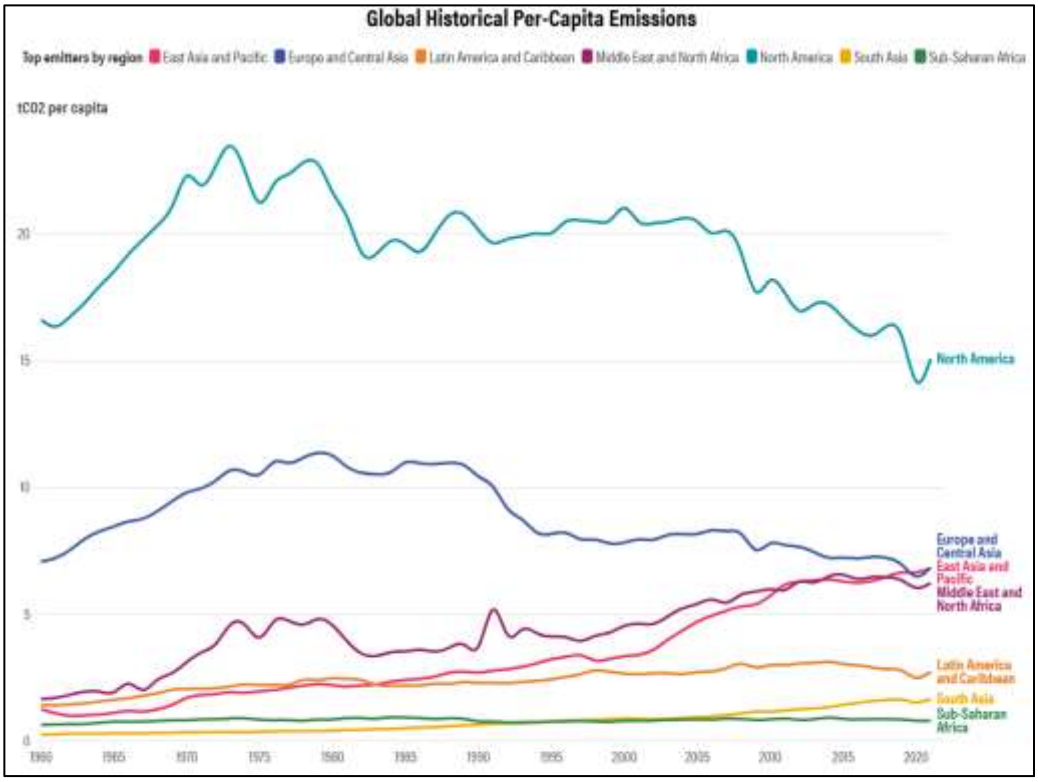


Fig. 15

10.5 The Impact of Human Activities on Feedback Mechanisms

- In **Lect. 9 Section 9.3**, we have learnt about how feedback mechanisms contribute to past climates. Feedback mechanisms too cannot be neglected in helping to explain contemporary climate change, especially in how human activities trigger them.
- Recall that a **feedback loop** is the equivalent of a natural process that **accelerates** or **decelerates** a change. **A <u>positive feedback loop</u> accelerates a temperature change, whereas a <u>negative feedback loop</u> decelerates it.** (See **Fig. 16**)

