THE
CURT BERGFORS
FOOD
PLANET
PRIZE

SPECIAL REPORT BY **JOHAN ROCKSTRÖM** AND **LILA WARSZAWSKI**
DIRECTOR AND RESEARCH ANALYST AT THE POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

# The Foul Breath of Climate Change

*Thousands of mussels steaming to death in the warm, low tide of a New Zealand beach, glaciers threatening to melt into summer avalanches in the Italian Alps, and the western U.S. ablaze. The foul breath of climate change is enveloping the world. Air temperatures have climbed steadily over the past decades, the last six years the warmest on record. At the current pace, global warming could push the planet into an unlivable hothouse. Our ability to feed ourselves – and survive as a species – is intimately linked to the health of the planet we inhabit. As things stand now, the world's food system could get in the way of meeting the Paris Agreement's 1.5°C targets.*

PHOTO: GETTY IMAGES

Los Angeles – "the Big Orange" – under an ominous sky, tainted tangerine by wildfires.

REPORT PUBLISHED
OCTOBER 2020

# Contents



**Johan Rockström.** Professor *Johan Rockström* is Director of the *Potsdam Institute for Climate Impact Research* (PIK) and Professor in Earth System Science at the *University of Potsdam*. He is an internationally recognized scientist on global sustainability issues and the pioneer of the Planetary Boundaries framework for human development in the current era of rapid global change. He is a leading scientist on global water resources, with more than 25 years of experience in applied water research in tropical regions, and more than 150 research publications in fields ranging from applied land and water management to global sustainability. https://www.pik-potsdam.de/members/johanro @jrockstrom

**Lila Warszawski.** Dr. *Lila Warszawski* is a research analyst at PIK. Starting out as an astrophysicist in Australia, in 2011 Lila shifted her focus to the global impacts of climate change. She has now spent almost 10 year working as a research analyst at PIK, contributing to a wide range of research topics ranging from the multi-sectoral global impacts of different levels of global warming, to the critical analysis of emissions pathways to achieving the 1.5°C global warming target.

# The furor of fire and wrath of ice

*We're currently experiencing the outcome of the most rapid global warming in thousands of years. With the planet pushed toward its hottest year on record, we'll see more extreme weather conditions and climate anomalies. The climate crisis and its impacts on our food system could very well make food security a luxury reserved for the richest few. It'll be an unpalatable pill for us all to swallow.*

The planet's dirtiest air is in the face of millions, spewing not only from rusty industrial practices in ramshackle facilities, it also hails from wildfires raging in one of the world's most highly developed countries. The West Coast of the United States has turned into a giant campfire. September saw record high temperatures, the sun barely visible in a peculiar, tangerine sky and ashes rained down on central Los Angeles. Children were kept indoors and morning runs warned against because of the hazardous air quality. Almost three million hectares ablaze, more than 30 people dead and tens of thousands displaced by the end of the month in what has become a familiar scenario in the past few years. Authorities in California, Oregon and Washington are trying to cope with an unprecedented new normal that is clearly exacerbated by climate breakdown. This is not a campfire you want to cozy up to.

*"We're on track for a global temperature rise of between 2.8°C and 3.2°C by the end of the century. This is well above the 2°C goal that was agreed upon at the international climate negotiations in Paris in 2015. It would mean warming beyond what our planet has experienced in the past three million years"*

A New York Times article explains how California has become ground zero for climate disasters. The state's engineered landscape turned it into an agricultural powerhouse that produces one-quarter of the United States' food. Some of America's greatest public infrastructure accomplishments were created to spur this development, among them nearly 1,500 reservoirs for water that is redirected from the mountains to the coast and from north of Sacramento, where three-quarters of the state's precipitation falls, to south of the state capital, where three-quarters of its water is used. None of this, however, was designed to accommodate the harsh extremes of rapid climate change. Precipitation patterns are becoming more extreme. The dry years are becoming drier, forcing cities and farmers to deplete underground aquifers, and the wet periods are becoming wetter, threatening to overwhelm the state's vast network of aqueducts, reservoirs and dams.

Suppressing fires that are part of forest ecosystems was also one of California's infrastructure achievements. Keeping wildfires in check has been central to establishing more housing developments – yet, building new homes so close to woodlands has proven disastrous as they frequently fuel the fires. This year is the state's worst wildfire season on record.

**Wildfires are certainly not exclusive to the U.S.**, they're ravaging many parts of the world. Siberian silk moths are somewhat unexpected precursors to the blazes, further illustrating the complexity of climate change on vulnerable ecosystems. The moths grow much faster in the rising temperatures, larvae feed on conifer trees, stripping them of needles and making them more susceptible to fires. Siberia has seen unfathomable daytime temperatures this past summer; 25°C in Khatanga where the previous record was 12°C; 30°C in Nizhnyaya Pesha; and 38°C in Verkhoyansk – the hottest temperature ever recorded in the Arctic, in one of the coldest inhabited places on Earth. In some parts of this region, 2019 was a whopping 4°C warmer than the pre-industrial average. While the farmers here typically light fires to clear vegetation, this time the heat, combined with strong winds, caused fires to burn out of control.


