Leopoldina
Nationale Akademie
der Wissenschaften

2021 | Factsheet

Climate change: causes, consequences and possible actions

Imprint

Publisher
Deutsche Akademie der Naturforscher Leopoldina e. V.
German National Academy of Sciences Leopoldina,
Jägerberg 1, 06108 Halle (Saale), Germany

Editors
Dr. Christian Anton, Johannes Mengel, Dr. Elke Witt
German National Academy of Sciences Leopoldina
Contact: politikberatung@leopoldina.org

Translation
Peschel Communications GmbH, Freiburg

Graphics
Erfurth Kluger Infografik GbR, Berlin

Cover image
Shutterstock

Typesetting
Klötzner Company, Hamburg

DOI
https://doi.org/10.26164/leopoldina_03_00409

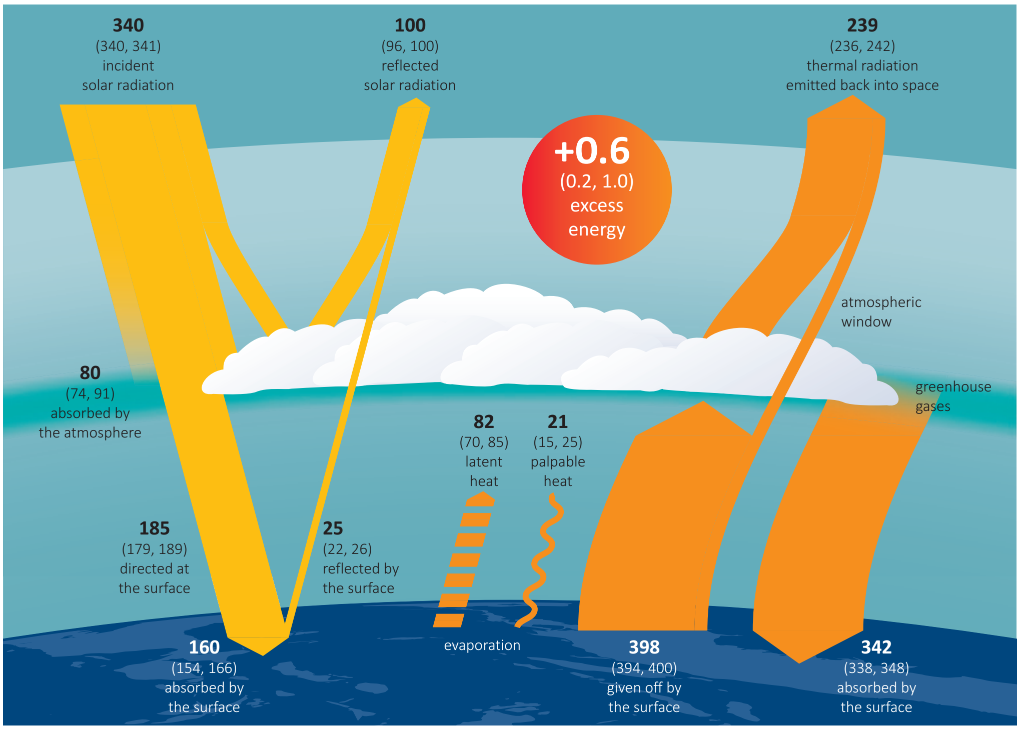
Recommended citation
German National Academy of Sciences Leopoldina (2021):
Climate change: causes, consequences and possible actions. Halle (Saale).

Editorial deadline
May 2021

Contents

Causes of climate change

Climate change upsets the Earth's energy balance
in watts per square metre



What causes climate change? The atmosphere is heated up when increased concentrations of greenhouse gases capture some of the sun's energy that is otherwise reflected back into space. The increased concentrations of greenhouse gases cause this reflection to take place at higher atmospheric altitudes, where it is colder. This means that less thermal radiation is released back into space. The excess energy is registered as a temperature increase on the Earth's surface and in the lower atmosphere. The numbers in brackets indicate the range of measurement uncertainty.

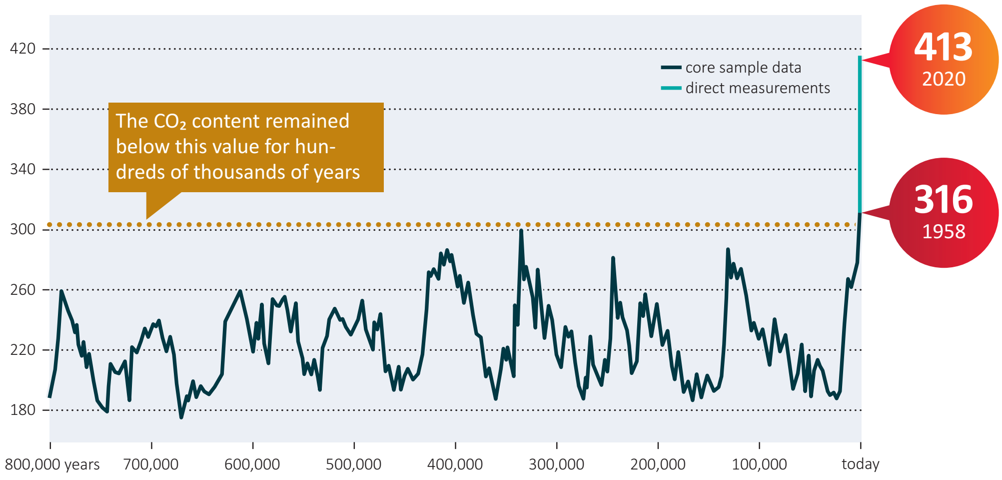
Source: Wild et al. (2014), Loeb et al. (J. Clim. 2009), Trenberth et al. (BAMS 2009)

The greenhouse effect: A simple energy balance determines the Earth's temperature

- The key to understanding human-induced global warming from a natural science perspective lies in the energy balance of our home planet and the physics behind the greenhouse effect.
- The sun emits radiation onto the Earth, where a third of this radiation is reflected and the rest is absorbed. The Earth gives off long-wave thermal radiation, counteracting the short-wave radiation coming from the sun (stable climate).
- Steam as well as carbon dioxide and methane molecules in the atmosphere prevent this radiation from being emitted back into space, trapping heat and sending a portion of it back down toward the Earth's surface. Without this natural greenhouse effect, the global average temperature would be about –18 °C instead of its actual 14 °C. This would not support life.
- Fossil fuel combustion has led to an increase in the concentration of carbon dioxide in the atmosphere. As a result, more heat is radiated back toward the Earth. The temperature on the Earth's surface and in the lower atmosphere has risen in turn.
- The greenhouse effect induced by humans has changed and continues to change the energy balance on Earth, which has led to an excess energy flow of 0.6 watts/m^2/second.
- At the same time, residues in the atmosphere left behind by the combustion of fossil substances (aerosols) have a cooling effect.

Source: Loeb et al. 2009, Trenberth et al. 2009, Wild et al. 2014.

CO_2 content of the atmosphere over the last 800,000 years
in parts per million (ppm)



Source: Lüthi et al. (Nature 2008), Keeling et al. (Scripps CO_2 Program Data)

The atmospheric concentration of CO_2 is higher today than ever before in the last 800,000 years

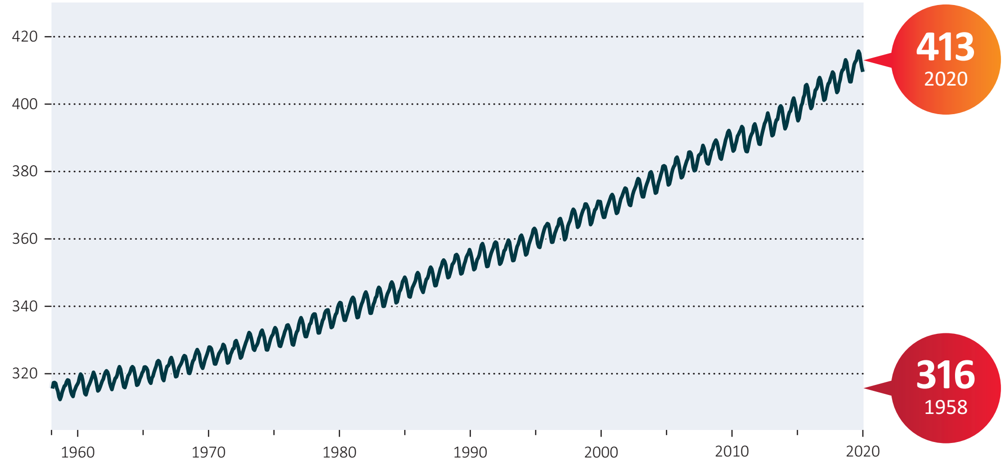
- The amount of CO_2 in the atmosphere (and thus the climate) has repeatedly undergone drastic change in the course of the Earth's history.
- These climate changes were the result of changes in the energy balance (see above) and could have been caused by various elements:
  1. Changes in the sun's luminosity.
  2. Changes in the Earth's orbit around the sun.
  3. Changes in the amount of climate-relevant gases (CO_2, methane) and aerosols (atmospheric particulate matter, e.g. from volcanic eruptions) present in the atmosphere.

4. Ice cover, cloud cover and the distribution of the continents, as even these influence how much energy is reflected back into space (Albedo effect).

- Most research surrounding historical climatology on Earth is based on deposits from the periods in question, for instance sediments on land and in oceans and seas as well as ice masses. Isotope analyses of the calcareous shells of microplankton offer information on temperatures in the past, while air bubbles trapped in ice provide samples of former atmospheric compositions – including greenhouse gas concentrations. Evidence from such sources has led researchers to the conclusion that in the last 800,000 years, there has not been a single period in which the atmospheric concentrations of CO_2 have even come close to those of today.
- The CO_2 concentration has remained relatively stable over the last 10,000 years at 250–275 parts per million (ppm).
- Since the Industrial Revolution beginning in the mid-18th century and the associated use of fossil fuels as well as deforestation, CO_2 and CH_4 (methane) concentrations have increased to well above the natural fluctuation range of the last 800,000 years.
- The latest research indicates that the concentration of CO_2 in the atmosphere is likely higher today than it ever was in the past 3 million years.
- These high atmospheric concentrations of CO_2 in the atmosphere have the potential to destabilise parts of the climate system in the long term, leading to severe consequences.