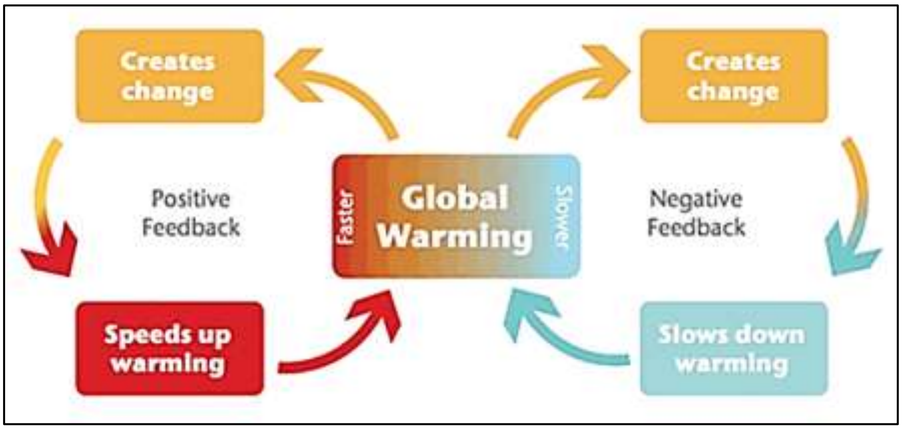


Fig. 16

10.5.1 Accelerating Warming through Positive Feedback

- Human activities that either increases carbon emissions or reduces carbon sinks would raise temperatures which in turn cause changes that enhance the warming.
- In the following, Examples 1 and 2 bear semblances to what have been covered in **Lect. 9** (but with some changes) as they apply to both past and contemporary climate change.

Example (1)

- Sea ice and continental ice have high albedos, reflecting much of the shortwave radiation that strikes them. **Global warming causes ice to melt and reduces ice cover**.
- For instance, the annual mean Arctic Sea ice extent decreased by 3.5-4.1% from 1979 to 2012. This in turn **reduces albedo** (% of radiation reflected) and **increases absorption** by the surface, which in turn lead to **higher terrestrial radiation,** giving higher temperatures and reducing ice cover – a positive feedback loop (see **Fig. 17**).

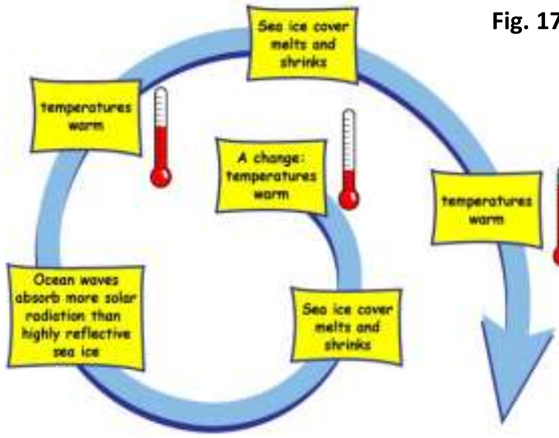


Fig. 17

Example (2)

- Deposits of frozen methane and carbon dioxide lie beneath permafrost in Arctic regions.
- About a quarter of the Northern Hemisphere is covered by permafrost. As temperatures increase and the **permafrost thaws**, these deposits can be released into the atmosphere and further contribute to global warming – a **positive feedback** loop. (See **Fig. 18**)

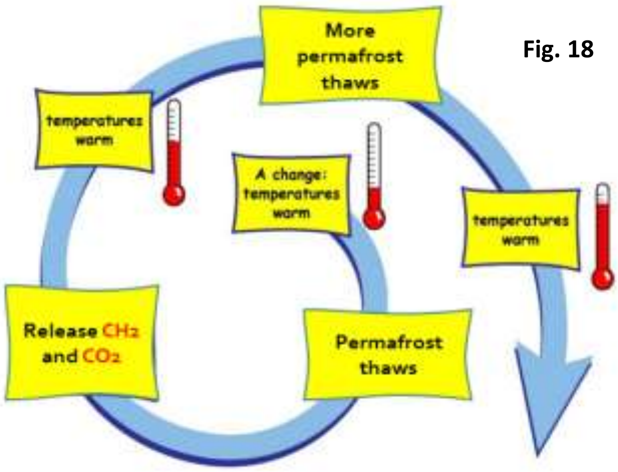


Fig. 18

Example (3)

- Cold ocean waters can store huge amounts of carbon dioxide. Due to **warming of ocean waters**, now they can **store less carbon dioxide** and reduces the effectiveness of oceans as carbon sinks.
- Thus, more carbon dioxide is in the atmosphere contributing to more global warming via a positive feedback loop.