Satellite images reveal a widening wound in the permafrost, bleeding methane at an alarming rate.
PHOTO: NASA

"The Gateway to the Underworld" is the local moniker for the world's largest permafrost crater, the Batagaika in Siberia.
PHOTO: NATIONAL GEOGRAPHIC

Verkhoyansk is a mere 75 kilometers from the world's largest permafrost crater, the Batagaika Crater, known to locals as the "Gateway to the Underworld". Its thawing permafrost is wreaking havoc as it grows at a rate of 12 to 14 meters per year, exposing the ice below and uncovering layers of ancient animal and plant remains that rot and release methane and other greenhouse gases, accelerating the rise in temperatures and creating a vicious circle. This could easily evolve into a major environmental disaster. On a global scale, the Siberian heat is helping to push the world toward the hottest year in our time.

**Down Under**, the latest Australian wildfires devastated approximately 18,500,000 hectares, destroyed 3,094 houses, killed 33 people and billions of animals, driving many species to, or near to, extinction. In New Zealand, hundreds of thousands of mussels broiled in the sun, on a beach in the country's North Island. The mollusks' mass die-off, sparked by a freak period of warm weather combined with low tides, exposed them to what could become a more common occurrence.

In Italy, summer tourists and locals alike are grappling with the fact that parts of the melting Mont Blanc glacier might end up in their laps.
PHOTO: GETTY IMAGES

*"Last year, Greenland shed about 532 billion metric tons of ice, contributing to rising sea levels that could drown New York Harbor, Miami Beach, Tokyo, Shanghai, London, and other vulnerable coastal cities"*

Back in Europe, in early August, dozens of people were evacuated from a valley in northern Italy amid fears that a chunk of ice the size of a soccer field would break off from a Mont Blanc glacier that has been under observation since 2012, a potential casualty of climate change. That's 500,000 square meters of ice, moving at more than one meter a day toward great destruction, and perhaps, your alpine vacation.

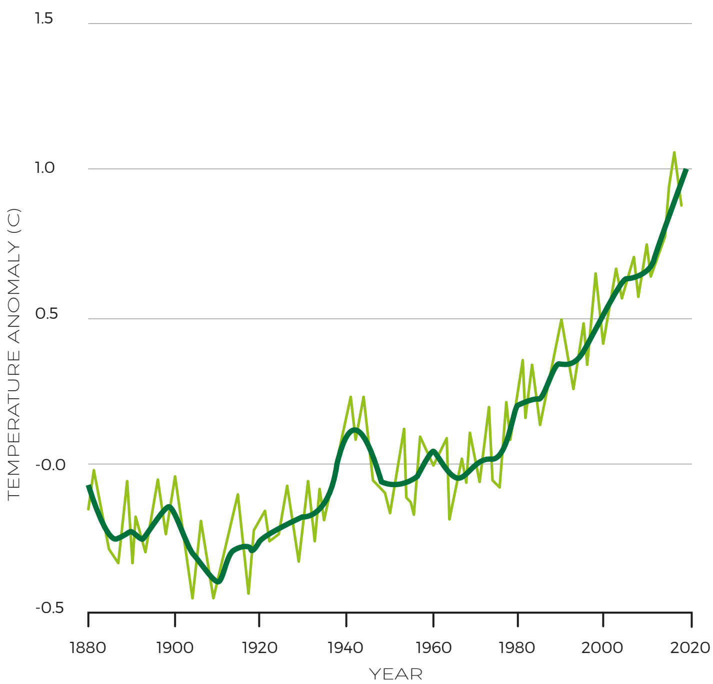
Last year, Greenland shed about 532 billion metric tons of ice (source: Sasgen et al. 2020), contributing to a rising sea level that could eventually drown New York Harbor, Miami Beach, Tokyo, Shanghai, London, and other vulnerable coastal cities. This just might have a direct impact on your life.

**Naturally the COVID-19 virus** has impacted all of our lives. With more than one million deaths and over 40 million cases worldwide (by mid-October), the pandemic owes much to global human connectedness in the 21st century. WHO health experts predict the global death toll could double by 2021.

The outbreak speaks of a global population that is no longer alert to the degradation of its natural environment or the importance of keeping wildlife habitats intact and avoiding confrontation between wild animals, domestic animals and humans. As we destroy natural habitats, the risks of spillover of animal viruses to humans increase. The key driver is our encroachment and adaptation of landscapes to make room for agricultural and urban expansions, all reinforced by climate change and pollution (source: Johnson et al. 2020).

*“19 of the 20 hottest years on record have occurred since 2001. The only heat record before that was in 1998 when the devastating El Niño caused extensive coral bleaching, disastrous floods in Africa, and droughts in parts of Asia”*

**While the most threatening impacts** of global warming lie in the future, already today, with 1.1° Celsius global warming (source: WMO 2020), we are experiencing widespread human suffering in the form of droughts, rising sea levels, air pollution and extreme weather.




