CLIMATOPIA SELF-TRAINING HANDBOOK

Climatopia Self-Training Handbook

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CLIMATOPIA

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Chapter 1

Basic scientific concepts related to climate change

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1 Background and Rationale

1.1 Why there is a need to learn and teach about Climate Change

The Earth's climate is a complex dynamical system. Different processes (atmospheric, oceanic, biological, geological, etc.) interlink a vast number of nested subsystems that all drive the climate system and result in regional variations of climate. There is a substantial set of independent evidence that **human-induced climate change** is occurring, **based on international scientific research** built across the last decades and consensus of published, peer-reviewed studies from research groups across the world. Climate is vital for life and thus, it is essential for all of us to have an accurate understanding of the findings of climate science: climate change is one of the most critical issues of the 21st century. It is important to know year by year what's happening with the local and global climate using monitoring stations, satellites and suitable scientific tools to see how well climate mitigation policies respond successfully.

Climate change is considered to be a highly interdisciplinary field of study. Recognition of the complexity of climate change and the high pressure to find sustainable solutions by addressing the problem with deeper, concrete, and actionable knowledge requires collaboration across disciplines in the natural sciences, social sciences and humanities. There is, however, scientific uncertainty about countless details such as the rates of change and interactions among components of the climate system; but this is the nature of research on all complex systems, which is important to understand as an aspect of scientific practices. This is the reason why knowledge about climate and its changes is continuously updated based on new scientific findings and should be also noted that what we know today far exceeds what we knew ten or even five years ago.

Science makes it clear that climate change is the biggest issue facing society today. A healthy society depends on a fairly stable climate, sustainable ecosystems, energy and water supply, clear sea waters for fishery products as well as good quality soil for agricultural production. All these sectors are interlinked while climate is a decisive component for securing their sustainability. So, a changing climate will result in adverse cascading effects for much of the world. For example, increasingly frequent extreme weather events could lead to more food insecurity and displacement of people, with subsequent effects on whole regions and the global economy. Also, impacts aren't confined to the vulnerable place where they happen. They cause a sequence of climate hazards that are global in their nature or at least cover large regions (e.g. flooding, droughts, wildfires).

The impacts climate hazards have, and our ability to deal with those impacts will depend on the resilience or vulnerability of our societies. Climate risks will affect societies to a different degree, as there are distinctively resilient and vulnerable regions in the world. Wealthier countries, including the European nations, could manage easily a flooding event avoiding lasting impacts on local agriculture and food supplies. Along the same line, advanced irrigation systems and water supply infrastructure make it easier to compensate for low rainfall during drought spells. A developed country can deal with a strike of a climate impact like a drought. On the other hand, less developed countries cannot easily face a drought which causes crops to fail, disruption of food supplies and poverty increase. Then, more people are unable to cope putting further strain on resources, which means that vulnerable communities become more vulnerable, creating a vicious cycle. Such a result is not restrained within the vulnerable region but it can cascade across borders and nations, creating conflicts, disrupting financial markets and international trade and causing migration[1].

Hence, it is imperative that the young generation is prepared with the knowledge and critical-thinking tools it will need to handle this inevitable hurdle of climate change and its impacts. Education is an essential factor in the ever-more urgent global fight against climate change. The

1 https://www.chathamhouse.org/2021/10/which-near-term-impacts-climate-change-are-most-worrying

knowledge regarding climate change offered to the youngest can:

1) Help them to understand the extent of the problem and tackle the consequences of global warming

2) Encourage them to change their everyday activities and way of living to mitigate the climate change effects

3) Allow them to adapt to what is already a global emergency.

In addition, climate education is stimulating for students by helping them to explore the links between local events and global effects, interweave knowledge from various scientific subjects and contemplate the big picture of the state of the environment in the future. Educating the young generation by teaching climate science at schools and raising awareness about climate change is a major step toward combating climate change in the coming years. Moreover, the young generation of today will become the decision and policy-making.

1.2 Coordination of scientific effort on climate change study

Climate change is addressed by international organizations and agreements that clearly indicate the urgency for immediate action by all nations worldwide. These international treaties are dedicated to raising public awareness and combating climate change. More information is provided below:

The United Nations Framework Convention on Climate Change[2], UNFCCC, signed in 1992 and ratified by 197 countries, constitutes the first climate agreement. The Convention established a Conference of the Parties (known as **COP**), a secretariat, and subsidiary bodies that oversee the implementation of the Convention and related instruments within its mandate. Conferences of the Parties take place every two years to assess progress in dealing with climate change and renew the solidarity between the countries in an effort to tackle climate change. The UNFCCC has instituted a process for countries to generate and share data about their national GHG emissions.

The Kyoto Protocol[3] is the first set of international rules designed to implement the UNFCCC. Kyoto is the name of the Japanese city in which the protocol was negotiated, but it is now commonly used in climate change discussions to refer to the protocol itself. The Kyoto Protocol entered into force following ratification by Russia in February 2005 and it commits industrialized countries and economies in transition to limit and reduce GHG emissions in accordance with agreed individual targets.

The Paris Agreement[4] is the first legally-binding global treaty on climate change, agreed in Paris in 2015 by 196 Parties and entered into force in November 2016. The Paris Agreement has a 'bottom-up' approach where countries individually decide by how much they will reduce their national emissions each year. Its ambition is to limit global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. The countries signed the Paris Agreement are committed to align finance flows with "a pathway towards low greenhouse gas emissions and climate-resilient development".

The World Meteorological Organisation (WMO), as a specialized agency of the United Nations, is dedicated to international coordination and cooperation on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources. WMO's mission is to monitor continuously via an integrated observational network of meteorological instruments the weather and to facilitate the maintenance of data management centers and telecommunication systems for the provision and rapid exchange of weather, climate and water-related data[5].

WMO has been reporting facts based on observational evidence about the state of climate and its changes to decision makers while the **Intergovernmental Panel on Climate Change (IPCC)** organization, which is the world's leading **scientific authority** on climate change, has been complementing

2 https://unfccc.int/?gclid=EAIaIQobChMIudq5t6iP-wIVaoBQBh1WdQ5sEAAYASAAEgIh1vD_BwE

3 https://unfccc.int/kyoto_protocol?gclid=EAIaIQobChMI94uJ_KWP-wIVjNPtCh24WQa-EAAYASAAEgIqw_D_BwE

4 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

5 https://public.wmo.int/en/our-mandate/climate

them with scientific reports based on updated scientific information.

1.3 Scientific evidence of Climate Change in brief

Scientific information taken from natural sources (such as ice cores, rocks, and tree rings) and from modern equipment (like satellites and instruments) reveals the signs of a changing climate. According to the latest scientific report of IPCC (AR6)[6], some observed evidence of a changing climate could be summarized in the following:

1. Earth's climate has changed throughout its history, but the current warming is happening at a rate not seen in the past 10,000 years. Each of the last four decades has been successively warmer than any previous decade since 1850. The **global mean surface temperature** (GMST) rises. It is a global average covering extreme variations of temperatures across regions and seasons. In 2021, GMST (was **1.11°± 0.13°C (degrees Celsius)** warmer than the pre-industrial baseline (1850-1900). Most of the warming occurred in the past 40 years.

GMST is measured using a combination of air temperature over land, and sea surface temperature in ocean areas, typically expressed as an anomaly from a baseline period.

2. The **atmospheric concentrations of greenhouse gases-GHGs- mainly, carbon dioxide, CO_2, methane, CH_4, nitrous oxide, N_2O, chlorofluorocarbons, CFCs, ozone, O_3, and water vapour, H2O** -reflect a total of emissions from nature (biogenic) and human (anthropogenic) activities, sources and sinks. Increasing levels of GHGs in the atmosphere due to human activities are a **major driver of climate change because they increase the global temperature.** Land ecosystems and oceans absorb about half of the CO_2 emitted and they act as a buffer (or else sink) against even greater temperature increase. But there is a risk that this sink maybe less effective in the future.

Carbon dioxide (CO_2) is the most commonly addressed greenhouse gas, and its atmospheric concentration is measured by parts per million of atmospheric particles (ppm). **Methane (CH_4)** and **nitrous oxide (N_2O)** are also extraordinarily important for the global climate and are measured by parts per billion of atmospheric particles (ppb).

Currently, observed (measured) concentrations and increases in GHGs:

- CO_2: 418.81ppm = **150% of preindustrial levels; [For millennia, CO_2 never exceeded ~300 ppm]**
- CH_4: 1889±2 ppb = **262% of preindustrial levels;**
- N_2O: 333.2±0.1 ppb = **123% of pre-industrial levels.**

3. **Abnormal precipitation observed over different regions**. Recently, large areas with **above normal precipitation** were Eastern Europe, Southeast Asia, areas of northern South America and south-eastern North America. Meanwhile, regions with **rainfall deficit** included southwest Asia and the Middle East, parts of southern Africa, southern South America and central North America.

4. **Heat extremes** (heatwaves) have become more frequent and intense in most rural regions since the 1950s, while **cold extremes** have occurred less frequently and less severely.

5. It is likely that the global share of **severe tropical cyclones** (category 3 to 5) has increased over the past four decades.

6. Ice at the Earth's surface includes **sea ice**, **glaciers**, and continental **ice sheets**, which altogether hold approximately 2% of the water on Earth. Scientists refer to this system as the **cryosphere**. Global warming causes **melting of the ice sheets**. Both major **ice sheets** of Greenland and Antarctica have been losing ice mass since at least 1990, with the highest loss rate during the last decade (2010–2019). Also, **Arctic sea ice is declining**. Both the extent and thickness of

6 IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Arctic sea ice has declined rapidly over the last several decades. The decrease was 40% in September and 10% in March.

7. All data sets agree that **ocean warming rates** show a particularly **strong increase in the past two decades**. Since 1969, the top 100 meters of the oceans show a warming of 0.33 degrees Celsius. The oceans cover about 70% of Earth's surface. **Oceans have a large role in Earth's environment and global climate**. As the Earth's atmosphere warms, water in the oceans soaks up energy (heat) and distributes it more evenly across the planet, to different parts of the world and to the atmosphere, through movements known as **ocean currents**. The oceans also absorb carbon dioxide from the Earth's atmosphere. The additional heat and carbon dioxide in the ocean can change the environment for the many plants and animals that live there. The top few meters of the oceans store as much heat as Earth's entire atmosphere. So, as the planet warms, it's the oceans that get most of the extra energy. More than 90% of global warming is going into the ocean. Warmer water expands and rises. In addition, extra water from the ice sheets melting causes sea level rise that can affect coastal areas. NASA reports that a child born today can expect the ocean level to rise between 0.3 and 1.2 meters. In 2021, the **global mean sea level** reached a new record high. However, the sea level does not rise equally everywhere: regional patterns of sea level change are dominated by local changes in ocean heat content and salinity. The oceans absorb about one-quarter of the CO_2 that humans create from burning fossil fuels (oil, coal, and natural gas). But too much carbon dioxide in the ocean causes a problem called ocean acidification, which can be harmful to ocean plants and animals.

8. **Snow cover is decreasing**. Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and the snow is melting earlier. . It is *virtually certain* that snow cover will decline over most land regions during the 21st century, in terms of water equivalent, extent and annual duration.

9. With few exceptions, **mountain glaciers** have retreated since the second half of the 19th century. This behavior is unprecedented in at least the last 2,000 years. The global warming-induced earlier onset of spring snowmelt and increased melting of glaciers have already contributed to seasonal changes in streamflow in low-elevation mountain catchments

All the above-mentioned changes will pose challenges for water supply, energy production, ecosystems integrity, agricultural and forestry production, disaster preparedness, and ecotourism.

Key message

Rising global temperatures have contributed to **more frequent and severe extreme weather events** around the world, including cold and heat waves, floods, droughts, wildfires and storms.

Ecosystems – including terrestrial, freshwater, coastal and marine ecosystems – and the services they provide, are affected by the changing climate and some are more vulnerable than others. **Ecosystems are degrading at an unprecedented rate**, limiting their ability to support human well-being and harming their adaptive capacity to build resilience.

According to the IPCC (Intergovernmental Panel on Climate Change) there will be more severe and frequent extreme weather events in the near future like floods, droughts, wildfires and hurricanes.

A fraction of a degree in average global warming can have massive consequences

1.4 Can we combat climate change?

Briefing reports from WMO recently informed the public that the message of the scientific community about climate change has been heard and the decision-makers are eager to solve this problem. International Agreements and Protocols on climate change signed by most countries manifest the general consensus on the urgency and tackling of the problem. According to the United Nations Environmental Programme (UNEP) Action Note[7], the world is in a climate emergency. We are on course for temperature rise by the end of this century far above the Paris Agreement[8] targets 1.5-2 °C. If we stopped emitting GHGs, the global average temperature would stop rising after a few years but remain elevated for many centuries. This is because the GHGs live for many years in the atmosphere. However, it might not be too late to avoid or reduce the worst impacts of climate change. Such actions would involve the following:

1. **Mitigation**: reduce the emissions of greenhouse gases into the atmosphere
2. **Adaptation**: come to terms with and adapt to the changing climate.

Many countries have set carbon-neutral targets to mitigate climate change effects. The European Union has set the target of zero greenhouse gas emissions by the year 2050. But these ambitions need to be transformed into actions. We need to reconsider the industrial operation, energy production and transport systems, and the whole way of life. We need to take action for the sake of our planet and the future of humanity.

2. Changes of climate in history and natural causes

Earth's climate has changed throughout history. Just in the last 800,000 years, there have been eight cycles of ice ages and warmer periods, with the end of the last ice age about 11,700 years ago marking the beginning of the modern climate era and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit (known as Milankovitch Cycles) that change the amount of solar energy our planet receives. Also, variation in the Sun's output radiation received on Earth due to solar cycles or else solar variability can play a role in Earth's climate. These two types of natural variations of climate are discussed below.