Example (4)

- **Higher temperatures** from global warming leads to **drier vegetation** which is susceptible to forest fires. During forest fires, many trees undergo **combustion**, **releasing carbon dioxide** into the atmosphere.
- Forest fires **reduce the availability of trees**. Trees perform photosynthesis, so their loss will **reduce the Earth's ability to uptake carbon dioxide**. This will reinforce the original change: the influx of greenhouse gases into the atmosphere and accelerate warming through positive feedback.

10.5.2 Suppressing Warming through Negative Feedback

- In theory, negative feedback loops help to cool the effects brought about by positive feedback loops. However, these are usually insufficient, hence the net result is the warming we are experiencing today.

Example (1)

- With increased global temperatures and melting ice caps, **more evaporation of ocean water** can occur. More evaporation increases the potential for **cloud formation**. Clouds contribute to the **reflection of solar radiation** back into space, which helps to **reduce global warming**.
    - However, low, thick clouds are the greatest reflectors of solar radiation, whereas high, wispy clouds do not reflect that well. A warmer atmosphere will result in water vapour only being able to condense in the colder, upper sections of the atmosphere and forming clouds that do not reflect radiation well.

Example (2)

- **Higher atmospheric carbon dioxide** levels from human activities result in an initial increase in **plant growth**, as plants require carbon dioxide for photosynthesis. In some parts of the world, such as the temperate zones, warmer temperatures encourage plant growth.
- Changes in precipitation patterns, such as **increased water availability**, may cause an increase in plant growth too.
- Plant growth could potentially **remove more carbon dioxide** from the atmosphere. This offers a negative feedback mechanism to global warming by reducing the greenhouse effect.
    - Despite so, carbon dioxide will only increase rates of photosynthesis up to a certain point before it becomes a limiting factor, as plants require water, light intensity and nutrients as well.

10.6 The IPCC: Contemporary Climate Change is Unequivocal

10.6.1 What is the IPCC?

- The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.
- Created in 1988, the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies.
- The IPCC is an organisation of governments that are members of the United Nations or WMO. The IPCC currently has 195 members. Thousands of people from all over the world contribute to the work of the IPCC.
- For the assessment reports, experts volunteer their time as IPCC authors to assess the thousands of scientific papers published each year to provide a comprehensive summary of what is known about the drivers of climate change, its impacts and future risks, and how adaptation and mitigation can reduce those risks.

10.6.2 What is IPCC's assessment about our climate today?

- In February 2007, the IPCC published its 4th Assessment Report (AR4) concluding that **warming of the climate system is unequivocal**. This can be found in evidence of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels (see **Figs 19a, b, c, d, e**).