Global warming has been on a steady rise since the 1910s, with a sharp upward trajectory since the 1970s. The last six years are the hottest on record.

19 of the 20 hottest years on record have occurred since 2001. The only heat record before that was in 1998, the devastating El Niño year that caused extensive coral bleaching and disastrous floods in Africa, and droughts in parts of Asia.

Despite most nations’ pledges to reduce emissions, we’re still moving toward a global temperature rise of between 2.8°C to 3.2°C by the end of the century. This is well above the 2°C goal that was negotiated in the 2015 Paris Climate Accord. Warming surpassing +2°C goes beyond what our planet has experienced in the past three million years.

Largely, this is all our doing. The Anthropocene epoch in which we live is defined by significant human impact on the Earth’s geology, climate and ecosystems. We’re now on a journey into the unknown of planetary conditions and, likely, on a fast track to wide-spread food insecurity, and for the most vulnerable, starvation. Our societies also face a highly increased risk of infectious diseases, climate-related conflicts and migration, and pressure on key infrastructure.

# The challenge – growth out of sync with our planet

*In the quest to feed people, every degree of global warming matters. Red flags everywhere signal how desperately exhausting food production could become and how serious the issue of food insecurity will be.*

The world population has more than trebled since 1950, from 2.5 billion to almost eight billion today. We all need food.
PHOTO: GETTY IMAGES

Keeping a growing world population alive and well-nourished without ruining the planet's biosphere – that's the overall Food Planet Challenge. Meeting this challenge is becoming increasingly difficult as current developments point in the wrong direction.

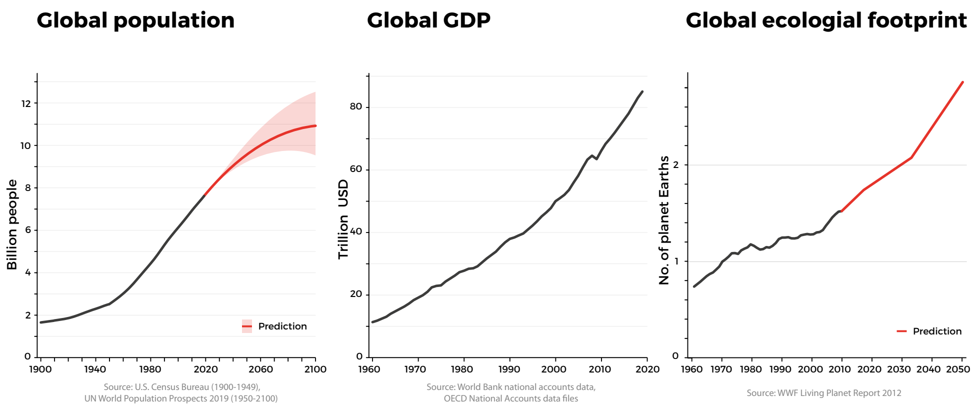
The world population is estimated to grow from close to eight billion today to nine or ten billion by 2050, and then – at a slower pace – to at least eleven billion by 2100. So far, several studies have shown that yes, we can in fact feed 10 billion within planetary boundaries (source: Stockholm Resilience Centre), but it requires a food revolution, including radically reshaping food production and drastically changing consumption patterns.

The focus has increasingly turned to what and how much we eat – and what and how much we ditch along the way. It's far from a simple numbers issue; it reflects the complex interplay and dynamic effects of climate change and its drivers, severely impacting natural resources, our shared living environment, and our remaining biodiversity. Growing regional imbalances – including the uneven geographic distribution of wealth – amplify this complexity, pushing the planet's capacity to provide into the danger zone.

*"With climate change already projected to be a 'poverty multiplier', mainly through impacts on agriculture and food prices, climate-driven disruptions of the food system will widen the poverty abyss and its regional imbalances"*

Today, more than 800 million people are undernourished, and 3 billion are malnourished. Yet, more people suffer from obesity than from undernutrition. Every year, 10 million people die of food related, non-communicable diseases such as cardiovascular illnesses and some types of diabetes and cancer.

With rising affluence in developing countries, an increasing part of the world's population is moving from being food-producing farmers to becoming food-consuming urbanites. In this process, their eating habits tend to conform to traditional Western patterns, often characterized by unhealthy, calorie-packed diets and rocketing consumption of fast and highly processed food.




Driven by a combination of population growth, economic growth and lifestyle choices, by 2030 we could be living as if we had two Earths, not one. By 2050 we may need three.

The parallel trajectories of global population and GDP growth, rising average incomes, urbanization, and related consumption pattern changes will strain the food system beyond its current capacity. Without radical changes to the way we produce and consume food, these trends will turbo-charge our global warming impact and make the fight against climate change even harder. By 2100, the impacts of continued global warming and regional climate change will leave no aspects of life untouched, anywhere.

