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Climate Change, volume 2

Edited by
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Climate Change, volume 2

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About this collection

Our climate refers to the different types of weather we have all around the world. Some places are hot, some are cold, some are dry and some are wet. But now, our climate is changing and it's affecting everything and everyone. We know that this is happening because of the pollution we make, like putting greenhouse-gases into the air that trap the sun's heat and make our world get warmer. This is called global warming.

The changes in the climate are hurting people, animals, and plants everywhere and will continue to do so. In this Collection, we will explain what is causing the climate to change, what we can do to adapt to it, and how we can stop it from changing even more.

Climate change is a big problem that affects everyone. That's why the world's governments ask scientists to help them make decisions. These scientists work for the UN's Intergovernmental Panel on Climate Change (IPCC) and every 7-8 years they make a big report to explain what they have learned about our changing climate. The most recent IPCC Assessment Report has been published over the last 2 years.

This Collection of articles will explain the important things that the IPCC report covers, like:

1. How and why our climate is changing
2. How climate change is affecting the world and people everywhere
3. What we can do to help stop climate change

This Collection will help kids understand what's happening to their world. Young people everywhere are getting more and more interested in taking care of our planet. This Collection can help support their goals by giving them accurate information about climate change. Please also read our previous Collection with a set of core articles on climate science.

Table of contents

Chapter 1, "Current state of our Climate, and what the future may hold"

Chapter 2, "How can we respond to the Climate Challenge?"

EARTH SCIENCES
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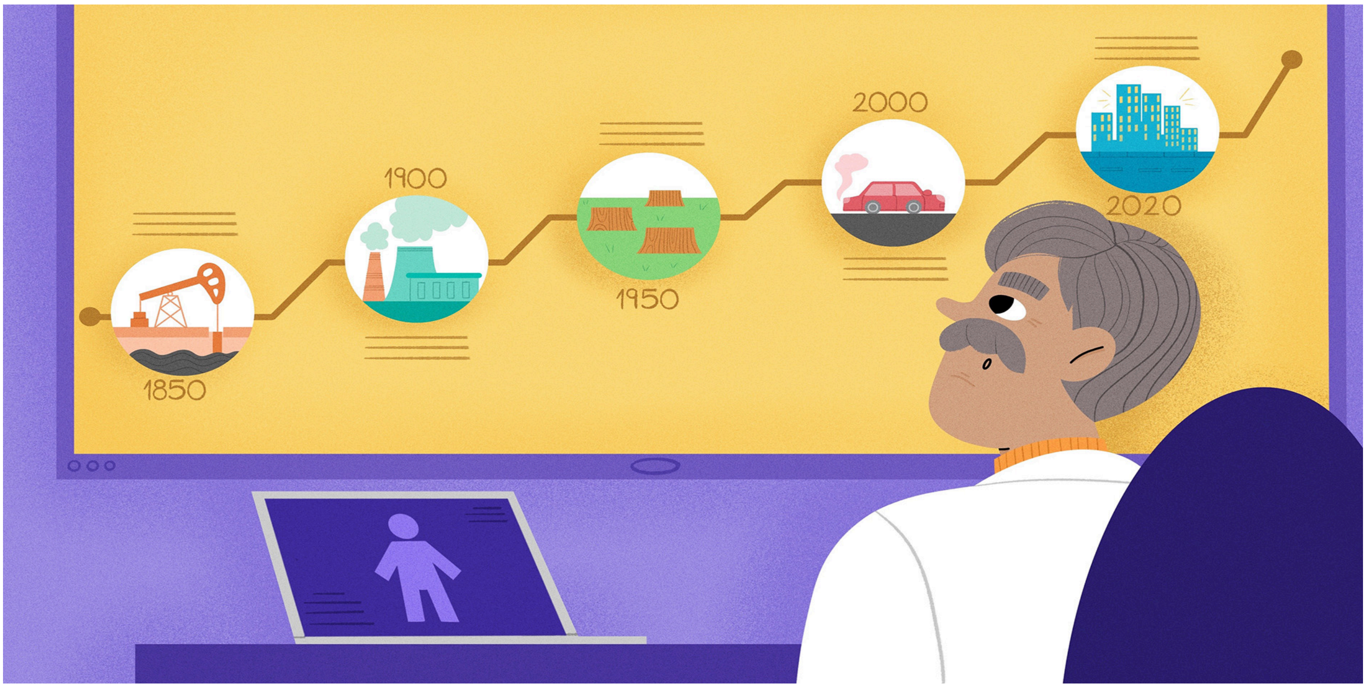

CLIMATE CHANGE IS HAPPENING AND HUMANS ARE RESPONSIBLE

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YOUNG REVIEWERS:


AYAT
AGE: 12


YASH
AGE: 14

We know Earth is warming. Clear evidence of warming can be seen in observations of the atmosphere, oceans, ice, and living things. Computer simulations can tell us what the world would have looked like without increases in greenhouse gases and other human influences, and Earth would not have warmed up like we have seen. By comparing the changes scientists have observed to computer simulations of the climate including or excluding various potential causes, scientists can work out what or who is responsible for the climate changes. Again and again, it has been shown that these simulations can only explain observed climate changes when historic emissions of greenhouse gases, principally arising from burning coal, oil, and gas, are included. The best estimate is that all the warming we have observed since 1850–1900 is due to greenhouse gas emissions produced by human activities.

CLIMATE CHANGE IS HAPPENING ALL AROUND US

Scientists have been directly observing Earth's climate system for around 200 years, using an ever-increasing range of techniques. In the early days, we used thermometers, barometers, and other instruments to measure weather at Earth's surface. Over time, our ability to monitor the changing climate has increased, and we can now measure from the depths of the oceans to the edges of space, using a broad range of techniques including balloons, satellites, aircraft, and ocean profilers [1].

We can also use things that change with the climate, to infer changes that happened to the climate long before we started taking modern measurements. These so-called **climate proxies** include amongst many others the annual growth of trees, measured through tree ring width, and analysis of ice cores which capture changes in greenhouse gas concentrations. Climate proxies are like fuzzy recordings of Earth's climate history—they can provide some indication of the past climate but not in the detail we can get from modern observations [1].

CLIMATE PROXIES

Changes in natural systems such as the annual growth of tree rings which vary mainly as a result of the climate and hence can be used to infer information about long-term changes in climate prior to the availability of modern observations.

The combination of direct measurements and proxy records tells us that Earth's surface temperature is warming faster than it has at any time in at least the last 2,000 years. Earth's oceans, ice, and living things are also now in states unseen for hundreds to many thousands of years [2]. This matters because the last several thousand years are the period in which humanity has developed from hunter-gatherers to our modern societies. The climate over this period was remarkably stable in the context of last several million years and this stability helped modern humans to flourish.

Earth's climate is warming rapidly. From 1850–1900 to 2013–2022, the best estimate is that the global average temperature warmed by 1.15°C, with much larger changes in some regions [3]. Overall, land is warming considerably faster than the oceans, and the Arctic is warming fastest of all [2]. 2023 was the warmest year on record, and 2024 may well-exceed 1.5°C warming for the first time. The **Paris Agreement**, which almost all countries have signed, has a goal to limit global warming since pre-industrial to well-below 2°C and to strive to limit it to below 1.5°C (Read more here). Because of natural variability, one year above 1.5°C will not mean this level has permanently been exceeded, but we expect 1.5°C to be exceeded within the next 15 years. We know that, even at 1.5°C of global warming, there will already be many negative impacts [4].

PARIS AGREEMENT

An international agreement that aims to limit long-term warming of the planet while minimizing the negative impacts of climate change on the planet and society.

Earth has probably not consistently been as warm as it has been this most recent decade for at least 125,000 years. However, observations of a warming surface climate are far from the only piece of evidence we have. Evidence across the atmosphere, oceans, frozen planet and living things all point to one inescapable conclusion: the world is warming (Figure 1) [2].

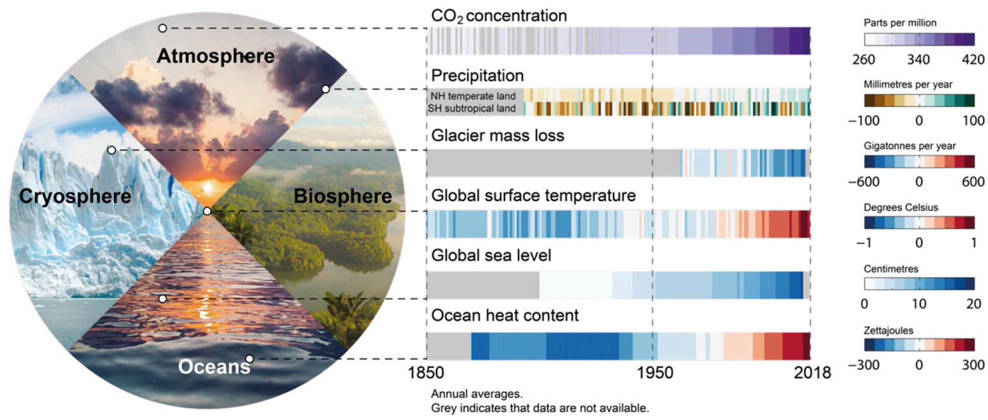

Figure 1

Figure 1

Evidence that Earth is warming comes from multiple sources across all components of the climate system. By measuring various indicators of climate change (middle bars, with scales shown by right hand bars), we can see the effects that these changes are having on the planet—the CO_2 concentration in the atmosphere is increasing, rainfall is increasing, glaciers are melting and contributing to sea-level rise, and the temperatures of both Earth's surface and the oceans are going up [figure Inspired by the warming stripes (https://www.reading.ac.uk/planet/climate-resources/climate-stripes)]. Source: IPCC AR6 WGI Figure 1.4 [1]. Reproduced with permission.

COMPUTER SIMULATIONS REPRESENT THE CLIMATE WELL

Scientists have a strong understanding of how the climate system works, and they can use this to simulate weather and climate using **computer models** of the atmosphere and climate system. As a well-known example, simulations of the atmosphere can be used to generate weather forecasts for the next 10–20 days. These weather forecasts have great skill and, in the case of extreme weather events, they can help to save lives and livelihoods. The same processes are simulated in climate simulations but, in addition, climate simulations also simulate the oceans, the frozen parts of the planet, and living things. Climate simulations can be used to simulate past changes and project into the future for hundreds of years, to understand how the climate has changed and how it might change in the future. These models cannot reliably tell us whether it will be sunny or rainy on a particular day 50 years from now, but they *can* tell us how the average weather, or climate, will change in response to increases in **greenhouse gases** and other factors (for more details on climate changes, see this Frontiers for Young Minds article).

Climate models have been developed at several institutes around the world, and having multiple models helps scientists understand the uncertainties in climate simulations. These models are used to run coordinated simulations of how the climate would have changed since 1850 in response to only natural influences, like changes in the sun's brightness and large volcanoes. They are also used to simulate climate change since 1850 in response to natural influences *and* human emissions of greenhouse gases and other chemicals. Finally, long climate simulations are also carried out with no changes in any **climate drivers**, to better understand climate variability [1].

Simulations of the present-day climate capture very many aspects of Earth's climate system well. They can simulate the seasonal cycle of

COMPUTER MODELS

Simulations of the climate system run on massively powerful supercomputers which provide estimates of changes in the atmosphere, ocean, frozen planet and living things under different assumptions of past and future climate drivers.

GREENHOUSE GASES

A subset of atmospheric gases which trap outgoing energy from the Earth and raise the temperature of our planet. Increases in greenhouse gases lead to increased warming.

surface temperatures over much of Earth within 1–2°C. They simulate seasonal rainfall and snowfall in most areas of the world realistically. Many models can also simulate changes in storms across seasons. The variability in the models also looks realistic with many models simulating realistic variability in the tropical Pacific where El Nino occurs [5].

The better simulations can capture key aspects of the climate system, the more confidence scientists can have in their use. Of course, computer models are not perfect, but they are certainly good enough for many purposes. Climate models have also improved over recent decades and will almost certainly continue to improve into the future (Figure 2) [5].

CLIMATE DRIVERS

Changes in factors such as the strength of the sun or the amount of greenhouse gases which can lead to changes in climate by altering the balance of incoming and/or outgoing energy from the Earth.

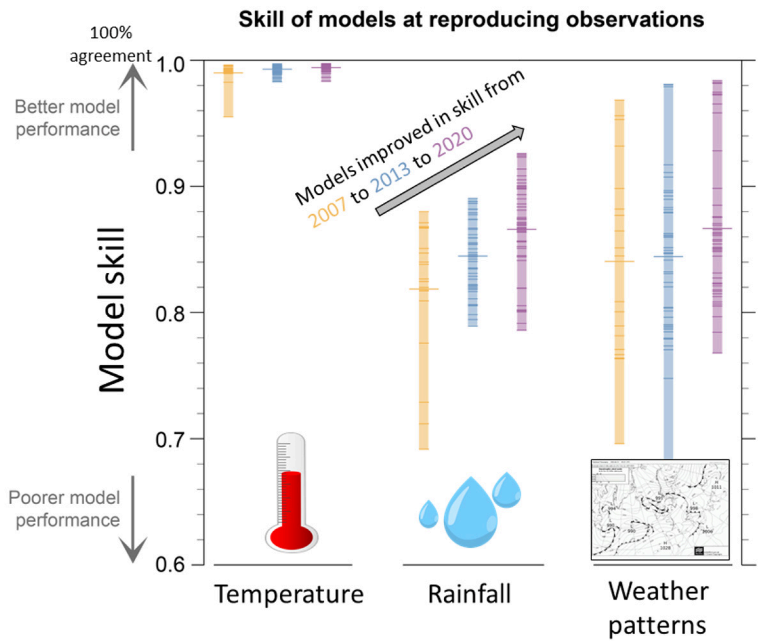

Figure 2

Figure 2

The skill of climate models at predicting climate behaviors like temperature, rainfall, and atmospheric pressure (which corresponds to weather patterns) has generally increased from 2006 to 2020. The vertical bars show data from many models and the average result of all those models is indicated by the horizontal line. Models closer to the top of the graph are more skillful, meaning they are better at simulating the temperature, rainfall or weather patterns, than those lower down. Overall, models perform better for temperature than rainfall or weather patterns. Source: IPCC WGI Figure FAQ 3.3 [5]. Modified with permission. Modifications undertaken by collection editor Dr. Chris Jones for this paper.

OBSERVED CLIMATE CHANGES CAN ONLY BE EXPLAINED BY HUMAN INFLUENCE

Scientists can use climate simulations to do the detective work of finding out what is responsible for observed changes in Earth's climate. This detective work includes in-depth statistical analysis to sort through the available lines of evidence and identify the culprit (or culprits).

The first question is whether the changes we have observed are unusual. Here, we can use the long simulations run without any changes in climate drivers, to see whether the observed changes are unusual compared to the variability we would expect by chance. If an observed change *is* unusual, then the next step is to work out what the most likely explanation is for the observed change.

To find the most likely cause(s), we can use simulations run from 1850 to near-present. Simulations including greenhouse gas increases and other human factors can reproduce the observed warming in surface temperature (Figure 3) and a broad range of other changes across the atmosphere, ocean, frozen planet, and living things, but simulations without these human factors cannot. Time and time again, it has been found that humans are principally responsible for the climate changes that have been observed [5].

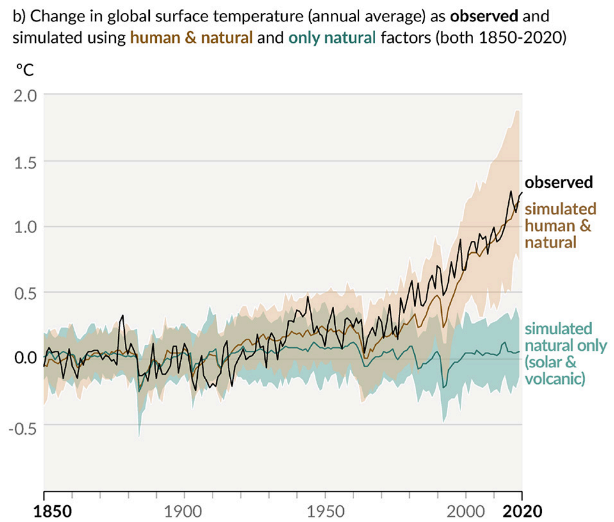

Figure 3

Comparison of observed warming at Earth's surface since 1850 using two sets of simulations: one with only changes in the sun's brightness and large volcanic eruptions (green), and one with these natural influences *and* human factors (mainly increasing greenhouse gases from the burning of coal, oil, and gas). The observed change can be explained only when human factors are included. Source: IPCC WGI AR6 Figure SPM1.b [6]. Reproduced with permission.

So, how much of the climate change scientists have observed is caused by humans? For surface temperature changes, this can be calculated. It turns out that the best estimate for the warming due to humans from 1850–1900 to 2013–2022 (1.14°C) almost exactly matches the observed warming over the same period (1.15°C). In other words, all of the warming we have experienced since the second half of the 19th Century is down to human activities [3].

TAKE HOME

Earth's climate is now in a state and changing at a speed unseen in at least thousands of years and probably considerably longer. Based on detailed comparisons of observed changes with climate model simulations, there is no doubt that human activities have warmed (and continue to warm) the climate, primarily through the burning of coal, oil, and gas. Those same computer model simulations can also tell us what potential futures await us depending upon the actions we take to slow and ultimately stop further global warming.

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YOUNG REVIEWERS

AYAT, AGE: 12

I am 12 years old and an elementary school student. I love sketching, painting, playing chess, and reading books. My favorite books include "Amari" and "The Magicians of Paris", and anything and everything about fantasy books. I like nature, cycling, badminton and frequently go out hiking to observe the beauty of nature, take notes and make sketches in my notebook.

YASH, AGE: 14

I am a rising high-schooler with a wide range of interests in math, science, music, downhill skiing, geography, and building large lego sets. I love volunteering in my community. I play the drums, and am learning to play many other instruments in my school band, most recent one being the Euphonium. I have a keen interest in public health and how our lifestyle, access to healthcare and the environment contributes to our overall wellbeing.

AUTHORS

PETER W. THORNE

I have long had a fascination for weather and climate. I remember flicking between TV channels to catch every forecast as a child. Nowadays I spend most of my time trying to work out how the climate has changed, why and what that might mean for the future. I advise policymakers and governments on what can be done through involvement in assessments and advisory bodies both nationally and internationally.

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NATHAN P. GILLETT

My work primarily focuses on the detective work of understanding the causes of past climate change and what this means for how climate might change into the future. I managed the development of the latest version of the Canadian climate simulations. I have been involved in numerous assessment activities both nationally and internationally. These inform policy decisions by governments around the world.

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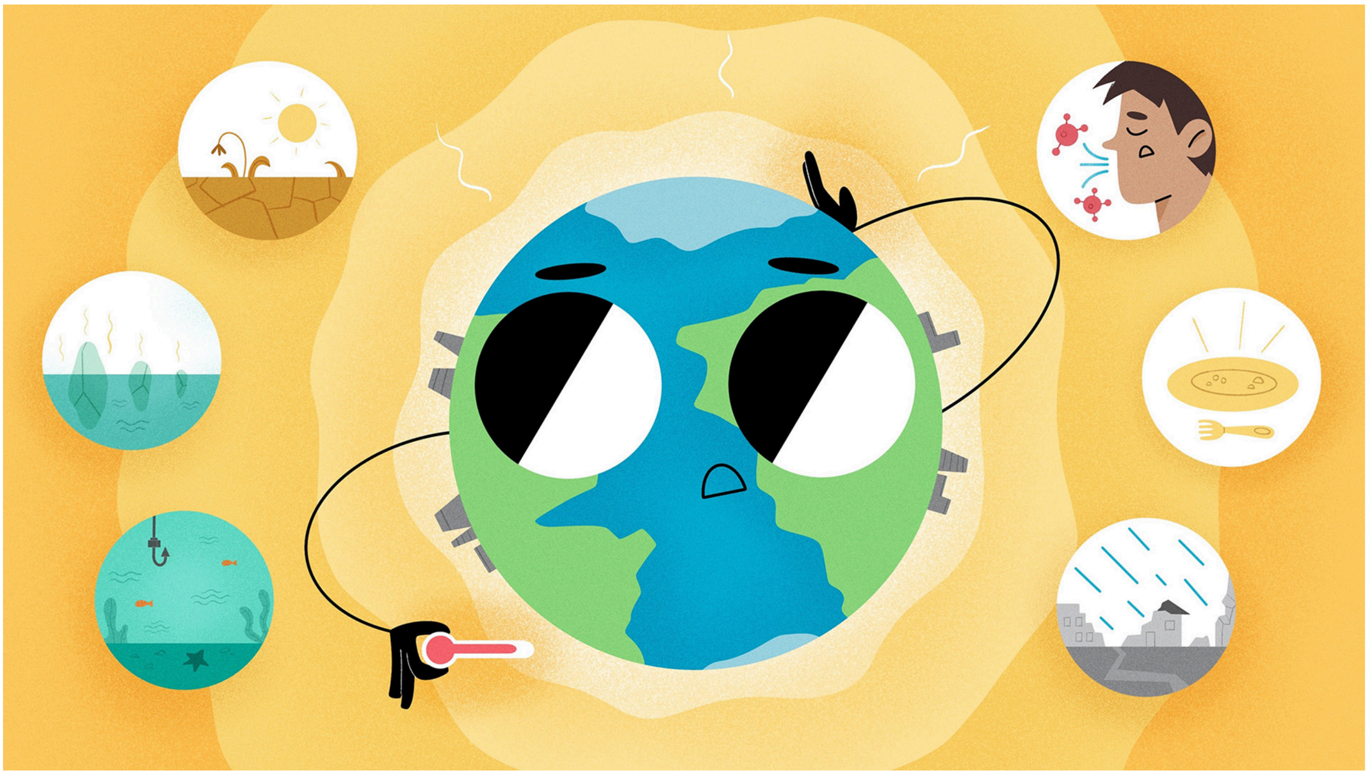

IMPACTS OF CLIMATE CHANGE

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AGE: 14

Climate change is already affecting the environment and people around the world. We have seen changes in the air, in water, and in plants and animals. These impacts include things like warmer temperatures, sea-level rise, heavy rainfall and more intense storms. Hundreds of plants and animals on the land and in the ocean have been lost because of very hot temperatures. Climate change has also made it more difficult for many people to access food or water, and has caused some people to lose their ways of earning a living. Unfortunately, people who have contributed the least to climate change are experiencing the worst effects. This shows that the effects of climate change are not fair and that there are uneven impacts on different people and places. It is important for us to understand the impacts of climate change on the environment and people so that we can find ways to solve these problems.

CLIMATE CHANGE HAS MANY IMPACTS

Climate change is already affecting the environment and people around the world. This article explores some of the many impacts of climate change, including warming air and oceans; melting ice; disruptions to plants, animals, and ecosystems; and negative impacts on people's health and the ways that people earn a living. However, while climate change is having impacts all over the world, it is important to recognize that the causes and consequences of climate change are not evenly distributed. People in places that have contributed the least to climate change are often the most negatively impacted.

While there are many impacts of climate change, as seen in Figure 1, there are also many solutions that are available to reduce these impacts and to stop climate change from getting worse. It is really important to understand the impacts of climate change, to persuade governments and people of the need to act straight away to reduce these impacts.