2.2 The effects of Milankovitch Cycles

There are three periodic motions of the Earth knowv as Milankovitch Cycles that contribute to a well-mathematically predictable amount of variation to the planet's climate over different time frames, ranging from tens of thousands to hundreds of thousands of years. Milankovitch cycles include the shape of Earth's orbit (its eccentricity), the angle that Earth's axis is tilted with respect to Earth's orbital plane (its obliquity), and the direction that Earth's spin axis is pointed (its precession). These cycles affect the amount of sunlight and therefore, energy, that Earth absorbs from the Sun. They provide a strong framework for understanding ***long-term*** changes in Earth's climate, including the beginning and end of the Ice Ages throughout Earth's history. The three cycles are briefly described below:

1. The shape of Earth's orbit around the Sun, known as **eccentricity** (100,000 years cycles). Earth's annual orbit around the Sun isn't perfectly circular. Over time, the pull of gravity from our solar system's two largest gas giant planets, Jupiter and Saturn, causes the shape of Earth's orbit to vary from nearly circular to slightly elliptical. Eccentricity measures how much the shape of Earth's orbit departs from a perfect circle. These variations affect the distance between Earth and the Sun.

When Earth's orbit is at its most elliptic, about 23 percent more incoming solar radiation reaches Earth at its closest approach to the Sun each year than at during its farthest departure from the Sun. Currently, Earth's eccentricity is near its least elliptic (most circular) and is very slowly decreasing, in a cycle that spans about 100,000 years. Every ~400,000 years, this change in eccentricity is even more pronounced.

The total change in global annual solar

7 https://www.unep.org/explore-topics/climate-action/what-we-do/climate-action-note/climate-action-progress.html

8 The Paris Agreement is an international treaty on climate change. Adopted in 2015, the agreement covers climate change mitigation, adaptation, and finance. The Paris Agreement was negotiated by 196 parties at the 2015 United Nations Climate Change Conference near Paris, France.

radiation due to the eccentricity cycle is very small. Because variations in Earth's eccentricity are fairly small, they're a relatively minor factor in annual seasonal climate variations.

2. The Earth's axis of rotation is tilted as it travels around the Sun, known as **obliquity (41,000 years cycles)**. Obliquity is why Earth has seasons. Over the last million years, it has varied between 22.1 and 24.5 degrees with respect to Earth's orbital plane, every ~41,000 years. Earth's axis is tilted because of the distribution of landmass on the planet, which makes the Northern Hemisphere heavier. The tilt of the Earth impacts how much solar radiation is absorbed by the planet at different latitudes. When Earth's axis is more upright with a lower angle of tilt, the poles receive less solar radiation.

The greater Earth's axial tilt angle, the more extreme our seasons are, as each hemisphere receives more solar radiation during its summer when the hemisphere is tilted toward the Sun, and less during winter when it is tilted away. Larger tilt angles favour periods of deglaciation (the melting and retreat of glaciers and ice sheets). These effects aren't uniform globally -- higher latitudes receive a larger change in total solar radiation than areas closer to the equator.

3. As Earth rotates, it wobbles slightly upon its axis, known as **axial precession** (**26,000 years cycles**). This wobble is due to tidal forces caused by the gravitational influences of the Sun and Moon that cause Earth to bulge at the equator, affecting its rotation. The cycle of axial precession spans about 26,000 years.

But Milankovitch cycles can't explain all climate change that's occurred over the past 2.5 million years or so. And more importantly, ***they cannot account for the current period of rapid warming Earth has experienced since the pre-Industrial period (the period between 1850 and 1900), and particularly since the mid-20th century. Scientists are confident Earth's recent warming is primarily due to human activities — specifically, the direct input of carbon dioxide into Earth's atmosphere from burning fossil fuels[9].***

2.3 How do we know Milankovitch cycles aren't causing the current change?

Milankovitch cycles operate on very long time scales, ranging from tens of thousands to hundreds of thousands of years. In contrast, Earth's current warming has taken place over time scales of decades to centuries. Over the last 150 years, Milankovitch cycles have not changed the amount of solar energy absorbed by Earth very much. In fact, NASA satellite observations show that over the last 40 years, solar radiation has actually decreased somewhat.

Finally, Earth is currently in an interglacial period (a period of milder climate between Ice Ages). If there were no human influences on climate, scientists say Earth's current orbital positions within the Milankovitch cycles predict our planet should be cooling, not warming, continuing a long-term cooling trend that began 6,000 years ago.

2.4 The effect of solar variability

The Sun is a gigantic sphere of hot gases rotating at an enormously fast rate. The Sun's gases are constantly moving. This motion creates a lot of activity on the Sun's surface, called solar activity that produces radiation and hence energy. Sometimes the Sun's surface is very active. Other times, things are a bit quieter. The amount of solar radiation changes with the stages in the solar cycle. Solar activity can have effects on Earth, so scientists closely monitor solar activity every day.

Scientists use a metric called Total Solar Irradiance (TSI) to measure the changes in energy the Earth receives from the Sun. TSI incorporates the 11-year solar cycle and solar flares/storms from the Sun's surface. Studies show that solar variability has played a role in past climate changes. For example, a decrease in solar activity coupled with increased volcanic activity helped trigger the Little Ice Age, a period of regional cooling, particularly pronounced in the North Atlantic region that occurred from the early 14th century through the mid-19th century.

Several lines of evidence show that current

9 https://climate.nasa.gov/ask-nasa-climate/2949/why-milankovitch-orbital-cycles-cant-explain-earths-current-warming/

global warming cannot be explained by changes in energy from the Sun:

- Since 1750, the average amount of energy from the Sun either remained constant or increased slightly.
- If a more active Sun caused the warming, scientists would expect warmer temperatures in all layers of the atmosphere. Instead, they have observed a cooling in the upper atmosphere and a warming at the surface and lower parts of the atmosphere. That's because greenhouse gases are slowing heat loss from the lower atmosphere because they trap it.
- Climate models that include solar irradiance changes can't reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases[10].

2.5. Effect of volcanoes

Volcanoes can affect the climate and impact climate change. During major explosive eruptions, huge amounts of volcanic material (gas, aerosol droplets, and ash) are injected very high into the atmosphere (reaching an atmospheric layer called "the stratosphere"; the stratosphere is the layer of atmosphere extending from about 10 km to 50 km (6-30 miles) in altitude). Then, the injected ash falls rapidly from the stratosphere towards the ground - most of it is removed within several days to weeks - and has little impact on climate change. **But volcanic gases like sulfur dioxide (SO_2) can stay at high atmospheric altitudes and reduce the air-temperature causing global cooling, while volcanic carbon dioxide, a greenhouse gas, has the potential to promote global warming.**

Sulfur dioxide released in contemporary volcanic eruptions has occasionally caused detectable **global cooling of the lower atmosphere** but carbon dioxide released in contemporary volcanic eruptions has never caused detectable global warming of the atmosphere. Examples of the most notable eruptions in the 20th century that resulted in the **most significant cooling events of the atmosphere** include that of **Novarupta**[11] (Alaska, June 6, 2012) and of **Mount Pinatubo** (Philippines, April 2, 1991).

There is no question that very large volcanic eruptions can inject significant amounts of carbon dioxide into the atmosphere. The 1980 eruption of Mount St. Helens released approximately 10 million tons of CO_2 into the atmosphere in only 9 hours. However, it currently takes humanity only 2.5 hours to emit the same amount. While large explosive eruptions like this are rare and only occur globally every 10 years or so, humanity's emissions are ceaseless and increasing every year.

Key message

The current warming trend evolves at a rate not seen over recent millennia. Meticulous analysis of paleoclimate data of tree rings, ocean sediments, coral reefs, layers of sedimentary rocks and ice cores (Antarctica, Greenland and mountain glaciers) yields that:

i) Climate does respond to the changes in atmospheric greenhouse gas concentrations

ii) Current warming is occurring roughly 10 times faster than the average rate of warming after an ice age.

iii) The annual rate of increase in atmospheric carbon dioxide over the past 60 years is about 100 times faster than previous natural increases, such as those that occurred at the end of the last ice age 11,000-17,000 years ago.

It is unequivocal[12] that GHGs emitted from human activities trap more solar energy in the atmosphere. Earth-orbiting satellites, surface monitoring networks and new technologies have allowed scientists to build knowledge about Earth's system, gathering data over many years that reveal the signs and patterns of a changing climate.

The claim that climate change is not happening is very hard to defend given the land-based and satellite datasets that clearly show rising average sea and land temperatures and shrinking ice masses worldwide.

10 https://climate.nasa.gov/causes/
11 https://www.nps.gov/articles/aps-v11-i1-c12.htm
12 https://climate.nasa.gov/faq/17/do-scientists-agree-on-climate-change/

3. Basic information about Climate Change

In this section, some basic information is provided to understand the concepts of atmosphere, weather, climate, the natural greenhouse effect, and the enhanced by the human activities greenhouse effect, aiming at elucidating the meaning of climate change.

3.1 Weather versus Climate

Weather refers to atmospheric conditions that occur locally over **short periods of time**—from minutes to hours or days. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure.

On the other hand, **climate** refers to the **long-term** (usually at least 30 years) local, regional or even global average values of temperature, humidity, and rainfall patterns over seasons, years, or decades. Thus, the climate is the average of weather over time and space. In short, the climate is the description of the long-term pattern of weather in a particular area.

When scientists talk about climate, they're looking at averages of precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather that occur over a long period in a particular place.

For example, after looking at rain gauge data, lake and reservoir levels, and satellite data, scientists can tell, if during summer, an area was drier than average. If it continues to be drier than normal over the course of many summers then it would likely indicate a change in the climate[13]. In addition to long-term climate change, there are shorter-term climate variations. This so-called **climate variability** can be represented by periodic or intermittent changes related to El Niño, La Niña, volcanic eruptions, or other changes in the Earth system.

When we talk about climate change, we talk about changes in long-term averages of weather.

13 https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html

3.2 What is the natural greenhouse effect?

The Earth's atmosphere is mainly composed of a mixture of only a few gases-nitrogen, oxygen, and argon; combined these three gases comprise more than 99.5% of all the gas molecules in the atmosphere. These gases which are most abundant within the atmosphere exhibit almost no effect on warming the Earth and its atmosphere since they do not absorb visible or infrared radiation. However, there are minor gases that comprise only a small portion of the atmosphere (about 0.43% of all air molecules, most of which are water vapor at 0.39%) that do absorb infrared radiation. These "trace" (very small quantities) gases contribute substantially to the warming of the Earth's surface and atmosphere due to their characteristic to absorb the infrared radiation emitted by the Earth (see below for details on the Greenhouse Effect). Since these trace gases influence the Earth in a manner somewhat similar to a greenhouse, they are referred to as GreenHouse Gases, or GHGs.

3.3 The mechanism explained

It is known that a greenhouse allows sunlight to enter while it retains the heat created to warm up the plants and air inside even during nighttimes. The atmospheric greenhouse effect is similar to that but instead of the glass walls and roof of a greenhouse, certain atmospheric gases absorb or else trap the sunlight i.e. energy from the Sun.

More precisely, about half the light energy reaching Earth's atmosphere passes through the air and clouds to the surface, where it is absorbed and radiated in the form of infrared heat. Most of this heat (~ 90%) is absorbed by atmospheric gases, which we call greenhouse gases (GHGs), and then re-radiated in all directions in the atmosphere warming the Earth. This process is called the natural greenhouse effect and it is beneficial as it maintains favorable living conditions for Earth's microbial, animal and plant inhabitants. Owing to this phenomenon, the Earth is much warmer than it would be without an atmosphere as the heat cannot escape to space[14], keeping the Earth's

14 https://www.britannica.com/science/greenhouse-effect

average temperature at approximately 15 degrees Celsius.

Naturally occurring GHGs are carbon dioxide, CO_2, methane, CH_4, nitrous oxide, N_2O, ozone, O_3, and water vapour, H_2O.

Key message

The atmosphere is important to maintaining heat on the surface of the Earth. Without the naturally occurring GHGs in the atmosphere, Earth's average temperature would be ~ -18 degrees Celsius instead of the ~+15 degrees Celsius it is now.

3.4 What is the enhanced greenhouse effect?

Changes observed in Earth's climate, since the mid-20th century, are driven by human activities.

Human activities – particularly burning fossil fuels (coal, oil and natural gas), agriculture and land clearing (e.g. deforestation) – are increasing the concentrations of GHGs in the atmosphere. Human activities do not only increase the naturally occurring GHGs (CO_2, CH_4, N_2O, O_3, H_2O) as previously mentioned but also introduce new chemical compounds that absorb heat in the atmosphere like **Chlorofluorocarbons (CFCs)**[15]. The higher greenhouse gas concentrations trap more heat in the atmosphere, they act like a blanket insulating the Earth, causing more **global warming** by increasing the Earth's average temperature and thus enhancing the greenhouse effect.

Since the pre-industrial period, human activities are estimated to have increased Earth's global average temperature by about 1 degree Celsius, a number that is currently increasing by more than 0.2 degrees Celsius per decade. The current global warming trend is unequivocally the result of human activity since the 1950s and is proceeding at an unprecedented rate over millennia.

3.5 Global warming versus climate change

The term "**global warming"** is not identical to the term "**climate change**".

Global warming drives climate change.

Heat is energy and when more energy is added to any system, it agitates it causing changes to take place. The global climate system depends on various systems or else components of the Earth (atmosphere, ocean, land and ecosystems) that are interconnected. Thus, adding heat energy into one system/component like the atmosphere causes the global climate as a whole to change.

The oceans cover more than 70 percent of the surface of the Earth. **Oceans exchange heat with the atmosphere and heat up.** Increased heating due to global warming causes more water to evaporate and form clouds inducing more in number and more energy-intensive storms. A warmer atmosphere makes glaciers, ice sheets, mountain snow and the Polar ice caps melt, raising sea levels. Also, changes in temperature alter the global patterns of wind that bring, for example, the monsoons in Asia and rain and snow around the world, making drought and unpredictable weather more common.