Source: Lüthi et al. 2008; Willeit et al. 2019., Keeling et al.

CO_2 content of the atmosphere since 1958
in parts per million (ppm)



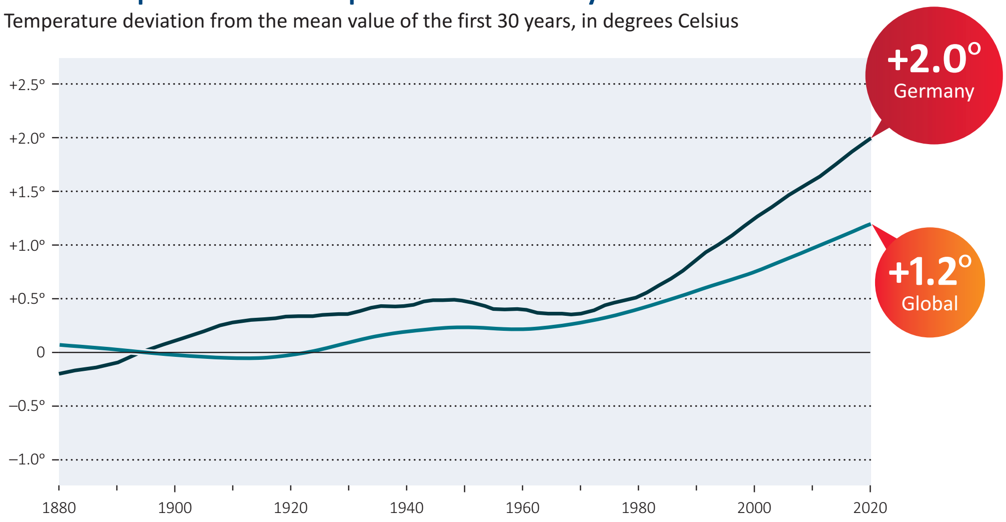
Direct measurements of the atmosphere's CO_2 content began on the island of Mauna Loa in 1958. The continuous rise is only interrupted by growing seasons in the Northern Hemisphere. Every year, this results in a periodical drop in CO_2 concentrations in the atmosphere.
Source: NOAA (2020), Keeling et al. (2001)

The concentration of CO_2 in the atmosphere has risen continuously over the last 60 years

- The CO_2 concentration has been directly measured on the Hawaiian volcano Mauna Loa since 1958. Since the measuring station is situated at a very high altitude (3397 m above sea level) and is hardly impacted by local factors, the values recorded there are considered to be a good approximation of the actual global CO_2 concentration.
- The concentration has been continuously increasing since researchers began taking measurements. In March 2021, it had reached a value of 417 ppm – the highest it has been in at least 800,000 years.
- This increase was only attenuated during the years of the oil crisis (from 1970) and following the collapse of the economic system in the former Eastern Bloc at the end of the Cold War (1990).
- This series of measurements was key in understanding the relation between the combustion of fossil materials and the concentration of the greenhouse gas carbon dioxide. The first measurement was taken in 1958 and recorded a concentration of about 316 ppm.
- The series of measurements illustrates characteristic fluctuation in the course of a year. During summer in the Northern Hemisphere, the global CO_2 concentration decreases since the increased amount of vegetation absorbs more carbon. In the winter, the global CO_2 concentration increases again, as plants drastically reduce photosynthetic activity. The comparatively little vegetation in the Southern Hemisphere cannot offset the increased release.

Source: Scripps Institution, NOAA (Global Monitoring Laboratory).

Global temperature and temperature in Germany since 1880
Temperature deviation from the mean value of the first 30 years, in degrees Celsius



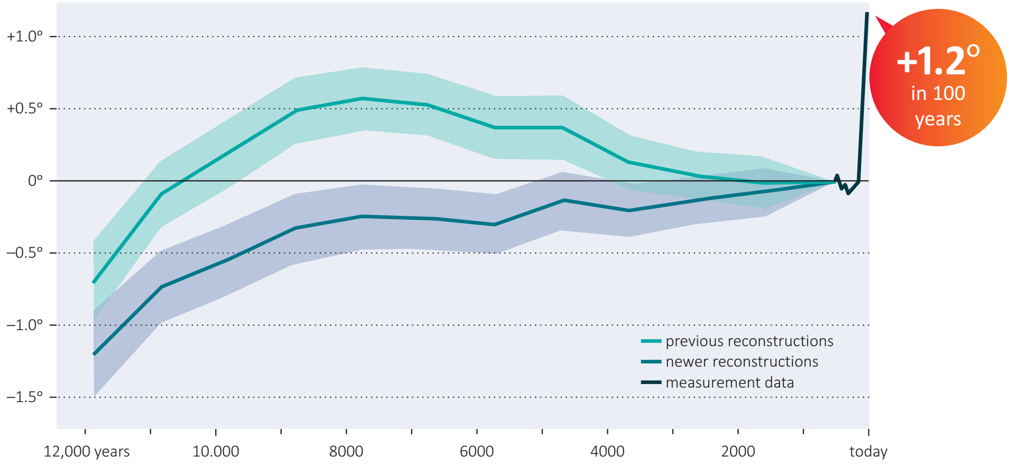
Temperature rises as a consequence of climate change occur faster over land than over the ocean. Consequently, the average temperature over Germany since 1880 has risen by 2 degrees. The curves illustrate the long-term trend.
Source: DWD/NASA GISTEMP

The global temperature has risen by 1.2 °C. In Germany, it has already gotten 2 °C warmer

- Weather stations have been in use since the 18th century to measure temperatures on Earth, and since the 19th century they have been spread across enough locations to generate a solid global average. The graphic illustrates three distinct phases with regard to global temperature. Until 1940, the Earth continuously warmed up slightly, followed by stable temperature values until the 1970s in particular due to an increase in cooling aerosols (air pollution). Since then, we have been in a phase of marked warming.
- Warming effects can typically be observed to a much greater extent over landmasses than over the ocean. Between 2015 and 2019, the global temperature over land was about 1.7 °C hotter than the values observed in pre-industrial times from 1850 to 1900.
- On average, the human-induced rise in greenhouse gases (in particular carbon dioxide and methane) caused increased temperatures on the Earth's surface (both land and ocean) by 1.2 °C since the 19th century.
- The annual average air temperature across the mean surface area of Germany increased by 2 °C from 1881 to 2019. The North Sea also became 2 °C warmer in this time.
- Fluctuations in solar radiation and volcanic eruptions as well as the climate system's natural variability have not had any measurable impact on global warming since 1951. The sun's luminosity even decreased slightly during this time.

Source: Deutscher Wetterdienst, NASA.

Global temperature since the end of the last ice age
Temperature deviation in degrees Celsius



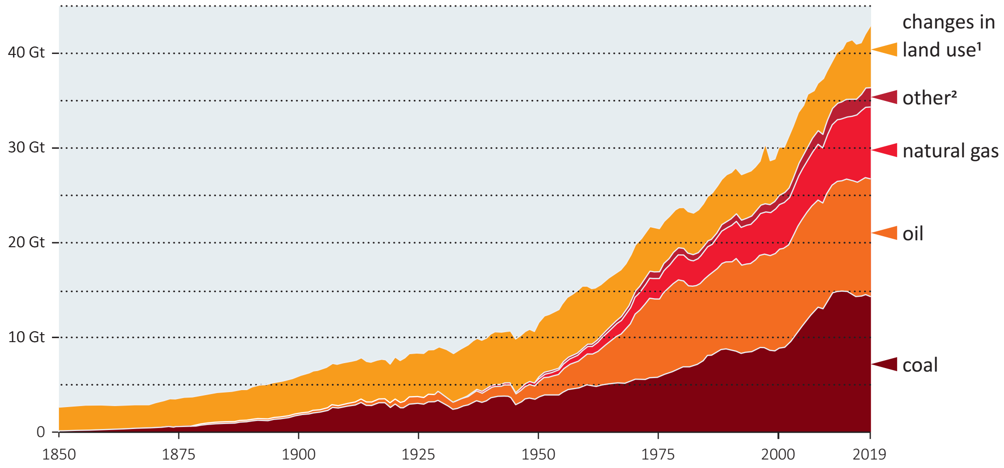
The Earth's climate has changed significantly during the course of the Holocene. But the changes we are currently experiencing are occurring more quickly than they would naturally.
Source: Bova et al. (2021), Shakun et al. (Nature 2012), Marcott et al. (Science 2013), NASA GISTEMP

Human-induced global warming is happening at a rapid pace

- Modern global warming is happening at an extremely rapid pace in comparison to what climate research has discovered thus far about natural global temperature increases in the course of the Earth's history.
- Sufficient data have now been collected from all parts of the world to be able to calculate the global average temperature over the last 20,000 years – since the height of the last ice age. These data indicate that the global temperature today is likely already warmer than at any other point during the Holocene and thus any other time in the history of human civilisation.
- These data are also consistent with the model calculations of earlier temperatures.
- At the same time, drastic and abrupt regional temperature changes have also been observed in the Earth's history.
- One example of this is the Paleocene-Eocene Thermal Maximum (PETM) from about 55 million years ago, where the temperature increased by about 6 °C within 4000 years. In relation to geological benchmarks, the PETM was a very brief but extreme period of warming. The climate change we are currently observing is occurring at an even quicker rate.