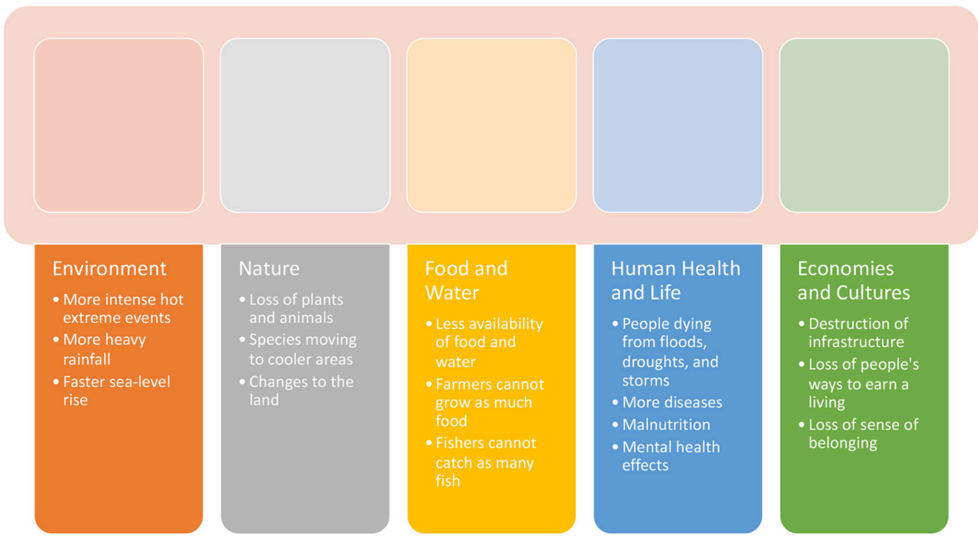

Figure 1

Figure 1

Climate change has widespread impacts.

IMPACTS ON THE ENVIRONMENT

Climate change has already caused widespread changes to the environment, and these changes are happening quickly. Human activities are responsible for releasing **greenhouse gases** such as carbon dioxide and methane. These greenhouse gases have resulted in an increase in the global surface temperature, which is the average temperature of the world over both the ocean and land. In the years 2011–2020, global surface temperature was around 1.1°C higher than it was in the years 1850–1900 [1]. Since 1970, global surface temperature has increased faster than in any other 50-year period over

GREENHOUSE GASES

Gases in the atmosphere which can absorb heat and cause the planet to warm up. These occur naturally, such as carbon dioxide and water vapor, but human activity is putting more greenhouse gases into the air leading to the planet getting warmer.

at least the last 2,000 years. This is a really fast change to global surface temperature and something that we have not seen in the past!

The increase in the global surface temperature is absolutely due to the actions of people. However, different regions of the world have contributed more or less to the greenhouse gas emissions that are causing global warming. Historically, North America, Europe, and Eastern Asia have contributed the largest amount of carbon dioxide into the atmosphere. These regions have contributed over half of the greenhouse gases that are causing climate change. However, as you will see in the following sections, regions that have historically contributed *the least* to climate change are experiencing the worst impacts.

The higher global surface temperature has resulted in many **weather and climate extremes** being affected. For instance, heatwaves are happening more often and are more intense than they have been in the past. Since the 1950s, most regions of the world have seen an increase in heatwaves that are due to human-caused climate change. On the other hand, cold extremes, including cold waves, have become less frequent and less severe. So, overall, we are experiencing more hot extremes than cold extremes.

WEATHER AND CLIMATE EXTREMES

When the weather or climate is doing something very different from normal, such as very hot temperatures or very intense storms.

Since 1950, heavy precipitation events, such as heavy rainfall, have also increased—both in how often they are happening and how intense they are. **Droughts**, which are long periods of unusually dry weather with not enough rain, are also happening more often. We also see an increase in the percentage of very strong **tropical cyclones**, which are also called hurricanes or typhoons in certain parts of the world.

DROUGHT

When there is not enough rain for a long time, causing the ground to dry up and making it hard for people, plants, and animals to get the water they need.

TROPICAL CYCLONES

A big, spinning storm that forms over warm ocean waters. It has strong winds and lots of rain and can cause flooding and damage when it moves over land.

Climate change is also causing impacts in the ocean. Marine heatwaves, which is when the water becomes much hotter than usual, are becoming much more common [2]. Since the 1980s, there has been about a 50% increase in these very hot ocean conditions. Sea levels are also rising. Global mean sea level increased by 0.20 m between 1901 and 2018. On average, sea level rose 1.3 mm every year between 1901 and 1971. This increased to 1.9 mm every year between 1971 and 2006. Sea levels then further increased by 3.7 mm every year between 2006 and 2018. Human influence was very likely the main driver of these increases since at least 1971. So, we are seeing sea levels rising faster than we have experienced in the past.

IMPACTS ON NATURE

Climate change is also causing loss of **biodiversity** and damaging Earth's ecosystems. Large numbers of plants and animals have died because of the increasing temperatures. As a result, hundreds of species in numerous areas, both on land and in the ocean, have been

BIODIVERSITY

The variety of all life on Earth, including plants, animals, and the ecosystems that they live in.

lost [3] (For more information on how organisms respond to climate change, see this article).

As temperatures increase, organisms move their living areas to environments that suit them better. Due to warmer temperatures, about half of the species that have been studied have moved toward the north and south poles, to higher elevations, or to deeper waters where it is cooler. Warmer temperatures have also led many plants and animals to change the times when they perform important activities, such as flowering, migrating, and reproducing.

Glaciers are getting smaller and ecosystems in mountains and in the Arctic are being affected by the thawing of **permafrost**—land that was once permanently frozen. We have seen land become too dry to support life (called desertification) and we have also seen the loss of land (called land degradation). These processes are the worst in low-lying coastal areas, river deltas, drylands, and areas with permafrost. Nearly half of the world's coastal wetlands have been lost in the last 100 years, due in part to climate change.

PERMAFROST

Ground that stays frozen all year round, even in the summer. It is found in very cold places like the Arctic.

IMPACTS ON FOOD AND WATER

These changes to the environment and to nature have had many impacts on people and societies. Increasing weather and climate extremes have caused millions of people to not have enough food to meet their basic needs. In areas with warmer temperatures, climate change is having negative impacts on farming. Some farmers cannot grow as much food as they could before. Changes to the ocean have negatively impacted **fisheries**. In some places, fishers are catching fewer fish than they used to. These impacts on farming and fisheries have contributed to the decreased food supply experienced by some people. Climate change also negatively impacts water availability. For at least some part of the year, about half of the world's population does not have access to enough water.

FISHERIES

Places where people catch fish and other sea animals for food. They can be in the ocean, lakes, or rivers.

These impacts on food and water availability are most severe in places and communities that have historically contributed *the least* to climate change. These are regions such as Africa, Asia, Central and South America, and other countries that are the least developed, including small islands and the Arctic. Across the globe, we also see more severe impacts affecting Indigenous peoples, small-scale food producers, and low-income households.

IMPACTS ON HUMAN HEALTH AND LIFE

Climate change has also negatively affected human health and life. Between 2010 and 2020, deaths from floods, droughts, and storms were 15 times higher in highly vulnerable regions compared to regions with very low vulnerability. Regions that are highly vulnerable are also those that have historically contributed the least to climate change. Around the world, we see that extreme heat events have resulted in deaths and negative impacts on people's health. Diseases including Lyme disease, malaria, and dengue have increased. Food safety has also been negatively impacted, with an increase in infections such as salmonella and an increase in toxins that are associated with cancer.

Climate change has also contributed to malnutrition, particularly for women, pregnant women, children, low-income households, Indigenous peoples, and minority groups. Mental health is also being affected. We see that people who have been exposed to disasters are experiencing trauma and distress. People, and particularly young people, are also experiencing mental health challenges when thinking about or anticipating the impacts of climate change. This shows why it is so important to learn not only about the impacts of climate change, but also about the solutions that can help to solve these problems!

IMPACTS ON ECONOMIES AND CULTURES

Climate change is also causing negative impacts on important parts of the **economy**, such as agriculture, forestry, fishery, energy, and tourism. Buildings, roads, and other types of infrastructure are being damaged or destroyed by floods and storms. This has resulted in high costs to repair or replace them. People are finding that their livelihoods, or ways of making a living, are being negatively affected due to impacts on farming, health, and even the destruction of their homes.

ECONOMY

How money and resources are made, used, and shared in a place. It includes jobs, businesses, and trade.

There are also impacts on people's culture due to climate change. In some cases, people have been forced to move because of climate change impacts. As you may imagine, being forced to move from their homes has had negative effects on people's sense of belonging to a particular place. For example, Indigenous peoples in coastal Alaska and in villages in the Solomon Islands and Fiji who have had to move because of climate change have experienced emotional distress and the loss of cultural and spiritual bonds to their homes.

CONCLUSION

To sum it up, climate change is causing negative impacts all over the world. The air and oceans are getting hotter, and it is changing where animals and plants live. Warming temperatures are making people sick and affecting how they make a living, and warming is also causing plants, animals, and people to die. The impacts of climate change are not fair because the people who did the least to cause it are suffering the most.

But there is hope! There are lots of ways we can stop climate change from getting worse. We need to understand how big the problem is so that everyone, from governments down to regular people, can work together to fix it fast. It is super important for all of us to join hands and take strong actions to fight against climate change.

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YOUNG REVIEWERS

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Alissar is not only dedicated to her academic pursuits but also actively involved in various volunteer activities to kickstart net-zero and SkyZero team, aims at serving and enhancing the needs of the Syrian society. Her love for literature and knowledge speaks to her curiosity and intellectual vigoru, which undoubtedly enriches her academic pursuits and personal development. She is also a remarkable individual who not only excels in her studies but also dedicates herself to making a positive impact in the community.

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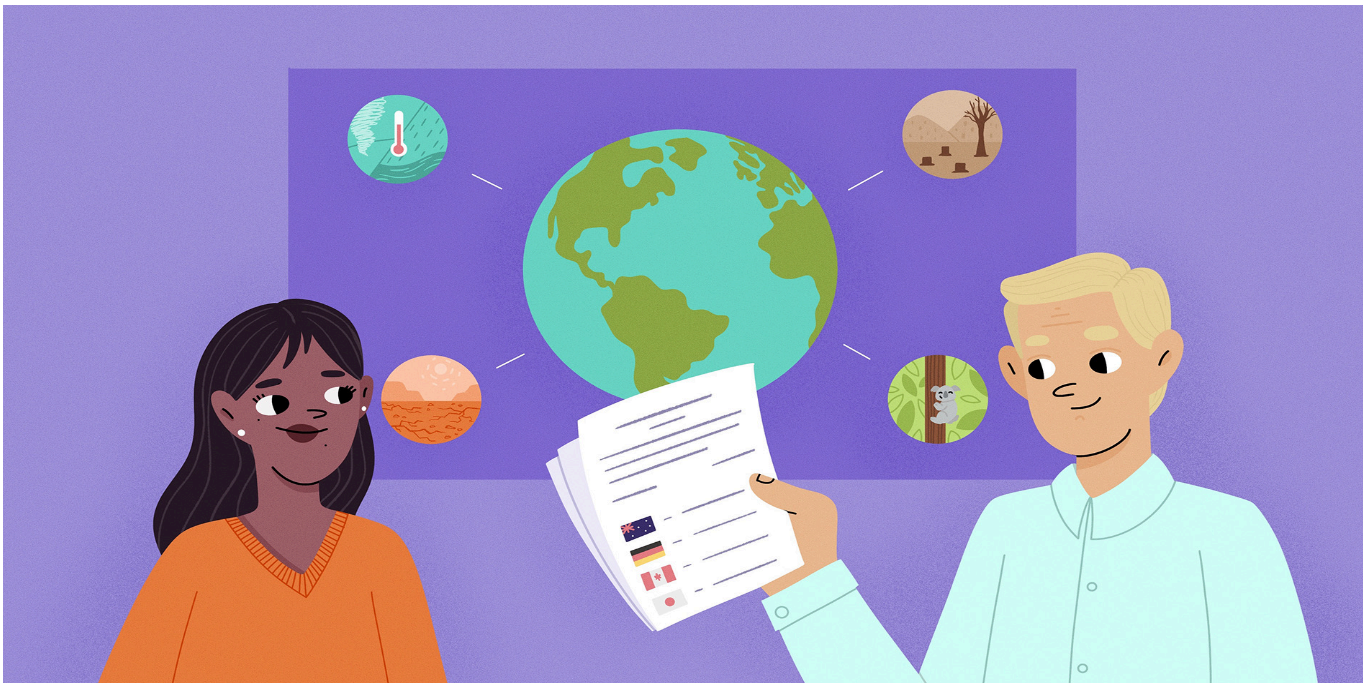

WE ARE NOT ON TRACK: GREENHOUSE GAS EMISSIONS ARE HIGHER THAN EVER!

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YOUNG REVIEWERS:

JUDE
AGE: 15

THE AMAZING SIX
AGES: 14–16

Even though we have known about climate change for more than 30 years, humans are releasing higher amounts of greenhouse gases, like carbon dioxide, than ever before. Scientists have shown that stopping carbon dioxide emissions could prevent global warming from getting worse. The single biggest source of greenhouse gas emissions is burning fossil fuels for electricity or transportation. Technologies like solar and wind power, electric vehicles, and advanced batteries can replace fossil fuels and help reduce emissions while also decreasing other problems like air pollution. Many countries have promised to stop their carbon dioxide emissions, and if their promises are backed up with laws, then global warming could be limited. Unfortunately, current laws are not good enough. We need to ensure that countries meet their promises, so that society can avoid the worst effects of global warming.

PAST ENERGY USE AND EMISSIONS

There have always been **greenhouse gases** (carbon dioxide, methane, and nitrous oxide) in the atmosphere due to natural emissions, such as decaying plants, wetlands, and soils. Thousands of years ago, our ancestors began to cut down forests, turning them into farmland. This started putting additional greenhouse gases into the atmosphere, but due to the small human population, the changes were minimal.

It was not until the start of the Industrial Revolution in the 18th century that greenhouse gas **emissions** really started to grow and build up in the atmosphere. Over time, the number of technologies hungry for **fossil fuels** increased. Today we burn record amounts of fossil fuels (Figure 1A) and cut down record levels of forests [1]. With the Industrial Revolution came widespread pollution. The water became toxic and the air became thick with smog. Society learned to reduce and manage much of this pollution, except for greenhouse gases. Greenhouse gases like carbon dioxide are invisible. While we cannot smell, feel, or see carbon dioxide, it still has serious effects on the atmosphere.

GREENHOUSE GASES

Gases that can trap the Sun's heat near the Earth, increasing the temperature of the planet.

EMISSIONS

Chemicals, like carbon dioxide, released into the atmosphere when burning coal, oil, or gas.

FOSSIL FUELS

Coal, oil, and gas that were formed underground from plant and animal remains millions of years ago.

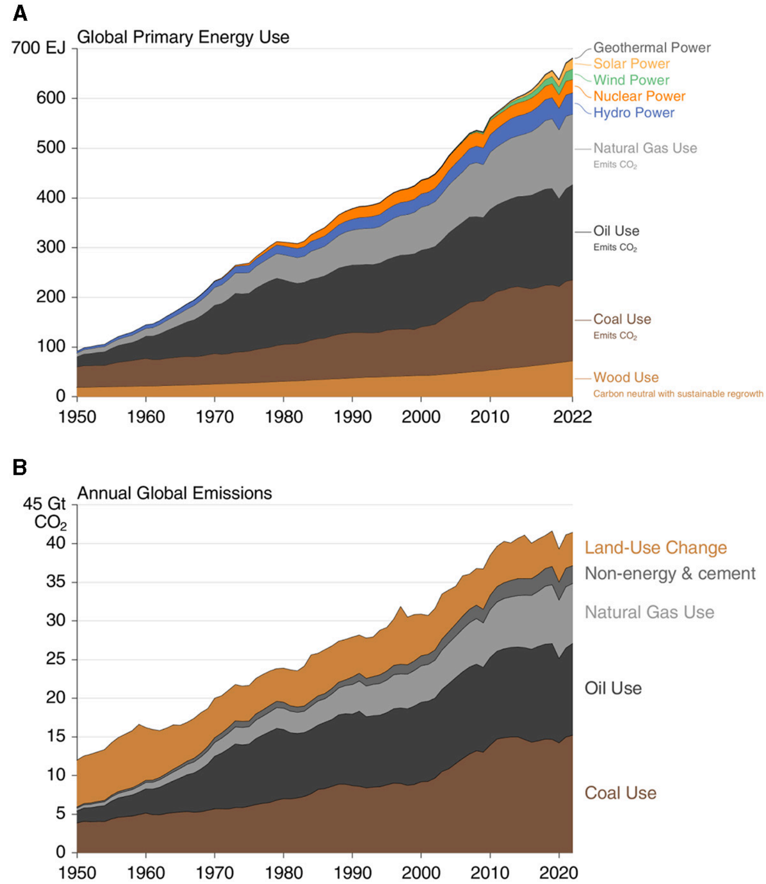

Figure 1

Figure 1

(A) The main types of energy used around the world since 1950, showing the dominance of coal, oil, and natural gas, with non-fossil sources (hydro, nuclear, solar, wind, geothermal) beginning to make a mark on the energy system. **(B)** Carbon dioxide emissions since 1950 come from burning coal, oil, and natural gas, as well as from cement production and the cutting down of forests to create farmland (land-use change), showing that only the fossil energy sources emit CO_2.

Since the 1800s, scientists have proposed that burning fossil fuels could change Earth's climate—a concept that is now proven beyond doubt [2]. Fossil fuels are the carbon-containing remains of dead plants and animals that have been hidden underground for millions of years. When fossil fuels are dug up and burned, the carbon they locked deep underground for all those years is released into the atmosphere as carbon dioxide (Figure 1B). Carbon dioxide accumulates in the atmosphere and is the main cause of global warming.

THE CLIMATE IS CHANGING

Climate scientists have shown that it is the *total amount* of carbon dioxide emitted over time that matters, not the emissions in a single year [3]. Carbon dioxide does not simply disappear from the atmosphere when we stop burning fossil fuels. Some of it remains in the atmosphere, essentially forever. The carbon dioxide emitted by our ancestors during the Industrial Revolution still sits in Earth's atmosphere. The carbon dioxide we emit today will cause global warming for our kids and grandkids. We can stop global warming from getting worse by not putting carbon dioxide in the atmosphere, but we cannot stop the global warming that has already occurred. We have already put enough carbon dioxide and other greenhouse gases into the atmosphere to increase the global average temperature around 1.3°C since the Industrial Revolution (for more on why our climate is changing, see this Frontiers for Young Minds article).

THE WORLD IS ACTING, BUT FAR TOO SLOWLY

Global warming has already increased **climate impacts** across many parts of the world. The Intergovernmental Panel on Climate Change (IPCC), the body that looks at the science behind climate change, was established back in 1988. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was formed, which aimed to prevent human-generated effects on Earth's climate. The Kyoto Protocol was adopted in 2007 and the Paris Agreement in 2015, both of which built on the UNFCCC and aim to ensure its objective is met. So, you can see that the world clearly recognizes the severity of the climate challenge, and we have the science and international agreements in place to address climate change, but we have not yet curbed global emissions.

CLIMATE IMPACTS

Changes in weather due to greenhouse gas emissions and climate change, such as more temperature extremes, heat waves, and intense rainfall.

In response to global warming, society has developed technologies like wind and solar power, which in many cases are even cheaper than fossil fuels. We know that these environmentally friendly help reduce carbon dioxide emissions. In the US and Europe, fossil fuel use has declined [4], which means that solar and wind power are replacing fossil fuels. Electric cars are starting to replace cars that use petrol (gas) and diesel fuel.

In some countries, like India and China, solar and wind power are also growing at a record pace. India is still considered a developing country, with many people in poverty, and Indian society strives to have living standards like those experienced in the US and Europe. In these fast-growing economies, even the rapid growth of environmentally friendly technologies is not yet sufficient to stop increasing carbon dioxide emissions [4]. If we look at the world as a whole, energy use and carbon dioxide emissions continue to grow, although the growth rate has slowed down over the last 10 years (Figure 1).

DO NOT FORGET ABOUT CUTTING DOWN TREES AND FARMING

It is not only fossil fuels and their carbon dioxide emissions that drive climate change. We use more wood today than our ancestors did hundreds of years ago. If this wood is not sustainably harvested and efficiently used, then carbon dioxide emissions rise. We still cut down forests (a process called **deforestation**) and turn them into farmland for cows, sheep, and crops at record levels, releasing yet more carbon dioxide.

DEFORESTATION

The cutting down of forests and conversion to another land use, such as cropland or pastures.

When we cut down forests to make places for food production, not only do we emit a lot of carbon dioxide when cutting down and burning the trees, but other greenhouse gases then follow. Methane comes from burping cows and sheep and from decomposing plant matter, like rice paddies and wetlands. Nitrous oxide (also known as laughing gas) is generated when fertilizers are used to help crops grow more efficiently. Fossil fuels also lead to emissions of other greenhouse gases like methane, either through leaks or through improper burning of those fuels. All these greenhouse gas emissions add up, but carbon dioxide is the most important.

AVOIDING THE WORST OF CLIMATE CHANGE

Today, many countries and companies around the world have **climate policies** to help slow the growth of greenhouse gas emissions [5]. Climate policies may include taxes that make it expensive to do things that harm Earth's climate. Climate policies can also include laws that forbid very inefficient cars to be sold. The climate policies followed today are expected to keep greenhouse gas emissions approximately the same until the end of the century. If this happens, then the global average temperature will increase about 2.2–3.0°C by the end of the century relative to the temperature at the start of the Industrial Revolution, approximately doubling the 1.3°C increase we are already experiencing today. Of course, we do not know exactly how much warmer it will be. It is not easy to predict greenhouse gas emissions for the next 80 years! Scientists understand the climate system well, but there are still many uncertainties. Instead of a 2.2–3.0°C increase by the end of the century, we could end up with only a 2°C increase, or an increase as high as 3.5°C. Governments have already agreed

CLIMATE POLICY

An incentive by the government to help reduce emissions, such as making people pay extra for coal, oil, or gas, or making it cheaper to use solar, wind, or electric vehicles.

CLIMATE PLEDGE

A promise made by a country or company to do something that they have not done yet.

NET ZERO EMISSIONS

When the amount of emissions put into the atmosphere is balanced by the amount that is taken out in the same year.

that climate impacts at 2°C of global warming will cause unacceptable risks to society, such as more temperature extremes, heat waves, and intense rainfall.

Many governments and companies have made additional **climate pledges**, promising to reduce emissions, but they do not yet have policies in place to meet these pledges. This is like promising to clean up your room, but staying on the sofa instead of starting the job. For example, many countries have pledged **net zero emissions**, but they have no policies yet to get there. Net zero means that any emissions that go into the atmosphere must be taken out again. Given the difficulty in removing carbon dioxide from the atmosphere, this means we need to try to stop all emissions as much as we can. It is a bit like spilling hot chocolate in your room. It is much easier to be careful *not* to spill it in the first place than to clean it up afterwards.

Any long task starts with the promise to do it. It is good that we have those promises to reach net zero emissions, but now we need to see some action. If climate policies are put in place to make sure these pledges are met, then global emissions would soon begin to decrease, and the global average temperature increase may be kept below 2°C by the end of the century [5].

Governments still have time to create climate policies to keep temperatures from rising to dangerous levels. This would require cutting greenhouse gas emissions in half by 2030, with carbon dioxide emissions reaching net zero around 2050 and all greenhouse gas emissions reaching net zero around 2080. That is a bit more than what all the governments have promised to do together so far. Now we need the countries to "clean up their rooms". Imagine not only having to convince your friend to clean up their room, but your whole school class! Since most countries have already pledged to clean up, the task now is to get them started.

LIGHT AT THE END OF THE TUNNEL

The good news is that studies show that we have what it takes to reach net zero emissions and keep global warming to around 1.5°C. We may exceed 1.5°C temporarily, but will likely return below 1.5°C again [5] (Figure 2B). The world has been great at developing solar and wind power, electric vehicles, and batteries. But the world has not been as good at stopping the burning of coal, oil, and gas. Instead, the world continues to look for more and more fossil fuels, making the problem even worse. Energy use and emissions continue to rise, although at a slightly lower rate than they would without any climate policies.