This is why scientists have stopped focusing just on global warming and now focus on the larger topic of climate change.

3.5.1 Greenhouse gases: a brief description

Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb the heat from the Sun (i.e. energy) (known as their "radiative efficiency"), and how long they stay in the atmosphere (known as their "lifetime"). Another term found frequently, when discussing GHGs, is that of 'Global Warming Potential".

The term ***Global Warming Potential*** **(GWP)** was developed to allow comparisons of the global warming impacts of different GHGs.

It provides a measure of how much energy the emissions of 1 tonne of a greenhouse gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon dioxide (CO2).

The larger the GWP, the more that a given greenhouse gas warms the Earth compared to CO2 over that time period. The time

15 https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/cfcs-ozone.html

period usually used for GWPs is 100 years.

The most common greenhouse gas is carbon dioxide. In fact, because it is so common, scientists use it as the benchmark or measure of things that warm the atmosphere.

The most important GHGs are:

Carbon dioxide, CO_2, a very important component of the atmosphere, is released through natural processes (like volcanic eruptions, outgassing from the oceans, animal and plant respiration, decomposition of organic matter, and forest fires) and through human activities any time something is burned (primarily the burning of fossils fuels like coal, oil and natural gas to generate energy). Fossil fuels like coal and oil contain carbon that plants pulled out of the atmosphere through photosynthesis over many millions of years; by burning fossil fuels, we are returning that carbon to the atmosphere in just a few hundred years. Human activities have increased the amount of CO_2 in the atmosphere by 50% since the Industrial Revolution began (1750). This sharp rise in CO_2 is the most important climate change driver over the last century. It is used as a marker by the United States Environmental Protection Agency, for example, because of its ubiquity. CO_2 can stay in the atmosphere for a long time between 300 and 1000 years. Carbon dioxide is assigned a Global Warming Potential, GWP, of 1.

Methane, CH_4, an important GHG, comes from both natural and human-caused sources. Methane is released during plant-matter breakdown in wetlands and from landfills and rice farming. Livestock animals emit methane from their digestion and manure. Leaks from fossil fuel production and transportation are another major source of methane, and natural gas is 70% to 90% methane. As a single molecule, methane is a far more effective greenhouse gas than carbon dioxide but is much less common in the atmosphere. The amount of methane in our atmosphere has more than doubled since pre-industrial times. Methane stays in the atmosphere approximately 10 years, but is a precursor of ozone (i.e., it helps form ozone). CH_4 has a GWP of 28-36.

Nitrous oxide, N_2O, is a potent greenhouse gas produced by farming practices, released during commercial and organic fertilizer production and use. Nitrous oxide also comes from burning fossil fuels and burning vegetation and has increased by 18% in the last 100 years. Nitrous oxide stays in the atmosphere for an average of 114 years. N_2O has a GWP of 265-298.

Chlorofluorocarbons, CFCs are manmade chemical compounds and entirely of industrial origin. They were used as refrigerants, solvents (a substance that dissolves others), and spray-can propellants. An international agreement, known as the Montreal Protocol[16], now regulates CFCs because they damage the ozone layer. Despite this, emissions of some types of CFCs spiked for about five years due to violations of the international agreement. Once members of the agreement called for immediate action and better enforcement, emissions dropped sharply starting in 2018. CFCs may remain in the atmosphere for 40-150 years. The GWP values for these gases can be in the thousands or tens of thousands.

Water vapor, H_2O, is the most abundant greenhouse gas, but because the warming ocean increases the amount of it in our atmosphere, it is not a direct cause of climate change. Rather, as other forcings[17] (like carbon dioxide) change global temperatures, water vapor in the atmosphere responds, amplifying climate change already in motion. Water vapor increases as Earth's climate warms. Clouds and precipitation (rain or snow) also respond to temperature changes and can be important feedback mechanisms as well.

Black carbon, BC, is in the form of solid particles of tiny diameter (not gas) and it is considered the second biggest contributor to global warming after CO_2 as it absorbs the Sun's heat millions of times more effectively than CO_2. It results from the incomplete combustion of fossil fuels and biofuels (industry, transport), and biomass (wildfires, residential traditional fires). After released

16 https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol

17 The term "forcing" is used to describe something acting upon Earth's climate that forces a change in how energy flows through it (such as long-lasting greenhouse gases). These gases slow outgoing heat in the atmosphere and cause the planet to warm because they trap it.

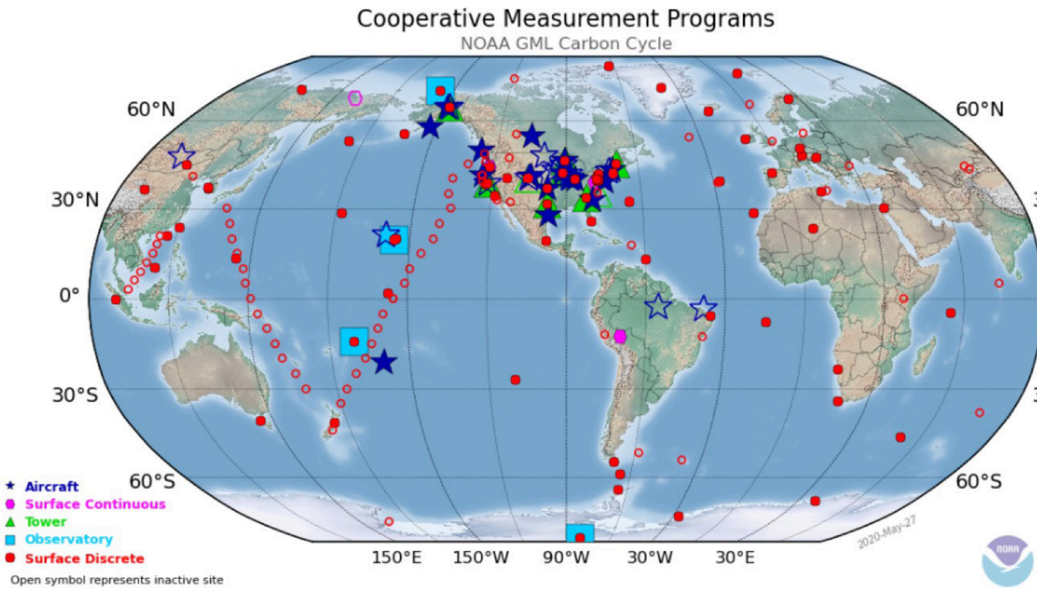


Figure 1

into the atmosphere, it stays a few days and then deposits on the Earth's surface. Black carbon is found worldwide, but its presence and impact are particularly strong in Asia. Concentrations of BC in the air cause also premature human mortality and disability as they pass from lungs into the bloodstream. The GWP values of BC range from 1,055–2,240 years.

3.5.2 How do we measure GHGs?

Scientists continuously measure the concentrations of GHGs worldwide using an observing system based on a combination of space-borne observations and ground-based monitoring networks. The measurements are thus performed in several ways using satellites, ground stations and devices mounted on ships, buoys, and airplanes (onboard regular passenger aircrafts)[18]. A number of networks have been formed that include a vast number of ground stations worldwide to record the concentrations of GHGs. An example of that is the Global Greenhouse Gas Reference Network, depicted in the figure below, which monitors the atmospheric distribution and trends of the three main long-term drivers of climate change, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Figure 1 has been adopted from NOAA, Global Monitoring Laboratory[19].

However, what is measured is the total concentration of gases emitted by both types of sources, natural and anthropogenic. To extract the anthropogenic contribution to rising GHG concentrations as accurately as possible, scientists continuously focus their efforts to challenge the current limitations in observation availability and methods.

The modern record of atmospheric CO_2 levels began with observations recorded at Mauna Loa Observatory[20] (at an altitude of 3400 m) in Hawaii, in the late 1950s. The figure below shows how the concentrations of CO_2 increase every year, as measured in Mauna Loa. The horizontal axis depicts the month of the measurement and the vertical axis the CO_2 concentration. The red line shows the monthly mean CO_2 values; the red line variability is due to the photosynthetic activity by plants. As plants begin to photosynthesize in the spring and summer, they consume (uptake) CO_2 from the atmosphere and eventually use it as a carbon source for growth and reproduction. This causes the decrease in CO_2 levels that begins every year in May. Once winter arrives, plants save energy by decreasing photosynthesis. The black line in the figure, which is the average of the red line, shows

18 Pinty B., P. Ciais, et al. (2019) An Operational Anthropogenic CO_2 Emissions Monitoring & Verification Support Capacity – Needs and high level requirements for in situ measurements, doi: 10.2760/182790, European Commission Joint Research Centre, EUR 29817 EN.

19 https://gml.noaa.gov/ccgg/about.html

20 https://gml.noaa.gov/obop/mlo/

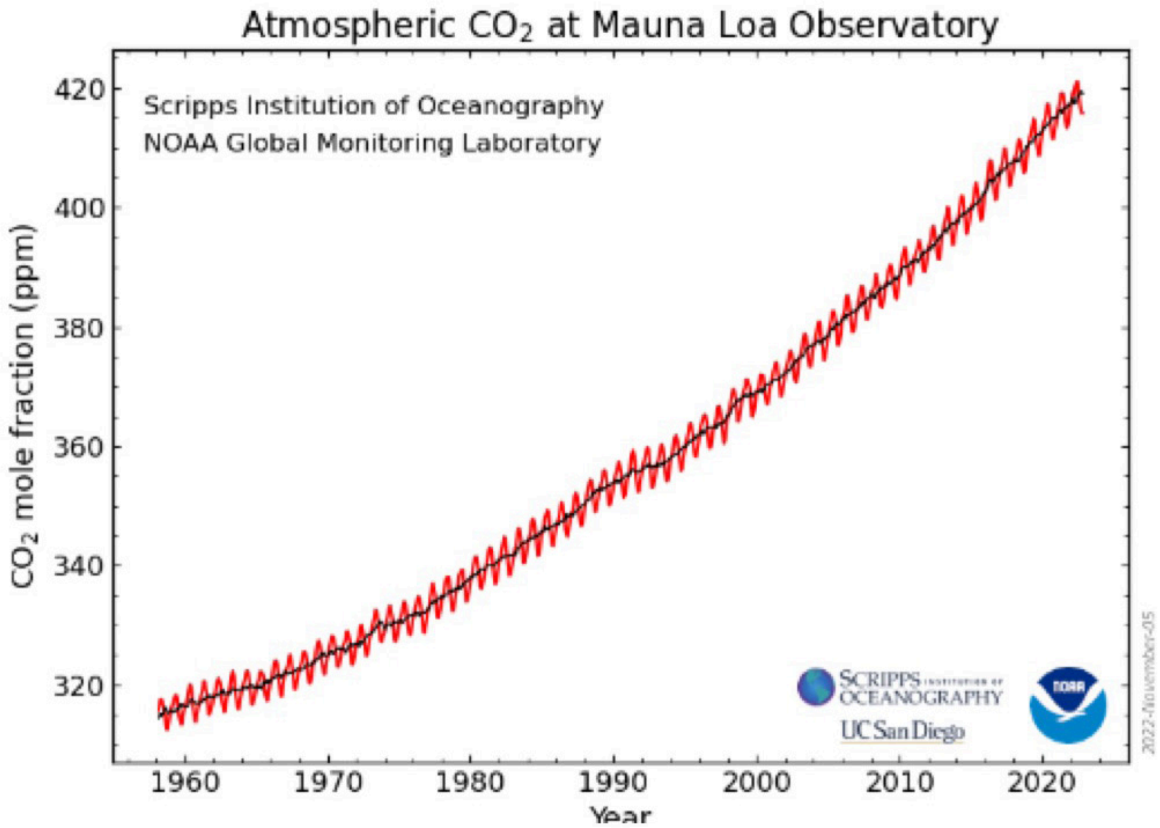


Figure 2

that there is an accelerating upward trend in CO_2 levels.

Figure 2 has been adopted from NOAA, Global Monitoring Laboratory.

Since the middle of the 20th century, annual emissions from burning fossil fuels have increased every decade, from an average of 3 billion tonnes of carbon (11 billion tonnes of carbon dioxide) a year in the 1960s to 9.5 billion tonnes of carbon (35 billion tonnes of carbon dioxide) per year in the 2010s, according to *the Global Carbon Update 2021*[21].

According to the IPCC AR6 report[22], in 2019, total releases of greenhouse gases from anthropogenic sources into the atmosphere were approximately estimated to be 59 billion tones, about 59% higher than the 1990 levels and 12% higher than those in 2010. The pie chart below shows graphically the percentage contribution of each GHG to the total emissions into the atmosphere from human activities.

21 https://climate.esa.int/en/news-events/carbon-emissions-rebound-in-2021-new-study-finds/#:~:text=Global%20fossil%20CO2%20emissions,after%20decreasing%205.4%20%25%20in%202020.

22 https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

Figure 3 shows a pie chart showing the percentage contribution of each GHG to the total emissions into the atmosphere from human activities, in 2019. Source IPCC AR6.

Emissions of GHGs have increased in most regions of the world but are distributed unevenly (see pie chart below), both in the present day and cumulatively since 1850.

Figure 4 shows a pie chart showing the percentage contribution of different regions in the world in 2019. Source IPCC AR6.

3.5.3 Carbon footprint

The **carbon footprint** is the total GHG emission into the atmosphere resulting from activities of individual humans, organizations, states, households, etc., **expressed in CO_2 equivalent**, for a specific period of time (month, year, decade, etc.).

CO_2 equivalent is a unique measure used to compare and add together emissions of all GHG (which have different global warming potentials, GWP, while the GWP of CO_2 is 1).