**With climate change already projected** to be a 'poverty multiplier', mainly through impacts on agriculture and food prices (source: Hallegatte and Rozenberg 2017), climate-driven disruptions of the food system will widen the poverty abyss, and its regional imbalances. It will also highlight the role of food insecurity as a conflict catalyst.

*"We know that existential threats such as [the] climate change will make the hunger crisis even worse"*

ANTÓNIO GUTERRES, UNITED NATIONS SECRETARY-GENERAL

Emphasizing the need to address hunger and its role in global and regional conflicts, this year's Nobel Peace Prize went to the United Nations' World Food Program (WFP), an organization working to combat food insecurity. In 2019, the WFP provided help to nearly 100 million people in 88 countries. The Nobel Committee stressed that war, armed conflict, and the coronavirus pandemic have accelerated global food insecurity. It has pleaded with governments to support the WFP as the world faces a worsening hunger crisis. The award is a powerful reminder that peace and zero hunger go hand-in-hand.

When commenting on the Prize, the UN Secretary-General, António Guterres, called for greater solidarity, to address not only the pandemic but other global challenges too: "We know that existential threats such as [the] climate change will make the hunger crisis even worse."

Climate emergencies, such as droughts and freshwater shortages, have already demonstrated their power to drive armed conflict and migration. While both conflict and migration result from a complex interplay of social and environmental factors, several events in the recent past have provided evidence for a causal link to climate change, including the ongoing civil war in Syria and increased migration out of Central America in 2019/2020. Looking forward, the World Bank estimates that up to four million people from Central America and Mexico could become "climate migrants" by 2050 if climate change continues along its current path (source: World Bank Groundswell Report).

*"The World Bank estimates that up to four million people from Central America and Mexico could become "climate migrants" by 2050 if climate change continues along its current path"*

**In the quest to feed people,** every degree of global warming matters. Rising global temperatures will dramatically impact crop yields negatively and affect people and food security at an even faster pace. As global warming jumps from 1.5°C to 3°C we could see a larger than a fifty-fold increase in the number of people exposed to food security issues – from less than 1% to around 20% of the world's population (source: IPCC Land Report, Byers et al. 2018). Those considered "vulnerable" would be the hardest hit.

Already today, extreme weather is the main culprit of agricultural loss. Heat stress and cold spells, torrential rainfall, drought and monster storms will become more frequent and more intense as climate change continues. Flooding and drought will degrade the soil, rising seas will invade and deplete freshwater supplies, rendering them worthless for irrigation, and the loss of glaciers will lead to water shortages for farmers relying on glacial meltwater.

Scientists have already detected a taste of things to come, noting that climate change caused global maize, wheat, and soybean yields to decrease by 1.8 to 4.5% between 1980 and 2010. In these thirty years, when temperatures "only" climbed around 0.3°C, maize crop losses alone cost the economy up to 22.3 billion USD annually. These reductions hit some of the world's neediest communities the hardest. In parts of Southeast Asia, Brazil, Central America, and sub-Saharan Africa, yield losses exceeded the 10% mark (source: Iizumi et al. 2018).

As a result of extensive bush fires in Australia, biodiversity is acutely endangered, with some ecosystem services threatening to collapse. PHOTO: GETTY IMAGES

By 2100, we may well have a different geography altogether, altered by the effects of climate change. While rising sea levels will threaten to engulf some of the world's most densely populated areas, some mega-cities included, water shortages will be the vital issue in other parts of the world, jeopardizing agriculture and food security.

*"Extreme weather – heat waves and cold spells, torrential rainfall, drought and monster storms – is the leading cause of agricultural loss, and future climate change is projected to make these events more frequent and more intense"*

**"No poverty",** "Zero hunger" and "Good health and well-being" by 2030, these are the three opening Sustainability Development Goals of the United Nations. Established to protect and enhance our economies and societies, each of the SDGs depends on a healthy planet with a stable climate and well-functioning ecosystems, based on biodiversity. After several years on the right track, these key SDG developments have swung the opposite way in the last six years, and rather dramatically so as an effect of COVID-19.

Even before the coronavirus outbreak, it was indisputable that large parts of the global food system are neither sustainable nor safe – with severe effects on human health as well as nature, climate, and the economy.

One-third of the world's population suffers from malnutrition and close to one billion are chronically hungry. Presently, over half the population in Africa, close to one-third in Latin America and one-fifth in Asia live in severe or moderate food insecurity, according to a recent estimate by the United Nation's FAO. In Europe and North America food insecurity is on the rise as well.

**When it comes to biodiversity,** we may already have reached a critical point. We're on course to lose one million species (source: IPBES), and WWF's 2020 Living Planet Report states that "The way we live and the food we eat is driving destruction at a rate faster than nature can recover". Humanity is currently using the resources of 1.6 planets to provide the goods and services we demand – food included – yet we only have one Earth. This bad math illustrates the threat to our lives, societies, economies, and living environment.