The less the world does today to reduce emissions, the worse the future climate impacts will be and the harder it will be to reduce emissions. The easiest path forward is to embrace renewable energy

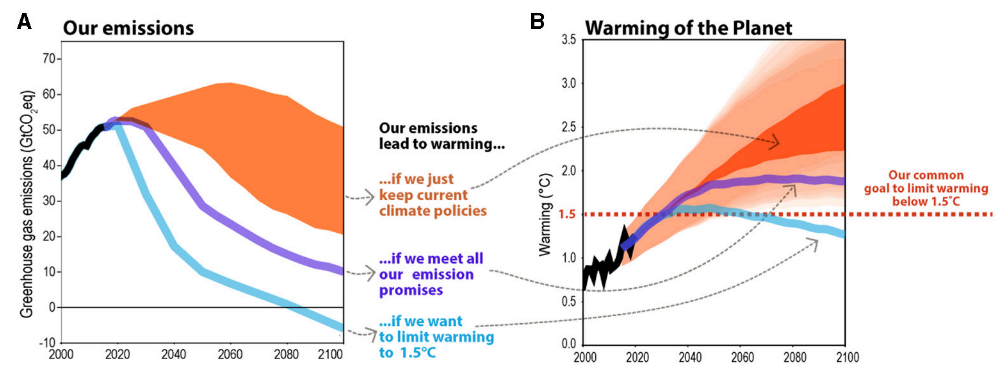

Figure 2

Figure 2

(A) Estimates of future greenhouse gas emissions and **(B)** the amount of warming they can cause. If we want to limit warming to around 1.5°C, we must achieve net zero emissions in the second half of the century (blue line). According to all the climate pledges, scientists' best estimate of warming would be around 2°C (purple line). Pledging countries must create climate policies to reduce emissions further. If we estimate only based on current policies, the world will not reduce emissions fast enough (orange area) and global warming will go well over 2°C, leading to worse climate impacts.

and not make a further mess by burning fossil fuels that we must clean up later. Just as our parents and ancestors made the decisions that caused the global warming we see today, the decisions society makes today will have profound impacts for our children and grandchildren. Future climate impacts will build on top of the impacts we are already experiencing. Since carbon dioxide accumulates in the atmosphere, it is necessary to act quickly. This is something the world is failing to do. We should try to work together—to do a bit more every day. We can all start by reducing our own emissions and asking others to do so, too.

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YOUNG REVIEWERS

JUDE, AGE: 15
I enjoy playing guitar in my spare time, when I am not walking my cat. I often spend time with my two loving brothers. In the summer, I enjoy doing water sports in the lake district along with hiking and paddle boarding. I have lived in the UK all my life and love the weather for about two weeks per year, so I look forward to doing more traveling.

THE AMAZING SIX, AGES: 14–16
Our study group brings together six teenagers interested in science and analytical research. The group was born in December 2023, when our Maths teacher asked us to join this interesting project. We decided to call our team: The Amazing Six. The study group is made up of cooperative and outgoing students between the ages of 14 and 16, coming from different small towns nearby Rome (Italy).

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WHAT IS CLIMATE JUSTICE?

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ELAINE
AGE: 13

SEA CREST SCHOOL
AGES: 12–13

“Climate Justice, Now!” is a banner you often see at climate protests. But what is climate justice? Changes in Earth’s climate impact the whole world, but the impacts are much harsher for some people, particularly poor communities, Indigenous and disadvantaged minorities, young people, and future generations. Importantly, the people who face the most serious impacts of climate change are often those who have contributed the least to the causes of climate change. In this article, we consider why the impacts of climate change are unfair and discuss some ways that we can help reduce this unfairness to bring about climate justice now.

WHY IS CLIMATE CHANGE UNFAIR?

While our changing **climate** effects everyone, the disruptions to everyday **weather** caused by the warming of the atmosphere are unfair because the most serious impacts are often experienced by people

CLIMATE

The long-term average pattern of weather conditions like temperature, rainfall, and wind over a period of months to years.

WEATHER

The short-term conditions of the atmosphere that can change from day to day. For example, is it rainy, cold and windy, hot and dry, or humid?

who have done the least to cause climate change and who have the fewest economic resources to protect themselves. Around the world, the people who are most at risk in a changing climate are often the poorest in any community. They may rely on the natural world for their livelihoods, or they may suffer disadvantages that make them more likely to lose everything in a major weather event. For example, if you live in a neighborhood that is likely to flood but your family does not have money to move away, you are at greater risk than people who can afford to buy a new house in a safer place or buy insurance to rebuild their homes.

People living on small islands in the Pacific produce a very small amount of the carbon emissions that drive climate change, but they are exposed to serious climate risks including destruction of the coastline (erosion), cyclones, and rising tides that threaten their homes. Even their community identity and history are at risk—for example, when storms erode the burial sites of village elders. However, for people living in large cities who already have the money and resources to protect their homes, the effect of a changing climate might simply mean longer and hotter summers or disruptions to their travel and work plans; but these disruptions do not cause serious risks to their lifestyles [1].

The impacts of climate change are not experienced in the same way by everyone around the world. The impacts of severe storms, droughts, wildfires, heatwaves, or floods are worse for the world's poorest people, including children living in rural communities, informal settlements, islands, or places where people rely on stable weather to grow their food [2]. These areas include parts of Africa, Asia, South and Latin America, the Pacific, and the Arctic. Climate risks are also more serious for older people who live alone, people who have been impacted by war, or new migrants who do not have access to health care or a network of friends and neighbors they can call on for support. Even within a country, some groups of people are at a higher risk, including for example, children in low-income rural communities and older people who are poor and have few friends or family nearby to help them in storms or heat waves [2].

Beyond impacting people differently in different places, if we do not take action now, climate change will have more serious impacts for very young children and people who are not yet born, because a bigger part of their lifetimes will be affected by our changing climate (Figure 1) [3]. Climate change is experienced unfairly across generations because babies born in 2020 will experience many more climate risks as they grow up than any generation before them—but we can change this if we take action on climate risks today.

In 2023, the United Nations (UN) declared that climate change was affecting human rights, especially the rights of children to live in a clean, healthy, and sustainable environment and the right to be

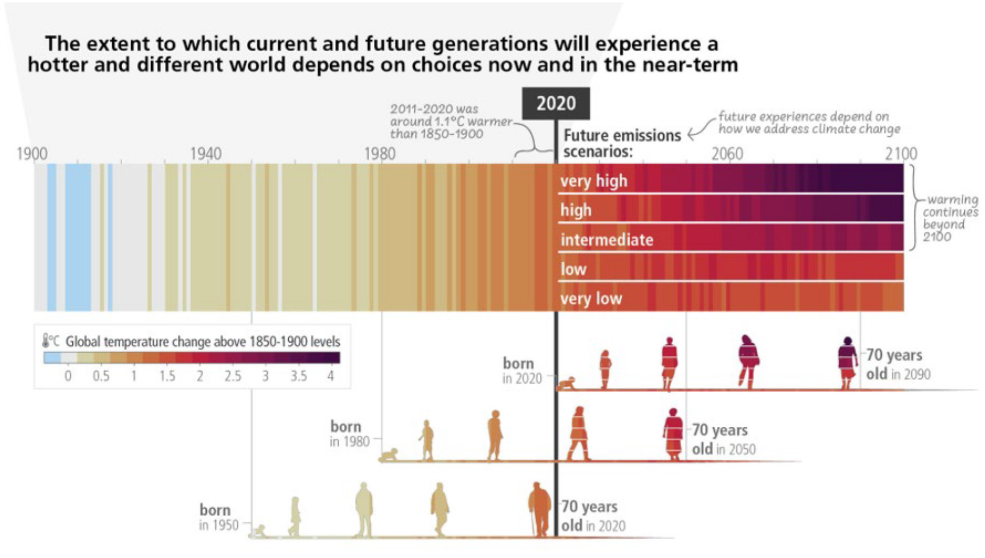

Figure 1

Figure 1

Unless we take action to help Earth's climate now, babies who were born in 2020 will face a much hotter world and more serious climate impacts than their parents and grandparents did. The figure shows how the climate has changed since 1900. Each year has a colored bar that reflects the world's temperature for that year. Blue years are cooler than average and red years warmer than average. The figure shows how the future might look too, and that children born in 2020 will experience climates that older people did not live through (Source: [3]).

protected from the impacts of a changing climate. One reason the UN took this action was because 16,000 children from 121 countries wrote to them to demand a fairer future. In 2024, the UN went a step further and agreed that climate change also affects the rights of future generations. The UN called this a Pact for the Future and it asked all countries to act to protect today's children's rights, including rights of children who are not yet born, and the future of the planet.

WHAT IS CLIMATE JUSTICE?

When we talk about climate justice we mean acting fairly, noticing how people are differently impacted by climate change, and working together to address climate problems in ways that treat everyone with respect. Climate justice means we do not discriminate against people based on how much money they have or what their religion or culture is, for example. But because the climate impacts different people in different ways, we cannot just treat everyone *equally* or the same. To be fair also means we need to think about **equity**. That means understanding how different people face different challenges and risks, and what kinds of resources and support they might need to cope in a changing climate.

EQUITY

Making sure people are treated fairly by recognizing their different situations, and sharing climate impacts, responsibilities, and decisions across society, generations, and genders.

FOUR PRINCIPLES FOR CLIMATE JUSTICE

Acting to bring about climate justice involves thinking about four big ideas [4].

Procedural Justice

The first idea is to make sure everyone impacted by climate change has a say in making decisions about climate change. This principle is called **procedural justice**. If a decision process is fair, people of all ages, communities, and religions can have a say when decisions are being made that impact their long-term future. This might mean that the whole community has a say in a government decision to continue to mine more coal, for example. Procedural justice also means that people whose lives and jobs will be impacted by any big changes are heard and their views are considered. People may not all agree, but taking time to listen to everyone's ideas and experiences can improve decisions. In 2024, the Council of Europe recognized that many young people want to be heard in climate decision making but are often excluded and sometimes face legal threats when they protest about climate change. The Council called on all European governments to protect the rights of young people, particularly "young environmental defenders", so that kids are free to protest and speak out about how the climate impacts the planet and their physical and mental wellbeing.

PROCEDURAL JUSTICE

Making decisions in a fair and open way where everyone can have a say, even if they do not agree with the final result.

Distributional Justice

A second way we can improve climate justice is to ensure the good and bad effects of climate change, and the benefits from climate solutions, are experienced, shared, or distributed fairly among everyone. This is called **distributional justice**. Right now, we do not have distributional climate justice because vulnerable communities and people continue to face some of the most serious impacts of climate change, while rich countries and the richest individuals continue to benefit from using more than their fair share of fossil fuels and resources. For example, global data shows an average Indian citizen emits 1.9 tons of CO_2 every year, while an average American citizen emits 14.9 tons, and a Ugandan emits 0.9 tons. As countries grow, the rich in every country consume much more than the poor do. To give you an idea of how severe this is, the richest 10% of the global population emits nearly half of the world's carbon emissions, while the poorest half of the world only emits about 12%.

DISTRIBUTIONAL JUSTICE

Where the good and bad effects of climate change, and the benefits from climate solutions, are experienced, shared, or distributed fairly among everyone.

Distributive justice also means we need to think about fairer outcomes and who should pay to help communities who have suffered losses and damages—including loss of sacred places, crops, or access to education. For example, some countries have benefitted for a long time from using fossil fuels like coal, oil, and gas. In 2024, a group of law students from the small Pacific nation of Vanuatu took a case to one of the highest courts in the world, the International Court of Justice. They asked what legal responsibilities governments have to prevent climate change from impacting small islands [5]. When some countries or groups of people face unfair risks caused by past and current actions of other countries (or companies), there are growing calls to compensate people for unfair losses and the damages they face.

Recognition Justice

A third principle of climate justice is **recognition justice**. Recognition justice means treating people with dignity, recognizing that different people have different needs based on their cultures, identities, and life experiences. For example, climate change can affect genders differently, so our solutions must be sensitive to these differences. Recognizing gender matters is important because women and girls are often faced with serious risks due to the kinds of jobs they may do in some communities. Collecting water is one example—when water is scarce, women and girls may have to walk longer distances, taking time away from other ways of earning a living or their education [6]. Yet women and girls can change their communities, particularly when they are recognized as having experiences, insights, and ideas that can help in decision making.

RECOGNITION JUSTICE

Treating people with dignity, recognizing that different people have different needs based on their cultures, identities, and life experiences.

INTERSECTIONALITY

People face unfair climate risks not only because of one thing, like their gender or whether they are rich or poor, but because of a combination of things like colonization, sexism, and racism, which can expose some people to even more serious harm. When we pay attention to these intersections of unfairness, it is easier to understand why some people and communities are exposed to greater risk from climate change [7]. For example, the impact of colonization on **Indigenous people** resulted in loss of land ownership, which has increased poverty and made it more likely that Indigenous communities might have to live in flood-prone areas where housing is cheaper. Being a member of an ethic minority or a member of a LGBTQIA+ community might make it doubly challenging for a person to have their voice heard and influence climate decisions, unless their human rights, like freedom of speech, are protected.

INDIGENOUS PEOPLE

Groups who differ from dominant societies, lived in a place before colonization, and have deep ties to their ancestral lands, unique cultures, languages, and traditions.

CLIMATE JUSTICE, NOW!

In summary, if we want climate justice now, we need to pay attention to the complex and unequal ways that climate risks impact diverse groups of people around the world and over time. Climate justice means thinking carefully about who is most vulnerable to climate change and what makes them vulnerable. The idea of climate justice makes us pause and question why, as global warming increases, some people always seem to be winners, and some people are always losers. It then pushes us to think of steps to change this to make the future fairer for everyone—through listening carefully and respectfully to a wide range of views and taking thoughtful action to meet diverse needs. Climate justice is making the future fairer and more equitable for everyone.

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YOUNG REVIEWERS

ELAINE, AGE: 13

I am Elaine, an 8th grader interested in topics that piques my curiosity. As someone who enjoys creative pursuits, I dance, but my greatest passion is writing as it allows me to share my imagination. Using facts and opinions, I can create a variety of ideas for stories. I also love asking questions, seeking answers, and sharing what I learn with others, whether it is through a conversation between friends or debates in school.

SEA CREST SCHOOL, AGES: 12–13

We are a curious group of 7th grade science students who live in coastal California. While we all have individual interests, we are united by a shared passion for environmental stewardship and, in all things, we are determined to "leave it better than we found it": our school's mantra.

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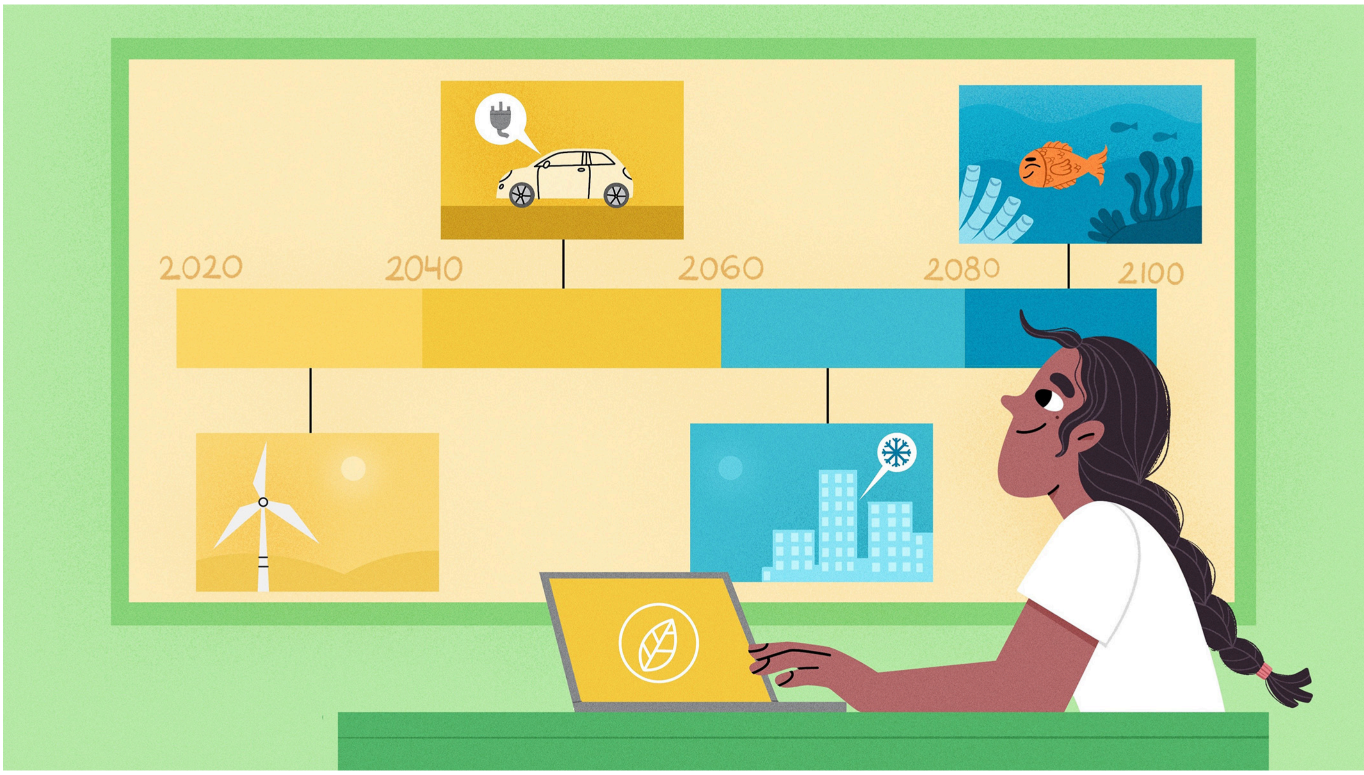

WHAT DO DIFFERENT LEVELS OF CLIMATE CHANGE MEAN FOR OUR FUTURE?

Wan Ting Katty Huang [1*]***, Lincoln M. Alves*** [2] ***and Sonia I. Seneviratne*** [3]

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YOUNG REVIEWERS:

AYAT
AGE: 12

SEA CREST SCHOOL
AGES: 11–12

Climate change, mostly caused by burning fossil fuels, is getting worse. Global warming is expected to reach 1.5°C by around 2030. Depending on the region and season, this would mean greater risk of heatwaves, heavy rainfall, droughts, or intense tropical storms. The strongest impacts would be on vulnerable regions or during extreme events. If global warming reaches 2°C or higher, it will affect even more people across the world. It would mean even worse impacts on our health, food and water supplies, wildfires, ecosystems, and the economy. Already now, people are dying due to hotter heatwaves fuelled by human-induced climate change. If we can understand the impacts better, we can motivate changes to reduce greenhouse gas emissions and protect vulnerable communities. It would also help us prepare for future climate-related events. Our actions today can

make a big difference in creating a safer and more sustainable future for everyone.

THE CLIMATE IS CHANGING

The Earth climate is a complex system, and people are an important part of it. For example, human activities that burn fossil fuels such as petrol, gas, and coal release carbon dioxide into the atmosphere. Carbon dioxide is a greenhouse gas which keeps the Earth warm by trapping heat in the system. Too much of it, however, would make the Earth too warm and lead to other changes in the climate. This is the main driver of human-induced climate change and affects people and society in many ways. For instance, it leads to stronger and more frequent extremely hot days and heavy rainfall across the world [1, 2] (Figure 1). It also leads to more extreme droughts in several countries. How bad global warming gets mainly depends on how much more greenhouse gases we emit. The more we reduce the emissions, the more we reduce the negative impacts.

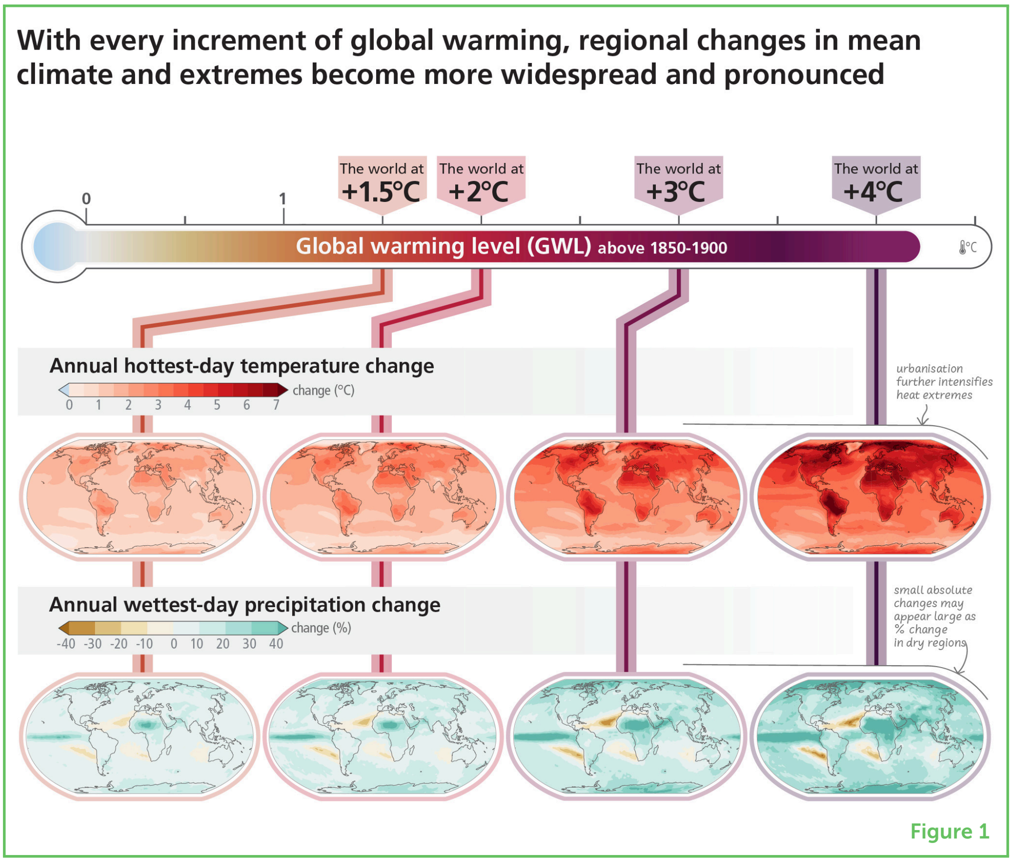

Figure 1

Climate change affects all regions of the world, and as global warming increases, its impacts become larger. For some regions, the consequences are severe even at 1.5°C of global warming. This figure shows the impacts of climate change on heat and rain extremes across the world. Here, climate change is measured by degrees of global warming, which is the increase in average global temperature compared to the average during 1850–1900. Figure adapted and modified from Figure SPM.2a,c from the IPCC 6th Assessment Synthesis Report, Summary for Policymakers [3]. Adapted and modified from Figure SPM.2a,c from IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 1-34, https://doi.org/10.59327/IPCC/AR6-9789291691647.001. Original figure caption: Projected changes of annual maximum daily maximum temperature and annual maximum 1-day precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900. Projected (a) annual maximum daily temperature change (°C), and (c) annual maximum 1-day precipitation change (%). The panels show CMIP6 multi-model median changes.

Understanding the impacts we can expect under different climate change conditions is important, because it shows us the possible effects of our actions. This can then motivate us to limit further greenhouse gas emissions. It can also help us plan for a future where some of these impacts may become inevitable. In this article, In panel (c), large positive relative changes in dry regions may correspond to small absolute changes. The WGI Interactive Atlas (https://interactive-atlas.ipcc.ch/) can be used to explore additional changes in the climate system across the range of global warming levels presented in this figure.

we present the latest findings on this topic as according to the 6th assessment report from the United Nations Intergovernmental Panel on Climate Change (IPCC) [1, 4]. IPCC reports are authoritative overviews of everything we know about climate change based on scientific publications from around the world. The 6th assessment report is the latest version, published between 2021 and 2023.

HOW DO WE PREDICT FUTURE CLIMATE CHANGE IMPACTS

Predicting how climate change will impact the future involves three main steps (Figure 2).