Source: Shakun et al. - 2012; Marcott et al. - 2013; Bova et al. - 2021.; NASA GISTEMP

Overall global CO_2 emissions, 1850–2019
by source, in billions of tonnes of CO_2 (Gt)



The overwhelming portion of carbon dioxide which is emitted annually through human activities comes from the combustion of fossil fuels such as coal, oil and natural gas.
1 e.g. deforestation, drainage of wetlands
2 e.g. cement production and gas flaring
Source: Global Carbon Project (2020)

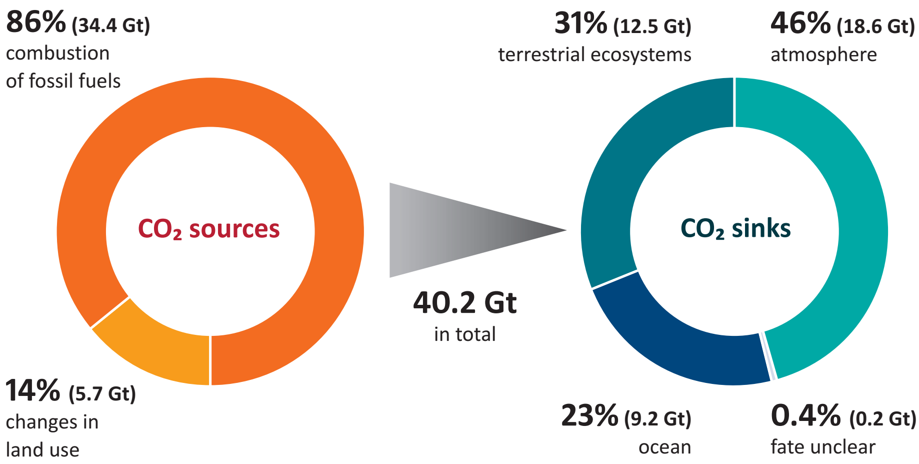
The primary cause of modern global warming is human activity: the combustion of fossil fuels and land use

- Overwhelmingly, the climate change we are witnessing now has been caused by humans.
- The observed warming of our climate system, in particular as it has been occurring since the 1950s, cannot be explained without taking into consideration the increase in greenhouse gases in the atmosphere.
- The sun's fluctuations within this time frame have only had a very small impact.

Source: Global Carbon Project - 2020.

Where does the CO_2 released by humans remain?

Annual amounts as a percentage and in billions of tonnes (Gt), 2010–2019



Only a portion of the carbon dioxide remains in the atmosphere. The ocean and terrestrial ecosystems (such as forests) also absorb carbon dioxide. Without these sinks, climate change would be even more extreme.

Source: Global Carbon Budget (2020)

Where does the CO_2 released by humans go?

- The sources of anthropogenic CO_2 as well as where it remains are analysed very precisely. 86 % of human CO_2 emissions between 2009 and 2018 were the result of fossil fuel combustion; 14 % came from changes in land use.
- A portion of these emissions (31 %) is absorbed by terrestrial ecosystems and another portion (23 %) by the ocean.
- The largest portion of human-induced CO_2 emissions remains in the atmosphere (46 %).

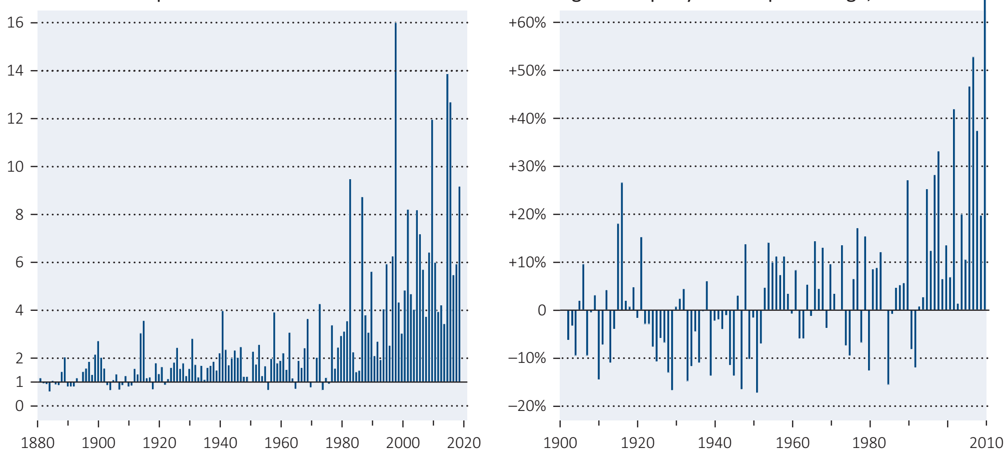
Source: Global Carbon Project - 2020.

Consequences of climate change

Record temperatures and precipitation are becoming more frequent and more extreme

Global record temperatures per year, 1880–2020, increase factor compared to a stable climate

Total precipitation: change in the number of record-breaking events per year as a percentage, 1900–2010



Temperature and precipitation records continue to be broken worldwide with greater frequency.

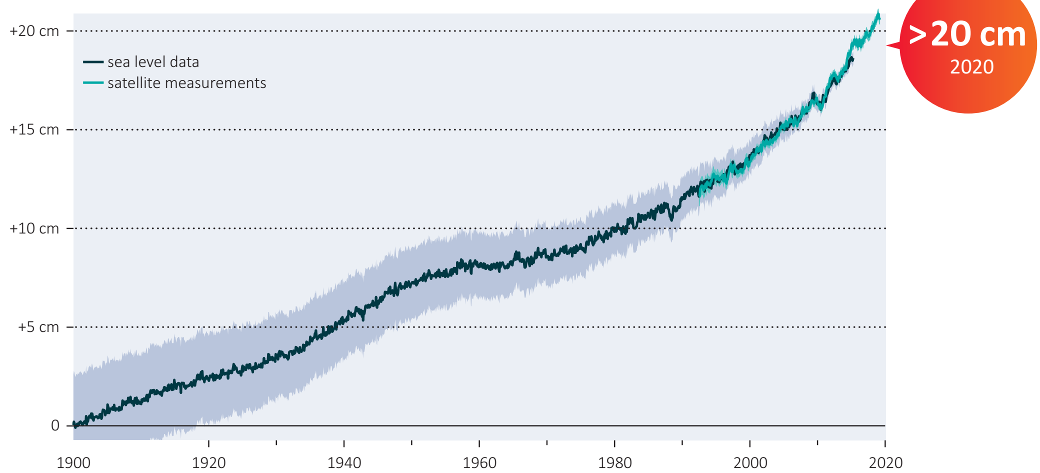
Source: Lehmann et al. (Clim. Change 2015), DWD

Extreme weather events are becoming more common and more intense

- Extreme weather events worldwide are the most direct palpable effects of climate change. These include the devastating 2020 forest fires in Australia, the perpetual drought in Southern Africa and the heat in the Arctic circle in the region of Siberia with temperatures reaching 38 °C.
- The frequency of extreme weather events is increasing worldwide, in particular extreme heat, droughts, extreme precipitation and powerful tropical storms. Statistically, it is quite difficult to provide proof of an increase in extreme weather. This has to do with the rarity of extremes and corresponding historical measurement data. Thus, whether or not particularly powerful tropical cyclones had indeed become more common, as predicted by physics and suggested by observational data, long remained the topic of controversial debate.
- It was not until 2019 that the expert commission on tropical storms from the World Meteorological Organization (WMO) came to the conclusion that the frequency of hurricane-strength tropical storms has measurably increased since the early 1980s.
- Increased instances of extreme temperatures can also be seen in Germany. For instance, temperatures of 40 °C or higher were observed on three consecutive days in 2019 for the first time since weather records began. The temperature rose to at least 40 °C at 23 individual measuring points. July 2019 was the hottest month overall in the history of recorded weather. This extreme heat is also evident in the high number of forest fires.
- Heat waves lead to increased mortality. Europe's exceptionally hot summer of 2003 cost 70,000 people their lives. Extreme weather events are also responsible for critical damage in the agricultural sector.
- In the medium term, extreme weather events such as drought pose a threat to Germany's supply of resources such as water and agricultural products.

Source: Robine et al. - 2008; Deutscher Wetterdienst; Lehmann et al. - 2015; Watts et al - 2020; World Desaster Report - 2020

Change in global sea level from 1900 to 2020
in centimetres



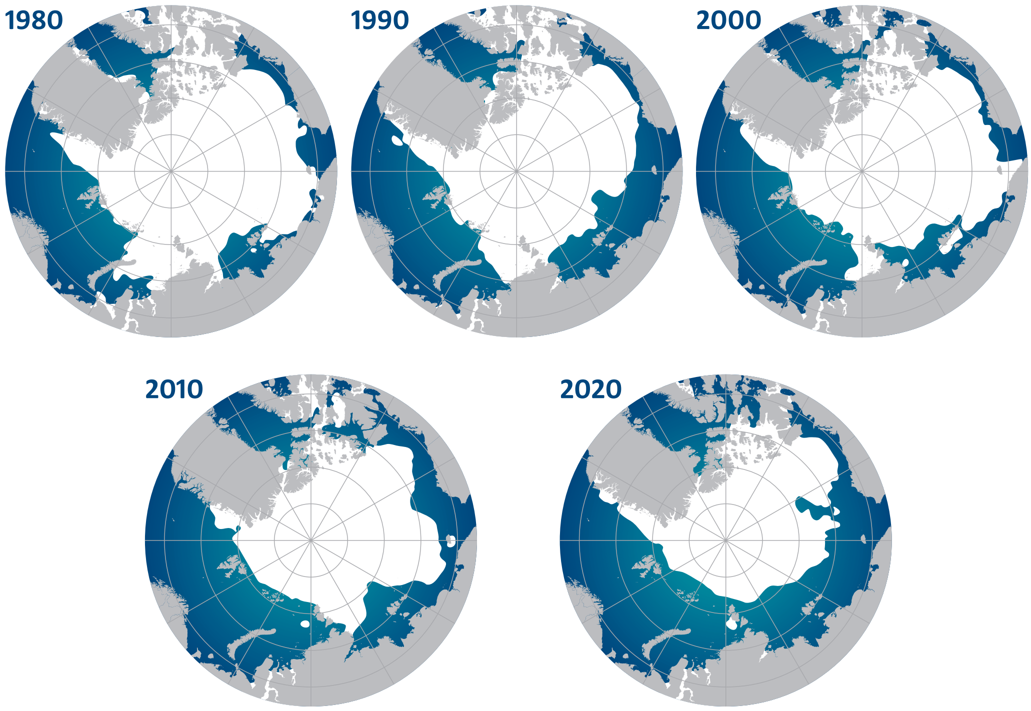
Sea level data and satellite measurements show that the sea level has risen by approximately 20 centimetres since 1900.
Source: Dangendorf et al. (2019)

The sea level is rising and the ocean is becoming warmer and more acidic

- Satellite measurements show that ice melt in Greenland and Antarctica occurring since 1990 has accelerated a loss of ice mass. The sea level has risen by nearly 10 cm since 1993.
- The melting of ice sheets, for instance in Greenland and Antarctica, as a result of global warming could cause the sea level to rise by several metres. This would affect about 400 million people.
- Global warming impacts much more than just the atmosphere. The oceans are particularly affected as well. Since 1970, the Earth's oceans have absorbed about 90 % of the additional warmth generated by the greenhouse effect. Marine heatwaves have become more intense, and their frequency has doubled since 1982.
- Warm water expands. The water expansion observed as a result of climate warming measures at 1.4 mm per year, making it responsible for about 40 % of the rise in sea level.
- Increasing warming and acidification of the oceans is a danger to marine organisms and thus also threatens the food supply for many people.