*""Over half of the global GDP – USD 42 trillion – depends on high-functioning ecosystems, with one-fifth of the world's countries facing the risk of ecosystem collapse"*

Biodiversity is increasingly recognized as an essential economic driver and its rapid decline as a risk factor. A recent study by the insurance firm Swiss Re suggests that 39 assessed countries have ecosystems in a fragile state on more than one-third of their land, the worst exposed being Malta, Israel, Cyprus, Bahrain, and Kazakhstan. Among the G20 economies, South Africa and Australia top the ranking of nations with frail biodiversity and compromised ecosystems.

According to the study, over half of the global GDP – USD 42 trillion – depends on high-functioning ecosystems, with one-fifth of the world's countries facing the risk of ecosystem collapse as biodiversity declines. If we end up there, the effects on the global economy would be devastating. Risk assessment is at the core of all insurance business, and the Swiss Re report indicates the economic values at stake. People, food security, wildlife, and planetary health will be exposed to even higher risk.

**Red flags** everywhere signal how desperately exhausting food production could become and how deadly serious the issue of food insecurity will be if we don't curb climate change. As the primary driver of biodiversity loss, the food system must be reshaped to maintain planet Earth as a provider.

# Eating our way to the last supper

*The global food system is the world's single largest greenhouse gas emitter. Pushing it toward a sustainable, zero-carbon, resilient future requires nothing less than a revolution in primary food production, and further across the value chain.*

**Intensive and semi-intensive livestock farming is putting increased pressure on the environment.**
PHOTO: GETTY IMAGES

*"The global food system contributes between 21% and 37% of all greenhouse gas emissions annually, with around 20% originating from agriculture – 'within the farm gate'"*

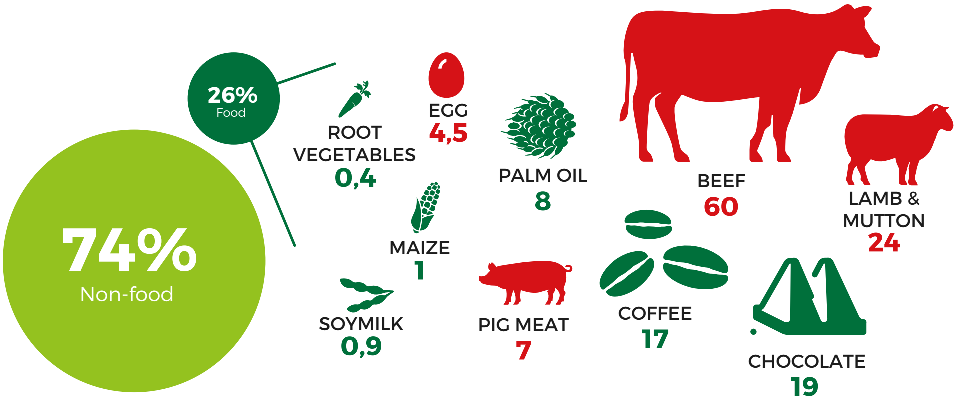
Our health, our survival and our ability to access nutritious foods are intrinsically linked to the health of our planet. The changing climate, together with overuse of land and water resources, is likely to put enormous pressure on the global food system – and vice versa.

If population growth and trends in eating patterns continue on their current paths, we will need to increase food crop production by 60% by the middle of the century (source: Bajzelj et al. 2014).

Already today, the global food system is the world's single largest greenhouse gas emitter, contributing between 21% and 37% of all greenhouse gas emissions annually, with around 20% originating from agriculture "within the farm gate" (source: IPCC Special Report on Land).

Strategies for achieving a sustainable food system typically combine a range of actions to change diets towards more plant-based products, improve land use and food production, and reduce food loss and waste.

**Global greenhouse gas emissions from food production**




The food system is our major greenhouse gas emitter, with livestock contributing the most.
SOURCE: OURWORLDINDATA.ORG

**Agriculture** – including land use, crop and livestock production – contributes more than one fifth of all greenhouse gas emissions. There's a dramatic emissions imbalance between plant-based and animal-based food sources. The latter uses 83% of the world's farmlands and contributes 56-58% of food productions' various emissions, despite providing only 37% of our protein and a mere 18% of our calories (source: Poore & Nemecek 2018). Livestock farming and the meat industry are responsible for circa 18% of total global greenhouse gas emissions and over half of all emissions from the food sector.

*"Livestock farming and the meat industry are responsible for circa 18% of total global greenhouse gas emissions and over half of all emissions from the food sector"*

Reducing the impact of red meat production is an acute concern, as ruminants are major offenders here: one cow can produce over 250 liters of methane per day. One kilo of beef generates the equivalent of ~60 kilos of $CO_2$, while the same amount of fruits and vegetables generate less that 1 kilo of the same.

Methane, nitrous oxide and other non-$CO_2$ greenhouse gases must be curtailed, especially in the short term. Methane is a potent greenhouse gas, with a warming potential thirty times that of $CO_2$, (source: US EPA). It does, however, break down after one or two decades, while $CO_2$ lingers in the atmosphere for a very long time, possibly thousands of years.