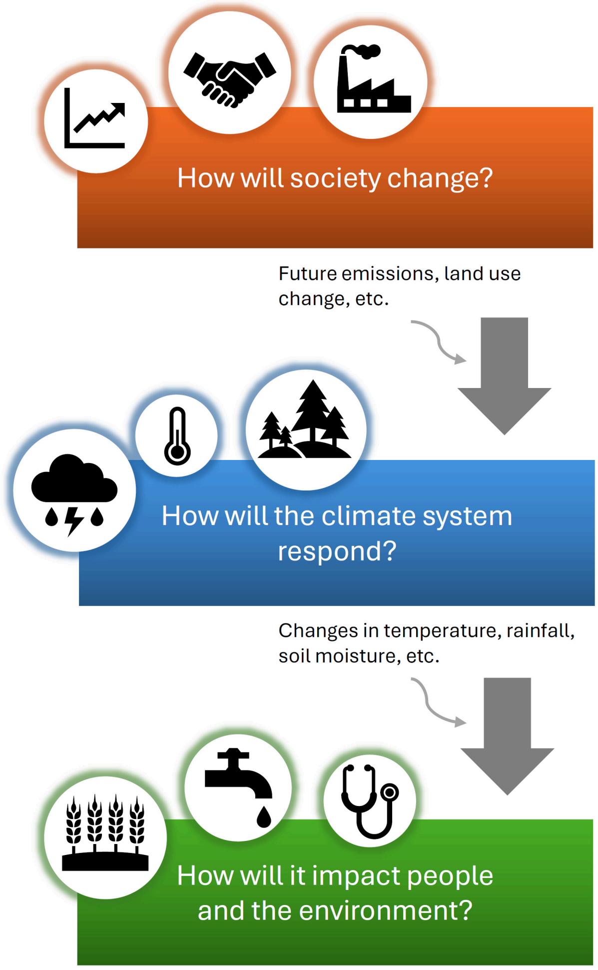

Figure 2

Figure 2

To understand what future climate change might mean for people and the environment, we need to consider three main questions: how will society change, how will climate respond to these changes, and how will these climate responses affect society. The answer to each of these questions is complicated and it is impossible to make a single perfect prediction. Instead, we consider many scenarios, models, and analysis methods. This helps us get an idea of a range of possible futures based on different assumptions.

The first question to think about is how the future society might look like. A range of possible scenarios are considered. For example, one scenario might imagine a world where countries work together to reduce climate pollution. Another scenario might imagine a world where countries continue to rely heavily on fossil fuels. There are many factors at play: how much the economy grows, how much countries work together, what climate policies are in place, etc.

Climate models are then used to study how the natural environment might respond to these different societal changes. Climate models are huge collections of computer code and equations that describe the physics and chemistry of our environment. They are continually being improved. However, no model is perfect, so the results of multiple climate models need to be considered.

Lastly, climate model outputs are analyzed to understand how changes in the environment can lead to impacts on people. Tools used may include statistics or impact models. Compared to climate models, impact models generally include more details but are focused on a specific sector. For example, a crop model may simulate how a specific crop deals with different conditions throughout its life cycle.

IMPACTS AT DIFFERENT DEGREES OF GLOBAL WARMING

Climate change can be measured by degrees of global warming. This is how much the global average temperature has gone up compared to the late 1800s (1850–1900), before people burned fossil fuels widely for energy. It generally refers to the average temperature over a period of 20–30 years. This way, a complete shift in the climate condition is captured instead of a single extreme year. Earth's average temperature is expected to reach 1.5°C warmer than the late 1800s by around 2030. By the end of this century (2081–2100), the global average temperature could be between 1.4°C and 4.4°C warmer than the late 1800s. Exactly how much it warms will depend on how much greenhouse gas is emitted between now and then.

In 2015, countries around the world signed the Paris Agreement. It is a commitment to keep global warming to well below 2°C and to try to keep it to 1.5°C. However, even at 1.5°C of warming, there will be important impacts on people and the environment [5]. Heatwaves will get hotter and last longer, which can lead to more people dying from heat. Depending on the region and season, other disasters such as heavy rain, drought, or intense hurricanes and typhoons, will also get worse. Many animals and plants will be at risk of extinction, and coral reefs will be severely damaged. Much more of the Arctic sea ice will be melted each year during summer melt season. It changes the Arctic environment greatly and affects polar bears, seals, and communities living in the region. More glaciers will also melt away and disappear. This is particularly bad for places that depend on water supply from glaciers and snow melt during warmer and drier seasons. Sea levels will rise by around 44 cm by the end of the century at 1.5°C [6]. Because oceans respond to warming very slowly, it will continue to rise even further for a long time even if warming is kept to 1.5°C.

If global warming reaches 2°C, these effects would get worse. Meeting people's food and nutrition needs would be harder, especially in poorer countries. More and worse droughts, floods, and heatwaves would affect crops and animals. Not having enough water to water farms will also become a bigger problem. It would become more likely that all the world's biggest grain-growing areas experience climate disasters at the same time [2]. The grain could then get very expensive or even run out because there is not enough on the market for everyone. Cities and buildings would also face more damage from natural disasters, costing more money to repair. Human health would be greatly affected too, with more intense heatwaves and diseases spread by mosquitoes, like Dengue and Malaria. At 2°C, there's a higher risk of reaching climate "**tipping points**", which are big, sudden changes in the climate. They are particularly bad because people are less prepared for them and their effects cannot be easily reversed.

TIPPING POINTS

When a small change leads to big, sudden changes that cannot be undone by reversing the process. Imagine nudging a glass across a table, eventually tipping it over the edge.

By 3°C global warming, climate change would impact most of the world. The problems would get worse everywhere. Some damage would be irreversible, meaning it could not be fixed even if global warming is later reduced. Some of these changes will also become so big that it would be impossible to **adapt** to. Arctic sea ice would completely melt away almost every September. Sea levels could rise by about 60 cm by the end of the century. It could reach 4–10 m in two millennia if global warming stays at 3°C [6]. Damages to the economy would also increase faster as temperatures climb. At this level of warming, some climate tipping points could be reached that would cause very serious problems.

ADAPT

To adjust or take action to deal with change.

At 4°C or warmer, the Earth would be drastically changed. About half of the plants and animals in tropical oceans would not be able to survive where they live now, and around a third of the land areas would change significantly. Wildfires would get a lot worse, with 50–70% more areas burnt. Problems with water supply and food production would be widespread, with around 4 billion people facing water shortages [4].

BEYOND NATURAL HAZARDS

The impact of climate change on people in the future will depend on more than just changes in the climate. It will also depend on how societies grow and change over time. The same event can lead to different results depending on how well people are protected against it. For example, if healthcare improves, fewer people who catch Malaria might die from the disease. However, there will also likely be more elderly people in the future. This means heatwaves would become even more problematic because older people have a harder time with them. On another hand, as cities near coasts get bigger, more people and buildings would be exposed to rising sea levels and coastal flooding.

To help reduce the risks from climate change, we need to plan ahead and think about these changing conditions. However, the best way to prevent the worst effects of climate change is to limit greenhouse gas emissions now, so we do not push the climate toward these extreme conditions.

TODAY'S ACTIONS WILL SHAPE THE FUTURE

Global warming is expected to reach 1.5°C soon. The more it warms, the worse the impacts and the more parts of the world are affected. If human-induced climate change is not stopped, it would cause big changes in society and nature over time. The changes may also happen suddenly if tipping points are reached. Some of these changes may be too extreme for people and nature to adapt to, leading to lasting damage and losses.

However, the future is not hopeless. By using less fossil fuel and planning for a changing future, we can reduce future warming and its harmful impacts. Important steps to take include cutting down on greenhouse gas emissions to reach **net zero** CO_2 emissions as soon as possible, switching to renewable energy sources, protecting **vulnerable** ecosystems and communities, and building stronger infrastructure to handle extreme weather. It is essential that countries work together globally and commit to climate action. How society prepares for the future can affect how well we cope, but it will get harder for people to adapt as human-induced climate change worsens. By understanding possible future outcomes and acting now, we can build a safer and more sustainable future for everyone (Figure 3).

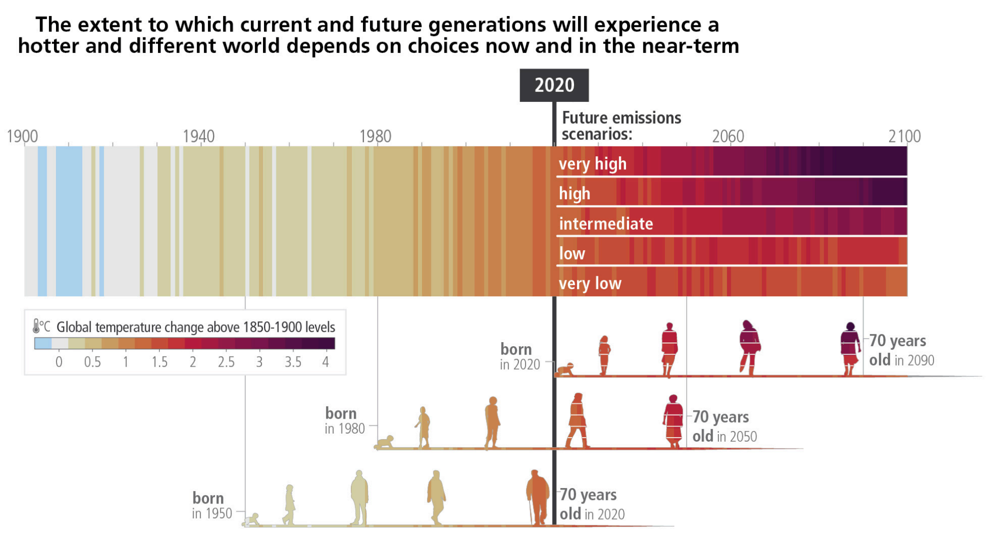

Figure 3

NET ZERO

A balance where the amount of greenhouse gases emitted into the atmosphere is the same as the amount removed, so there is no extra impact on the climate.

VULNERABLE

At risk, easy to get hurt. This may be because it is sensitive to something and/or because it cannot easily respond or adapt to change.

Figure 3

How the future climate will look like will depend on decisions now and in the near future. The impacts of these decisions will be felt most strongly by younger generations. A very low emission future would mean a stable climate even as young people reach old age. In contrast, a very high emission future would mean climate change continues to get worse for years to come. Figure adapted and modified from Figure SPM.1c from the IPCC 6th Assessment Synthesis Report, Summary for Policymakers [3]. Adapted and modified from Figure SPM.1c from IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1–34, https://doi.org/10.59327/IPCC/AR6-9789291691647.001. Original figure caption: Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850–1900), which are linked to changes in climate conditions and impacts, illustrate how the climate has already changed and will change along the lifespan of three representative generations (born in 1950, 1980 and 2020). Future projections (2021–2100) of changes in global surface temperature are shown for very low (SSP1-1.9), low (SSP1-2.6), intermediate (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) GHG emissions scenarios. Changes in annual global surface temperatures are presented as 'climate stripes', with future projections showing the human-caused long-term trends and continuing modulation by natural variability (represented here using observed levels of past natural variability). Colours on the generational icons correspond to the global surface temperature stripes for each year, with segments on future icons differentiating possible future experiences.

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YOUNG REVIEWERS

AYAT, AGE: 12

I am a 12-year-old with a big passion for sketching and painting, especially when nature sparks my creativity. My favorite books, like "Amari" and "The Magicians of Paris", along with other fantasy stories, fuel my imagination. I love cycling, playing chess and badminton, and hiking to uncover nature's hidden treasures. Along the way, I enjoy taking notes and drawing detailed sketches of the plants and animals I encounter!

SEA CREST SCHOOL, AGES: 11–12

We are a fun and diverse crew with a singular goal: to leave toe world better than we found it! We share the gift of living and learning in coastal California, and we are always ready to dive into big ideas like sustainability, climate action, and, of course, science!

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EARTH SCIENCES
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ROUTES TO A CARBON-FREE WORLD

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YOUNG REVIEWERS:


ALEX
AGE: 14


CALEB
AGE: 11


ESTHER
AGE: 14


MARCUS
AGE: 14


MOMO
AGE: 12

Humans need to cut CO_2 emissions rapidly to limit global warming and prevent dangerous climate change. Policies adopted so far in countries worldwide are not enough. The good news is that there are many things we can do. First, we can save energy by using the most energy-efficient technologies and by changing our lifestyles. Second, we can use CO_2-free energy sources, such as solar, wind, or hydropower. Third, we can invest in technologies that can remove CO_2 from the atmosphere. Finally, we can regrow forests all over the planet. Scientists imagine alternative future "scenarios" including different combinations of technology, energy, and lifestyle solutions. We know it is possible, but we need to act now to reduce CO_2 emissions, even if it means making hard choices.

THE WORLD NEEDS TO REDUCE GREENHOUSE GAS EMISSIONS

The world's climate is warming because of human activities, such as burning coal, oil, and natural gas to produce electricity, heat our homes, and fuel our cars (Figure 1A). In the **Paris Agreement** of 2015, countries worldwide promised to limit the increase in global average temperature to well below 2°C and to pursue efforts to stay below 1.5°C compared to temperatures before the Industrial Revolution, when humans started to use a lot of fossil fuels. These goals were chosen to prevent the potentially disastrous impacts of climate change. At the moment, Earth is already around 1.4°C warmer, and the impacts of climate change are becoming noticeable.

PARIS AGREEMENT

The international treaty adopted in December 2015 in Paris, France, in which countries agree to mitigate climate change by limiting global warming to well below 2 degrees Celsius above pre-industrial levels and pursue efforts to keep warming below 1.5 degrees.

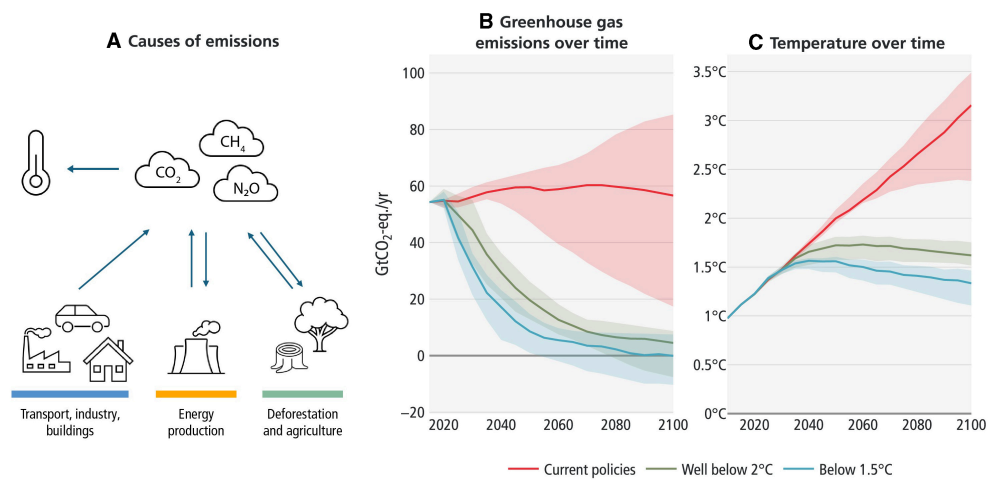

Figure 1

Figure 1

(A) Greenhouse gas emissions mostly result from burning fossil fuels in industry, houses, and transport; from producing electricity; and from cutting down forests and other emissions related to agriculture. **(B)** Based on current policies and trends, emissions are likely to stay constant, while for the goals of the Paris Climate Agreement emissions need to go down. **(C)** This means that the temperature projections stay above those of the Paris Climate Agreement (well below 2). Figure based on IPCC [1, 2].

The most important action we can take to limit global warming is to stop releasing CO_2 (the main greenhouse gas), as well as other greenhouse gases, such as methane (CH_4) and nitrous oxide (N_2O), into the atmosphere. There is a direct relationship between the amount of CO_2 we put in the atmosphere and the level of global warming. Based on this, climate scientists often refer to the remaining **carbon budget**, which is the maximum amount of CO_2 that can be emitted before global warming passes a temperature goal. To stay below 1.5°C, we cannot release more than about 250 billion tons of CO_2 from today onward, while also reducing **emissions** of other greenhouse gases. This is only about 6 times the CO_2 emissions released in 2023 alone [1]. To stay below 1.5°C, CO_2 emissions need to be deeply reduced now and reach **net zero emissions** around 2050 (Figure 1B). To stay well below 2°C, emissions need to be reduced rapidly as well, reaching net zero around 2070 [1]. While these years might sound far away, they actually imply that immediate action is needed. Clearly, it will be much more difficult to limit warming to 1.5°C than well-below 2°C, but if we do so the damage of climate change will be much less.

CARBON BUDGET

The amount of CO_2 that still can be emitted into the atmosphere given a selected goal for limiting global warming.

EMISSIONS

The release of greenhouse gases into the atmosphere due to human activities such as burning fossil fuels.

NET ZERO EMISSIONS

Balancing the amount of greenhouse gases released and removed from the atmosphere to stop adding to climate change.

COMPUTER MODELS

Computer simulations of systems that determine future climate change, such as energy use and production, agriculture, nature, the climate system itself, and possible consequences, such as sea level rise. Models are used to explore possible scenarios or pathways for future climate change.

SCENARIOS

Descriptions of possible future developments based on a consistent set of assumptions (such as population growth or technology development). Scenarios help in understanding the potential consequences of different actions.

Some countries are already reducing emissions, but in others emissions continue to grow. Overall, greenhouse gas emissions have been increasing. Taking into account the current actions and policies that countries are implementing, temperatures will likely increase to around 2.5°C–3.5°C of warming by the end of this century, with negative consequences for all life on Earth (Figure 1C) [1–4].

CO_2 emissions mostly come from burning fossil fuels and deforestation. It will not be easy to reach net zero. Fossil fuels are used all across society. For example, think about the boilers installed in homes for heating purposes, the coal and gas power plants that provide electricity, and the oil used in cars and planes. How fast can we shift away from these technologies and adopt new ones? What are the main changes we need to make to stop global warming? These are the topics we discuss in this article.

REACHING NET ZERO EMISSIONS

To find out what changes can help us get to net zero, scientists collect data on possible technological and social changes. They then use **computer models** to develop **scenarios**, which are possible choices or action plans that the world could follow to stay within the remaining carbon budget [5]. Next, we will describe four types of actions that people could take to limit greenhouse gas emissions.

Reducing Energy Use in Buildings, Transport, and Industry

We use energy in our daily lives for heating, cooling, and lighting our homes, schools, and offices, and for cooking and other daily tasks. Industries need energy to manufacture products like clothing. Energy is also used to transport goods and passengers in cars, ships, and airplanes. Today, most of this energy comes from fossil fuels. There are several ways that we could reduce our overall use of energy for these purposes. For example, we can insulate our buildings better, keep the temperature to a comfortable level (not too cool or too warm), and switch to more efficient heating systems, like heat pumps. Together, such changes could reduce emissions by 40%–70% in 2050. Using less energy overall will also make it much cheaper and quicker to move away from fossil fuels, because we will not have to produce as many windmills, solar panels, and other renewable sources.

Replacing Fossil Fuels With Renewable Energy Sources

Renewable energy sources, like wind and solar power, have become cheaper over the last decade. This makes them good alternatives to fossil fuels for generating electricity without creating greenhouse gas emissions. However, sun and wind cannot always supply all our energy—sometimes the sun does not shine and the wind does not blow and for some purposes, electricity is not an alternative. Therefore, additional solutions are needed, such as powerful batteries to store

BIO-ENERGY

Energy generated from burning products generated from plants or trees. This can be wood, but also fuels (like biodiesel) created from crops.

CO_2 CAPTURE AND STORAGE

Removing CO_2, mostly from fume gases but possibly from the atmosphere and storing it in reservoirs like empty natural gas fields.

REFORESTATION

The planting of forests on lands which have, historically, previously contained forests.

energy, large energy grids to move electricity around, or **bioenergy**, in which sustainably grown crops or trees are used for energy. We could also continue to use fossil fuels in combination with removing the CO_2 from the fume gases and store it underground, called **CO_2 capture and storage**, or we could use nuclear power. Still, some emissions are very difficult to reduce.

Reducing Emissions in Difficult Sectors

Some emissions are especially difficult to reduce, such as emissions from cement and steel production, long airplane flights, and meat and dairy farming (scientists call them "hard to abate"). Why are these difficult sectors? The main reason is that right now we have limited technologies to help reduce emissions in these sectors. For example, wind and solar power cannot be used to power airplanes because current batteries are too heavy and do not store enough electricity to keep a plane flying for a long time. Researchers think that hydrogen produced from renewable energy sources—so-called green hydrogen—could be used in steel-producing furnaces, but we do not currently produce much green hydrogen, so it tends to be very expensive. Livestock is another challenge: cows and sheep produce methane emissions when they fart and burp. There may be some technologies to reduce such emissions, but it is likely that we will not be able to stop them completely.

Due to the difficulty in reducing emissions from these sources, it is important to consider alternatives. For example, people could make lifestyle changes like eating less meat or flying less. Nonetheless, scientists think that to stabilize global temperatures we will also need to remove some CO_2 out of the atmosphere to compensate for these hard-to-abate emissions. We also may want to remove some of the CO_2 emissions we have put in the atmosphere later. Captured CO_2 can be stored for long periods of time in trees, other plants, soils, rocks or underground in reservoirs (see this Frontiers for Young Minds article for more information).

Stop Cutting Down Forests—Plant Forests Instead

When trees and other natural vegetation are cut down and burned, they produce a lot of carbon emissions. Trees are usually cut down to create new areas to produce food. How do we prevent this? First, we could protect existing forests and we could plant new ones, which is called **reforestation**. Second, we could improve food production on current farms in a sustainable way, so that we can meet the growing demand for food without using more land. And lastly, we can reduce food waste and change what we eat. Shifting toward diets with less meat, especially in countries with high meat consumption, can decrease the amount of land needed to produce our food. Shifting diets not only helps the environment but could also improve human health.

COMBINING ELEMENTS INTO PATHWAYS

Scenarios can help us learn more about possible solutions for reducing emissions: How much renewable energy do we need? How can we reduce energy use? From all the scenarios found in the scientific literature, a report from a group of experts called the **Intergovernmental Panel on Climate Change (IPCC)** presents a few choices [1–4]. These are called the illustrative mitigation **pathways**. All of them meet the goals of the Paris Agreement and limit temperature increase close to 1.5°C, but their implications and risks are different (Figure 2).

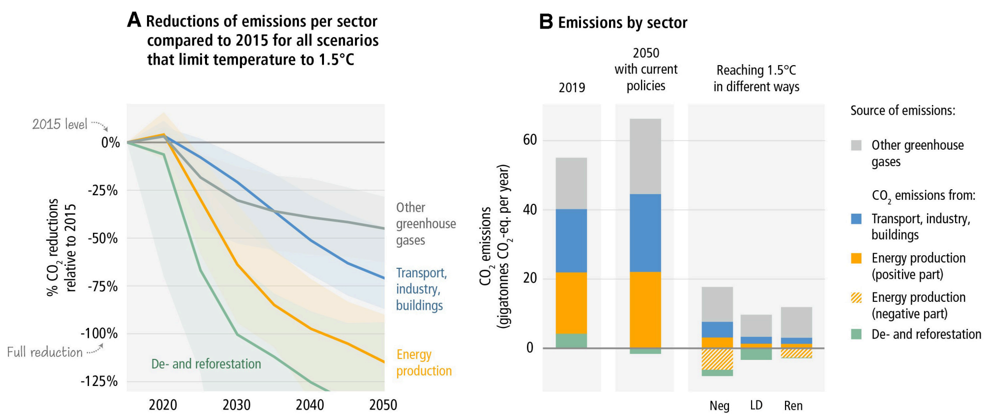

Figure 2

Figure 2

(A) To limit warming to 1.5°C, emissions must be reduced in multiple sectors, including CO_2 emissions from transport/industry/buildings, CO_2 emissions from energy and electricity production, net CO_2 emissions from de- and afforestation and other greenhouse gases (mostly from agriculture and energy production). **(B)** Examples of pathways to reach net zero CO_2 emissions. Emissions can be negative if CO_2 is taken from the atmosphere (e.g., due to regrowing trees). The graph on the right shows three scenarios to stay below 1.5°C: the negative emissions pathway (neg), the low-demand pathway (LD), and the renewable energy pathway (ren). The first column shows emissions in 2019 and the second column shows what will happen in 2050 following current policies [3]. Figure based on IPCC [1, 2].

The *Negative Emissions Pathway* relies heavily on CO_2 removal technologies. These include reforestation, the use of bioenergy combined with CO_2 storage underground, or direct capture of CO_2 from the atmosphere. This scenario might allow us a slightly slower transition now, but it heavily relies on future generations to invest in these removal technologies. There may be a risk that the technologies do not work, and many of them require land, which could compete with food production.