Source: Dangendorf et al – 2019; Shepherd et al. – 2019.

Extent of Arctic sea ice from 1980 to 2020
in August of the corresponding year



The surface area at the North Pole which is covered by ice in summer has been continuously receding for decades.
Source: NSIDC

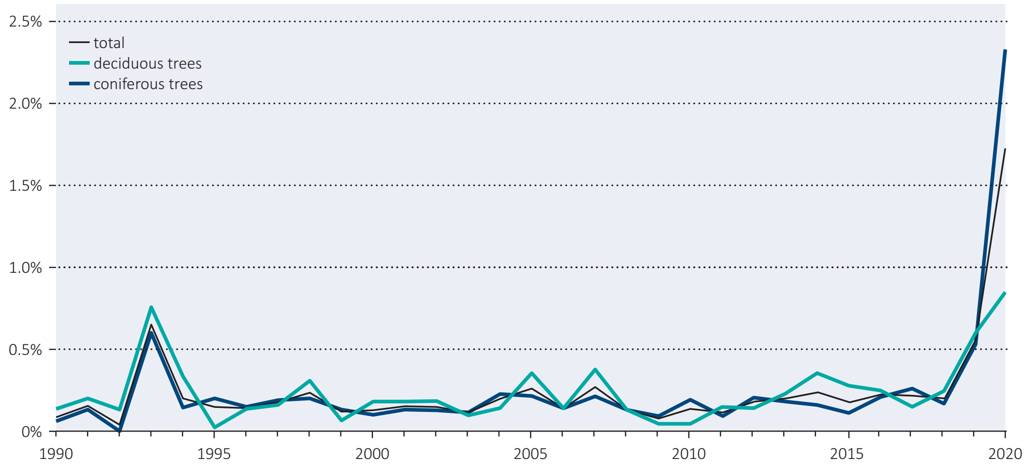
Ice-based habitats are impacted the most

- The observed loss in ice mass across the globe is more dramatic than was predicted in even the most negative scenarios. The rate of ice loss has increased by 57 % since the 1990s. The ice sheets of Greenland and Antarctica are losing mass at a particularly rapid pace.
- Greenland's ice masses could melt completely if temperatures increase by 1.6 °C. Since the Greenland ice sheet covers solid ground, its melting would have a dramatic impact on the sea level, life in coastal regions and even for Europe's climate.
- Antarctica is the largest ice store in the world. But especially marine ice sheets in Western Antarctica (in particular in the Amundsen region) are becoming increasingly instable. The destabilisation of the glacial border (ice shelf) also affects the Antarctic inland ice.
- If sea ice disappears, solar energy will be absorbed by the oceans and the atmosphere instead of reflected by ice. This will cause the Arctic to warm up more quickly than any other region of the Earth.
- Even mountain ranges are impacted by climate change. This is made most apparent by glacial decline. Glaciers tend to lose ice mass during warmer periods by nature, but the current rate of loss is unprecedented.
- Around 220 million people in Asia alone fully depend on glaciers for their water supply, irrespective of periods of drought.
- Climate change has even had a negative impact on human settlements, infrastructure and tourism in the European Alps. Altered freezing processes mean increased risk of natural hazards including avalanches, landslides and flooding.

Source: Spehn & Körner – 2017; IPCC – 2019 ; Pritchard – 2019; Slater et al. – 2021; NSIDC; NASA 2021.

Tree death rates

as a percentage, 1990–2019



Each year, 10,000 selected trees are evaluated for the forest status report. The past years' drought makes trees more susceptible to pests and has led to an extreme spike in death, particularly of spruces, but also of oak and pine trees.

Source: BMEL 2021

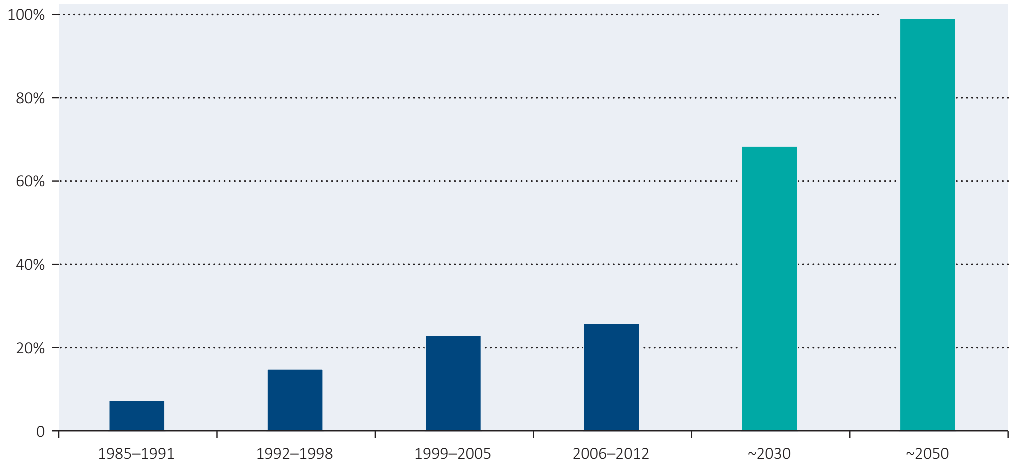
Periods of drought endanger the forests

- Forests are particularly vulnerable to climate change. A temperature increase of just 1 °C can endanger the functioning of a forest's ecosystem. The forest then releases CO_2 instead of absorbing it.
- Storms, heat and drought endanger forests even in Germany. The direct effects of multiple especially hot summers are evident. Tree species such as spruces and beeches suffer from water shortage. This makes them more susceptible to pests. At 27 percent on average, the mean crown defoliation of all species of tree, in 2020, was higher than ever.
- The risk of forest fires in Germany will increase.

Source: IPBES – 2019; BMEL - 2020; IPCC - 2018 Sonderbericht 1,5°C; CBD

Ocean warming endangers coral reefs

Percentage of damaged corals from 1985 to 2012 and prognosis



Between 1985 and 2012, the proportion of damaged corals has risen to about 25%. The reason for coral bleaching and subsequent death is climate warming. By 2050, nearly all coral reefs could be affected.

Source: Heron et al. 2016

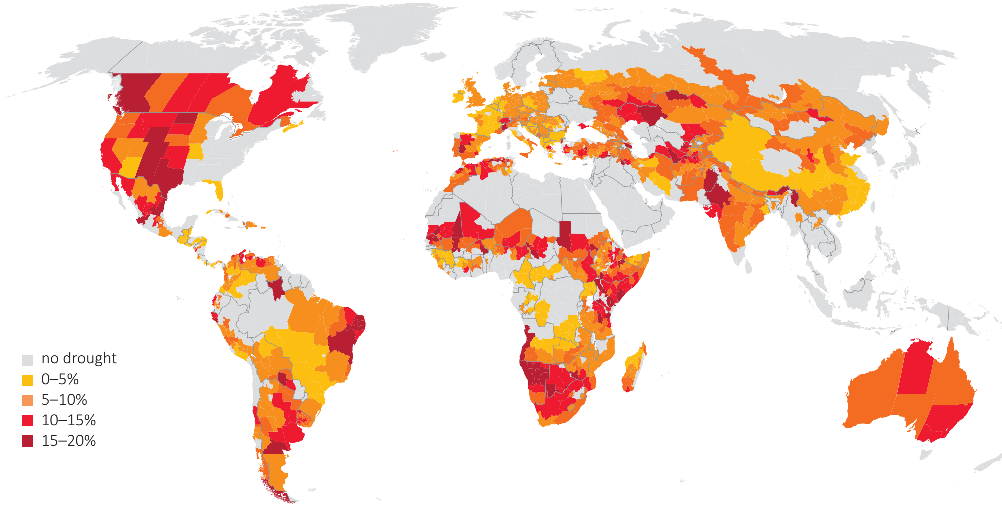
A 1.5 °C increase in temperature leads to the loss of many coral reefs

- Coral is sensitive to warmer temperatures. When suffering from heat stress, coral expels the algae living in it. This causes the coral to lose its colour, an effect known as coral bleaching.
- Major consequences of climate change for biodiversity can therefore be observed in the oceans. The periods of regeneration after extreme warming will likely become shorter for coral reefs. This will lead to extensive coral bleaching and death on a large scale.
- The latest studies (from 2016) show that 50–70 % of all coral reefs are already damaged.
- If the global temperature increases by 1.5 °C, 70–90 % of all coral reefs will disappear. At an increase of 2 °C, this figure will rise to over 99 %.
- Corals have an important role as reef builders, and their disappearance has massive effects on fish stocks within and outside of coral reefs.

Source: Jones et al. - 2004; Heron et al. - 2017; IPCC – 2018, 2019; IPBES – 2019; Hughes et al. – 2020.