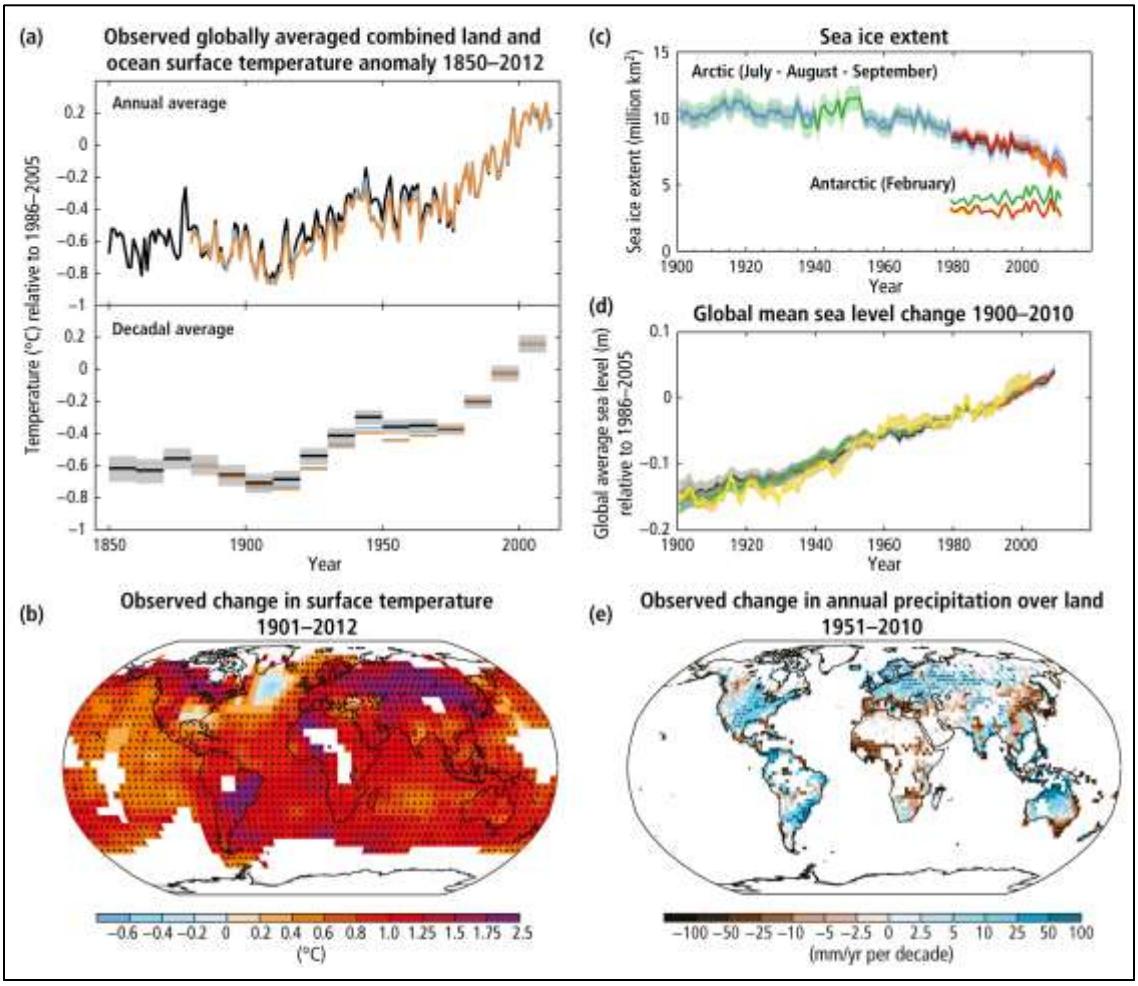


Fig. 19

- Climate change is "very likely" to be caused by humans. In AR5, published in 2014, IPCC concluded that there was a 95% probability that human activities have warmed our planet over the last 50 years.
- Since then, the evidence has only become more conclusive. Emissions are at their highest level in human history. In 2019, emissions were about 12% higher than they were in 2010 and 54% higher than in 1990. Essentially, the report is a "final warning for humanity" – unless we cut emissions quickly and meaningfully, we will bring about a climate catastrophe.
- The latest IPCC report, AR6, published February 28, 2022, has reiterated that "**human-induced** climate change is causing dangerous and widespread disruption in nature and is affecting the lives and livelihoods of billions of people, despite efforts to reduce the risks."

10.6.3 Significance of Anthropogenic Activities in Contemporary Climate Change

- Firstly, **most of the greenhouse gases in the atmosphere have been released by human activities (**see **Table 2** and **Fig. 20** to **22).**

Table 2

Estimated contribution of greenhouse gases to global warming for concentration changes, 1985–2100

A. Sources by chemical compound

Greenhouse gas	Relative contribution (%) Instantaneous[a]	Total[b]	Source of emission
CO_2	76.1	94.7	Largely from combustion of fossil fuels
Methane	9.6	0.8	Unknown; from a wide variety of biological and agricultural activities
CFCs	11.6	3.3	Wholly industrial, from both aerosols and nonaerosols
Nitrous oxides	2.7	1.2	From fertilizers and energy use

SOURCE: Nordhaus 1990a.

a. Instantaneous contribution measures the impact of concentration change at the instant of release.

b. Total impact estimates the relative contribution to global warming over indefinite future.