The *Low-Demand Pathway* relies heavily on reducing energy demand by efficiency and lifestyle changes. It imagines that we can avoid using products that we do not need, and that we can buy products that last longer, eat less meat and dairy, and live in smaller but more efficient homes. However, the question is how quickly and easily such changes can be adopted.

The *Renewable Pathway* relies heavily on renewable energy sources, assuming that we can support these technologies with energy storage solutions and well-connected electricity grids. This scenario also has a shift toward using more electricity for transport and buildings, like electric cars and heat pumps. This could be attractive, but it will require significant investments in renewable energy and power infrastructure starting now, which will increase demand for certain materials needed

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

The international organization consisting of scientists with the task to assess scientific knowledge on climate change and its impacts.

PATHWAYS

Equivalent to the word scenarios.

for these technologies (while also decreasing demand for fossil fuel materials).

MEETING THE PARIS AGREEMENT CLIMATE GOALS

Moving forward through any of these pathways will be challenging but the pathways show that it can be done! This is a major conclusion of the most recent IPCC report: we know how to meet the objectives of the Paris Agreement. However, meeting the objectives to limit global warming will require society to move toward a very different type of path, giving up our addiction to fossil fuels for the good of all life on Earth.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ALEX, AGE: 14

Alex is an 8th grader who likes science, math, history, and English. He enjoys playing video games, role-playing Dungeons and Dragons, and playing Texas Hold'em (and winning).

CALEB, AGE: 11

Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

ESTHER, AGE: 14

My name is Esther, and I am 14 years old. I enjoy playing the flute and drawing and painting in my free time.

MARCUS, AGE: 14

Marcus is a supporter of STEM. He is in 8th grade as of writing this review. He spends his time researching a wide variety of topics, especially sciences such as biology and physics. He is involved with mock trial, welding, and more.

MOMO, AGE: 12
Momo loves to travel the world and see new places. Even so, she is a self-proclaimed couch potato when she is at home. The two extremes can coexist in one person! Her favorite couchmate is her fuzzy and affectionate dog, Lita.

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WHAT CAN WE DO ABOUT THE CLIMATE CRISIS?

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YOUNG REVIEWERS:


CALEB
AGE: 11


KYLA
AGE: 12


MAX
AGE: 11

Understanding how our planet's climate is changing because of human actions is super important if we want to keep living here. A changing climate means hotter weather, droughts, wildfires, heavy rains, storms, and floods. To fix things, we need to figure out which human activities are making the climate act this way and how we can change those activities. Everyone has a part to play—politicians, companies, engineers, and citizens. Small things like changing how we travel or use energy can help a lot. When the younger people who will inherit the planet come together and demand action on climate change, they can have a big impact. It helps when young people combine these demands with personal action, to show others that they, and lots of other people, care about this issue: by eating less red meat, using transportation wisely, pushing for changes in how businesses operate, and voting for leaders who care about the environment.

Earth's climate is changing, getting warmer and more extreme and unpredictable, leading to ever more frequent catastrophes like hurricanes, floods, and wildfires. These changes result from the big increase in human-caused **greenhouse gas emissions** since the Industrial Revolution. Climate changes will get much worse if there is no action.

The climate crisis requires two types of action. One is to find ways to slow down or stop the changes, and the other is to figure out how to adapt to the unavoidable changes we are already experiencing. These two goals require action from everyone. Scientists and engineers can look for new ways to generate energy without emitting more greenhouse gases, politicians can pass laws regulating emissions and provide tax breaks for companies that develop climate-friendly technology, and companies can lead the way in reducing their own emissions and selling products that have lower **carbon footprints**. Young people like you also have an important role to play! [1].

GREENHOUSE GAS EMISSIONS

Gases like carbon dioxide and methane released into the air from activities like burning fossil fuels, which trap heat in the atmosphere and contribute to global warming.

CARBON FOOTPRINT

The amount of pollution, like carbon dioxide, that we create when we use energy, like driving a car or turning on the lights.

People have learned a lot about how the way we live affects the climate. It is not just about the emissions from our cars or factories, it is also about where we live, how we get around, and even what we eat. Some of us walk to school; others take a school bus or the subway; still others get there in a chauffeured car. Some of us have never left the area we live in, even for vacations; others expect to travel regularly with family and friends to faraway places, for fun or education. Some of us live in huts in rural villages without regular electricity and running water; others live in apartments or mansions in big cities. We eat differently, sometimes by choice and sometimes due to financial and cultural circumstances. Some of us barely have enough to eat, for others, overeating leads to obesity and poor health. What we eat, and specifically how much red meat we consume, has impacts on the climate, as the farming of cows and other livestock emits much more greenhouse gases per calorie than growing grains and vegetables does. All these lifestyle factors add up and can change the average temperature and rainfall around the globe, making extreme weather like droughts, floods, hurricanes, and cyclones happen more often [2].

CITIZENS

Does it seem like individuals—and especially children and teens—cannot make much of a difference? As a child, your ability to take action is limited because most housing, transportation, and even food decisions are made by your parents or other adults. But things may be better than they seem. Parents are often influenced by their children's concerns. Greta Thunberg is a great example. As a teen, she convinced her whole family to change the way they were living. Her mother, an opera singer, no longer flies to engagements, and her father fully supports Greta's climate activism as her manager. There are many other examples in which children and teens, by expressing their concerns and fears about the future and their confusion and anger over the apparent failure of adults to take significant actions to protect the climate, have motivated parents and grandparents to change their personal or professional lives. There are personal stories from the leaders of big companies (e.g., Air France, Unilever), and a recent opinion poll in the USA found that 74% of Americans feel they have a "moral obligation" to make the world a better place, by addressing climate change not only for their own children and grandchildren but for all children to come.

Personal activism is a way to express your hopes and fears, to find others who share your values and concerns, and to let the world know about your feelings through physical actions and social media. The FridaysforFuture movement, started by a single teen as a protest in front of the Swedish parliament in 2018, now includes 14 million students in 7,500 cities around the world. Making your worries, wishes, and opinions known by talking about them at school and at home can help you to see how many others share your views. Because many people (adults included) think that others might not share their views, sometimes we do not talk about what we think and thus never find out how common our views really are. Talking about our opinions and taking action based on those views have many multiplying effects and can change how society, politicians, and companies think about climate action.

Leading by personal example is a good thing and often major effects. Social youth movements like FridaysForFuture have spawned other social movements like Seniors for Climate Action Now! (SCAN). Knowing how widespread youth climate anxiety and support for climate action is has also encouraged adult activists to take legal action against governments on behalf of children. Attorneys from Our Children's Trust, a non-profit environmental group, have brought legal actions against U.S. state governments on behalf of youth in all 50 states. In 2023, this organization won its case in the state of Montana, where a judge ruled that the state was violating the rights of the 16 young people who had filed the lawsuit to "a clean and healthful environment", as well as their rights to dignity, health and safety, and equal protection under the law (Figure 1).

GOVERNMENTS

In the quest for a sustainable and healthy future, governments are like the captain steering the ship through stormy seas. Governments play a crucial role in creating an environment where everyone—from individuals to businesses—can contribute to the fight against climate change. Governments have the power to plan strategies to make societies more environmentally friendly. By investing

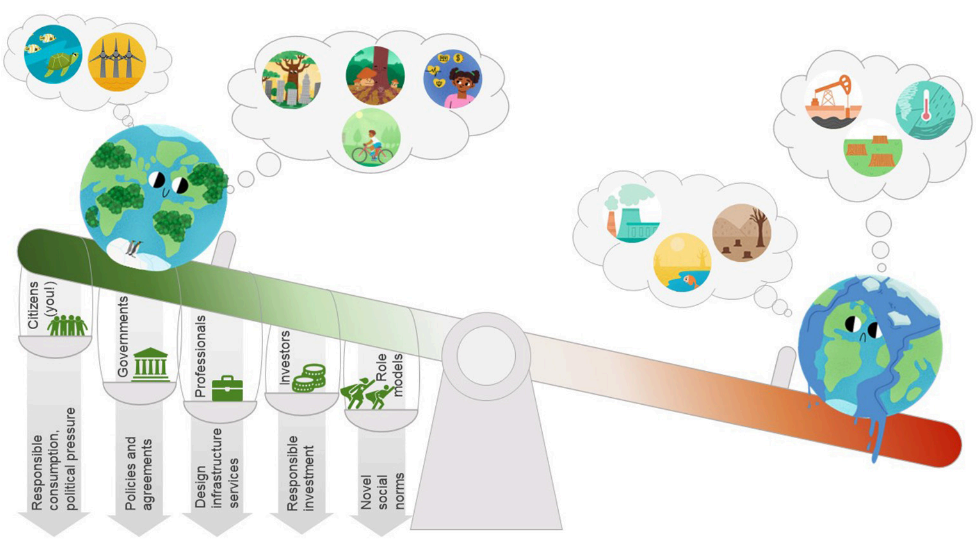

Figure 1

Figure 1

The two different worlds on opposite sides of the seesaw show the choices we face. Our current social, economic, and political actions are tilting us toward an Earth that is not inhabitable by humans. The actions illustrated on the left can tip the seesaw toward a sustainable future.

RENEWABLE ENERGY

Power we get from nature, like the sun, wind, or water, that can be used again and again without running out.

in **renewable energy** sources and eco-friendly transportation, for example, governments pave the way for a cleaner, more sustainable planet.

Climate change knows no borders, so the governments of all countries must work together to address this global challenge. Through collaborations, agreements, and shared responsibilities, nations can pool resources and knowledge to tackle climate change collectively. For example, the United Nations, an international organization of 193 countries, organizes meetings to assess the progress being made in dealing with climate change and negotiating agreements on actions that countries can take together to reduce its impact (Figure 1).

PROFESSIONALS AND INVESTORS

Did you know that businesses and professionals can also play important roles in protecting Earth's climate? Professionals can offer eco-friendly services, such providing shared bikes or scooters for transportation, or they can install and maintain solar panels to help generate electricity. Investors—people or organizations that put money into a business for financial returns—can play an important role by providing the money to support sustainable practices, businesses, and projects that benefit the environment [3]. More importantly, investors can refuse to invest in the fossil fuel industry. When investors choose to invest in companies that use clean energy or contribute to the protection of our planet through green technologies, infrastructure, and services, they actively contribute to making the world a better place (Figure 1).

ROLE MODELS

Celebrities and role models can use their influence to educate and inspire people on the importance of environmental and climate conversations. Actors like Leonardo DiCaprio use their fame to advocate for clean energy and animal protection. Even individuals like Greta Thunberg, though not traditional celebrities, are recognized as heroes for speaking up about climate change. However, the power to drive positive change is not limited to public figures; it extends to all young leaders (Figure 1).

Your generation could significantly contribute to shaping a sustainable future by supporting actions and lifestyles that are good for the climate. You can be a leader, too! Start by taking simple but impactful steps, like cycling or walking to school, reducing air travel, and eating less meat and more plant-based foods. You can also involve your family and friends by sharing information about sustainable practices—like installing solar panels, adjusting the temperature settings for cooling or heating your home, and avoiding the use of fossil fuels. You could also consider getting involved in local groups or projects centered around protecting the environment. In those groups, you will meet other people with the same views and learn new ways to help save the climate [3]. But please note that the best actions are positive, peaceful, and respectful. Refrain from joining groups or protests that may cause harm to people or objects—such protests can push away the people you need to help your cause.

By actively participating in positive efforts, you can contribute to the collective effort to build a world where both nature and humanity thrive. Together, through collaboration and dedication, we can forge a more sustainable future.

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YOUNG REVIEWERS

CALEB, AGE: 11

Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

KYLA, AGE: 12

Kyla is going into 7th grade. She likes coding, digital design and maker projects. She also likes cats and narwhals. In her free time, Kyla likes to code games. Kyla also likes to mess around with digital drawing tools to create animations and art. In the future, Kyla is excited to learn more about robotics. Over the summer, Kyla is looking forward to reading good books, going to improv camp, and spending time with her family.

MAX, AGE: 11
Max is a fun-loving 11 year old who loves to read and play video games. He cares very much about the climate change crisis and has read up on it a lot. He has a business with is best friend Armen.

AUTHORS

LEILA NIAMIR
Leila Niamir is a passionate young scientist dedicated to studying and preserving the Earth. Her childhood love for nature led her to pursue a career in science, focusing on Earth science, climate change, and energy. Now, she collaborates with scientists worldwide to combat climate change and improve the planet's health. Leila's research emphasizes the importance of cooperation between scientists, governments, and individuals to protect the environment and ensure a high quality of life for all. She strives to understand how our actions impact the climate and environment, and advocates for collective efforts to create a happier, healthier Earth for everyone. *niamir@iiasa.ac.at

ELKE U. WEBER
Elke U. Weber is a psychologist who has been trying to understand for a long time why we often do not do the things that we know we ought to do, and how to redesign the way we describe decisions and consequences in ways that make us more concerned about the future and willing to contribute to a livable climate and fair world. Born and raised in Germany, she has lived and worked in Canada and the United States for the last half century.

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TREES, SOIL, AND CLIMATE: WHAT IS THE CONNECTION?

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YOUNG REVIEWERS:


ATHARV
AGE: 12


TAHIYAT
AGE: 11


TAHMID
AGE: 13


TANVIR
AGE: 14

Land plays an important role in climate, biodiversity, and people's lives. Plants and soils absorb carbon dioxide, store carbon, and recycle rainwater, affecting the planet's temperature and weather. Land also provides food, timber, and other products that we need to survive. Some land activities, like planting trees, can take carbon dioxide out of the atmosphere, reducing global warming. Other land activities, like restoring wetlands, can help protect infrastructure and ecosystems from the results of a changing climate, like flooding. This article will explain how land management can help reduce greenhouse gas emissions, help people respond to changes in climate, and improve biodiversity. We will also talk about how scientists measure and understand these activities and their effects.

THE ROLE OF LAND

Land plays an important role in climate, **biodiversity**, and people's lives. Land absorbs carbon dioxide, a **greenhouse gas** affecting Earth's temperature. Plants use carbon dioxide, sunlight, and other nutrients to grow and produce oxygen. Carbon is stored in plants and soils, but can be lost when land is cleared, such as by **deforestation** and **degradation**. When carbon dioxide is released by burning fossil fuels or by deforestation, some of it goes into the ocean, some of it is absorbed by plants as they grow, and some stays in the atmosphere. The carbon dioxide that stays in the atmosphere traps heat, warming our planet. Cows and sheep also produce methane, a potent greenhouse gas, as they digest their food. Light-colored and snow-covered land surfaces reflect sunlight, but darker surfaces like trees absorb sunlight, making the air above them hotter. Plants affect how energy flows across the land surface, influencing local temperature, winds, and rainfall.

Over the last 150 years, changes in land cover, such as cutting down trees to plant crops and grow livestock, have led to a release of greenhouse gases, contributing to global warming. Those changes have also produced more light-colored surfaces on Earth, which reflect more sunlight, and have caused some cooling [1]. However, the total global warming from increases in greenhouse gases is larger than the cooling from changing land cover. So, overall, Earth has warmed over the last 150 years by 1.15°C.

Land provides food and recycles and stores water. Farmers use land to grow crops, like wheat, maize, fruit, and vegetables. Land is also used for livestock, like cattle, pork, and poultry—both for the animals to live on and to grow their feed. Today, about 12%–14% of Earth's land is used to grow crops, around 37% is used for livestock, and 30% is covered by forests (both natural and managed) [2]. Forests can provide timber for building, paper, and energy production. Some forests are untouched and provide homes for a wide variety of plants and animals, which means they have high biodiversity. Ecosystems with high biodiversity are more resilient to future climate change.

Land is also impacted by changes in climate. Temperature over land has risen considerably faster than temperature over the ocean. Rainfall has also changed, with some parts of the world becoming drier and more at risk of drought and wildfires. Other areas are having more powerful floods and storms. These changes in weather patterns are affecting when, where, and how well plants grow, and whether animals thrive.

HOW DO WE KNOW?

Scientists have several ways of understanding the role of land in climate. We can take measurements of land cover from the ground,

BIODIVERSITY

The variety of all living things around the world, including plants, animals, and the ecosystems that they live in.

GREENHOUSE GASES

Gases in the atmosphere that can absorb heat and cause the planet to warm up. Human activity is putting more greenhouse gases into the air, leading to global warming.

DEFORESTATION

Removing forest and replacing it with another type of land cover, such as crops.

DEGRADATION

Damaging the forest but leaving it to remain as forest—but with fewer trees and bare areas within it.

from airplanes, and from space. For example, satellites can tell us where forests and crops are by taking very precise pictures from space. There is also an instrument on the International Space Station that uses lasers to measure how tall trees are (Figure 1A). Some of the tallest trees in the world are redwood trees in California, USA (Figure 1B). From the ground, we can measure the size of individual trees in a forest, and we can also measure the uptake and emissions of greenhouse gases from plants and animals. We can also get data from timber producers and farmers. We use all these types of data to work out how much carbon is stored, gained, or lost. By taking these measurements repeatedly, we can see how things change over time, and under different environmental conditions.

Scientists also use **computer models** to understand land and climate. These models use mathematical equations to represent various processes that happen on Earth, such as the way a tree grows, how much carbon it absorbs, how much sunlight the land reflects, and more. With these models, scientists can ask questions about what has happened in the past and what might happen in the future. For example, we can use a computer model to understand what would happen to the climate if we planted many more trees. This way, we can test what might happen before we try it in the real world.

COMPUTER MODELS

Computer programs which build a virtual copy of the world so that scientists can study how it might change.

HOW LAND CAN HELP ADDRESS CLIMATE CHANGE AND IMPROVE SUSTAINABILITY

The way we manage land can help limit climate change. Reducing deforestation and improving land management can reduce carbon dioxide emissions, while planting trees can remove carbon dioxide from the atmosphere (although it can take several decades for new trees to grow). People may consider changing their diets to eat less meat, or they may try to waste less food, because these actions will reduce greenhouse gas emissions. Good land mana gement can also free up land for forests and other natural ecosystems, increasing biodiversity and **food security** at the same time. Restoring natural ecosystems, like wetlands, can also help slow down natural river flow and prevent flooding. Increasing how much carbon is stored in soils can help farmers grow more food on the same amount of land.

FOOD SECURITY

Ensuring all people have reliable and affordable access to enough food.

BIOENERGY

Energy made by burning plants or wood rather than fossil fuels like coal, oil, or natural gas.

Land products can replace goods and services that produce a lot of greenhouse gases. For example, we can burn wood or crops (called **bioenergy**) as an energy source instead of fossil fuels like oil and coal; or we could use timber instead of concrete and steel in buildings. While these steps could reduce greenhouse gases, we would need to use large areas of land to produce this bioenergy. This might mean there is less land available to grow crops for food, which could lead to challenges for food security and **sustainability** [2]. While land can help limit climate change, it cannot stop it all: greenhouse gas emissions

SUSTAINABILITY

Acting in a way so that our actions now do not damage the ability of future generations to also benefit from the land in the same way.

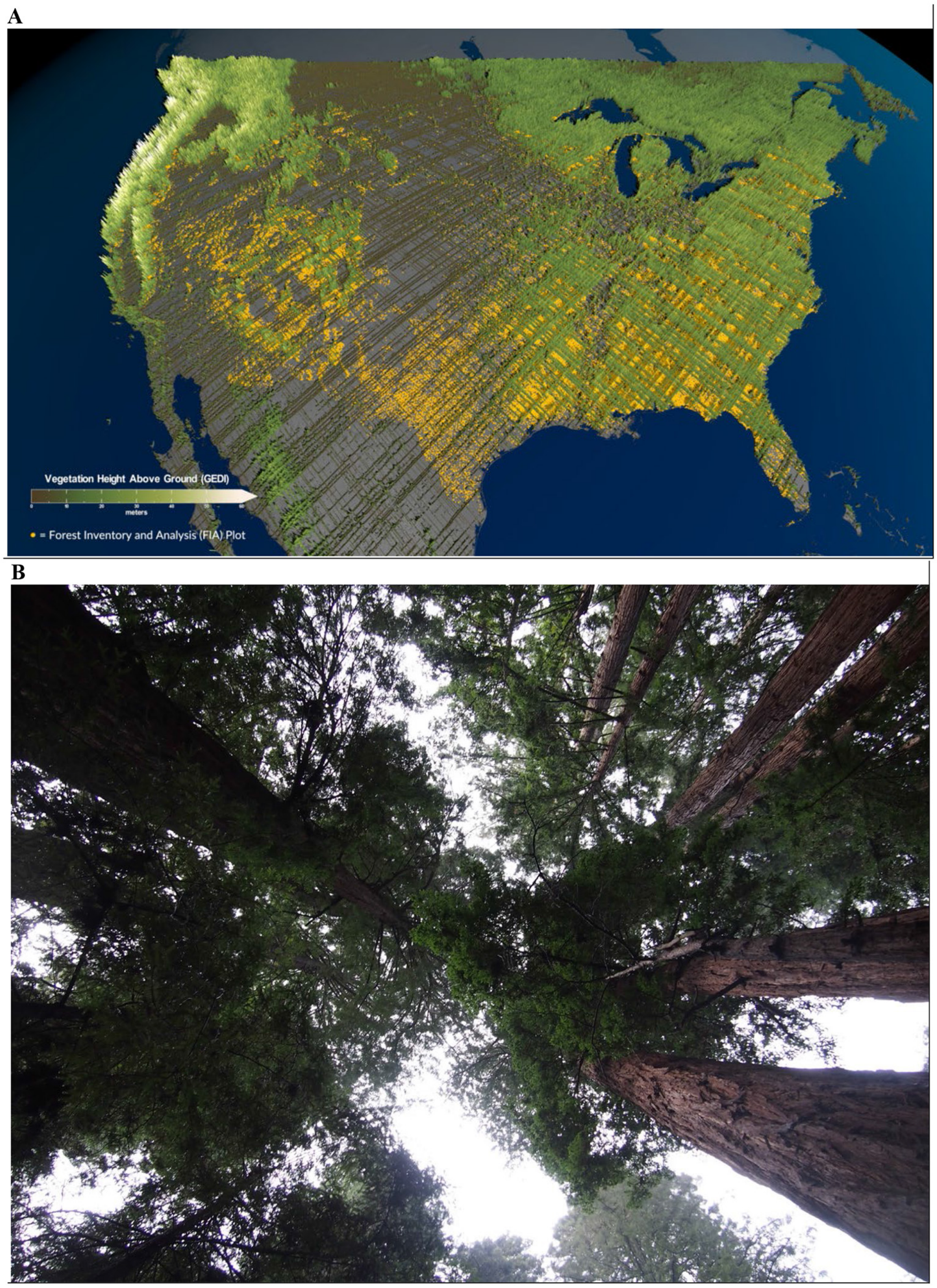

Figure 1

Figure 1

(A) How we measure the land: the orange dots show places where the U.S. Forest Service has special plots of land where people on the ground can measure the trees directly. The other colors show the height of the trees measured from space, by the Global Ecosystem Dynamics Investigation (GEDI)—an instrument onboard the International Space Station. **(B)** A stand of old-growth coast redwoods appears to reach to the sky in Muir Woods, a primeval forest north of San Francisco (Figure credits: NASA/Karlin Younger).

from burning fossil fuels would need to be reduced to near zero to stop global warming.

Using computer models, scientists can look at how different choices people make will change the land in the future. There are many choices we can make now that can improve life on land and limit climate change. For example, we could have a future in which the Earth has grown back much of the forest areas that have been cut down. Improved farming technology could help ensure that food is available to everyone around the world, while still increasing forest areas.

Looking at the same area of North America shown in Figures 1, 2 shows the results of a computer model predicting how the world would look in the year 2100 if tree cover increased and greenhouse gas emissions were reduced. The green colors show where there are more trees—partly because more trees are planted in this scenario and partly because higher levels of CO_2 allow trees to grow a bit better. We hope that having this knowledge of our possible options for the future will help society make better plans to tackle climate change and produce enough food.