Example of agricultural damage: drought in grasslands

Percentage of grasslands afflicted by drought between 2004 and 2018



The map illustrates the proportion of global grassland which was afflicted by drought in the period between 2004 and 2018.

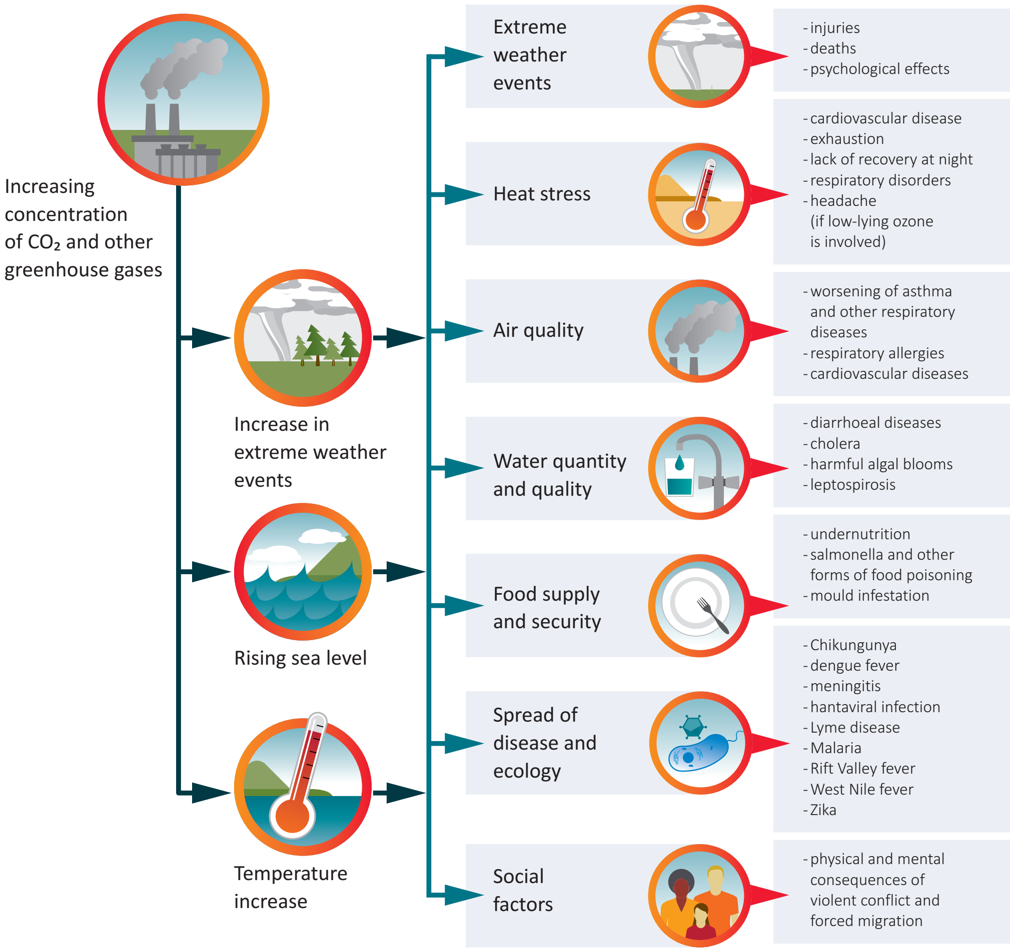
Source: EU JRC ASAP

Climate change causes hunger and food crises

- The consequences of climate change will be most apparent in agriculture. Climate change impacts the production of food as well as its quality, price and availability. This makes climate change an additional factor preventing the achievement of the UN's Sustainable Development Goal (SDG) of Zero Hunger.
- Increased temperature, shifting climatic zones and extreme weather events are all ways in which climate change negatively impacts agricultural yields, livestock farming and fishing.
- The climate-related spread of pests and diseases leads to harvest and post-harvest losses, which in turn result in an additional shortage of agricultural yields.
- In the long term, it can be assumed that climate change-induced shifts in global agricultural production will change international food trade.

Source: Chakraborty & Newton – 2011; Elliot et al – 2014; Rosenzweig et al. – 2014; Grace et al. – 2015; FAO - 2018.

Health risks induced by climate change



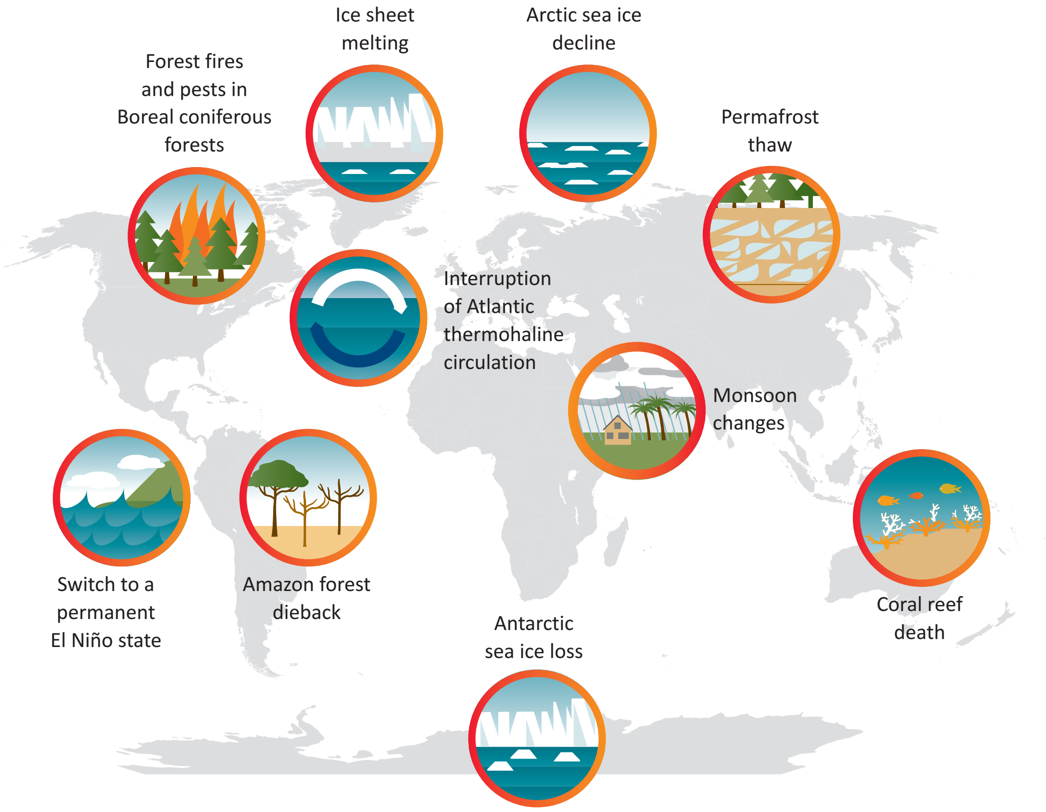
Modified after Haines et al. (NEJM 2019)

Climate change impairs health

- Consequences of climate change with a direct effect on human health include heat stress leading to increased mortality. In 2018, Germany had the third-highest rate of heat-related death worldwide with over 2000 cases.
- The human body can only adapt to severe heat to a very limited extent. Heat stress strains the cardiovascular system, reduces recovery during sleep, impairs cognitive performance, lowers work productivity and increases the risk of accident.
- Warmer temperatures can also facilitate the spread of infectious diseases, including those carried by mosquitoes and ticks. These include Lyme disease and tick-borne encephalitis (TBE) as well as other illnesses formerly associated with travel medicine, such as those caused by Rickettsia or West Nile fever, which is spread by indigenous mosquitoes.
- Moreover, mosquitoes and ticks from warmer domains – including Asian tiger mosquitoes, which spread dengue fever, Zika and Chikungunya – are increasingly found as invasive species in other parts of the world, including Europe.
- The World Health Organization predicts that, between 2030 and 2050, climate change could result in an estimated 250,000 deaths per year purely on account of malnutrition, malaria, diarrhoeal diseases and heat stress.

Source: Watts et al. – 2020; Haines & Ebi – 2019.

Tipping points in the climate system



Geological and ecological systems around the globe are losing their equilibrium as a result of climate change. Some of these changes have a reinforcing effect on climate change, making it accelerate to the point that it can no longer be stopped.
After Lenton et al. (Nature 2019)

Tipping points in the climate system could enhance climate change or even make it irreversible

- Some elements of the climate system have critical threshold values. Exceeding these values could lead to extreme and in some cases inexorable and irreversible changes.
- Changes in ocean currents could lead to a change in climatic conditions. One example of this is the weakening of the Atlantic Ocean circulation underpinning the Gulf Stream. This would result in major cooling in European weather conditions.
- The Greenland and Antarctic ice sheets also have tipping points which, if exceeded, would mean the permanent loss of ice regions. The causes for this are multiple self-enforcing ice-climate feedback loops (in particular marine ice sheet instability, ice-albedo feedback and melt elevation feedback).
- Ice loss in Western Antarctica has tripled in the last 25 years.

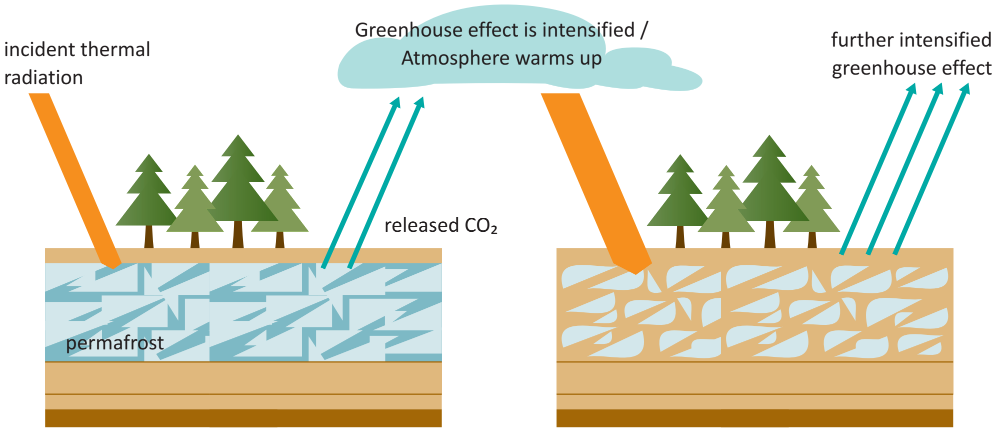
Source: Heron et al. - 2017; Caesar et al. - 2018; Lenton et al. - 2019; Steffen et al. - 2019.