B. Sources by economic activity

Greenhouse gas	Relative contribution (%) Instantaneous	Total	Source of emission
Energy	62.8	76.2	CO_2 emissions, nitrous oxides, methane
Agriculture	20.6	19.8	CO_2, methane, nitrous oxides
Industry	0.7	0.1	Methane
Natural	4.3	0.7	Methane, nitrous oxides
Other	11.6	3.3	CFCs

SOURCE: Nordhaus 1990b. Estimates of emission sources are from EPA 1989b, vol. 1, ch. 2.

Note that sources are highly uncertain for methane and nitrous oxides.

Fig. 20 Human sources of carbon dioxide

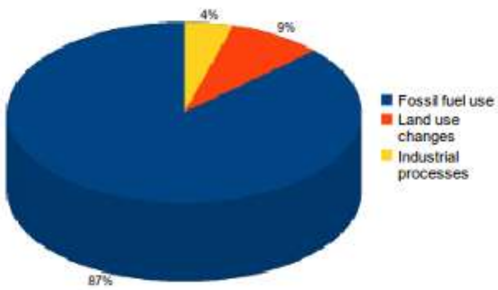


Fig. 21 Human sources of methane

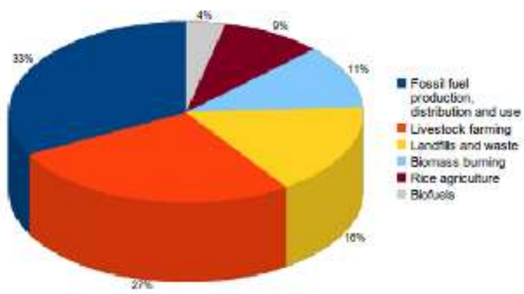
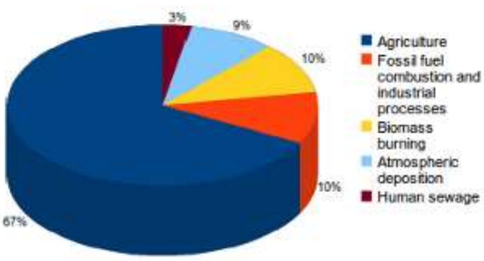


Fig. 22 Human sources of nitrous oxide



- This has been largely due to the increase in world population (see **Fig. 23**) and a corresponding growth in human activities, especially agricultural and industrial activities. The atmospheric concentrations of carbon dioxide, methane and nitrous oxide since the industrial revolution are unprecedented in at least the last 800,000 years. By adding these gases to the atmosphere, we are changing the chemical composition of the atmosphere which is causing the Earth to trap more heat in the atmosphere and therefore to warm up, **enhancing** the greenhouse effect (see again, **Fig. 4**).