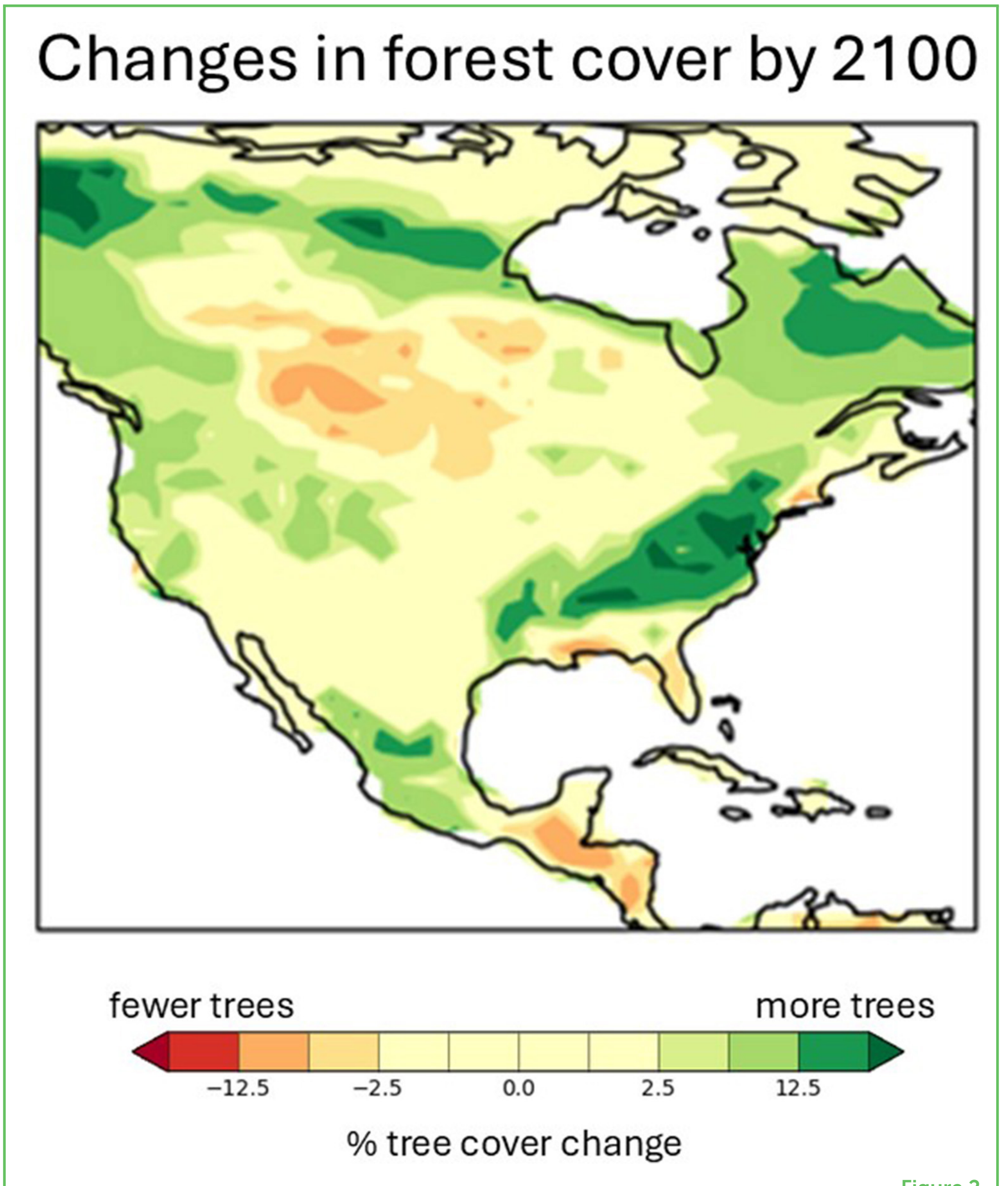

Figure 2

Figure 2

Changes in tree cover by the year 2100, from the UKESM1 computer model predicting the climate under a scenario known as SSP1-2.6 [3]. This scenario aims to limit global warming to around 2°C and includes a large increase in forest cover. The colors show changes in the percentage of land covered by trees, with the green areas showing where there are more trees.

Land is vital for our lives, and we know how to use it responsibly. Over many centuries, some communities and nations have learned how to use land sustainably. However, land is vulnerable to changes in climate as well as changes made by people. In recent decades, our use of the land has grown rapidly affecting climate, natural ecosystems, and biodiversity. We know that land management can help reduce greenhouse gas emissions and limit global warming. Our scientific knowledge of the problem can help us understand these issues and plan for a sustainable future.

AI TOOL STATEMENT

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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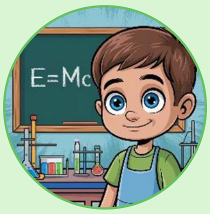
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ATHARV, AGE: 12
A curious and imaginative 12-year-old with a love for stars, stories, and science. Equally drawn to books, building things, and big questions about the universe. Calm yet adventurous, thoughtful yet playful, always exploring the world with wide eyes and a creative mind. Whether sketching dragons, designing paper airplanes, or decoding constellations, this young dreamer blends wonder with logic and magic with meaning, finding inspiration in the night sky and joy in every small discovery.

TAHIYAT, AGE: 11
My name is Tahiyat and I am 11 years old. I love drawing, painting and making paper crafts. I enjoy much wathing craftsmaing and “Origami” in youtube. My aim in life is to be a good doctor. In free time I love to sing and dance. My favorite cartoon character is Dipper, Mabel and Grunkle Stan from Gravity Falls.

TAHMID, AGE: 13
I am Tahmid and I am a big fan computer games. I love coding and making new friends in my virtual sports community. I also love music and spend a lot of time playing my guitar. My hobby is gardening and I love to germinate any seed I find. I wish one day I will be a great plant scientist.



TANVIR, AGE: 14
I am Tanvir. I love science and reading story books. Specially the universe, star, galaxy and science experiment attract me so much. My favorite TV show is Brainchild—A fun, science-based show answering cool kid-friendly questions.

AUTHORS

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Dr. Kate Calvin is NASA's chief scientist and co-chair of Working Group III of the Intergovernmental Panel on Climate Change for the 7th assessment cycle. She has also worked as an earth scientist at the Pacific Northwest National Laboratory's Joint Global Change Research Institute, where her research focused on relationships between human and Earth systems in the context of climate change. Calvin received her doctorate in management science and engineering from Stanford University and a Bachelor of Science in computer science and mathematics from the University of Maryland. Kate is also affiliated with Pacific Northwest National Laboratory, which did not provide specific support for this paper.

JO HOUSE

Dr. Jo House is a professor in environmental science and policy at Bristol University. Her research focuses on land and climate interactions, including carbon emissions from land use changes and climate mitigation through carbon dioxide removal techniques like afforestation and bioenergy. Her aim is to provide better evidence for climate policy. Jo has worked as head of climate advice for the Government Office for Science and has been an author for many reports of the Intergovernmental Panel on Climate Change including the Special Report on Climate Change and Land.

CHRIS D. JONES

Dr. Chris Jones is a climate research fellow at the Met Office Hadley Centre in Exeter in the UK, and a professor in climate science at the University of Bristol. He has over 30 years' experience writing computer programmes to model how climate affects our natural ecosystems and how the carbon cycle helps reduce the amount of CO_2 pollution in the atmosphere. He leads a research programme with partners in Brazil and has visited research sites in the Amazon rainforest. The photo here is on top of the Mauna Loa volcano in Hawaii where CO_2 is measured.

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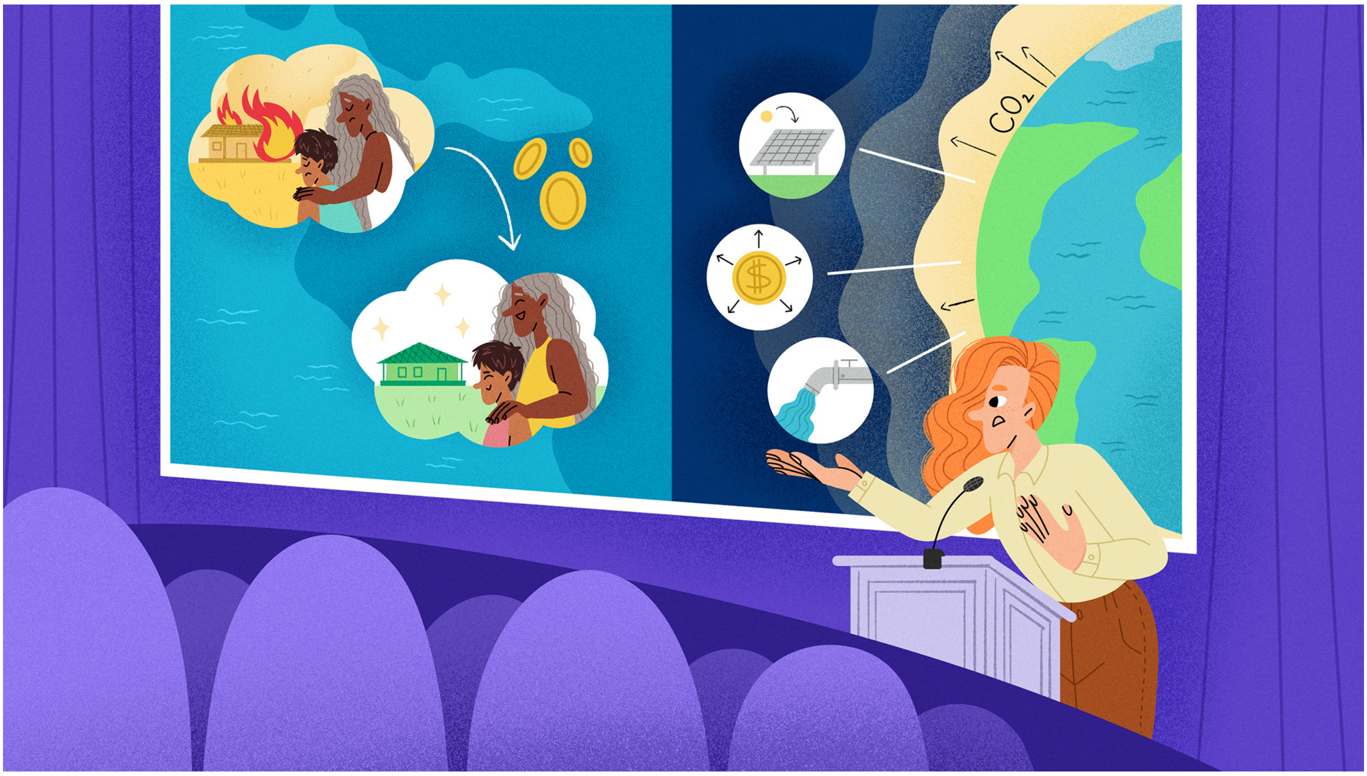

THE MONEY CHALLENGE OF CLIMATE CHANGE

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YOUNG REVIEWERS:


CALEB
AGE: 11


ELAINE
AGE: 14

Climate change is a pressing challenge to human wellbeing and the health of our planet. As global temperatures rise, so will the climate impacts and risks faced by all of us. Not all regions and people will face these climate risks equally. Poorer countries and small islands will face much bigger climate risks and disasters. People in these vulnerable regions have contributed the least to climate change. We must make huge changes to the way we live to ensure a just and sustainable future for all. These changes will need trillions of dollars each year that is fairly distributed. This article examines the goals of fair global climate finance in building a safer future. We discuss why global climate finance is still only a trickle and how governments, big companies, and others can come together to deliver on climate action.

CLIMATE CHANGE AND US

Over the past several years, most of us have experienced or heard of a nearby extreme climate event—floods, storms, fires, and droughts (see this paper). The impacts of these events can differ widely, including missed school and play, disrupted work and travel, social and emotional distress, and physical damage to our homes and neighborhoods. Some damages are catastrophic, while others are slow and long lasting.

In May 2023, the Intergovernmental Panel on Climate Change (IPCC) concluded its latest assessment, the Sixth Assessment (AR6) [1]. The IPCC is a United Nations (UN) group established in 1988, tasked with assessing the science related to climate change. The IPCC reviews all available published scientific literature to arrive at this assessment. The IPCC's work has led it to receive the Nobel Prize in 2007 and the Gulbenkian Prize for Humanity in 2022. The IPCC's assessments clearly show that global warming will increase the frequency and intensity of extreme climate events. Even the wealthiest nations will not be safe from climate change. However, developing countries and the least-developed countries with large poor populations are more vulnerable. When we look at where fossil fuel emissions happen [2], we see nearly half of the world's 8 billion people, who have contributed the least to climate change, stand to suffer the most losses and damages (Figure 1).

LOTS OF MONEY MUST BE INVESTED FOR A CLIMATE-RESILIENT, JUST TOMORROW

The science and the evidence are clear: all of us need to come together to make some fundamental changes in how we live, to ensure a **sustainable and just** future for all adults and young people (see this paper for details). The top 10% of all households globally cause some 35%–40% of global greenhouse gas emissions that lead to global warming and climate change, while the bottom 50% of households contribute only 13%–15% of emissions. Lifestyle changes will take time. We have some urgent tasks immediately ahead, especially in finding the large amounts of money needed to drive this change.

SUSTAINABLE AND JUST

Caring for the planet in ways that protect nature and people today, while also being fair so everyone now and in the future can live well.

What is climate finance? Climate finance is all of the public and private money required to be invested to address climate change goals (see below). This includes government budgets and investments in renewable energy and **climate-resilient infrastructure**. Without enough money, we cannot hope to reach the goal of limiting future global warming to 1.5°C or well below 2°C, which was agreed on by all countries in the Paris Climate Agreement of 2015. We will also not be able to address the rising costs of climate change, especially for poorer communities and countries.

CLIMATE-RESILIENT INFRASTRUCTURE

Buildings, roads, and other systems that people depend on, designed to keep working and protect communities even as climate change brings floods, heat, or storms.

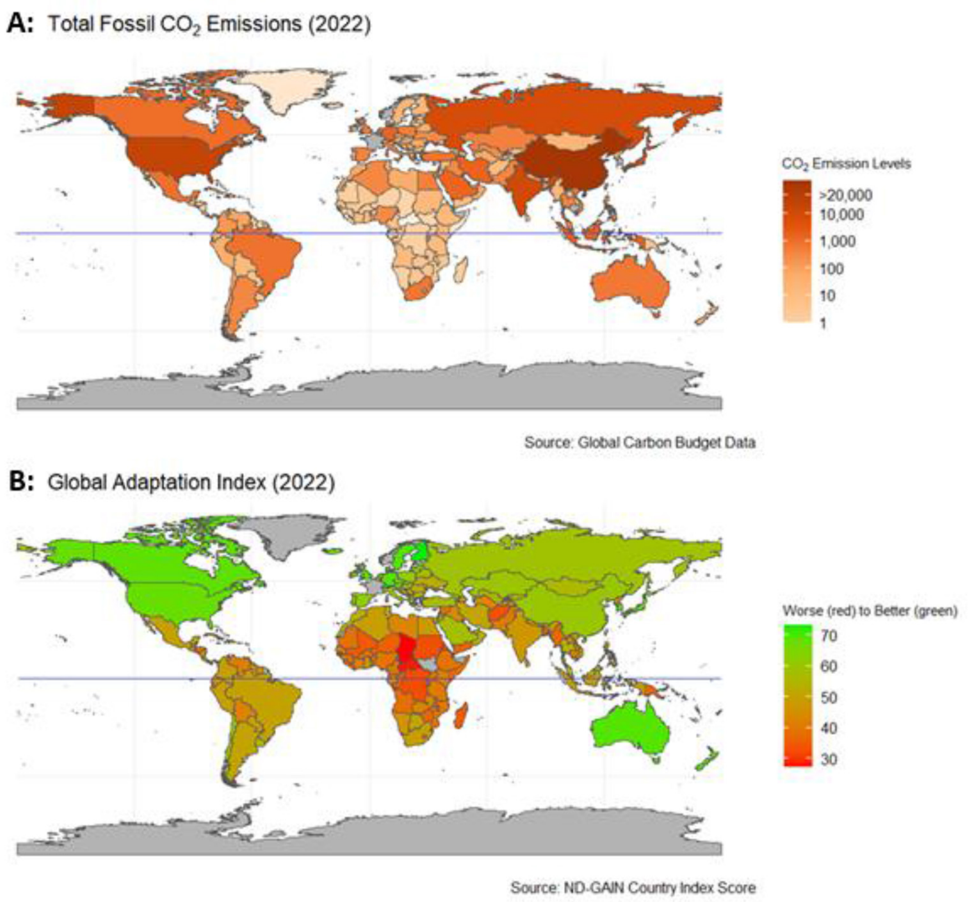

Figure 1

Figure 1

(A) Map showing where fossil fuel CO_2 emissions come from. **(B)** Map showing where most of the expected impacts from climate change will occur. You can see that the countries that face the biggest challenges from climate change have generally released the least CO_2, and thus contributed the least to causing it. Therefore, climate finance is required to help to spread the cost of climate change more fairly (Data are sourced from https://explore.globalcarbonbudgetdata.org/timeseries.html and https://gain.nd.edu/our-work/country-index/ respectively).

CLIMATE RESILIENT DEVELOPMENT (CRD)

Working to both slow climate change and adjust to its effects, while making sure communities can grow in ways that are fair and sustainable for everyone.

CLIMATE CHANGE MITIGATION

Reducing greenhouse gas emissions, primarily through replacing fossil fuels with renewable energy sources.

CLIMATE CHANGE ADAPTATION

Actions people and communities take to adjust to the effects of climate change, like building flood defenses, planting drought-tolerant crops, or creating early-warning systems for storms.

This collective investment covers the financing required for **climate-resilient development (CRD)** To enable CRD, 193 country governments agreed to speed up two kinds of climate action. The first is **climate change mitigation**, and the second is **climate change adaptation**. These climate actions go along with the UN's 2030 sustainable development goals (SDGs), which call for working together to fight climate change and protect people and the planet. Climate change will require massive amounts of targeted financing over the next several decades to address CRD.

Trillions of Dollars are Needed Annually for Mitigation Investments

Other articles in *Frontiers for Young Minds* elaborate on scientifically proven reasons for global warming and climate change, especially rising greenhouse gas emissions from fossil fuels and **deforestation** (see this collection for more details). The urgent challenge is to reduce (mitigate) such emissions drastically, which requires trillions of US dollars in investment every year. We must stop using and burning fossil fuels (oil, coal, and gas) and try to power our homes, transport, and industries with low- or zero-carbon renewable energy sources such

DEFORESTATION

Cutting down large areas of trees and forests, which can harm animals, people, and the environment.

as solar, wind, geothermal, and green biomass energy. We also need to reduce deforestation (see this paper).

Billions of Dollars are Needed for Adaptation Funding

At the same time, countries need to improve their ability to deal with the impacts of ongoing global warming. We must speed up such adaptation because global warming from a past century of emissions already in the Earth's atmosphere cannot be reversed. Adaptation requires billions of US dollars annually. One method of adaptation is to design our cities and infrastructure better, to withstand the impact of rising climate risks like increased rainfall and flooding. For example, increasing storm water drainage into rivers and lakes can limit urban flooding. Another method is to protect poorer people from catastrophic climate events and shocks such as floods and droughts by providing universal access to food, basic services like clean water and energy, financial support, and affordable insurance.

Billions of Dollars are Needed for Loss and Damage

Despite our best efforts, some unavoidable risks of climate change will remain, requiring special targeted funds to be set aside to compensate poor communities for loss and damage—communities that had nothing or very little to do with causing past global warming and climate change and its future effects. Wealthier countries have recently agreed to compensate poor communities and countries for the unavoidable and irreversible risks of rising damages caused by global warming, such as storms, floods, droughts, sea-level rise, and other negative impacts. The international community has agreed to put such a fund into action, although it remains very small.

All of us, from local communities to national governments, must actively choose all these options to improve the current unsustainable situation. But it is expensive—these changes need to be backed by serious global funding that is equitably distributed, so that poorer countries can meet their development needs and climate goals. For instance, nearly 500 million people in sub-Saharan Africa still have no access to clean energy. They are heavily reliant on cutting trees and burning biomass, charcoal, or fossil fuels, while it is hard for them to get private investments because lenders see them as too risky.

DO WE HAVE THE MONEY?

The world is running desperately short on climate finance. In 2021/2022, about $1.3 trillion was used for climate projects, which is more than twice what was spent in 2019. But experts say we need a lot more, about $8.6 trillion every year until 2030, and about $10.4 trillion until 2050, adding up to about $250 trillion in total. Right now, we are only covering one-fifth of what is needed. While adequate climate finance is lacking everywhere, not surprisingly, its biggest shortfall is in developing countries that need it the most.

While this seems like a very large number, the world spends much more on many other things. For example, we continue to spend more on new fossil fuels projects (several trillion dollars a year) than we do on renewable energy. We also spend more on wars, and on fossil fuel infrastructures, such as cars, trucks, housing, and cities (Figure 2). The developed countries have the most money but are falling well behind their own obligations to reduce greenhouse gas emissions, and to meet their promises to help developing countries financially (a long-term target of $1.3 trillion a year and some $200–300 million a year in the near term).

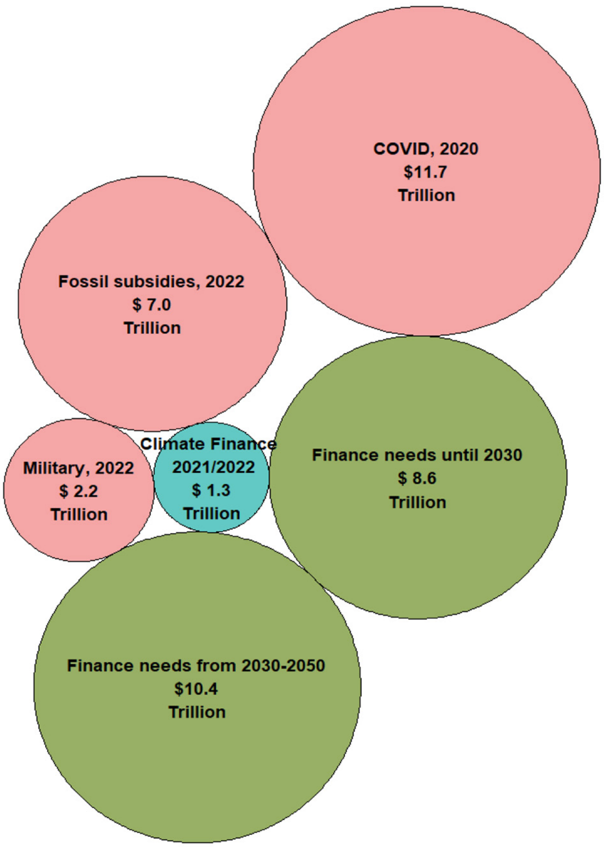

Figure 2

Figure 2

How the current and future needs of climate finance compare with other major costs. The blue circle shows how much we spent per year on climate finance during 2021 and 2022. The pink circles show how much was spent on fossil subsidy (government financial support), military, and responding to COVID-19. The green circles show how much we need to spend each year for climate finance up to 2030, and then up to 2050. Amounts are in US dollars (Data sourced from Climate Policy Initiative).

CHALLENGES, BARRIERS, AND SOLUTIONS TO GLOBAL CLIMATE FINANCE

The challenge is to overcome these barriers through greater international cooperation. Nations do not want to move money abroad, and companies who want to make profits do not wish to invest in developing countries, which they see as a risk to their money. Many solutions are possible.

Switching investments into renewable energy instead of fossil fuels is the easiest. This does not require large public grants (government money given for free), since it can be done by creating better opportunities and by setting government rules that encourage private companies to join in. New technologies and falling costs could speed up this transition. For example, solar energy use is increasing across the world thanks to falling costs of solar panels and many incentives being provided by governments to speed up this change—from China and India, to the European Union, and US states like California. During this transition, the biggest need is for easier access to long-term finance for energy-efficient infrastructure and buildings. Lots of money is needed for this: between $15–30 trillion over a decade. But we could fill this gap by using just 2.4 percent of global savings annually [3].