There are many simple applications available that can be used to calculate the carbon footprint. Here is an example of a web application available on the UN Carbon Offset Platform:

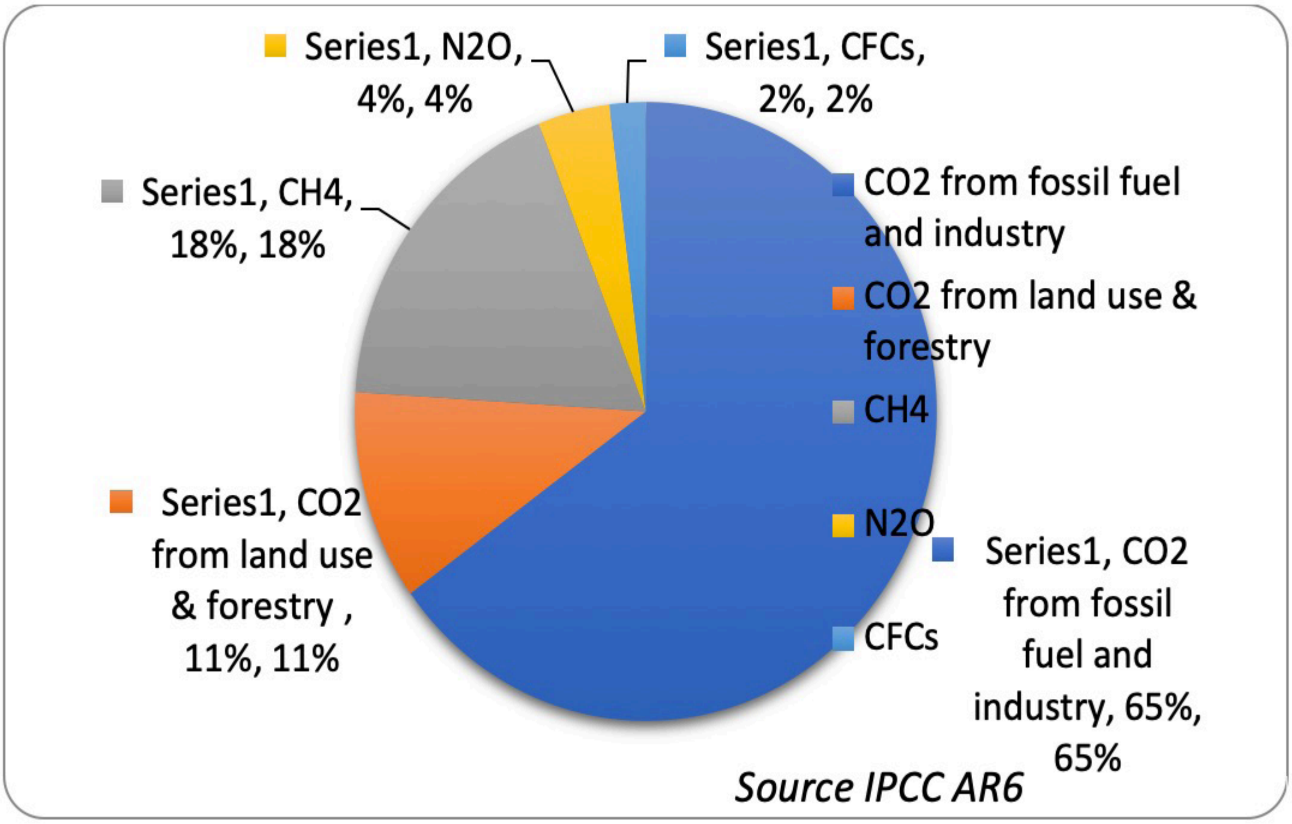


Figure 3

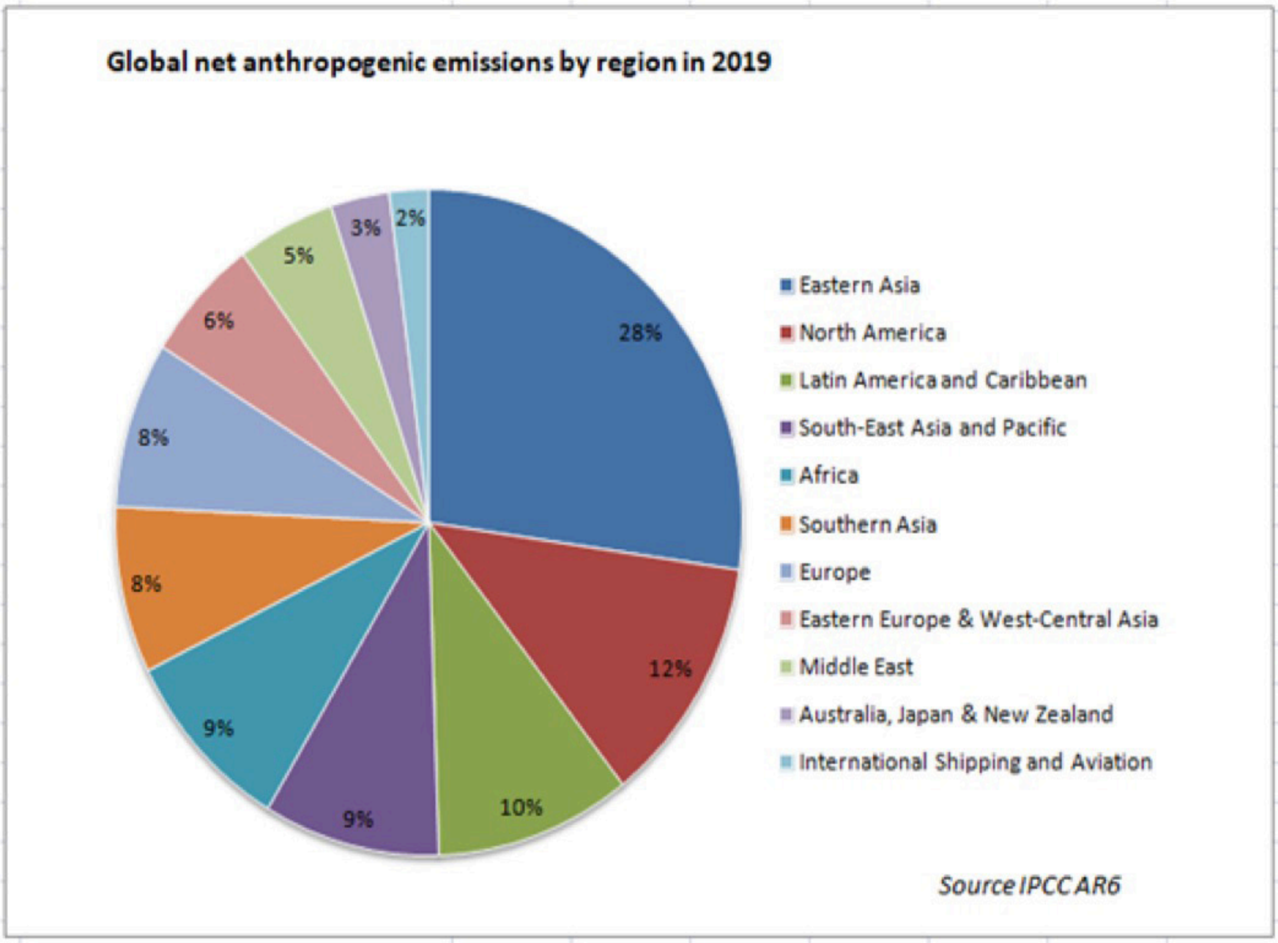


Figure 4

https://offset.climateneutralnow.org/footprintcalc

The average carbon footprint for a person in the United States is 16 tonnes, one of the highest rates in the world. Globally, the average carbon footprint is closer to 4 tonnes. To have the best chance of avoiding a 2º rise in global temperatures, the average global carbon footprint per year needs to drop to under 2 tons by 2050[23].

We can reduce our carbon footprint by starting to make small changes in our everyday lives. All of us use transport, wear clothes, eat food, and consume electricity and other goods of the modern era. However, the choices that each of us makes can make a difference. Some more activities are detailed in the last section.

3.6 How do we make future predictions about climate change?

It is very important to know how the climate system will evolve in order to make early decisions toward the reduction of GHG emissions and adaptation to changes. Scientists draw valuable information to understand Earth's climate mechanism and its changes by performing experiments and continuously collecting and analyzing measurements from observational systems. This knowledge is then translated into a computational code/program, called **Climate Model** with the use of programming language, which mimics how the weather patterns change over long time periods. In many ways, climate modelling is just an extension of weather forecasting, but focusing on changes over months, years and decades rather than hours.

There are two variants of global climate models, the **General Circulation Models (GCM)** and the **Earth System Model (ESM)**. A GCM generally represents physical processes occurring in the atmosphere, oceans, and the cryosphere, as well as the interactions between these domains, including changes in the Sun's energy output. In addition to representing oceanic and atmospheric dynamics, ESMs also include information on biogeochemical cycling in terrestrial and marine ecosystems. Therefore, an ESM can simulate how these components change over time in response to anthropogenic activity and changing climate conditions. There are also climate models that cover only parts or regions of the world, called regional climate models (RCM) that are used to study how climate change affects sectors like agriculture, diseases, and specific ecosystems, and for making plans to adapt to future climate change.

Scientists use climate models to simulate the climate in the past and to predict how the climate might change in the future, especially as human actions, like adding GHGs to the atmosphere, change the basic conditions of our planet. Climate models agree on many important facts about our observed climate. For instance, models reliably show that adding more greenhouse gases to the atmosphere will cause average temperatures to rise. Models also try to predict how climate change will affect rainfall, sea levels, ice cover, and other parts of the natural world.

Climate models are run on massive supercomputers because they require vast computing power. Simpler forms of climate models were built in the late 1950s and over time they have increased in complexity. **A climate model will have taken hundreds of scientists of different disciplines many years to build and improve.** Yet, the Earth's climate is too complex and there is no perfect model to describe it. Just as modern weather models cannot tell us with certainty whether it will rain next week, climate models can only predict a likely range of outcomes.

Nonetheless, **climate models are a crucial tool for understanding climate change, and are continually growing more detailed and accurate**. New discoveries in climate science are improving our understanding of natural climate processes, and providing more real-world data about the Earth's climate system, which allows for more accurate simulations of complex features like clouds, the water cycle, ocean currents and interactions between the different components of the Earth. At the same time, advances in computer technology are making it possible to simulate weather and climate patterns

23 https://www.nature.org/en-us/get-involved/how-to-help/carbon-footprint-calculator/

on finer spatial and temporal scales than ever before[24].

GHGs emissions scenarios: plausible patterns of future GHG emissions

To describe in quantitative terms the anthropogenic activity in the climate models, scientists have compiled scenarios of GHG concentrations that change over time depending on a number of different assumptions of changes in global and regional socio-economic activities. These scenarios are, therefore, estimates of plausible, quantitative evolutions of all GHGs emissions - known as representative concentration pathways - globally from the present time to the end of the 21st century. These estimates are based on population growth, urbanization, global energy production, land use, trade, technological advances and the world economy[25].

The most updated GHG concentration pathways developed by the Intergovernmental Panel on Climate Change (IPCC) and central to the work of the UN climate reports are the Shared Socioeconomic Pathways (SSPs). There are five key SSPs (SSP1-SSP5) that are used in the research, which scenarios differ in their assumptions about socioeconomic and technological development in the coming decades.

They present baselines of how things would look in the absence of climate policy, and allow researchers to examine barriers and opportunities for climate mitigation and adaptation in each possible future world when combined with mitigation targets[26].

More details about the SSPs and the resulting emissions and global average temperature changes can be found below.

SSP1: Sustainability – Taking the Green Road

SSP1 provides the most positive scenario for both human development and environmental action. *The world shifts gradually, but pervasively, toward a more sustainable path.* We continue to see improvements in education and health across the world; large reductions in poverty; and a shrinking in global inequalities. This is a scenario in which the researchers at the same time envision that the world is moving into a much more sustainable direction.

GHG emissions peak between 2040 and 2060 – even in the absence of specific climate policies, declining to around 22 to 48 gigatonnes of CO2 (GtCO2) per year by 2100. This results in 3-3.5 °C of warming by 2100.

SSP2: Middle of the Road

The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceed unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals.

GHG emissions continue to increase through the end of the century, reaching between 65 GtCO2 and 85 GtCO2, with resulting warming of 3.8-4.2 °C.

SSP3: Regional Rivalry – A Rocky Road

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. A pessimistic scenario.

GHG emission increases up to around 76-86 GtCO2 by 2100 and global warming estimated at 3.9-4.6°C.

24 https://climate.mit.edu/explainers/climate-models
25 https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide
26 https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

SSP4:
Inequality – A Road Divided

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour-intensive, low-tech economy. Technology development is high in the high-tech economy and sectors. A pessimistic scenario. **GHG emissions range from 34 GtCO2 to 45 GtCO2 by 2100, with a warming of 3.5-3.8°C.**

SSP5:
Fossil-fuelled development

SSP5 is similarly optimistic to SSP1 in terms of development but achieves this through a large use of fossil fuels. This is therefore leading to continued large negative effects on the environment.

The highest emissions range from 104 GtCO2 to 126 GtCO2 in 2100, resulting in a warming of 4.7-5.1°C.

4. Which are the impacts of climate change?

Climate change impacts are happening and have become important as they interact with the various systems of nature and sectors of society causing significant changes. According to IPCC[27], the observed impacts of climate change are summarized to the following sectors:

1. Ecosystems and biodiversity
2. Extreme Weather events
3. Food systems, food security and forests
4. Water systems and water security
5. Health and well-being
6. Migration and displacement
7. Human vulnerability
8. Cities, settlements and infrastructure
9. Economic sectors

27 https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_TechnicalSummary.pdf

Below follows a short discussion on the above listed impacts.

4.1 Ecosystems and biodiversity

Ecosystems all around the world have been impacted by climate change according to scientific evidence. The changes have altered marine, terrestrial and freshwater ecosystems according to the latest IPCC report [19]. The effects are more widespread with more far-reaching consequences than anticipated. Biodiversity is a term that means the variety of life on Earth, in all its forms. Biological diversity responses, including changes in physiology, growth, abundance, geographic placement and shifting seasonal timing, are often not sufficient to cope with recent climate change. Climate change has caused increases in areas burned by wildfire and the loss of local species, increased diseases, and driven mass mortality of plants and animals, resulting in the first climate-driven extinctions.