Example of a tipping point: permafrost

Arctic permafrost stores around half of all carbon stored in soils worldwide

1. Global warming leads to soil thaw. This allows stored carbon to escape.

2. The released carbon intensifies the greenhouse effect as CO_2 in the atmosphere.



Permafrost thaw releases more greenhouse gases

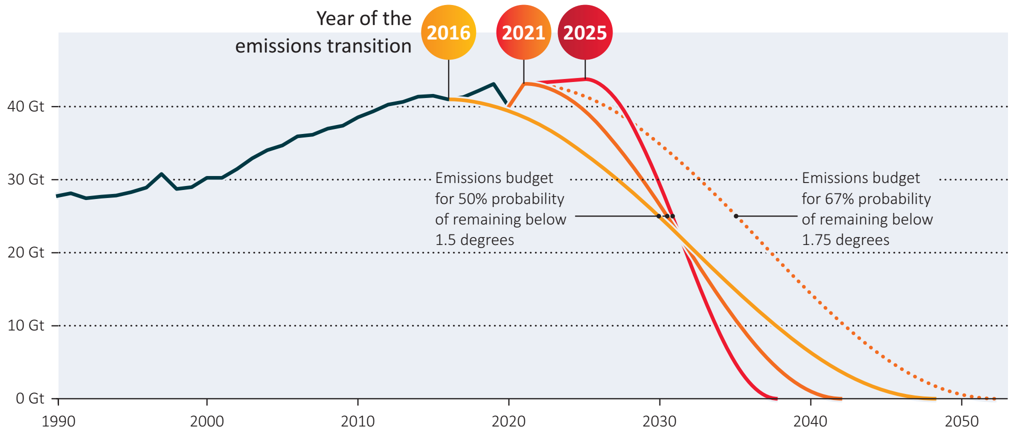
- The permafrost regions of Siberia are increasingly afflicted by heat waves. Each summer, deeper portions of the upper soil layer thaw out for a longer period of time.
- The consequences of warming in the Boreal and Subboreal Arctic are more frequent and widespread fires, erosion of Earth mass and the disappearance of large bodies of water.
- It is easier for microorganisms to break down plant and animal biomass in thawing soil. This process releases the greenhouse gases methane and carbon dioxide. The Arctic could change from a store to a source of greenhouse gases, thus accelerating climate change.
- Thus, permafrost thaw is designated as a tipping point in the climate system. A cascade of other consequences of climate change could also be triggered from a certain point.
- Estimates show that Arctic permafrost stores about twice as much carbon than currently exists in the atmosphere.
- Permafrost thaw also poses a threat to the stability of cities, transport routes, pipelines and industrial plants.

Source: IPCC – 2019 ; Nitze et al. - 2018; Turetsky et al. - 2019

Measures to counteract climate change

Limited carbon budget

Annual CO_2 emissions in billions of tonnes (Gt)



If the global rise in temperature is to be kept to a maximum of 2 degrees, a total of only about 1050 billion tonnes (gigatonnes) of CO_2 can still be emitted. Limiting global warming to just 1.5 degrees would mean restricting the total amount of emissions to less than 300 gigatonnes of CO_2. The longer we wait to reduce emissions, the quicker and more radical later climate protection measures will need to be.

Data: IPCC SR15 (2018).

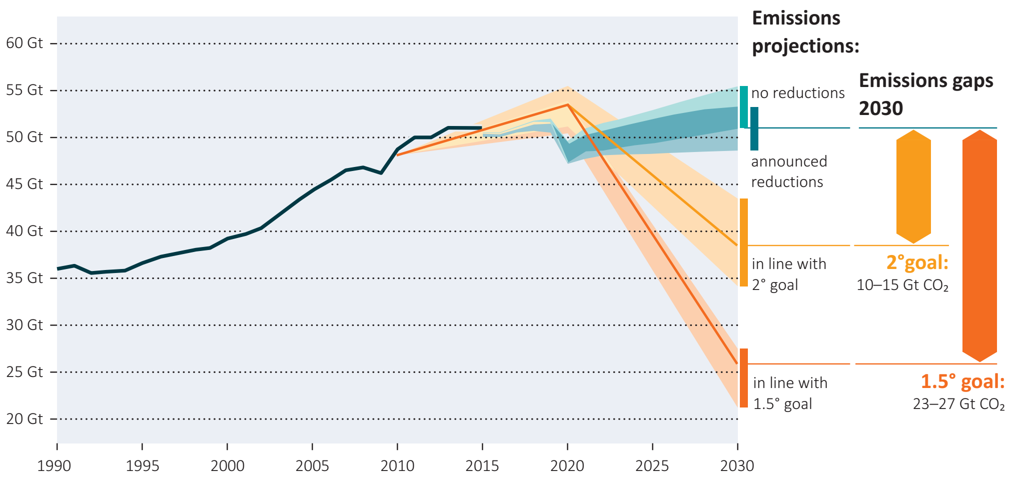
Humanity only has a limited carbon budget remaining

- The undersigning parties to the 2015 Paris Agreement pledged to restrict global warming to between 1.5 °C and significantly below 2 °C.
- If the global rise in temperature is to be kept to a maximum of 2 °C, a total of only about 1050 billion tonnes (gigatonnes) of CO_2 can still be emitted by all of the world's countries together. Limiting global warming to just 1.5 °C would mean restricting the total amount of emissions to less than 300 gigatonnes of CO_2 by the year 2100. This will likely require the use of technologies capable of removing CO_2 from the atmosphere. But with regard to the size of the budget, there are still many uncertainties associated with divergent definitions of the 1.5 °C target, differing assumptions on climate sensitivity and the degree of warming to date as well as the future development of other greenhouse gases, amongst other factors.
- Climate stabilisation pursuant to the Paris Agreement requires a rapid, sustainable and global departure from the use of fossil fuels. The longer we wait to reduce emissions, the more radical later climate protection measures will have to be in order to prevent the global emissions budget for limiting global warming from being exceeded.

Source: Edenhofer & Jakob – 2019; Die CO_2-Uhr des MCC: https://www.mcc-berlin.net/forschung/co2-budget.html; IPCC 2018.

Emissions must be substantially lower by 2030 than planned by governments

Projections for CO_2 emissions and emissions gaps in billions of tonnes of CO_2 (Gt)



Based on emissions projections from countries around the world, it is clear that the intended emissions reductions are completely insufficient for achieving the targets laid out in the Paris Agreement. Limiting climate change to 2 °C would require cutting down the already intended CO_2 emissions reductions by a further 10–15 gigatonnes by 2030. To limit it to 1.5 °C would mean a further reduction of 23–27 gigatonnes.

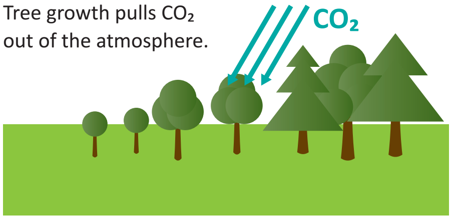
Source: Carbon Action Tracker (Sept. 2020)

The previously announced emissions reductions are insufficient

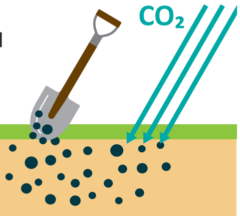
- All member states of the Paris Agreement approved to make nationally determined contributions (NDCs) to enact the agreement's resolution to limit global warming to well below 2 °C. Via these NDCs, the member states set the degree to which they pledge to reduce their own emissions.
- Pursuant to the target of the agreement, these planned reductions in combination should suffice to limit climate change as envisaged. To ensure this, the agreement stipulates regular auditing of the member states' contributions. Should these reductions prove insufficient pursuant to the audits, the states will be prompted to make the necessary improvements.
- Indeed, the latest round of updates five years subsequent to the Paris Agreement has already proven the countries' planned emissions reductions substantially insufficient for limiting climate change to 1.5 °C or well under 2 °C.

Examples of negative emissions technologies

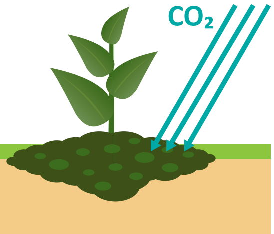
Reforestation
Tree growth pulls CO_2 out of the atmosphere.



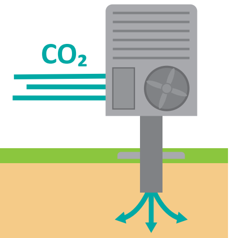
Forced weathering
Crushed minerals are introduced into the soil to absorb CO_2.



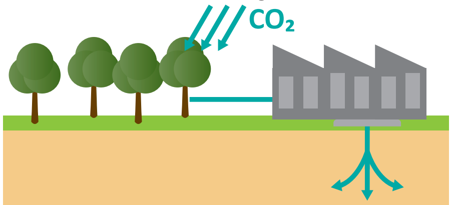
Biochar
Partially combusted biomass is introduced into the soil and absorbs additional CO_2.



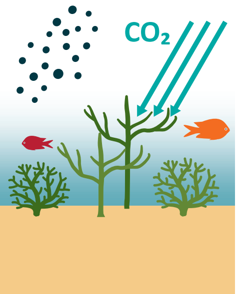
Air filters
CO_2 is pulled from the ambient air through chemical reactions and stored underground.



Bioenergy with CO_2 separation and compression
Plants convert CO_2 into biomass, which is used as an energy carrier. The CO_2 released by the combustion is collected and stored underground.