Second, we need to make it easier for money to be channeled to developing countries in creative ways, through new financial instruments, such as **public guarantees** Nearly three-quarters of global climate finance currently stays in high-income countries [3], while low-income countries such as in sub-Saharan Africa receive less than 5 percent of global climate finance flows.

PUBLIC GUARANTEES

A promise from the government to cover some financial losses if a project fails. This safety net lowers risk so investors are more willing to fund climate projects.

Third, poorer nations need money to rebuild after climate disasters and to protect themselves for the future. This money can come from richer countries by raising some global betterment taxes (fees on polluting industries).

To reach these solutions, the world's governments and institutions like the World Bank will have to come together. Rich nations need to deliver on their promise of $200–300 billion of public financial assistance each year, and raise it to $1.3 trillion a year rapidly (as was agreed after failing to meet the previous target of $100 billion a year in the past decade). For example, creating reliable **green labels** can help everyone easily identify real climate-friendly projects. Furthermore, when governments pass strong laws supporting clean energy, investors feel confident and are more willing to fund new projects.

GREEN LABELING

Labeling that identifies a certain product or service as less harmful to the environment than other similar products or services.

TURNING IDEAS INTO ACTION

We have more financial resources today than ever before in human history—enough to meet all the climate investments we need. But those funds are just not put into the right places and purposes fast enough to deal with the climate change issue in a fair way. We know what works, and we have many options to scale up climate action. Together, we must commit to serious financial and governance reforms to accelerate a transition to a low-carbon economy. Our climate is our future.

AI TOOL STATEMENT

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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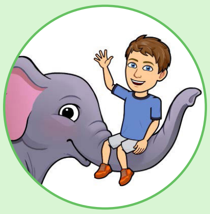
YOUNG REVIEWERS



CALEB, AGE: 11

Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

ELAINE, AGE: 14

I am Elaine, an 8th grader interested in topics that piques my curiosity. As someone who enjoys creative pursuits, I dance, but my greatest passion is writing as it allows me to share my imagination. Using facts and opinions, I can create a variety of ideas for stories. I also love asking questions, seeking answers, and sharing what I learn with others, whether it is through a conversation between friends or debates in school.

AUTHORS

DIPAK DASGUPTA

Dipak is a distinguished fellow at TERI, India, and an economist specializing in climate change, finance, and economic development. He has contributed to major IPCC reports and the UNEP Emissions Gap Report. He was a founding board member of the Green Climate Fund and principal economic adviser to India's Ministry of Finance. He worked at the World Bank for nearly 30 years, focusing on economic policies and investments in various regions. Educated at Delhi and Cambridge Universities, he has received prestigious awards and published over 100 works on climate finance and agriculture.

AROMAR REVI

Aromar is the founding director of the Indian Institute for Human Settlements (IIHS) and the Vice-Chancellor of IIHS University. He is a global practice and thought leader and educator with 40 years of interdisciplinary experience. Aromar has led close to 250 practice, policy, and research assignments worldwide and is a top-10 globally cited scholar across half a dozen fields. His interdisciplinary work spans sustainable development, urbanization, infrastructure, finance, climate science and disaster risk reduction. He is one of the world's leading urbanists and coordinating lead author of multiple IPCC reports, including the Special Report on 1.5°C and the forthcoming Special Report on Cities and Climate change.

SANIA WADUD

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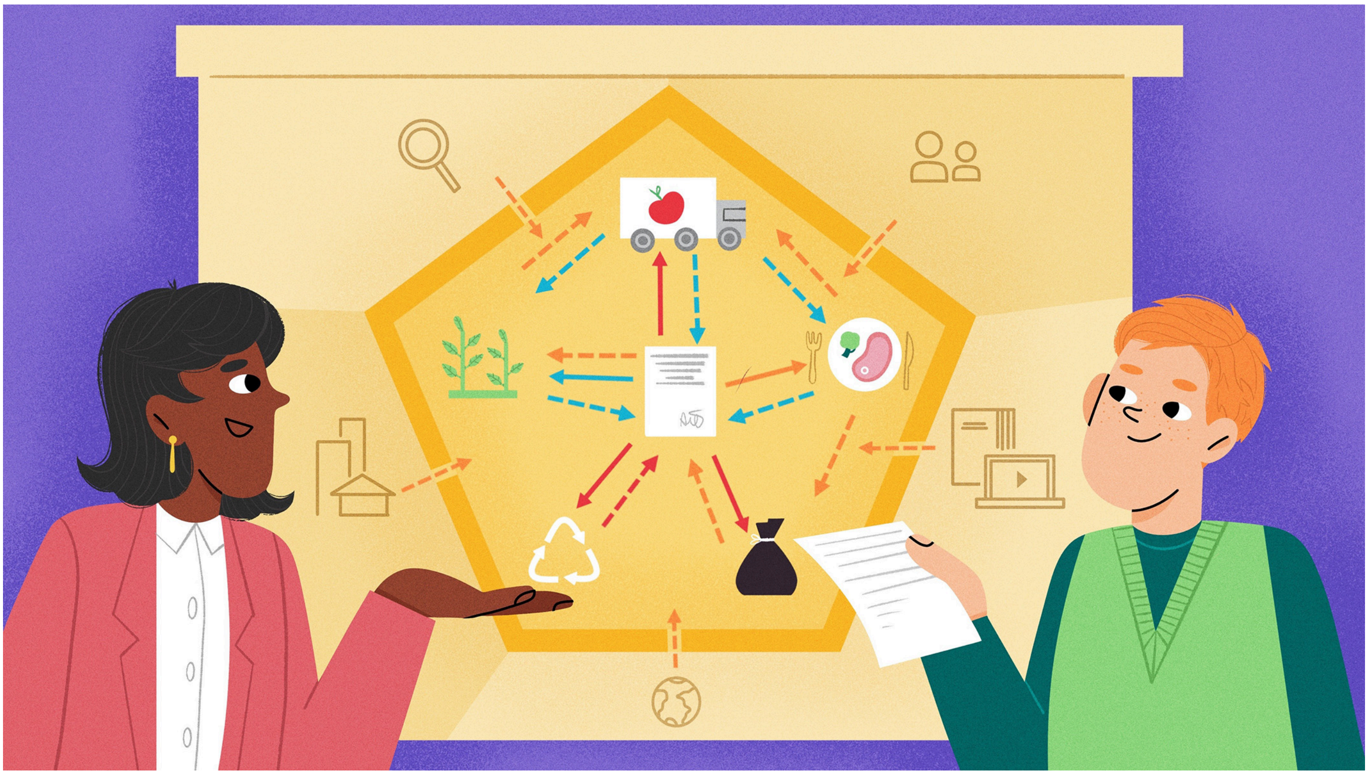

THE FOODS WE CHOOSE CAN CONTRIBUTE TO CLIMATE CHANGE

***Adrian Leip*[1*], *Göran Berndes*[2] *and Diana Ürge-Vorsatz*[3]**

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YOUNG REVIEWERS:

AYAT
AGE: 12

YOUNG SCIENTIST ACADEMY
AGES: 11–13

What should I eat? Many people ask this question several times a day. What we eat determines whether we get all the nutrients and energy that we need. But our choice of foods is also important for the environment and Earth's climate. Which diets are nutritious, healthy, *and* climate friendly? There is no easy answer. All the activities involved in putting food on our tables—farming, food processing, transport, storage, and cooking—can cause greenhouse gas emissions. In this article we will explain what food systems are, how some food systems can be harmful to the environment, how we can eat diets that are both healthy *and* climate friendly.

FOOD PRODUCTION CAN DAMAGE THE ENVIRONMENT

Everybody needs to eat! Food keeps us healthy and gives us the energy to go about our daily lives. However, producing the foods we eat requires a lot of natural resources. For example, farmers must use a lot of land to grow crops or animals, they use fuels to power their farming equipment, and they often apply fertilizers to enhance crop growth. If there is too little rain, farmers may need to use water from the ground or from lakes and rivers to irrigate their crops.

This resource use can be bad for the planet, but there are even more ways that the foods we eat can cause environmental problems. For example, excessive use of fertilizers or pesticides can cause pollution of nearby land and water and can even affect human health [1]. Consequently, or when land is cleared for food production, the number of different plants, animals, and other living things on those lands can be reduced, decreasing Earth's natural **biodiversity**. Pesticides can also harm pollinator populations (such as bees) that are very important for plant growth. Another environmental problem caused by farming is the overuse of medicines called antibiotics that protect farm animals against harmful bacteria, which then makes those medicines less effective for humans. Finally, food production can be a major source of **greenhouse gas** (GHG) emissions—this is what we will focus on in the rest of this article.

BIODIVERSITY

The variety of all life on Earth, including plants, animals, and the ecosystems that they live in.

GREENHOUSE GASES

Gases in the atmosphere which can absorb heat and cause the planet to warm up. These occur naturally, such as carbon dioxide and water vapor, but human activity is putting more greenhouse gases into the air leading to the planet getting warmer.

WHAT ARE FOOD SYSTEMS?

Food systems include the entire life cycle of a food. This includes its production on farms, processing it to get it ready for sale, transportation to places where it will be sold, cooking or other preparation to get it ready to eat, consumption of food, and management of food loss and waste. Food systems also include everything that is needed so that these activities are possible, such as building roads, developing new technologies, or providing clean water [2].

FOOD SYSTEMS

Food systems include the entire life cycle of a food. This includes its production on farms, processing it to get it ready for sale, transportation to places where it will be sold, cooking or other preparation to get it ready to eat, consumption of food, and management of food loss and wastes.

Current food systems not only harm the environment and release greenhouse gases; often the food that is consumed leads to health problems. Many of us eat or drink more than what we need. This can lead to overweight, which today affects more than 2 Billion people [3, 4]. At the same time, more than 700 million people were affected by hunger in 2021 [5]. Some foods, we should be careful not to eat too much of, for example those high in sugar, salt or saturated fats. For other foods, many people should eat more than what they currently do. For example, fruits and vegetables, nuts, and seeds.

HOW DO FOOD SYSTEMS RELEASE GREENHOUSE GASES?

The **GHG footprint** of a food includes all GHG emissions that occur during the life cycle of that food product, from the farm all the way through food preparation and the management of food waste. For example, a fruit will have a larger GHG footprint if it has been stored in a refrigerator for several months vs. if it is fresh from the tree. A fruit will also have a larger GHG footprint if it was harvested from farmland created by cutting down a lush forest. The amount of a food that is lost or wasted during its life cycle also affects its GHG footprint.

GHG FOOTPRINT

All emissions of greenhouse gases which occur during the life of a product, from input required for its production over processing, transport, consumption, and waste management.

Researchers have calculated that roughly one third of the warming caused by human GHG emissions is associated with the global food system [6]. Food system-related GHGs include CO_2 from energy use (46%); **methane** from ruminants, rice fields, and waste management (38%); and **nitrous oxide** from fertilizers, grazing animals, and soil breakdown (13%). Figure 1 shows increases in food system GHG emissions since 1990, which are mainly due to energy and industrial processes. In 2015, 17 gigatons of CO_2 equivalent emissions were produced by the global food system, which means the combined effect of those GHGs on the climate is the same as if 17,000,000,000 tons of CO_2 were emitted!

METHANE (CH4)

A greenhouse gas that is mainly emitted from some animals that eat grass, from land under water tables as rice or wetlands, and from waste management.

NITROUS OXIDE (N2O)

A very powerful greenhouse gas that is mainly emitted from nitrogen sources, such as fertilizers used to enhance crop growth, from animal excretions, or in sewage systems.

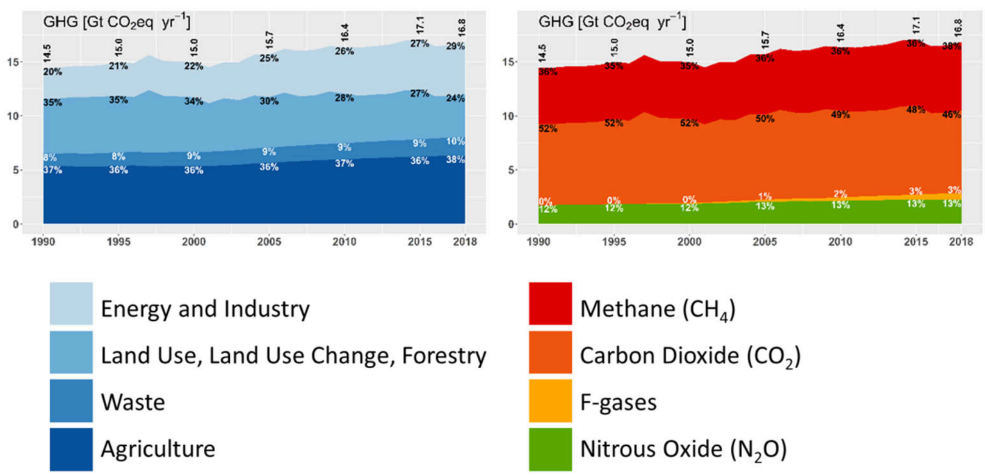

Figure 1

Figure 1

Food system GHG emissions from agriculture, Land Use, Land Use Change and Forestry, waste, and energy & industry sectors. Data source: IPCC 2022 [7].

Meat products are among the foods with the highest GHG footprint, especially when the meat comes from **ruminant** animals, such as cattle, sheep, and goats. These animals eat a diet of grass and leaves, which causes them to release methane—a powerful greenhouse gas. Ruminant meats are produced in many different ways, with varying levels of GHG emissions (Figure 2). Based on greenhouse gas emissions data, the International Panel on Climate Change (IPCC) concluded in 2022 that “diets high in plant protein and low in meat and dairy are associated with lower GHG emissions” [7]. The high GHG emissions of meats, especially from ruminants, are due to several

RUMINANT

Ruminant animals are animals that are able to eat a diet of grass and leaves. Examples of ruminant animals are cattle, sheep, and goats.

factors. First, lots of land and energy are required to produce the animals' food. Also, as we mentioned, these animals release the GHG methane. Finally, if forests are cleared to make way for animal pastures and farmland to grow the animals' food, this causes CO_2 emissions *and* negatively impacts biodiversity.

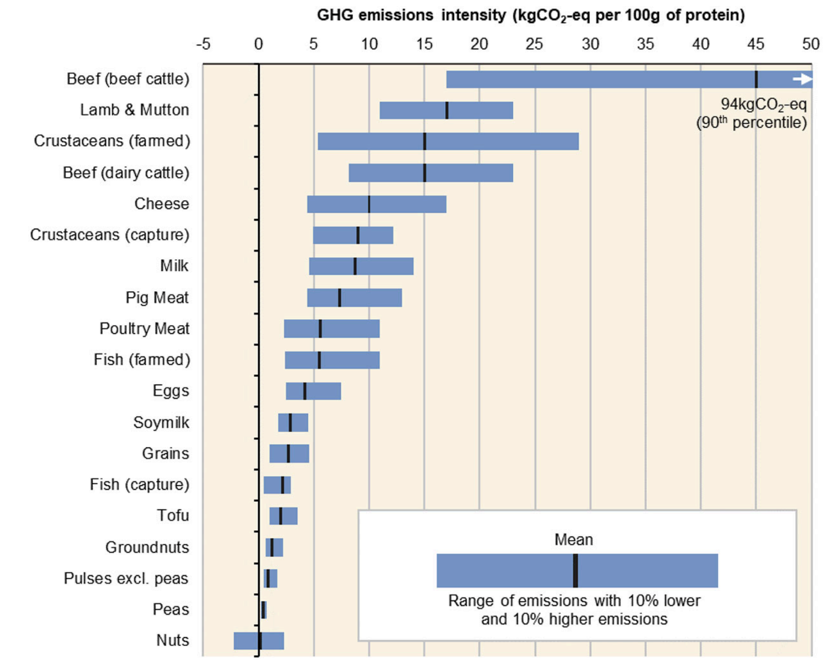

Figure 2

Figure 2

GHG emissions produced by various types of foods. Units are $kgCO_2$-eq per 100 g of protein. The black bars indicate the mean (average) emission while the blue bars indicate the emissions at which only 10% of emissions are lower and 10% of emissions are higher. Source: IPCC 2022 [7].

REDUCING GREENHOUSE GAS EMISSIONS FROM FOOD SYSTEMS

There are many options for reducing the climate impacts of the food system (Table 1). For example, improving the efficiency of food production or reducing food waste would require less resources for food production. Some types of farming practices, such as growing certain crops, can increase the amount of carbon stored in the soil and thus reduce GHG emissions. Eating plant-based alternatives to animal products, like peas, beans, or tofu, can also substantially reduce GHG emissions.

Changing eating habits is not easy. Foods for a healthy, sustainable diet are often more expensive and can be difficult to find in supermarkets. Good-quality information about the environmental effects of foods is also difficult to find. Changing farming practices is not easy, either. Environmentally friendly farming practices are often more expensive and require more land to produce the same amount of food. Often, farmers sell their products to large companies that transport and sell their products all over the world, giving these companies considerable power over what people buy.

Table 1

Ways to reduce greenhouse gas emissions from food systems. Green color means a positive effect; red color means a negative effect. The yellow color indicates that the effect can be both positive or negative, or that is is uncertain. Based on IPCC 2022 [7].

Food system emission reduction options		Effect on GHG emissions, energy use or food loss and waste, and possible co-benefit			
Agricultural food production and fisheries	Dietary shift, in particular increased share of plant-based protein sources	Direct emissions decrease			Good for land use and animal welfare
	Digital agriculture	Direct emissions decrease			Good for land use and animal welfare
	Gene technology	Direct emissions decrease			
	Sustainable intensification	Direct emissions decrease			Good for land use
	Agroecology	Direct emissions decrease	Energy use decreases	Food losses are reduced	Good for biodiversity
Controlled environment agriculture	Soilless agriculture	Direct emissions decrease	Energy use increases	Food losses are reduced	Good for land use
Emerging Food Production technologies	Insects			Food waste is reduced	
	Algae and bivalves	Direct emissions decrease			Good for land use and animal welfare
	Plant-based alternatives to animal-based food products	Direct emissions decrease			Good for land use and animal welfare
	Cellular agriculture	Direct emissions decrease	Energy use increases	Food losses are reduced	Good for animal welfare
Food processing and packaging	Valorization of by-products, FLW logistics and management			Food waste is reduced	
	Food conservation		Effect on energy use uncertain	Food waste is reduced	
	Smart packaging		Effect on energy use uncertain	Food waste is reduced	
	Improved energy efficiency in Food processing		Energy use decreases		
Storage and distribution	Improved logistics (location, timing, efficiency etc.) in food distribution	Direct emissions decrease			
	Measures to reduce food waste in retail and catering		Energy use decreases	Food waste is reduced	
	Use of alternative fuels or transport modes	Direct emissions decrease			
	Improved efficiency in refrigeration, lighting, climatization etc.		Energy use decreases		
	Replacing refrigerants	Direct emissions decrease			

Table 1

To effectively reduce food system GHGs, new technologies need to be developed, tested, and scaled up. Figure 3 gives some examples of how food systems could be made more **sustainable** through research and innovation [8]. Policies also need to be developed to help sustainable food products reach stores faster— those foods need to be easily available and affordable. Dietary guidelines, information campaigns, and proper food labeling can help consumers to make good choices. In summary, reducing food-related GHG emissions requires changes at all levels, from the producers to the consumers. This works best if there are laws or policies in place that are fair and acceptable to all.

SUSTAINABLE

Sustainability means using resources in a way that protects the planet, so future generations can enjoy it too.

HOW CAN WE HELP—SHOULD WE ALL GO VEGAN?

Everyone who wants to reduce their own food-related GHG footprint can do so, but the options that are available to each person may vary

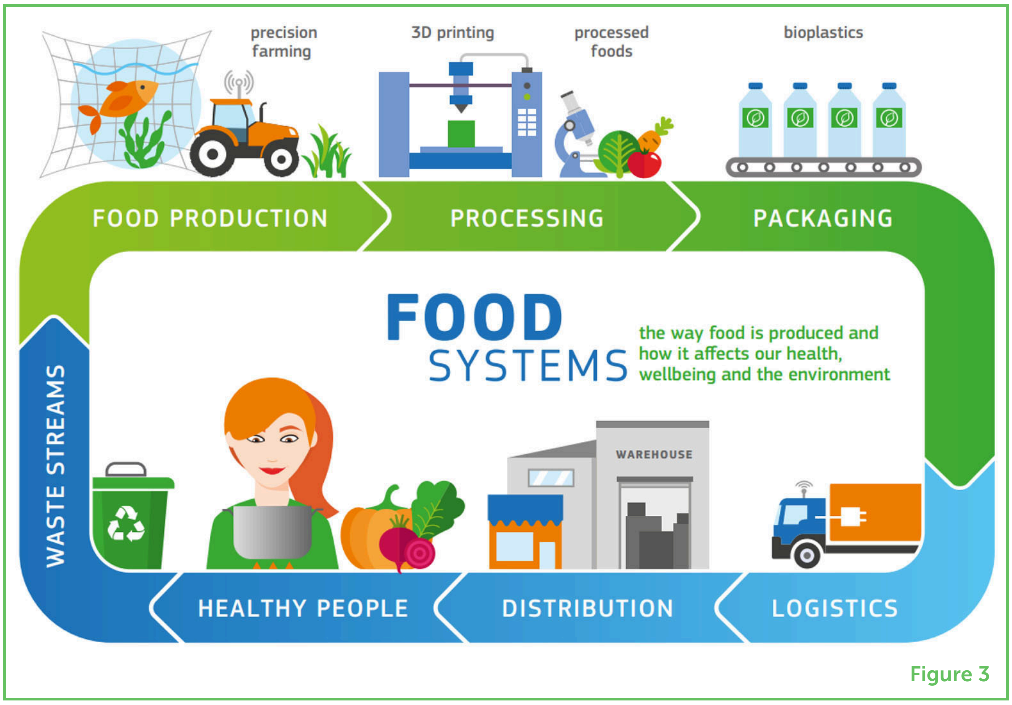

Figure 3

A food system includes all aspects of a food's life cycle, from production all the way to the generation of food waste. Ideas on how research and innovation can help to make the food system more sustainable are shown. Source: European Commission [8].

depending on income, culture, and where they live. Some options are free or even save money. Examples include reducing food waste, eating less, or eating more plant-based proteins instead of meat. Our own actions can also make it more likely that others will follow.

According to the IPCC, eating diets with more plant protein while eating less animal products, added sugars, salt, and saturated fats could reduce food-related GHG emissions. These changes are healthy for both the environment and humans [7]. However, this does not mean that everyone must go **vegan** to make an impact. Some livestock-production systems can keep ecosystems biodiverse while providing nutritious food. There are also places where the land is not good for any type of food production except livestock grazing, like pastures in mountainous areas.

VEGAN

A vegan diet is a way of eating that includes only plant-based foods, like fruits, vegetables, grains, nuts, and beans, without any animal products such as meat, dairy, or eggs.

A report to the United Nations recommended that Europeans should decrease the amount of meat and dairy they eat by 50%, along with making technical changes in farming and food-production practices that can help to reduce environmental impact [9]. In some places, like the Global South, there are not enough plant-based foods available to keep people healthy, so people are more dependent on animals for their nutrition. It is important that everyone can obtain the necessary amount of protein in their diets to stay healthy.

In conclusion, if we want to reduce the impact of our food systems on the environment, the world does not need to go completely vegan. However, we *do* need to decrease the amounts of animal-based foods that we produce and consume. Most people can do this by eating less meat—namely by replacing animal-based foods with plant-based foods.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

AYAT, AGE: 12

I love sketching, painting, playing chess, and reading books. My favorite books include “Amari” and “The Magicians of Paris”, and anything and everything about fantasy books. I like nature and frequently go out hiking to observe the beauty of nature and take notes and make sketches in my notebook.