**Changes to agricultural management** practices – use of synthetic fertilizers, livestock and manure management, and water and residue management of rice fields (rice cultivation produces surprisingly large amounts of methane) – could deliver greenhouse gas savings equivalent to up to 1 gigaton (one thousand million tons) $CO_2$. Yet another ~1 gigaton CO2e (e=equivalent) could be saved if around half the world's population shifts to a plant-based diet.

Farmers and the agricultural industry can contribute by altering land management practices to increase the uptake and storage of carbon in vegetation and soils, and by implementing modern, technological solutions, less dependent on fossil energy. For example, digital agriculture combines big data and high-performance computing to maximize the efficiency of fertilizer application, cropping and planting decisions, for both sustainability and profitability goals (source: Basso & Antle 2020).

Finding solutions to providing more food while using less land – or no land at all – is imperative. Plant-focused aquaculture will play an increasingly important role, both as a source of nutrition and as a system for carbon capture. Radical new technologies must be devised and deployed to create proteins and other raw materials for food staples, without putting any burden on our natural resources. A number of promising projects in this area are in the works, some of them attacking the problem at both ends by using polluted air as a resource in creating proteins.

*"Between 2010 and 2050, as a result of expected changes in population and income levels, the environmental effects of the food system could increase by 50–90%"*

**Finally, if we want to avoid** eating our way to the last supper, we must ensure that as little as possible of our painstakingly produced food is squandered. The "farm to table" chain has a trashy twin – "barn to bin". If we halve our total food waste and loss, we can reduce emissions by an additional 1 gigaton $CO_2$e. Cutting down on waste must include supply chain technology, increased use of food waste in biogas production, better storage practices and improved food labeling. We also need to scale down our food portions to minimize leftovers.

China recently launched an official "Clean Plate" campaign, addressing the rising food waste problem resulting from the convergence of increased prosperity and cultural patterns of generous hospitality. On September 22, the nation also pledged to become carbon neutral by 2060, leaving no "plate" unturned.

**Industrialized poultry farming rapidly expands its share of animal husbandry.**
PHOTO: GETTY IMAGES

*"If we want to avoid eating our way to the last supper, we must ensure that the food we painstakingly produce is not squandered. The 'farm to table' chain has a trashy twin: 'barn to bin'"*

As things stand now, the world's food system could get in the way of meeting the 1.5°C target (source: WWF 2020). In fact, a 2018 study showed that between 2010 and 2050, as a result of expected changes in population and income levels, the environmental effects of the food system could increase by 50–90% (source: Springmann et al. 2018).

Transforming the food sector from a carbon source to a carbon sink – while at the same time feeding a growing world population – will be an existential challenge over the coming 30 years.

Looking into the future, each degree of global warming will put downward pressure on agricultural yields worldwide. Pushing the food system into a sustainable, zero-carbon, resilient future requires nothing less than a revolution.

"Looking into the future, each degree of global warming will put downward pressure on agricultural yields worldwide"

# We are what we breathe

*Now, deep into the human era, we are altering the composition of the atmosphere at an unprecedented rate, putting the life-support systems of our societies and the stability of the planet at risk.*

A healthy planet makes for healthy people – an established scientific fact, made vividly clear during the COVID-19 crisis. Our wellbeing and security depend on air quality and a stable climate, two of our most important global commons – shared entities crucial to supporting life on Earth. Air and climate are intrinsically interwoven: The composition of our atmosphere and the intactness of nature determine not only the medium and long-term state of our Earth systems, but also the vitality and longevity of humans everywhere.

*"There are indications that long-term exposure to air pollution increases susceptibility to airborne and respiratory-related diseases, including COVID-19"*

We're altering the composition of the atmosphere at an unprecedented rate, putting the life-support systems of our societies and the stability of the planet at risk. We must address the deteriorating air quality to reduce airborne and respiratory-related diseases and to ensure our resilience to novel viruses. Its effect on human health has to be put in the bigger context of climate change and environmental degradation.

**Like climate change, the global food system** is both a contributor to, and a victim of, air pollution. Our shameless hunger for energy and food is not just posing a threat to a stable climate, it's also ruining the air we breathe. The almost impenetrably thick smoke that draped the U.S. West Coast in September is a stark reminder of the impact climate change is already having on wildfire patterns and, indirectly, on declining air quality.

After a short break during the lockdown, air pollution is once again surging in Delhi, risking an accelerated spread of COVID-19. PHOTO: GETTY IMAGES

Indoor pollution, including soot, is a killer in many parts of the world that rely on primitive stoves for cooking.
PHOTO: FLICKR © DOMINIC CHAVEZ/WORLD BANK

The biggest agents of air pollution include some of the most climate-damaging greenhouse gases, emissions, including ozone and soot. Recent studies suggest that exposure to air pollution can result in neural damage. If confirmed, the arguments for taking drastic and immediate action on air pollution just became even stronger. Already, four million premature deaths per year are a direct result of outdoor air pollution. An additional three million annual, premature deaths are caused by indoor smoke and pollution, mostly related to cooking on primitive stoves.