Climate-driven impacts on ecosystems[28] have caused measurable economic and livelihood losses and have altered cultural practices and recreational activities around the world.

On land, higher temperatures have forced animals and plants to move to higher elevations or higher latitudes, many moving towards the Earth's poles, with far-reaching consequences for ecosystems. The risk of species extinction increases with every degree of warming.

In the ocean, rising temperatures increase the risk of irreversible loss of marine and coastal ecosystems. Live coral reefs, for example, have nearly halved in the past 150 years, and further warming threatens to destroy almost all remaining reefs.

Overall, **climate change affects the health of ecosystems**, influencing shifts in the distribution of plants, viruses, animals, and even human settlements. This can create increased chances for animals to spread diseases and for viruses to spill over to humans. Human health can also be affected by reduced ecosystem services, such as the loss of food, medicine and livelihoods provided by nature.

28 https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_CCP1.pdf

4.2 Extreme weather events

Human-induced climate changes have increased the frequency and/or intensity and/or duration of extreme weather events, including droughts, wildfires, terrestrial and marine heatwaves, cyclones (and floods causing widespread and severe loss and damage to human populations and natural systems. Extremes are surpassing the **resilience** of some ecological and human systems and moreover, they are challenging the **adaptation** capacities of others.

Climate-related extremes have affected the productivity of the agricultural, forestry and fishery sectors. Droughts, floods, wildfires and marine heatwaves contribute to reduced food availability and increased food prices, threatening the food security, nutrition and livelihoods of millions of people across regions.

Extreme climatic events have been observed in all inhabited regions, with many regions experiencing unprecedented consequences, particularly when multiple hazards occur at the same time or within the same space. Climate-related extreme events are followed by negative impacts on mental health, well-being, life satisfaction, happiness, cognitive performance and aggression in exposed populations.

4.3 Food systems, food security and forestry

Climate change is already stressing food and forestry systems, with negative consequences for the livelihoods, food security and nutrition of hundreds of millions of people, especially in low (areas near the Earth's equator) and mid-latitudes. The global food system is failing to address food insecurity and malnutrition in an environmentally sustainable way.

Climate change impacts are negatively affecting agriculture, forestry, fisheries and aquaculture, increasingly hindering efforts to meet human needs.

Warming is negatively affecting crop and grassland quality and harvest stability. Warmer and drier conditions have increased tree mortality and forest disturbances in many temperate and boreal biomes. Ocean warming has decreased the sustainable yields of some wild fish populations by 4.1% between 1930 and 2010. Ocean acidification and warming have already affected farmed aquatic species.

The impacts of climate change on food systems affect everyone, but some groups are more vulnerable.

4.4 Water systems and water security

Currently, roughly half of the world's population is experiencing severe water scarcity for at least 1 month per year due to climatic and other factors. Water insecurity is manifested through climate-induced water scarcity and hazards and is further exacerbated by inadequate water governance. Extreme events and underlying vulnerabilities have intensified the societal impacts of droughts and floods, negatively impacted agriculture and energy production and increased the incidence of water-borne diseases. The economic and societal impacts of water insecurity are more pronounced in low-income countries than in middle- and high-income ones.

Climate change has intensified the global hydrological cycle, causing several societal impacts, which are felt disproportionately by vulnerable people. Worldwide, people are increasingly experiencing unfamiliar precipitation patterns, including extreme precipitation events. Furthermore, the glaciers are melting at unprecedented rates, causing negative societal impacts among communities that depend on cryospheric water resources. The cryosphere change has affected ecosystems, water resources, livelihoods and cultural uses of water in all cryosphere-dependent regions across the world.

The climate-induced changes in the hydrological cycle have negatively impacted freshwater and terrestrial ecosystems. Climate trends and extreme events have had major impacts on many natural systems. More specifically, the climate-induced trends and extremes in the water cycle have impacted agricultural production positively and negatively, with negative impacts outweighing the positive ones. Droughts, floods and rainfall variability have contributed to reduced food availability and increased food prices, threatening food and nutrition security, and the livelihoods of millions globally. Drought years have reduced thermoelectric and hydropower production by around 4–5% compared to long-term average production since the 1980s.

Changes in temperature, precipitation and water-related disasters are linked to increased incidences of waterborne diseases such as cholera, especially in regions with limited access to safe water, sanitation and hygiene infrastructure.

4.5 Health and well-being

Climate change has already harmed human physical and mental health. Women, children, the elderly, Indigenous People, low-income households and socially marginalised groups within cities, settlements, regions and countries are the most vulnerable. Observed mortality from floods, drought and storms is 15 times higher for countries ranked as highly vulnerable compared to less vulnerable countries in the last decade. Mental health challenges increase with warming temperatures, trauma associated with extreme weather and loss of livelihoods and culture.

Increasing temperatures and heatwaves have increased mortality and morbidity, with impacts that vary by age, gender, urbanisation and socioeconomic factors. Extreme climate events have been key drivers in the rising under-nutrition of millions of people, primarily in Africa and Central America.

Climate-related food safety risks have increased globally. These risks include Salmonella, Campylobacter and Cryptosporidium infections, mycotoxins associated with cancer and stunting in children, and seafood contamination with marine toxins and pathogens.

Higher temperatures, heavy rainfall events and flooding are associated with increased water-borne diseases, particularly diarrhoeal diseases, including cholera and other gastrointestinal infections (high confidence) in high-, middle- and low-income countries. Climate change-driven range shifts of wildlife, exploitation of wildlife and loss of wildlife habitat quality have increased probabilities for pathogens to spread from wildlife to human populations, which has resulted in increased emergence of zoonotic disease (transmitted to humans from animals), epidemics and pandemics. Zoonoses that have been historically rare or never documented in Arctic and sub-Arctic regions of Europe, Asia and North America are emerging as a result of climate-induced environmental change.

Several chronic, non-communicable respiratory diseases are climate-sensitive based on their exposure pathways (e.g., heat, cold, dust, small particulates, ozone, fire smoke and allergens), although climate change is not the dominant driver in all cases.

4.6 Migration and displacement

Climate hazards associated with extreme events (drought, tropical storms and hurricanes, heavy rains and floods) and variability act as direct drivers of involuntary migration and displacement and as indirect drivers through deteriorating climate-sensitive livelihoods. Most climate-related displacement and migration occur within national boundaries, with international movements occurring primarily between countries with contiguous borders. Since 2008, an annual average of over 20 million people has been internally displaced annually by weather-related extreme events, with storms and floods being the most common.

Extreme climate events act as both direct drivers (e.g., destruction of homes by tropical cyclones) and indirect drivers (e.g., rural income losses during prolonged droughts) of involuntary migration and displacement. The largest absolute number of people displaced by extreme weather each year occurs in Asia (South, Southeast and East), followed by sub-Saharan Africa, but small island states in the Caribbean and South Pacific are disproportionately affected relative to their small population size.

4.7 Human vulnerability

Vulnerability significantly determines how climate change impacts are being experienced by societies and communities. Vulnerability to climate change is a multi-dimensional, dynamic phenomenon shaped by intersecting historical and contemporary political, economic and cultural processes of marginalisation.

Societies with high levels of inequity are less resilient to climate change. About 3.3 billion people are living in countries with high human vulnerability to climate change.

Climate variability and extremes are associated with more prolonged conflict through food price increases, food and water insecurity, loss of income and loss of livelihoods, with more consistent evidence for low-intensity organised violence within countries than for major or international armed conflict.

4.8 Cities, settlements and infrastructure

Cities and settlements (particularly unplanned and informal settlements and in coastal and mountain regions) have continued to grow at rapid rates and remain crucial as concentrated sites of increased exposure to risk and increasing vulnerability. More people and key assets are exposed to climate-induced impacts, and loss and damage in cities, settlements and key infrastructure since the previous decade.

Such impacts of climate change include sea level rise, heatwaves, droughts, changes in runoff, floods, wildfires and permafrost thaw that cause disruptions of key infrastructure and services like energy supply and transmission, communications, food and water supply and transport systems in and between urban and peri-urban areas. The most rapid growth in urban vulnerability and exposure has been reported in cities and settlements where adaptive capacity is limited, including informal settlements in low- and middle-income communities and in smaller and medium-sized urban communities.

4.9 Economic losses

The effects of climate change impacts have been observed across several economic sectors, although the magnitude of the damage varies by sector and by region. Recent extreme weather and climate-induced events have been associated with large costs through damaged property and infrastructure, and supply chain disruptions, although development patterns have driven much of these increases. Adverse impacts of extreme weather events on economic growth have been identified with large effects mainly in developing countries. Widespread climate impacts have undermined economic livelihoods, especially among vulnerable populations. Climate impacts and projected risks have been insufficiently internalized into private- and public-sector planning and budgeting practices and adaptation finance.

Key message

Changes in temperature, rainfall, and extreme weather have increased the frequency and spread of diseases in wildlife, agriculture, and people. We see a lengthening wildfire season and increases in the area burned. Roughly half of the world's population currently experiences severe water shortages at some point during the year, in part due to climate change and extreme events such as flooding and droughts. Drought conditions have become more frequent in many regions, negatively affecting agriculture and energy production from hydroelectric power plants.

People living in cities nowadays face higher risks of heat stress, reduced air quality because of wildfire, lack of water, food shortages and other impacts caused by climate change and its effect on supply chains, transport networks and other critical infrastructure. Globally, climate change is increasingly causing injuries, illness, malnutrition, threats to physical and mental health and well-being, and even deaths. It is making hot areas even hotter and drastically reducing the time people can spend outside, which means that some outdoor workers cannot work the required hours and thus will earn less.

Climate change impacts are expected to intensify with additional warming. It is also an established fact that they are interacting with multiple other societal and environmental challenges.

5. What changes are expected in the future?

According to the latest assessment report of IPCC (AR6), many changes in the climate system are becoming greater in direct connection with increasing global warming. A summary of the projected changes is provided below:

- Under all emission scenarios considered, the global surface temperature will continue to rise until at least the middle of the century. Global warming of 1.5°C and 2°C will be exceeded over the course of the 21st century unless greenhouse gas emissions are greatly reduced in the coming decades. The last time the global surface temperature was 2.5°C or more above the 1850–1900 level was over 3 million years ago.
- More specifically, compared to 1850–1900, the global surface temperature is very likely to rise by 1.0°C to 1.8°C on average over the years 2081–2100 in a scenario with very low greenhouse gas emissions. With medium greenhouse gas emissions, the temperature will rise by 2.1°C to 3.5°C. In the scenario of very high greenhouse gas emissions, the increase will increase by around 3.3°C to 5.7°C.
- Changes in climate include the increase in the frequency and intensity of extreme heat waves, heavy precipitation and, in some regions, agricultural and ecological droughts. On a global scale, it is projected that extreme daily precipitation events will increase by about 7% per 1°C of global warming.
- An increase in the proportion of intense tropical cyclones and a decline in Arctic sea ice, snow cover and permafrost are foreseen.
- It is almost certain that mean global sea levels will continue to rise in the 21st century. Compared to 1995–2014, the likely rise in global mean sea level by 2100 is 0.28–0.55 m in the very low greenhouse gas emission scenario; in the scenario with medium greenhouse gas emissions 0.44–0.76 m, and with very high greenhouse gas emissions the increase will be 0.63–1.01 m.
- In the next years, the global mean sea level will rise by about 2 to 3 m if global warming is limited to 1.5°C. It will rise by 2 to 6 m if it is limited to 2°C and by 19 to 22 m if increased to 5°C.
- Many changes due to past and future greenhouse gas emissions are irreversible over centuries to millennia – especially changes in the oceans, ice sheets and global sea levels. In the longer term, due to the continued warming of the deep sea and the melting of ice sheets, sea levels will rise for centuries to millennia and will remain elevated for thousands of years.

Key message

Climate change will impact water quality and availability for hygiene, food production and ecosystems due to floods and droughts.
Multiple climate hazards will occur simultaneously more often in the future. They may reinforce each other and result in increased impacts and risks to nature and people that are more complex and more difficult to manage. Climate change impacts will continue to increase if drastic cuts in greenhouse gas emissions are further delayed. But science is also clear: with immediate action now, drastic impacts can still be prevented.

6. Climate change adaptation

Climate change risks and impacts can be reduced, within limits, if humans and nature adapt to the changing conditions. The scale and scope of actions to reduce climate risks (adaptation) have increased worldwide. Individuals and households along with communities, businesses, religious groups and social movements are adapting to climate change already. However, the latest IPCC report (AR6) identifies large gaps between ongoing efforts, and adaptation needed to cope with current levels of warming, with the scale of the challenge varying in different regions. The report also highlights that the effectiveness of available adaptation options decreases with every increment of warming. Successful adaptation requires urgent, more ambitious and accelerated action and, at the same time, rapid and deep cuts in greenhouse gas emissions. The quicker and further emissions fall, the more scope there is for people and nature to adapt. From a scientific point of view, limiting man-made global warming to a certain level requires a limit of cumulative CO2 and other greenhouse gas emissions. At the minimum, a net zero value for greenhouse gas emissions must be achieved!

Adaptation for plants and animals means either adjusting to the changing climate and its effects by spending more time and energy on life-sustaining measures (like regulating their body temperature, selecting cooler places or staying hydrated) or, if possible, shifting to regions where environmental conditions are still in the climatic range that organisms are used to. For people and society, adaptation to climate change means adjusting our behaviour (e.g. where we choose to live; the way we plan our cities and settlements) and adapting our infrastructure (e.g. greening of urban areas for water storage) to deal with the changing climate - today and in the future.

Adapting successfully requires an analysis of risks caused by climate change and the implementation of measures in time to reduce these risks. The good news is that awareness and assessment of current and future climate risks have increased worldwide. National and local governments as well as corporations and civil society acknowledge the growing need for adaptation.