Ocean fertilisation
Iron or other nutrients are introduced into the ocean to increase CO_2 absorption.

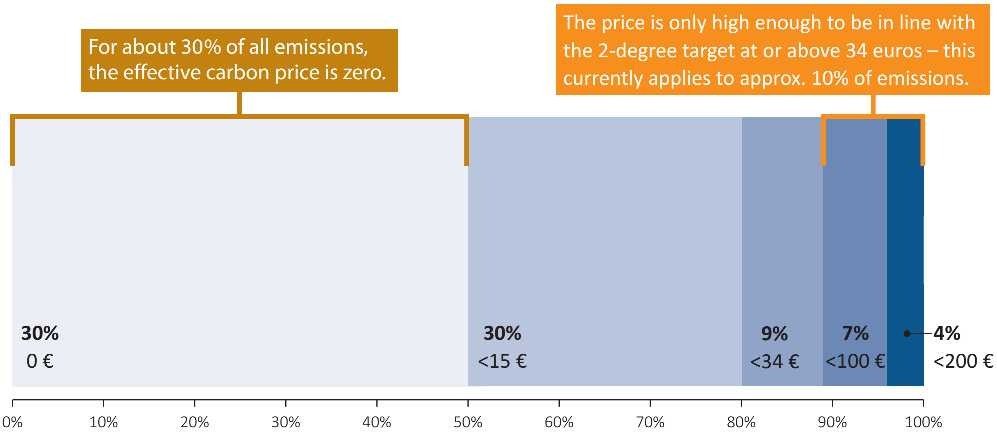


"Negative emissions" can only make a limited contribution

- In view of the target to limit temperature increase to a maximum of 1.5 °C, it seems likely that humanity will initially emit more CO_2 than should be allowed if climate change is to be limited.
- "Negative emissions" refer to the process of removing CO_2 from the atmosphere. Negative emissions technologies (NETs) would allow the world to pay back the "credit" it has already taken out of the carbon budget.
- However, many of the possible NETs lead to a conflict of aims. For instance, large-scale reforestation would reduce the land available for food production.
- Many of the planned NETs have only been tested in small, localised applications. It is unclear to what extent these can be used on a large scale around the world.
- These CO_2 storage options should therefore be cautiously integrated into an overall strategy for limiting climate change. Climate policy must prioritise short-term emissions reduction and a restructuring of the energy systems.

Source: MCC (2016)

Effective carbon price
in euros per tonne of CO_2



Proportions of CO_2 emissions from energy utilisation

A carbon price serves as an effective tool for creating incentives to minimise emissions. However, this only works if the price is set high enough. The price for the vast majority of emissions is set at zero, or it is much too low to actually provide an incentive to control emissions. The data refer to 42 OECD and G20 countries responsible for 80% of global emissions.
After UNEP Emissions Gap Report (2018)

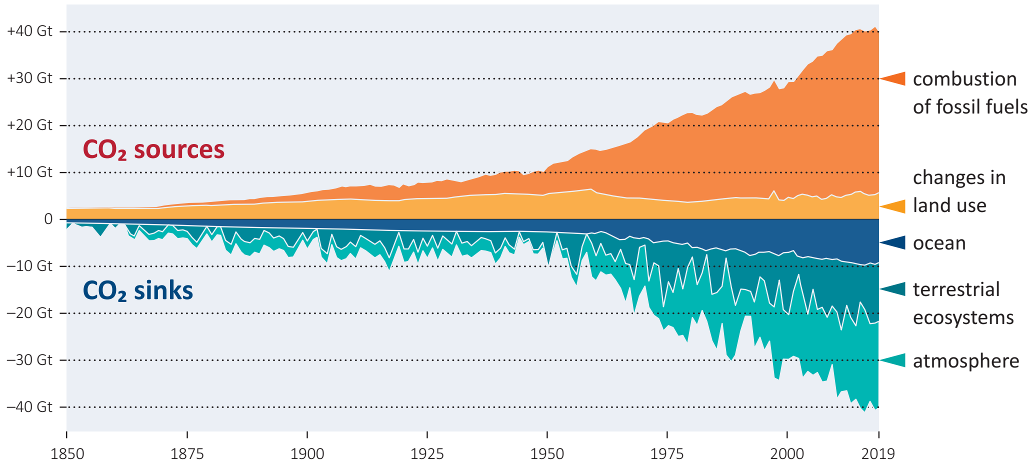
Carbon pricing would be an effective method for reducing emissions

- Carbon pricing serves as an incentive to prevent emissions, first and foremost in applications where this can be achieved in the most cost-effective way possible.
- To successfully stabilise the global climate, an appropriate carbon price should be introduced worldwide.
- However, the current price for the vast majority of emissions is set at zero, or it is much too low to actually provide an incentive to control emissions.
- The implementation of carbon pricing can be achieved via an emissions trading system, which deals with certificates that grant the right to deposit a limited amount of CO_2 into the atmosphere. A tax on CO_2 emissions would be an alternative option.

Source: UNEP – 2018

CO_2 sources and sinks from 1850 to 2019

in billions of tonnes of CO_2 (Gt)



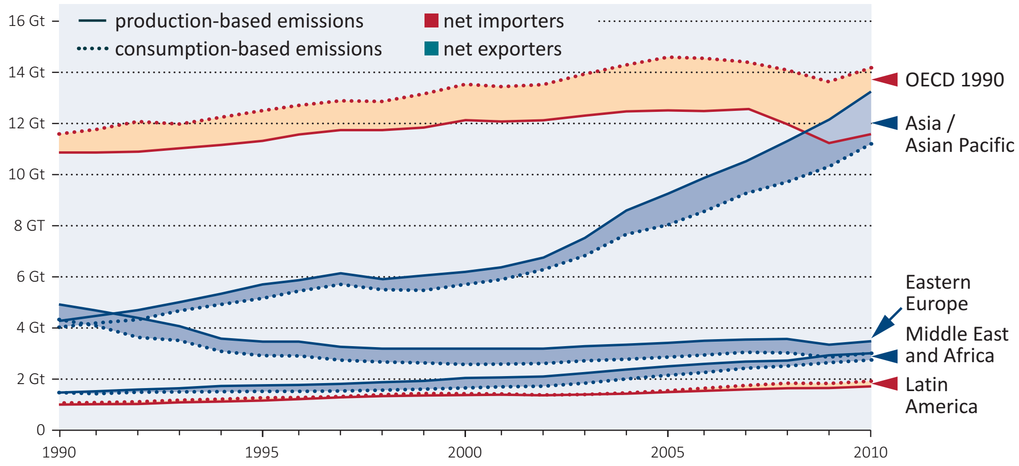
Only a portion of the carbon dioxide remains in the atmosphere. The ocean and terrestrial ecosystems (such as forests) also absorb carbon dioxide. Without these sinks, climate change would be even more extreme. It is unclear where a small portion of emissions – about 4% – remains. This is illustrated by the discrepancy visible between sources and sinks. *Source: Global Carbon Budget (2020)*

The existing carbon sinks such as soils, forests and oceans must be safeguarded

- In the last decades, soils, forests and the ocean have absorbed about half of all human-induced CO_2 emissions.
- It is unclear how long soils and forests will be able to continue absorbing CO_2. Starting from around 2050, this effect might be reversed and these carbon sinks may instead emit additional CO_2 instead of absorbing it, in turn intensifying global warming.
- The ability of these sinks to absorb carbon must be safeguarded. But intensive use causes forests and soils to lose their storage abilities.
- In Germany, bog soils play an important role in climate protection. Grassland used for agricultural purposes is often built on former bogs. Grassland like this makes up 7 % of agricultural area, but it is the root of 35 % of agricultural emissions. Re-establishing the sink function of these bog soils requires comprehensive wetland restoration.

Source: Thünen-Institut – 2011; WBAE – 2016; Global Carbon Project — 2020

Annual CO_2 emissions by region
in billions of tonnes (Gt)



In many countries, for instance those in Asia, emissions have skyrocketed in the last years. However, many goods produced there are consumed in western countries. The emissions from the production of goods in one country which are consumed in another raise the issue of just distribution of the remaining CO_2 budget.
Source: Edenhofer et al. (2019)

The international distribution of the remaining budget is a political and ethical issue

- The solid line in the graph above measures CO_2 emissions originating from the production of goods. The dotted line represents the CO_2 balance of products consumed in each labelled region. The increasing importance of the trade balance can be gauged by anyone who is aware that a quarter of global CO_2 emissions stem from internationally traded products.
- While industrialised countries have produced high CO_2 emissions for a long time, emissions in Asia have skyrocketed in the last years.
- There are a number of reasons which explain the observed export surpluses or deficits in emissions: differing techniques for generating energy, uneven balances of trade or specialisation in the export of high-emission products.
- The emissions from the production of goods in one country which are consumed in another raise the issue of just distribution of the remaining CO_2 budget.
- Dividing the burden of climate protection is an important political and ethical issue which is too complex to be regulated on the basis of consumption- or production-based emissions alone.
- With reference to the goals of the Paris Agreement and the urgency of decarbonisation on the global scale by the middle of this century, industrialised countries such as Germany are called up on in particular: In light of the over-proportionally high emission rates, the transformation process must be advanced more quickly, with the goal of achieving carbon neutrality substantially earlier than by 2050.

Source: IPCC – 2014; Edenhofer & Jakob – 2019.

Contributors

This climate fact sheet was created in collaboration with:

Prof. Dr. Antje Boetius, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven
Prof. Dr. Ottmar Edenhofer, Potsdam Institute for Climate Impact Research
Prof. Dr. Sabine Gabrysch, Potsdam Institute for Climate Impact Research & Charité – Universitätsmedizin Berlin
Prof. Dr. Nicolas Gruber, Swiss Federal Institute of Technology Zurich
Prof. Dr. Gerald Haug, German National Academy of Sciences Leopoldina
Prof. Dr. Daniel Klingenfeld, Federal Environment Agency, Dessau
Prof. Dr. Stefan Rahmstorf, Potsdam Institute for Climate Impact Research
Prof. Dr. Markus Reichstein, Max Planck Institute of Biochemistry, Jena
Prof. Dr. Thomas Stocker, University of Bern
Prof. Dr. Ricarda Winkelmann, Potsdam Institute for Climate Impact Research

References

Bundesministerium für Ernährung und Landwirtschaft – 2020. Ergebnisse der Waldzustandserhebung 2019. Berlin.