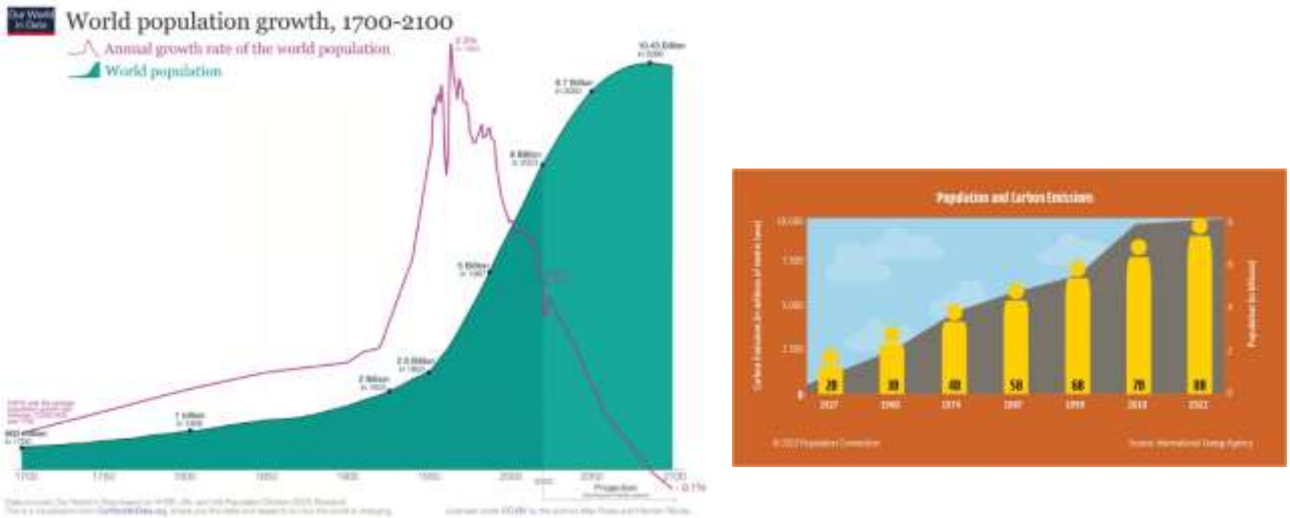


Fig. 23

- Thirdly, there is a **correlation between the rate of increase in GHG concentrations in the atmosphere and temperature increase**. This can be seen in **Fig. 24** below.

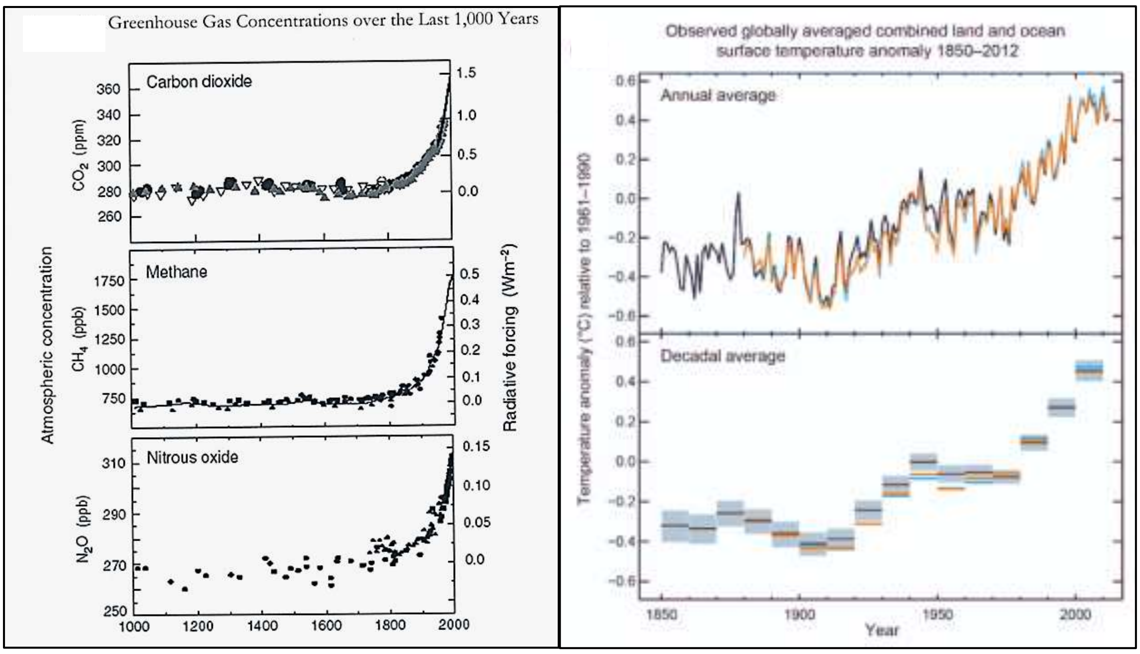


Fig. 24

10.7 Conclusion

- In conclusion, there is consensus within the scientific community, represented by the Intergovernmental Panel for Climate Change (IPCC), that climate change in the last two centuries is unequivocal and it is very likely caused by human activities. The enhanced greenhouse effect is the mechanism that drives contemporary climate change. Human activities are significant for three key reasons. Firstly, human activities have affected the carbon cycle in ways that increased the concentration of carbon dioxide (the **dominant** greenhouse gas) in the atmosphere. Secondly, human activities have the **net effect of accelerating warming** through feedback. Thirdly, these changes all occurred **within a short amount of time** in geological history, i.e., from 1750 onwards.