6.1 Some examples of ways to adopt to climate crisis

Our economies and societies need to become more resilient to climate change impacts. This will require large-scale efforts, many of which should be orchestrated by governments. **National Adaptation Plans**[29] are a crucial governance mechanism for countries to plan for the future and strategically prioritize adaptation needs. The UN Environment Programme (UNEP) and partners launched a global movement to restore the world's ecosystems in 2021 called the "**UN Decade on Ecosystem Restoration**"[30]. This global restoration effort will not only absorb carbon but also increase 'ecosystem services' to defend the world from its most devastating impacts.

Roads and bridges may need to be built or adapted to withstand higher temperatures and more powerful storms. Some cities on coastlines may have to establish systems to prevent flooding in streets and underground transport. Mountainous regions may have to find ways to limit landslides and overflow from melting glaciers. Re-greening mountain slopes protects communities from climate-induced landslides and avalanches. Some communities may even need to move to new locations because it will be too difficult to adapt. This is already happening in some island countries facing rising seas. Scientific studies report that by 2030, one-in-two people are expected to face severe water shortages[31]. Investing in more efficient irrigation will be crucial, as agriculture accounts for 70% of all global freshwater withdrawals. In urban centres, roughly 100-120 billion cubic metres of water could be saved globally by 2030 by reducing leaks.

In cities, restoring urban forests cools the air and reduces the effects of heatwaves. Individuals can take some simple measures. One could plant or preserve trees around his /her home, for instance, to keep temperatures cooler inside. On a normal sunny day, a single tree provides a cooling effect equivalent to two domestic air conditioners running for 24 hours. Clearing bush might reduce fire hazards. A business owner may start thinking about and planning around possible climate risks, such as hot days that prevent workers from doing outside tasks.

Everyone should be aware of the possibly greater potential for natural disasters where they live and what resources they

29 https://www.unep.org/explore-topics/climate-action/what-we-do/climate-adaptation/national-adaptation-plans

30 https://www.decadeonrestoration.org/

31 https://www.unep.org/news-and-stories/press-release/half-world-face-severe-water-stress-2030-unless-water-use-decoupled

have in case these happen. That might mean purchasing insurance in advance, or knowing where you can get disaster information and relief during a crisis.

Evidence shows that one of the most powerful ways to adapt to climate change is to invest in **Early Warning Services (EWS)** so that we know in advance when a storm, cold spell, heatwave, flooding or dry period is coming. By developing EWS, we can avoid human and economic losses. Research shows that just 24 hours of warning of an oncoming heatwave or storm can reduce the subsequent damage by 30%[32]. Early warning systems that provide climate forecasts are one of the most cost-effective adaptation measures, yielding around nine dollars of total benefits for every dollar invested.

7. Climate change mitigation

Measures to reduce GHG emissions and enhance sinks are referred to as "mitigation". Many of these measures refer to energy efficiency in the construction industry, the use of renewable energy sources, sustainable forest utilization and more efficient transport, etc. To preserve a livable climate, greenhouse-gas emissions must be reduced by half by 2030 and to net zero by 2050. But the transition to a low-carbon world also requires the participation of citizens – especially in advanced economies.

Reducing GHG emissions across the full energy sector requires major transitions, including a substantial reduction in overall fossil fuel use, the deployment of low-emission energy sources, switching to alternative energy carriers, and energy efficiency and conservation. Electricity systems powered predominantly by renewables are becoming increasingly viable[33].

7.1 Individual activities to mitigate climate change

Around two-thirds of global GHG emissions are linked to private households. The electricity we use, the food we eat, the way we travel, and the things we buy all contribute to a person's "carbon footprint," the amount of greenhouse gas emissions associated with an individual's activities.

Here are some suggestions as to what each individual can do to help reduce GHG emissions.

- Reduce your Carbon Footprint from driving. Use a bike or public transport instead of a car whenever possible. Drive a low-carbon vehicle. Electric cars emit no CO2 if they're charged with clean electricity (from renewable sources).
- Take fewer connecting flights.
- Use less energy by lowering your heating and cooling, switching to energy-efficient electric appliances, washing your laundry with cold water, or hanging things to dry instead of using a dryer. Replace old bulbs with modern LED bulbs that consume less energy, produce the same amount of light, and last much longer.
- Make sure that you correctly regulate the temperature on the thermostats of a thermoregulation device. Immediately shut the refrigerator door. Improve your home's energy efficiency, through better insulation.
- Turn off the lights, TV sets and computers when you do not need them.
- Unplug all adapters and chargers from the electricity supply sockets.
- Eat locally-produced and organic food. High emissions of GHGs result from the production and transport of food. Transporting food requires petroleum-based fuels, and many fertilizers are also fossil fuel-based.
- Reduce the beef and dairy products. It takes a lot of resources to raise cows, and it's especially bad if you buy beef from somewhere like Brazil, where it was grazed on land that used to be tropical forest but was cleared for agricultural use. Deforestation is a top contributor to carbon emissions and thus climate change.
- Throw away less food. When you throw food away, you're also wasting the resources and energy that were used to grow, produce, package, and

32 https://gca.org/wp-content/uploads/2019/09/GlobalCommission_Report_FINAL.pdf

33 https://www.ipcc.ch/report/ar6/wg3/

transport it. And when food rots in a landfill, it produces methane, a powerful greenhouse gas. So use at most what you buy and compost any leftovers.

- Reuse and Recycle whenever possible. A considerable amount of GHG emissions results from the "provision of goods," which means the extraction of resources, manufacturing, transport, and final disposal of "goods" which include consumer products and packaging, building components, and passenger vehicles, (but excluding food). By buying used products and reselling or recycling items you no longer use, you dramatically reduce your carbon footprint from the "provision of goods."
- Use as little paper as possible, because that is how you can save trees.
- Use tap water as much as possible. Take water with you in recyclable bottles. Make water-efficient choices when purchasing shower heads, faucet heads, toilets, dishwashers and washing machines.
- Buy products that do not require robust packaging.
- Plant a tree.
- Install solar panels on the roof to generate energy for your home.
- Support clean energy sources. Whenever you can, advocate for clean alternatives to fossil fuels, such as wind, solar, geothermal, and appropriately designed hydroelectric and biomass energy projects.

Chapter 2

Instructions on how to continue the comic

The Climatopia Research Team
University of the Aegean
Greece


ROBOTICS LAB
TECHNOLOGY LAB
ELECTRICITY
ENGINEERING
COMPUTER LAB
CHEMISTRY LAB
NEW CONTINENT
GREAT CONTINENT

In this chapter teachers will find useful instructions on how to help their students to create their own comic strips.

The length of the comic strips will be decided by the students. According to the available means and their preferences the students can either choose to use paper, pencil, ink and colors or an application that allows them to create a digital comic.

Teachers should be aware from the outset that:

- Comics are informal and often read for fun.
- Comics are a unique blend of dynamic illustration and descriptive text.
- Comics can be rich literary/artistic resources.
- Comics are about telling stories.

Paper and pencil comic

The classic way of making a comic is by using paper and pencil. At class level the teacher says to the students something like:

"The comic has not ended. You will decide what will be the end of the story. The three friends along with the other kids leave the Research Center and return to their homes. They have experienced a lot and have a thorough understanding of the problem of climate change. They followed the Four Elements to six different environments (homes, schools, work, city hall, the meeting of the Middle Epirus Countries and the Conference of 20) and discovered some major problems related to these environments, regarding the climate crisis in Climatopia. They are strongly convinced that young people need to take action to change the future of Climatopia. Are they going to do something for this? Will they succeed in preventing future crises? Let's travel in time and look at these six different environments in two future moments: after 10 years and after 80 years. Imagine what will happen at the two houses, the two schools, the farm, what the town councilors and the countries' leaders will be discussing at these two future moments."

The teacher then asks the students to continue the comic following eight steps.

Step 1: Deciding about the concept of the comic

At class level the teacher asks the students to

The ending of the CLIMATOPIA comic, in which the disappointed children walk away from a fruitless discussion imagine the future of Climatopia. Students are asked to provide answers:

a. What the future of Climatopia would be: Climatopians will take steps to a better future or the planet is heading to a total climate disaster.

b. What the role of the three friends and the other kids would be: Will they try to inform and activate their communities and the world to take drastic measures and save Climatopia or will they fail and life on Climatopia will become unaffordable?"

c. The students might come up with another slant that interests them, and that does not necessarily answer questions a and b. They should be allowed to explore this, letting their imaginations run free.

Step 2: Group formation

The students are divided in groups. Depending on their number each group will undertake to continue the comic story at one or two of the six environments. The teacher asks:

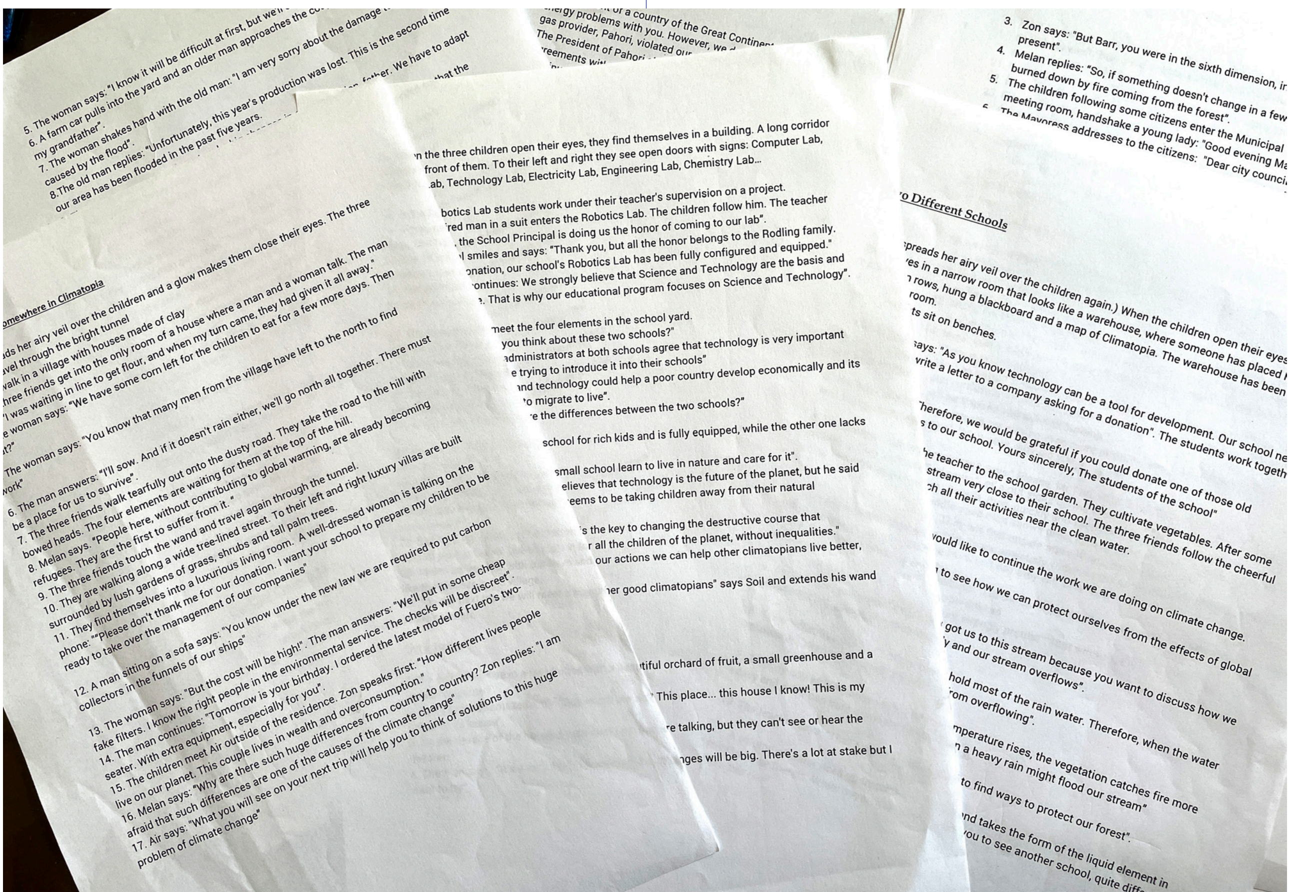
"Now that you decided what the future of Climatopia would be, you have to continue the comic book. Each group will continue one (or two) of the stories. You have to imagine what would happen to the climatopians at the six different environments at two different future moments (for example, after 10 years, or after 40 years, and then after 80 years)".