*"Four million premature deaths per year are a direct result of outdoor air pollution. An additional three million premature deaths are caused by indoor smoke and pollution, mostly related to cooking on primitive stoves"*

Nearly three billion people rely on open fires and traditional, primitive stoves to prepare their meals. Cooking over open fires or on inefficient stoves emits one-quarter of global black carbon emissions (soot particles), the second-largest contributor to climate change after $CO_2$ (source: Clean Cooking Alliance).

Air pollutants do not just have a warming effect on the climate, they contribute to other regional climate changes, including global dimming and monsoon weakening and drying, the effects of which can be just as devastating. In the case of global dimming – when air pollutants directly reflect and absorb sunlight before it reaches the Earth's surface – air pollution is actually masking some of the global heating caused by greenhouse gases. This cover-up is just one of the many factors that add to the complexity of predicting future global warming.

Staggeringly, 91 % of the world's population lives in places where air quality does not meet WHO guidelines. It's a tragic fact that the poorest and most vulnerable communities suffer a disproportionately large share of air pollution-related health issues. Nevertheless, in the EU alone, 400,000 premature deaths are attributable to poor air quality, according to a European Union report published in September.

**Long-term exposure** to air pollution interacts with respiratory-related illnesses, plaguing millions globally. It can cause chronic inflammatory response and increase the risk of infection by viruses that target the respiratory tract. Unsurprisingly, a University of Cambridge study has found a link between the severity of COVID-19 infection and long-term exposure to air pollutants, including nitrogen oxides and ground-level ozone from car exhaust fumes or burning of fossil fuels.

Having experienced clean air and blue skies, even enjoying a glimpse of the Himalayas for the first time in decades during the coronavirus lockdown, India's population went into the dreaded pollution season again this fall. The worsening air quality will likely result in a rapid increase in COVID-19 cases and deaths. By mid-October, the country had the world's second-highest caseload and the third-highest death toll caused by this virus. Delhi, one of the world's most polluted cities, will most likely bear the brunt of the nation's rise in COVID-19 cases as hazardous pollution levels continue to plague its residents.

While the measures to combat the COVID-19 pandemic have been drastic, the ensuing economic slowdown has had a direct positive effect on air pollution in cities across the world, resulting in a brief dip in global greenhouse gas emissions. By September, however, emissions had almost fully recovered to pre-pandemic levels. The temporary reduction, equivalent to some 6-8 %/year, happened for the wrong reasons, we cannot rely on destroying the economy and creating mass unemployment to save the planet.

*"Livestock farming and rice production account for over a third of human sources of methane, contributing to atmospheric methane concentrations 2.5 times higher than before the Industrial Revolution"*

**Rice production requires vast volumes of freshwater and is a significant emitter of methane.**
PHOTO: FLICKR, INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

**The benefits of mitigating** climate change will result in direct and wide-reaching benefits for air quality, and in turn, for human health. Similarly, by directly reducing air pollution, powerful greenhouse gases are removed from the atmosphere.

A 2020 declaration by the Pontifical Academy of Sciences (including now deceased Stephen Hawking) argued to include the health effects of air pollution in what is known as the "social costs of carbon", putting a price on the impacts of emitting a single ton of $CO_2$ (source: Health of People, Health of Planet and Our Responsibility, 2020). Such an instrument would ensure that climate policy reflects the intrinsic link between climate change, air pollution and universal human health. Many scientists and policymakers are now starting to recognize that the benefits of reducing air pollution can even serve as an economically compelling justification for climate action in the near term.

*"91% of the world's population lives in places where air quality does not meet WHO guidelines"*

## GREENHOUSE GASES AND AIR POLLUTANTS

Soot is formed when biomass and fossil fuels are incompletely burned. It comes from diesel engines, cooking with coal or biofuels, coal-fired power plants, open burning of agricultural fields, and wildfires. This powerful greenhouse culprit is one component of fine particulate matter (particles circa 30 times smaller than the width of a human hair), which is the most damaging air pollutant to human health and the primary cause of death due to air pollution. Soot settles on ice and snow, reducing these surfaces' ability to reflect sunlight, resulting in increased absorption of heat on the Earth's surface.

Methane does not directly affect human health, but it is a precursor to ground-level ozone, which is not only responsible for respiratory diseases and premature death, but also leads to a reduction in crop productivity (source: Avnery et al. (2011)). Livestock farming and rice production account for over a third of human sources of methane, contributing to atmospheric methane concentrations 2.5 times higher than before the industrial revolution.

When ammonia from synthetic fertilizer and livestock farming is emitted into the atmosphere it bonds with nitric oxides (from combustion processes) to form a range of inorganic aerosols, which are potent greenhouse gases (source: Bauer et al. (2016)) and belong to the health-damaging fine particulate matter. Synthetic fertilizers and livestock are also a major source of nitrous oxide, which is a greenhouse gas almost 300 times stronger than $CO_2$.