Bundesministerium für Ernährung und Landwirtschaft – 2021. Ergebnisse der Waldzustandserhebung 2020. Berlin.

Bova, S. et al. – 2021. Seasonal origin of the thermal maxima at the Holocene and the last interglacial. Nature 589: 548-553. https://doi.org/10.1038/s41586-020-03155-x

Caesar, L. et al. – 2018. Observed fingerprint of a weakening Atlantic Ocean overturning circulation. Nature 556: 191-196. https://doi.org/10.1038/s41586-018-0006-5

CBD – n. d. Convention on Biological Diversity. Forest Biodiversity and climate change. Montreal.

Chakraborty, S. & Newton, A. C. – 2011. Climate change, plant diseases and food security: an overview. Plant Pathology 60: 2–14. https://doi.org/10.1111/j.1365-3059.2010.02411.x

Climate Action Tracker – n. d. https://climateactiontracker.org/global/cat-emissions-gaps/

Dangendorf, S. et al. – 2019. Persistent acceleration in global sea-level rise since the 1960s. Nature Climate Change 9: 705–710. https://doi.org/10.1038/s41558-019-0531-8

DWD – n. d. Deutscher Wetterdienst. https://www.dwd.de/DE/Home/home_node.html

Edenhofer, O. & Jakob, M. – 2019. Klimapolitik. Ziele, Konflikte, Lösungen. C.H.Beck, 2nd revised and amended edition.

Elliot J. et al – 2014. Constraints and potentials of future irrigation water availability on agricultural production under climate change. PNAS 111: 3239–3244. https://doi.org/10.1073/pnas.1222474110

EU JRC ASAP – n. d. Anomaly Hotspots of Agricultural Production. European Commission Joint Research Center. https://mars.jrc.ec.europa.eu/asap/

FAO – 2018. http://www.fao.org/climate-change/en/

Global Carbon Project – 2020. Carbon budget and trends 2020. https://doi.org/10.5194/essd-12-3269-2020

Grace, D. et al. – 2015. Climate and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios. CCAFS Working Paper no. 116. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen.

Haines, A. & Ebi, K. – 2019. New England Journal of Medicine 380: 263-273. https://doi.org/10.1056/NEJMra1807873

Heron, S. F.et al. – 2016. Warming Trends and Bleaching Stress of the World's Coral Reefs 1985-2012. Scientific Reports 6: 38402. https://doi.org/10.1038/srep38402

Hughes et al. – 2020. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 359, 80–83. https://doi.org/10.1126/science.aan8048

IPBES – 2019. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services – 2019. The Global Assessment Report on Biodiversity and Ecosystem Services. Summary for Policymakers. IPBES secretariat, Bonn. https://doi.org/10.5281/zenodo.3553579

IPCC – 2014. Intergovernmental Panel on Climate Change: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar5/wg3. Retrieved on 16th April 2021.

IPCC – 2018. Intergovernmental Panel on Climate Change. Global Warming of 1.5°C. https://www.ipcc.ch/sr15/

IPCC – 2019. Intergovernmental Panel on Climate Change – Special Report on the Ocean and Cryosphere in a Changing Climate. https://www.ipcc.ch/srocc/download/

Jones et al – 2004. Coral decline threatens fish biodiversity in marine reserves. PNAS 101: 8251– 8253. https://doi.org/10.1073/pnas.0401277101

Keeling C.D. et al. – n. d. Exchanges of atmospheric CO_2 and $13CO_2$ with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects, SIO Reference Series, No. 01-06, Scripps Institution of Oceanography, San Diego, 88 pages, 2001. http://escholarship.org/uc/item/09v319r9

Lehmann, J. et al. – 2015. Increased record-breaking precipitation events under global warming. Climatic Change 132, 501-515. https://doi.org/10.1007/s10584-015-1434-y

Lenton, T. M. et al. – 2019. Climate tipping points — too risky to bet against. Nature: 575, 592-595. https://doi.org/10.1038/d41586-019-03595-0

Loeb et al. – 2009. Toward optimal closure of the Earth's top-of-atmosphere radiation budget. Journal of Climate 22(3): 22, 748–766. https://doi.org/10.1175/2008JCLI2637.1

Lüthi et al. – 2008. High-resolution carbon dioxide concentration record 650,000–800,000 years before present. Nature 453: 379–382. https://doi.org/10.1038/nature06949

Marcott et al. – 2013. A Reconstruction of Regional and Global Temperature for the Past 11,300 Years. Science 339 (issue 6124): 1198-1201. https://doi.org/10.1126/science.1228026

MCC (2016): MCC-Kurzdossier „Negative Emissionen“ https://www.mcc-berlin.net/forschung/kurzdossiers/co2-entnahme.html

NASA – 2021. https://www.nasa.gov/feature/esnt/2021/earth-s-cryosphere-is-vital-for-everyone-here-s-how-nasa-keeps-track-of-its-changes

NASA GISTEMP – n. d. National Aeronautics and Space Administration

NASA Goddard Institute for Space Studies GISTEMP. https://data.giss.nasa.gov/gistemp/

Nitze et al. – 2018. Remote sensing quantifies widespread abundance of permafrost region disturbances across the Arctic and Subarctic, Nature Communications, 9(1): 5423. https://doi.org/10.1038/s41467-018-07663-3

NOOA (Global Monitoring Laboratory). https://www.esrl.noaa.gov/gmd/

NSIDC – 2021. https://nsidc.org/

Pritchard – 2019. Asia's shrinking glaciers protect large populations from drought stress. Nature 569, 649–654. https://doi.org/10.1038/s41586-019-1240-1

Robine et al. – 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies 331: 171-178. https://doi.org/10.1016/j.crvi.2007.12.001

Rosenzweig et al. – 2014. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. PNAS 11: 3268–3273. https://doi.org/10.1073/pnas.1222463110

Scripps Institution. https://scrippsco2.ucsd.edu/

Shakun et al. – 2012. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. Nature 484: 49–54. https://doi.org/10.1038/nature10915

Shepherd et al. – 2019. Mass balance of the Greenland Ice Sheet from 1992 to 2018. Nature 579: 233-238. https://doi.org/10.1038/s41586-019-1855-2

Slater et al. – 2021. Review article: Earth's ice imbalance, The Cryosphere, 15, 233–246, https://doi.org/10.5194/tc-15-233-2021, 2021

Spehn & Körner – 2017. Auswirkungen des Klimawandels auf die Natur in den Alpen. Natur und Landschaft: 92: 407-411. https://doi.org/10.17433/9.2017.50153499.407-411

Steffen et al. – 2019. Trajectories of the Earth System in the Anthropocene. PNAS 115: 8252–8259. https://doi.org/10.1073/pnas.1810141115

Thünen-Institut – 2011. Klima Hotspot Moorböden. Forschungsreport Nr. 2. Braunschweig.

Trenberth et al. – 2009. Earth's global energy budget. Bulletin of the American Meteorological Society: https://doi.org/10.1175/2008BAMS2634.1

Turetsky et al. – 2019. Permafrost collapse is accelerating carbon release. Nature, 569: 32-34. https://doi.org/10.1038/d41586-019-01313-4

UN – 2018. Emissions Gap Report 2018. United Nations Environment Programme, Nairobi.

UN – 2020. Emissions Gap Report 2020. United Nations Environment Programme, Nairobi.

UNFCCC – 2021. NDC Synthesis Report. UNFCCC, Bonn.

Wild et al. – 2015. The energy balance over land and oceans: an assessment based on direct observations and CMIP5 climate models. Climate Dynamics 44: 3393-3429. https://doi.org/10.1007/s00382-014-2430-z

Watts et al. – 2020. The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. The Lancet: 10269, 129-170. https://doi.org/10.1016/S0140-6736(20)32290-X

WBAE – 2016. Wissenschaftlicher Beirat Agrarpolitik, Ernährung und gesundheitlicher Verbraucherschutz und Wissenschaftlicher Beirat Waldpolitik beim BMEL (2016) Klimaschutz in der Land- und Forstwirtschaft sowie den nachgelagerten Bereichen Ernährung und Holzverwendung. Gutachten. Berlin.

Willeit et al. – 2019.Mid-Pleistocene transition in glacial cycles explained by declining CO_2 and regolith removal. Sciences Advances 5: 7337. https://doi.org/10.1126/sciadv.aav7337

World Disaster Report – 2020. International Federation of Red Cross and Red Crescent Societies. World Disaster Report. Genf.

Deutsche Akademie der Naturforscher Leopoldina e. V.
– German National Academy of Sciences –

Jägerberg 1
06108 Halle (Saale)
Phone: 0049 345 472 39-867
Fax: 0049 345 472 39-919
Email: leopoldina@leopoldina.org

Berlin offices:

Reinhardtstraße 14
10117 Berlin

Unter den Linden 42
10117 Berlin

The Leopoldina originated in 1652 as a classical scholarly society and now has 1,600 members from almost all branches of science. In 2008, the Leopoldina was appointed as the German National Academy of Sciences and, in this capacity, was invested with two major objectives: representing the German scientific community internationally, and providing policymakers and the public with science-based advice.

The Leopoldina champions the freedom and appreciation of science. It promotes a scientifically enlightened society and the responsible application of scientific insight for the benefit of humankind and the natural world. In its interdisciplinary discourse, the Academy transcends thematic, political and cultural boundaries. It is also an advocate of human rights.

It is the role of the Leopoldina, in co-operation with other national and international organisations, to identify and analyse scientific issues of social importance. The Leopoldina presents its policy recommendations in a scientifically qualified, independent, transparent and prospective manner, ever mindful of the standards and consequences of science.

www.leopoldina.org/en