Step 3: Developing the plot

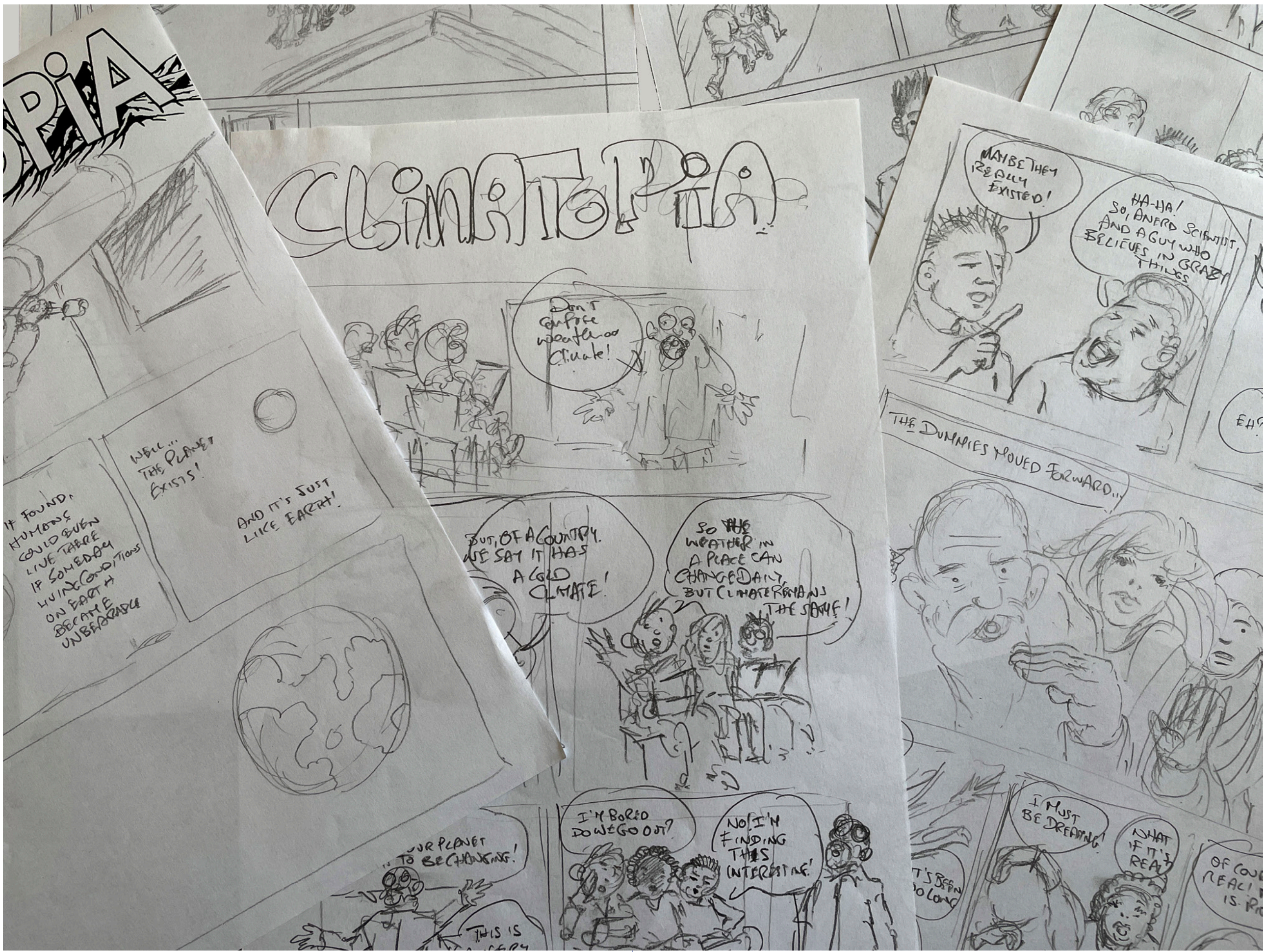
Based on the general idea of what the future of Climatopia would be, the students at each group write down the outline of the plot. The plot should provide answers to the questions: a. **when** the plot takes place (10 or 80 years after the students have returned to their homes), b. **where** it happens (e.g., in the rich school, at the Townhall etc.), c. **who** is involved, that is, which are the characters of the story and d. **what** do the character do and say. The students may discuss and decide about the plot. One of them undertakes the responsibility to write the whole plot or just to make short notes about.

Step 4: Script writing

One or two members of the group write the script, that is they break the plot in a sequence of scenes. They write a short description of each scene, including the



The original script for the CLIMATOPIA comic, written by Dr Christos Ioannides



Preliminary rough sketches for the CLIMATOPIA comic laid out by Dr Ġorġ Mallia

dialogues. The dialogues should be short enough to fit in the "balloons". The script is the basis for everything that follows.

Step 5. Roughs

The member of the group who is more efficient at sketching produces the comic based on the script.

First, he/she divides the paper page in equal frames. If A4 pages are used, they could be divided into six or eight equal frames, although sometimes a few larger frames may be required for larger scenes. The frames should not tangent each other but there should be a small gap between them.

Then very rough sketches of the way the action should be portrayed in the panels should be laid down.

Since they are drawn very fast, which is why they are rough, this will give the group a first glance as to how the visual story will flow across the page.

All of the comic should be done in this way before the next step is attempted.

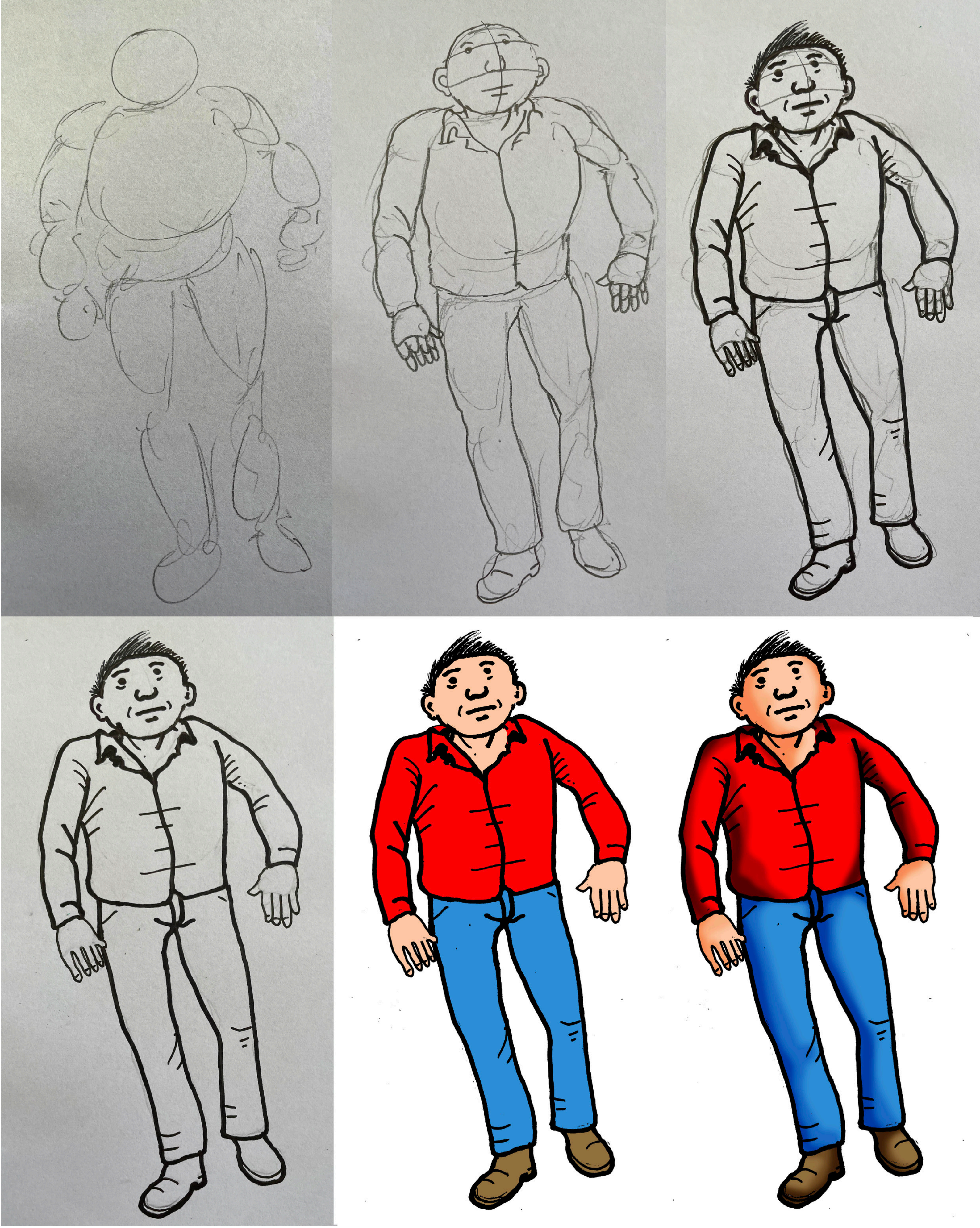
Step 6. Penciling

Once the roughs are all done, the artist of the group can capture the scenes in the frames using a pencil ("penciling"), following the script and verbal instructions of the script writers (of course, the "penciler" could be one of the script writers).

These pencils can be done as tight, finished drawings over the rough sketches. But the best way to do this is to trace the rough sketches onto new sheets of paper, tightening the drawings so that they are now fully rendered.

Sketches should be drawn faintly so that corrections can be easily made and unnecessary lines can be erased, when Step 8 ("inking") is completed. Many professional comic artists draw their pencil art using a blue pencil, because this will give the inker a better chance of not mistaking the ink lines for the pencil lines. However, if the sketches in pencil are faintly drawn, there will not be a need for the use of blue line.

Although, ideally, the drawings should be done accurately, the penciler and the



A typical sketch from start to finish. First there is a very rough outline sketch, where only geometrical shapes are used to define the figure that is to be drawn. Then guidelines are drawn for the face and hands, and a more accurate drawing done in pencil. This is gone over with black ink, using a felt marker or nib pen. Then fill-in colour is applied, and finally, though not necessarily, tones are put in to give the figure a more rounded feel.

Siome of the inked pages of the CLIMATOPIA comic. Since lettering was done digitally, here is was applied after the inking was done and not after the pencilling, which is what would be needed if the lettering is put in by hand.

"inker" (see below) should not worry too much about their drawing skills. Even simple figures with a circle for the head and lines for the body and limbs will do. An idea is to imitate the characters of the comic at hand. They can trace them from the comic. If they want to add more characters, they can try out the simple steps below on how to draw comic characters:

Start with a simple circle.

Draw two circles for the eye, a mouth and a tiny curved dot for the nose.

Sketch any rough hairstyle.

Draw a triangular-looking rectangle for the body.

Roughing sketch in the legs and tiny shoes.

Add in character's arms and hands.

Step 7: Lettering

At this stage, another member of the group, "the letterer", inserts dialogue balloons/ boxes into the panels of the comic and places all of the text. Dialogues are enclosed in balloons (speech, with straight lines; thought, with rounded, bubble like lines; or shout balloons, with jagged edges like an explosion), while texts with information are enclosed in boxes of different size (captions).

During the penciling step consideration has to be taken so that there will be enough space for proper placement of balloons/ boxes so that they do not compete with the composition or cover important art.

It is very important that the balloons are put in sequence. That is, the person who speaks first has the first balloon (top left) and the person who speaks second has the second balloon (top right). The penciller needs to make sure that the figures are in that position, according to the sequence they are speaking in the script.

The letterer first writes the text and then he/she encloses it in a balloon/box.

Like the penciler, the letterer first uses pencil and then ink.

Step 8: Inking

Now that the scenes have been captured in the frames and the lettering is in place, the basic part of the comic has been already completed. Another member of the group, the "inker", is responsible for taking the rough pencils provided by the penciller and using them as a guide to produce the final lineart of the comic in ink. He/she does not simply "trace" the pencils. The inker has to decide which lines are necessary for the finished image. When the ink has dried the unnecessary lines may be removed using a soft eraser.

The inker is him or herself an artist in his or her own right. The style of line drawing used by the inker can enhance the style of the penciller.

Step 9: Coloring

The final lineart of the comic is handed off to the colorist who uses colored pencils or markers to color the black and white images. This step may be skipped if the group decides to make a black and white comic.

If it is not skipped, the colour may remain flat, that is, only filled into the outlines of the drawings, with no tones applied.

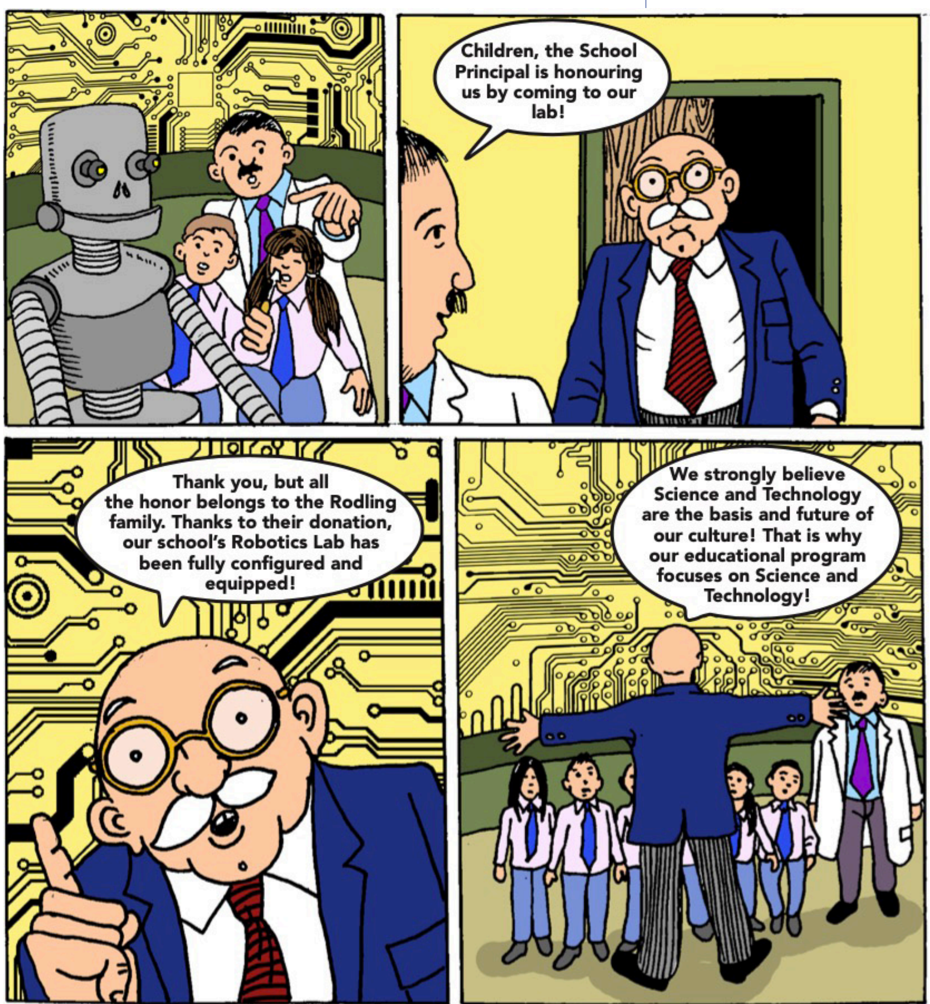
One final step which is not, however, necessary, if the comic is coloured in, is to use coloured pencils or crayons to create tones that will make the drawing look more rounded. But this is extra and can definitely be skipped.