YOUNG SCIENTIST ACADEMY, AGES: 11–13

The young reviewers are students at Williston Middle School and participants at Young Scientist Academy (YSA) all aged 11–13 years old: Hala, Ruby, Jeremy, Amaya, Maite, Charles, Jonah, Julia, Millie, Robert, Justin, Evan, Chris, Corbin, Kate, Miabella, Claire, Wisdym, Quinlan, Justin, Parker, Theodore, Paige, Zy, Nayden, Ra’Jaun, Lillian, Evelyn, Naurice, Danny, Caleb, and Steve. YSA is a youth science NGO headquartered in North Carolina that empowers all youth to become community ambassadors in science and technology.

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Adrian Leip has worked at the European Commission on the Bioeconomy Strategy since 2021. Before that, he worked at the European Commissions’ Joint Research Centre as a scientist studying various topics related to agriculture and food systems. For example, he helped compile the EUs’ annual greenhouse gas emissions for agriculture that are submitted to the United Nations Framework Convention on Climate Change, and he did computer simulations on the EUs’ agri-food system to see how nitrogen and greenhouse gas emissions can be reduced. Adrian contributed to the 6th Assessment Reports of the International Panel on Climate Change (IPCC), mainly to a section on how greenhouse gas emissions from food systems can be reduced. *adrian.leip@ec.europa.eu

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Diana Ürge-Vorsatz has been IPCC vice-chair since July 2023. She served as vice-chair of IPCC's Working Group III in AR6 and was coordinating lead author in two IPCC Assessment Reports. She is a professor at the Department of Environmental Sciences and Policy at the Central European University (CEU). She holds a Ph.D. from the University of California (Los Angeles and Berkeley). Diana is regularly invited to high-level review panels, such as that evaluating the work at Lawrence Berkeley National Laboratory and the EU's Joint Research Centre. She received the Hungarian Republic's Presidential Award "Medium Cross" in 2008, as well as the "Role Model" award in 2009 and was invited as a member of Academia Europaea in 2017.

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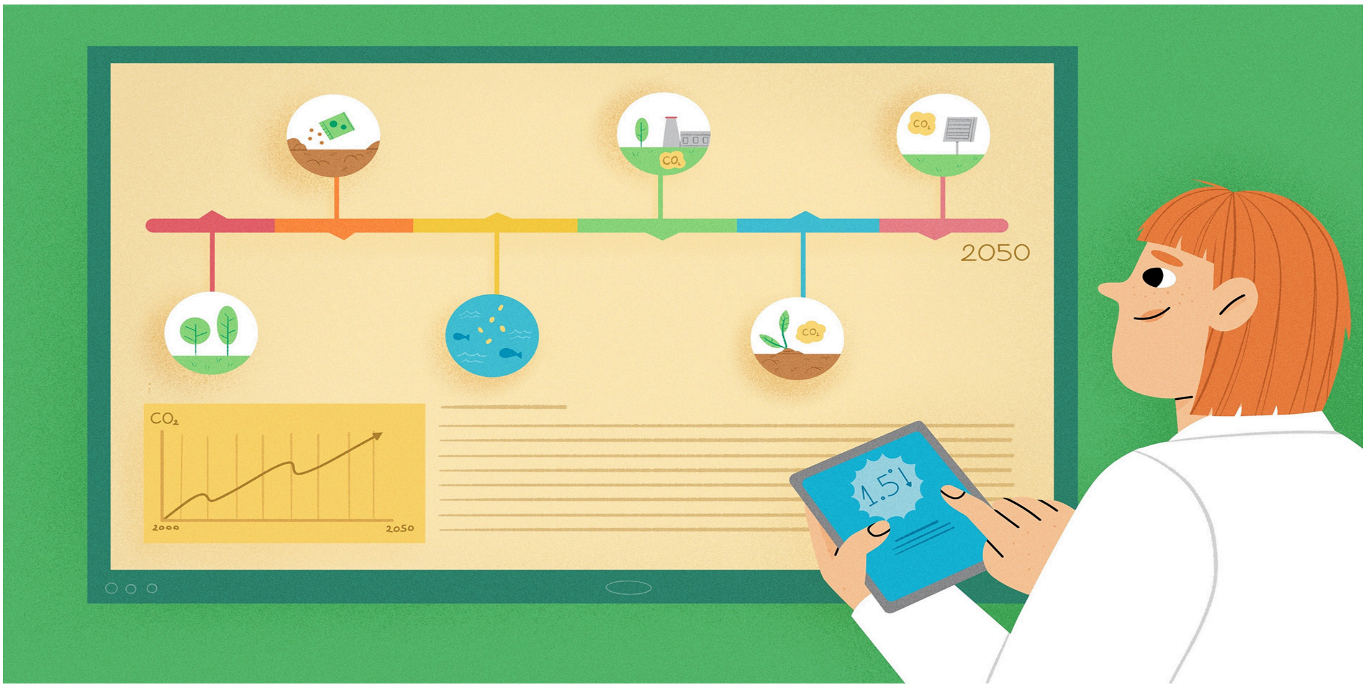

CLEANING UP AFTER OURSELVES: THE ROLE OF CARBON DIOXIDE REMOVAL

Sabine Fuss [1,2*], ***Chris D. Jones*** [3,4], ***Ingrid Schulte*** [1] ***and Naomi Vaughan*** [5]

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YOUNG REVIEWERS:

LEAF

AGE: 10

SHANMUKH

AGE: 15

The latest science shows that, to stop global warming, we must reach "net zero" emissions by 2050. This means that any carbon dioxide (CO_2) humans are still releasing into the atmosphere in 2050 would need to be balanced out by *taking* CO_2 from the atmosphere and locking it away. The process of removing CO_2 from the atmosphere is called carbon dioxide removal (CDR). This article will explain why CDR is needed and will introduce some methods of removing CO_2, including the strengths and weaknesses of those methods. There are many actions we can take. Many bring lots of other benefits, while some have drawbacks too. But overall, Carbon Dioxide Removal has a big role to play in successfully tackling climate change.

WHAT IS CARBON DIOXIDE REMOVAL?

It is well known that carbon dioxide (CO_2) released into the atmosphere by human activities is causing our climate to change, read more in this Frontiers for Young Minds article, and that something needs to be done about it. The science is clear and shows that, to stop global warming, we must reach "net zero" emissions by 2050 [e.g. [1, 2]]. In other words, we must take action to make sure we are not putting any more CO_2 into the air. In this article, we will explain how **carbon dioxide removal (CDR)** can be one of those helpful actions. Imagine a bathtub that is filling up with water. If we do not turn the water off, the bathtub will soon be full. This is exactly the stage we are at with CO_2 **emissions** in Earth's atmosphere (Figure 1). If we continue to put the same amount of emissions into the atmosphere as we have been, there are less than 6 years left before the bathtub flows over, which means we are emitting more CO_2 than we should if we wish to keep global warming below 1.5°C. We have set 1.5°C as the goal because, if global warming exceeds that number, the risk of dangerous impacts from climate change is increased and our societies and the Earth may even experience irreversible harm. Luckily, CDR can be used to "mop up" some of the overflow by taking some of the CO_2 out of the atmosphere and locking it away.

CARBON DIOXIDE REMOVAL (CDR)

Human actions that remove CO_2 from the atmosphere and lock it away.

EMISSIONS

Greenhouse gases, such as CO_2, that are released into the atmosphere by human activities and harm the planet.

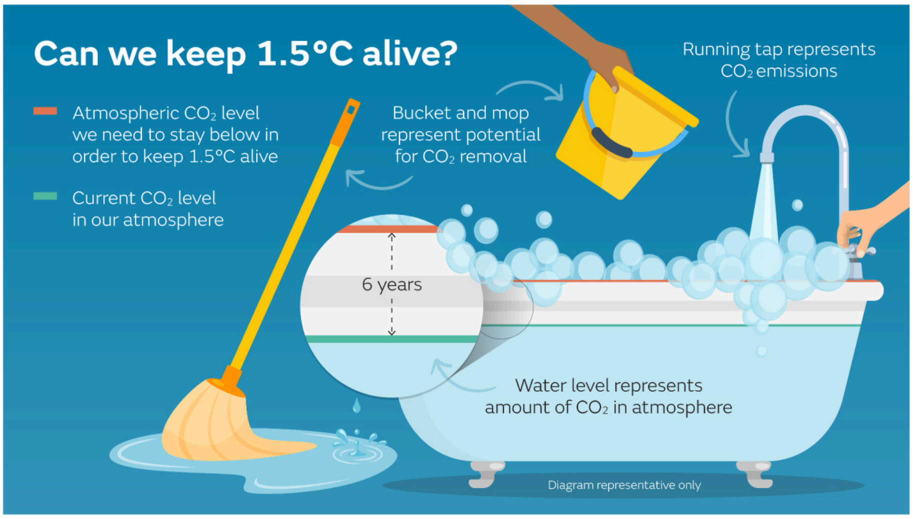


Figure 1

Figure 1

Can we keep 1.5°C alive? The water level in the bathtub represents the amount of CO_2 in Earth's atmosphere. The tap represents ongoing CO_2 emissions caused by human activities. The tub will overflow if too much CO_2 is emitted, which scientists predict will happen within 6 years if CO_2 emissions are not reduced. The overflow can be "mopped up" by CDR. We can also capture CO_2 as it is being released (represented by the bucket) to keep CO_2 in the atmosphere from increasing.

CDR can help in two ways. First, it can help us to deal with CO_2 emissions that are difficult to completely eliminate. In our bathtub example, that means that the water is still trickling out into the bathtub, so we must take a bucket and remove some of the water, so that the water level does not rise any further. Second, if we have already emitted more CO_2 than we are allowed and therefore cause global temperatures to rise more than 1.5°C, we can use CDR to try to reverse this extra warming. In terms of our bathtub story, that means if the bathtub really flows over, we can clean the water off the floor.

However, we want to avoid the bathtub overflowing if we can. Turning off the water is better than cleaning up the mess afterwards, and there is a limit to how much we can mop up if water continues to overflow! This is why we must prioritize reducing CO_2 emissions and not become too dependent on CDR. We know that some effects of climate change (like the loss of certain species) will be irreversible, even if we manage to bring global warming back on track. So, avoiding the CO_2 mess rather than cleaning it up is our main goal. There are several methods to remove CO_2 from the atmosphere (Figure 2) and we will summarize a few of them in the sections that follow. All of these techniques have strengths and weaknesses [3], as summarized in Figure 3.

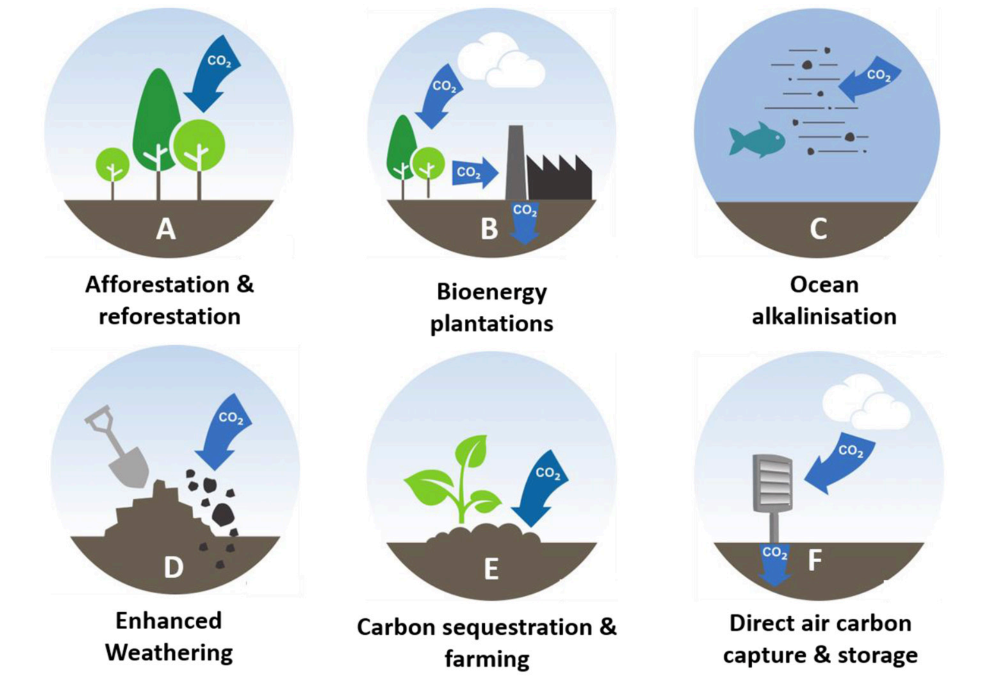


Figure 2

Methods of CDR include: **(A)** planting trees to remove CO_2, **(B)** capturing CO_2 in crops that are then burned for energy, **(C)** adding crushed minerals to the oceans to absorb CO_2, **(D)** crushing minerals like those found in rocks to speed up weathering, **(E)** adding biochar to soils, and **(F)** removing CO_2 from the air with filters and storing it underground. All of these have some advantages. They also have disadvantages. Which means that none of them are the perfect solution, and we will likely need to use a combination of methods.

GROWING PLANTS TO ABSORB CO_2

The most straightforward way to remove CO_2 from the atmosphere is **afforestation**. This means planting additional trees, which can remove CO_2 from the air by photosynthesis. Afforestation has a couple of advantages. Planting trees does not require a lot of materials, so it can be done right away. It is also much cheaper than other methods of CDR. Afforestation can also have many other benefits. For example, regrowing forests can expand and connect habitats for wildlife and thus help biodiversity. More trees can also help improve the local climate by lowering temperatures and cleaning the air.

AFFORESTATION

Planting trees on land that previously did not have forests on it, or on land that had forests that were cut down.

In addition to planting trees, we can also use land to grow crops that can be burned to produce energy in place of fossil fuels. This

Figure 3

All methods of CDR shown in Figure 2 have advantages and disadvantages, as listed in this table.

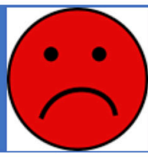
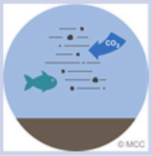
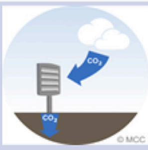
		
	Advantages	Disadvantages
	Growing plants	
	• Simple and easy • Can be done right away • Large potential, cheap • Good for biodiversity and nature	• Might compete with food production • Might be vulnerable to fire
	• Produces energy and replaces fossil fuels • Permanently stores CO_2	• Might compete with food production • Need to bury the carbon
	Burying carbon	
	• Can be done on agricultural land • Can improve yields • Does not compete with food production	• Limited capacity
	Using chemistry to absorb carbon	
	• Could increase crop yield	• Not well understood how to scale up • Expensive and needs lots of energy
	• Could make the ocean less acidic	• Unknown side-effects on ocean ecosystems • Hard to do on huge scales – needs millions of tonnes of rocks!
	Using technology to capture carbon	
	• Does not need large amounts of land	• Expensive! • Needs lots of energy and storage requirements underground

Figure 3

BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS)

Bioenergy is energy made by burning plants rather than fossil fuels. Carbon capture and storage means catching the CO_2 before it goes into the atmosphere and burying it underground.

is known as **bioenergy with carbon capture and storage (BECCS)**. In BECCS, CO_2 is captured in plants and then used to produce energy. The trick is not to let the CO_2 escape when we burn the crops to create energy, but rather to capture the CO_2 and store it underground. The advantages of BECCS are that energy is produced and CO_2 is stored permanently. However, the systems and structures needed to transport and store CO_2 have not yet been fully developed. BECCS would greatly benefit from politicians creating policies to support this method, so that it becomes established in society.

There are also downsides to BECCS. If it is done incorrectly, then biodiversity, water flow, and other important benefits that forests provide for people can be disturbed. Forests are already suffering from climate change, and the CO_2 held in those forests can quickly be released again if forests burn in wildfires or die because of pests like bark beetles. Also, if BECCS is done on a large scale, it would take up a lot of land, which is also needed to feed Earth's growing population and as habitat for wildlife.

Burying Carbon in the Land

Further land-based techniques for CDR include storing carbon in the soil. This can be done by growing special plants called cover crops on farm fields, or by plowing the fields less, for example. These techniques are good for farmers because they can actually improve the amount of food that can be grown. Also, these methods do not cost much or require additional land, which is an advantage compared to afforestation and BECCS.

Heating up biomass in an oxygen-free environment (a process known as **pyrolysis**) produces a substance called **biochar**—a type of charcoal that stores a lot of CO_2 and can then be mixed into soils or used in products like building materials. If biochar is created in a large facility, the gases and heat generated in the process can also be used to produce energy. Applying biochar to soils can have many additional benefits, like improving soil quality and filtering harmful substances out of rainwater. The Indigenous people of South America improved their soils using biochar as far back as 4,000 years ago!

PYROLYSIS

This means heating up wood or other material, but without oxygen so that it cannot catch fire and burn. This leaves a special type of charcoal which lasts a long time and can store carbon if we bury it.

BIOCHAR

A kind of charcoal obtained by burning trees and plants in the absence of oxygen.

Using Chemistry

Earth's minerals, like those found in rocks, usually break down very slowly—over thousands of years—by a process called **weathering**. Weathering absorbs CO_2. It is possible to enhance the natural process of weathering by grinding the minerals. Grinding makes the surface area much larger, allowing more CO_2 to be taken out of the atmosphere in a much shorter time. If ground-up minerals are spread on agricultural fields, crop yields can be increased. However, more experiments are needed to better understand how this works at a large scale and what the side effects are. Also, the grinding needs a lot of energy, and generating that energy must not release CO_2.

WEATHERING

A natural process that happens over thousands of years as minerals are broken down and can absorb CO_2. Speeding up weathering might help to reduce CO_2 in the air.

Other techniques use the ocean to absorb CO_2. **Alkalinisation** involves putting crushed minerals that can bind CO_2 (much like what was described for enhanced weathering) into the ocean. This would also make oceans less acidic, which protects marine life from other bad effects of dissolved CO_2. But with this technique too, more work is

ALKALINISATION

A chemical process that involves adding minerals to the ocean so that ocean water can absorb more CO_2.

needed to better understand its effects on ecosystems and whether any unintended damage might be caused.

Using Technology

One CDR technology that does not need much land is **direct air carbon capture and storage (DACCS)**. In DACCS, CO_2-containing air is sucked into a collector, where it flows through a filter. CO_2 sticks to the filter and, when the filter is full, the collector closes and is heated up to 100°C, so the CO_2 molecules are released from the filter and can be captured and stored. Similar to BECCS, using DACCS on a large scale will require development of systems and structures to transport and store CO_2. Also, DACCS needs a lot of energy, which is currently not yet CO_2-free and makes DACCS a relatively expensive technology compared to the others. However, there is a lot of activity around DACCS, with large sums of money promised for its development, and several companies are interested in working on this technology.

DIRECT AIR CARBON CAPTURE AND STORAGE (DACCS)

Filtering CO_2 directly out of the air and storing it underground.

WHAT ABOUT SUSTAINABILITY?

As we have explained, all the methods to clean up CO_2 have their own disadvantages. Some need lots of land, which might be used for growing food, some need lots of energy, others cannot be used widely before we fully understand their side effects. In the end, none of these techniques will save us on its own—we will most likely use a combination of techniques to remove CO_2, depending on location, timing, and amount of CO_2 that must be removed. The most important message, however, is that there will be far less CO_2 to remove if we reduce the amount we are emitting as quickly and completely as possible. To go back to our bathtub example once more, it is far better to prevent the tub from overflowing than to clean up the mess later on. Just because we have the technology to clean up after ourselves *does not* mean it is OK to increase the mess we have already created! So, in addition to continuing to develop CDR, people should keep working to decrease the amount of CO_2 released into the atmosphere.

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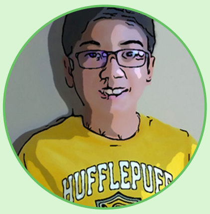
LEAF, AGE: 10

I am in fourth grade, and my favorite subject is art and science. I love observing changes in the world. I like to work as a Young Reviewer as I can observe many more changes using scientist's equipment. In my spare time, I like hiking, swimming, and riding bikes with my friends.



SHANMUKH, AGE: 15

My name is Shanmukh and I am 15. I have a strong interest in science and math, and hope to pursue a career in data science.

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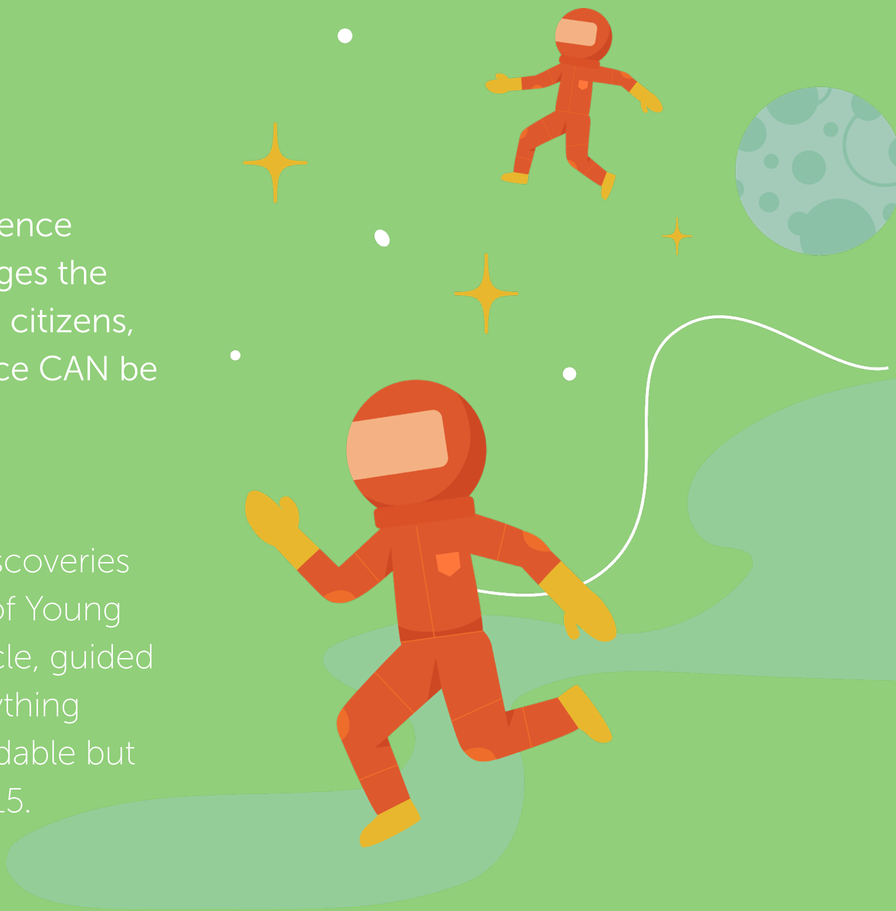

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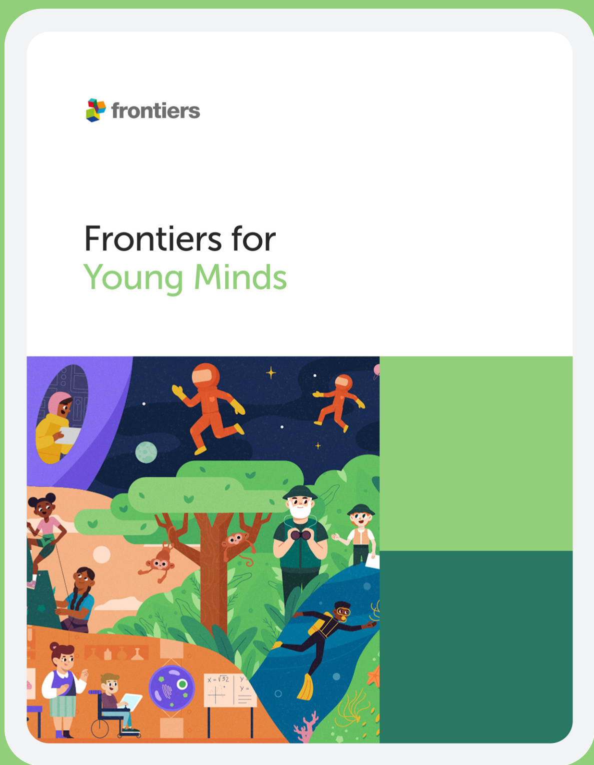

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