Digital comic

All of these steps can also be done digitally on a tablet. There are a number of applications that can be used for this, with the roughs, pencils and inks done on a sketching program, and the lettering done on other applications. In this case, the lettering step comes after the inking, and not after the pencillig step, as when the drawing is being done by hand.

There are also free applications that can be easily used by the students to continue the comic, developing a digital comic. The comic applications provide galleries of objects such as characters, backgrounds, balloons, etc. that can be inserted in the boxes and create the desired strips. In this case the students will be asked to follow the first 4 steps and when the scripts are written they will be ready to use the application to develop their digital comic.

All the applications provide detailed descriptions which help even young users to use them.



Part of a page from the CLIMATOPIA comic, with inking, colouring and lettering in place.

Chapter 3

Open Educational Resources for comics creation

The Climatopia Research Team
Fundación Siglo22
Spain

Introduction

The use of open educational resources for the creation of comics has numerous benefits. More and more teachers are using the creation of comics in their classes to encourage a more dynamic and fun way of learning.

In this chapter we provide a number of free educational tools for creating comics in the classroom:

- Make Beliefs Comix
- Pixton
- Smilebox
- Creately
- Canva

Benefits of comics in the classroom

As we have already mentioned, the creation of comics develops skills and competences that can be very beneficial in the classroom. Some of the benefits we find are the following:

More dynamic and fun learning.

Reflection on possible real-life situations.

Learning lessons on different topics (environment, climate change, bullying...).

Work on social skills and conversation.

Acquisition of new vocabulary.

Work on writing and everything related to it: grammar, spelling, lexis....

Encouragement of creativity and imagination, as we can illustrate other times, places, and even create our own avatars and those of our friends.

Possible practice of a foreign language.

Use of this type of creative tools for the development of stories, tales or personal experiences.

These are just some of the benefits of using comics as an educational tool.

Make Beliefs Comix

Make Beliefs Comix is a web application for the creation of comics and stories. It works in a very simple way following a narrative sequence formed by vignettes. These vignettes offer images and text.

It also offers other resources such as: activity ideas for students with special educational needs; printable resources; or free e-books in English.

This web application has different features that make it very easy to use:

It is free to access.

You do not need to create an account to register.

It has several languages, it is multilingual.

You have the option of printing the comics you create or sending them by post.

On the other hand, it has a number of small, easily solvable drawbacks that may limit its use:

Requires an internet connection.

It has limited options to create comics, related to characters, environments, landscapes, objects or colours.

You need to have installed computer programs such as Paint or Photoshop.

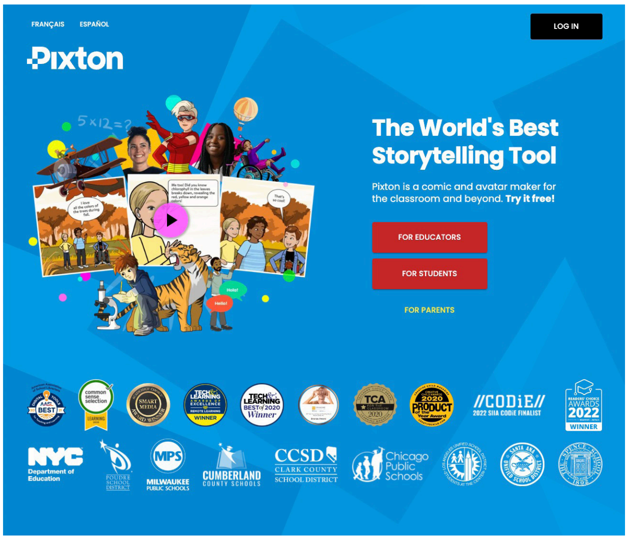
It does not allow you to save the comics in the cloud if you do not register with a user.

Pixton

Pixton is a web 2.0 tool used to create comics through the development of language skills, reading comprehension and creativity.

It consists of a toolkit that works on all browsers and platforms, such as MAC, Windows, Linux, iOS and Adroind.

It has different levels of registration, where the most basic, called "Pixton for fun", is free and for individual use. There is also



"Pixton for classrooms", which is intended for educational centres and is paid for. Or "Pixton for business", which is intended for companies and is also paid for.

Pixton has some features that you should know before you start using it:

It offers templates, shapes and presets if you don't want to start from scratch.

Allows you to upload your own photos so you can customise them as you like.

Allows you to edit the shape and position of each panel of the comic.

Allows you to create text and speech bubbles for the characters.

Allows users to create their own comics, as well as share them with others.

It is free for individual accounts, and this version contains many options.

It offers an unlimited range of expressions.

Before you start, remember to log in or register with an email account and password. Once inside, you must select the comic format you want to create from the following: quick comic, classic, Sunday jokes, large format, pixtor avatar, 4-kroma, super long, freestyle.

Smilebox

[Smilebox] is a comic strip maker to create comics for free, easily and in a few minutes. It has default templates that you can edit and change to your liking.

You can choose templates for letters, invitations, slideshows, collages, flyers, announcements and others.

You need to create an account to register, an email address and password is enough.

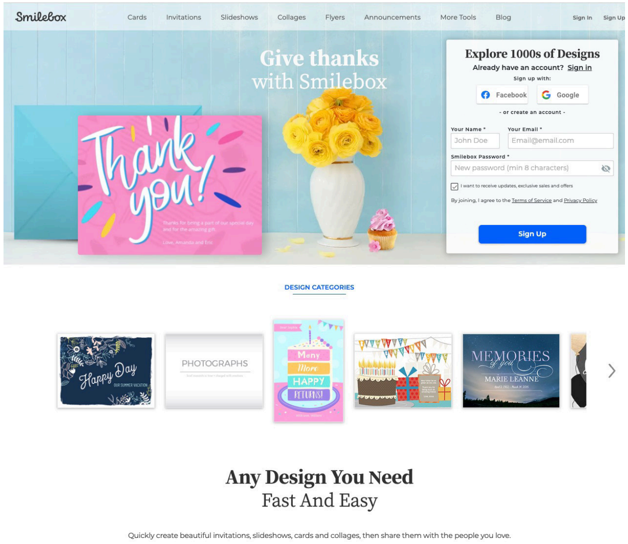
Follow four easy steps to create comics with Smilebox:

Choose a free comic strip tempalte and click on "customize".

Upload your photos. You can add photos to your template by clicking on "add more photos" to access the images saved on your device or social media accounts.

Customise your comic. Change and edit the template to your liking to add your own text, characters and images.

Share it. You can preview and save the comic on your device. Share it or send it via email or social networks.



Creately

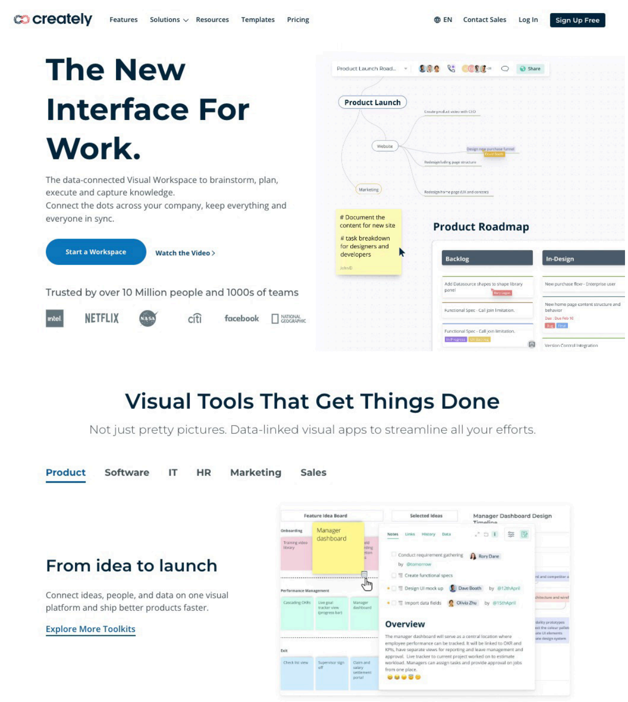
[Creately] is a comic strip maker to create comics for free, easily and in a few minutes. It has default templates that you can edit and change to your liking. No registration is required to try the trial version and use any of its templates.

If you register, you have different plans with different options:

Free: with an email account and the free plan you have the option to create 3 canvases with a maximum of 60 elements, one folder, limited storage, and raster image only exports.

Starter: 5$ per month, recommended for individuals or small teams. You have unlimited canvases, as well as unlimited elements, 20 folders, 5gb of storage, all formats for export, basic collaboration with people and email support.

At $90 and above you get other benefits related to more storage, more equipment, more accounts, and more export formats.



To create a Comic Strip with Creately you need to follow these steps:

Select a template that works for you based on the concept or scenario you want to follow.

Import images from any source, your device or browsers.

Add text in the speech bubbles.

Customise with available colours and styles to make your comic more creative.

Export in JPEG, PNG, PDF and SVG format or embed a link to automatically share with anyone or download in high resolution for printing.

Canva

Canva is a simple graphic design web application with multiple options for creating resources and elements. It has different plans, but it has a very complete free plan.

It offers an option to bring stories to life through a graphic novel. You can find hundreds of templates with pre-designed panels for you to edit and add your dialogue. You also have the option to create your comic from scratch with a blank layout.

The app offers five easy steps to create a comic book on Canva:

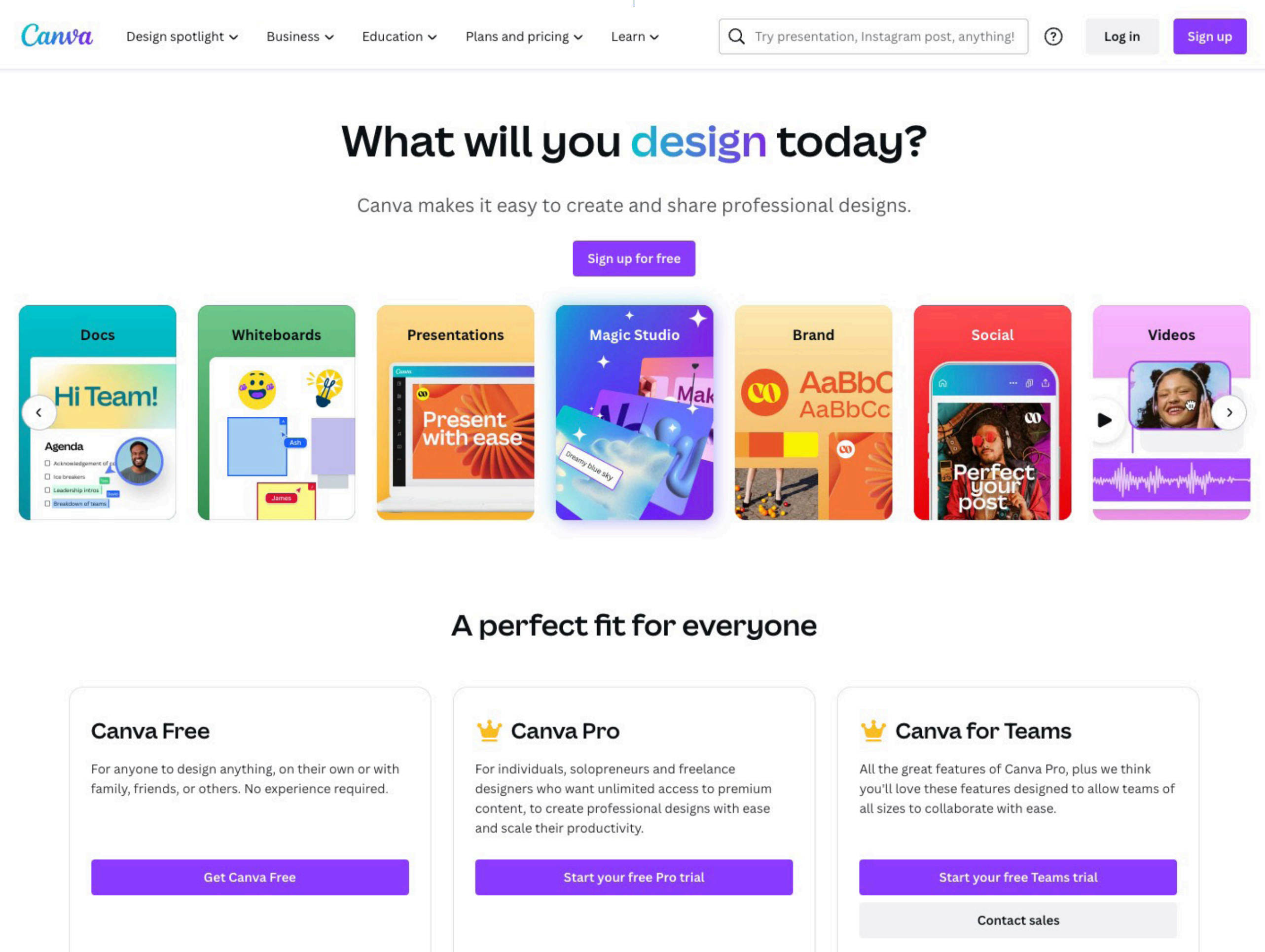
Open the web application and register. Then search for "comic".

2. Search for a template.

Experiment with the functions that Canva offers for editing your storyboards.

Customise your comic. Use your own colour scheme, font style, mix stickers, icons and illustrations. Arrange dialogue balloons and frames as you see fit, or upload your own images.

Publish and share. You can download it, share it on social networks or by email.



CLIMATOPIA

UNIVERSITY OF LATVIA

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Fundación Siglo22

ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΙΓΑΙΟΥ

UNIVERSITY OF THE AEGEAN

ΔΗΜΟΚΡΙΤΟΣ

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