# Climate change – the big picture

*Exceeding 2°C means the world may be pushing Earth-system-regulating factors – ice sheets, permafrost, ocean heat circulation, and forests – to tipping points, triggering irreversible shifts and potentially forcing the planet toward a "hothouse" trajectory.*

*"After failing to evolve over tens of thousands of years of previous human history, agriculture emerged in up to nine geographically separated areas around the same time"*

Engineered landscapes, a landmark of the Anthropocene. Crop circles in Kansas, USA, illustrate our systematic exhaustion of water resources. PHOTO: NASA

At the Paris Climate negotiations, the world's nations agreed to keep global warming well below 2°C and to aim at limiting it to 1.5°C. However, according to the Intergovernmental Panel on Climate Change (IPCC), exceeding 1.5°C will result in rapidly increasing climate impacts, undermining food production and sparking more frequent, more intense extreme weather events.

These large and looming risks with possibly irreparable consequences of global warming beyond 1.5°C is why the climate planetary boundary – $CO_2$ concentration in the atmosphere – was set at 350 parts per million (ppm). This corresponds to long-term global mean temperature rise at, or below 1.5°C compared to the pre-industrial average.

Exceeding 2°C could mean pushing Earth-system-regulating factors – ice sheets, permafrost, ocean heat circulation, and forests – toward tipping points, triggering irreversible shifts and potentially forcing the planet along a "hothouse" trajectory.

*"The Earth owes this exceptional resilience to its biophysical systems – ice sheets, oceans, soils and forests – which absorb and dampen the effects of planetary volatility"*

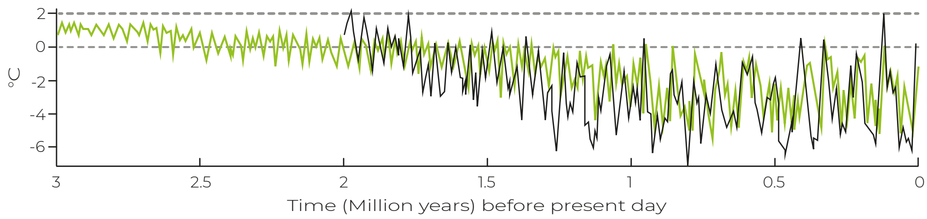
**The latest climate modeling** of the global mean temperature on Earth over the past three million years is a true scientific breakthrough. The findings make it abundantly clear that we need to keep global warming far below 2°C. For the very first time, and by means of physical equations, scientists were able to accurately reproduce the cycles between warm and cold periods. These predictions were matched against observed temperatures from ice-core measurements of the concentration of $CO_2$ in the atmosphere deep in the Greenland ice sheet, and deeper back in time (more than one million years) from tree-ring data, which provides a proxy measurement of $CO_2$ concentration.

This analysis confirmed something of extraordinary importance: Despite variations in orbital forcing from the Sun, shifts in the Earth's angle and wobbling of its spin axis, abrupt geological events like volcanic eruptions and earthquakes spitting massive volumes of air pollutants and greenhouse gases – despite all these "punches to the system" – the Earth was able to self-regulate, to keep fluctuations in global temperature within a relatively small window (and likely never more than 2°C).

Large parts of the Amazon rainforest are burning to make way for soybean and livestock farming, contributing to the risk of one of the world's major carbon sinks becoming a carbon emitter.

PHOTO: GETTY IMAGES

The Earth owes this exceptional resilience to its biophysical systems (ice sheets, oceans, soils and forests), which absorb and dampen these effects. In fact, what these paleoclimatic studies tell us today is that over the past three million years (the epoch when the Earth has been reasonably similar to the planet we know today), our planet has been swinging in and out of ice ages and interglacial periods, but always within the relatively narrow range of -6°C (deep cold) and +2°C (warm interglacial), based on average conditions in the pre-industrial human era (source: Willeit et al. 2019).




Earth as we know it has only been around for the past three million years, during the geological Quaternary period. The latest climate modelling shows that during this entire period, global mean temperature has never exceeded 2°C (as compared to the pre-industrial temperature of approximately 14°C on Earth). The green oscillating line is the model simulation, showing how Earth has been swinging between warm inter-glacials and cold ice ages, always within a very narrow corridor; +2°C and we reach the warmest inter-glacial and -4°C and we are in deep Ice age. The black line is the observed temperature variability, from ice core data and other proxy data.

*"Records of global mean temperatures, based on ice-core measurements, going back three million years, illustrate how the planet's temperature has always fluctuated slightly, but never surpassed the +2C mean"*

Starting roughly one million years ago, the Earth entered a phase of more regular swings between warm interglacial – phases of relative heat, with high sea levels and lush vegetation – and colder "Ice Ages", in which large amounts of ocean water were frozen in continental-scale ice sheets. Going even further back in time, it might be surprising to discover that as far as we know, our planet has over the past one billion years only existed in three different states: "Snowball Earth", "Hothouse Earth", and "Interglacial".

**"Snowball Earth" is an extreme state** the Earth last experienced some 700 million years ago. In it, a runaway albedo effect (whereby light-colored ice reflects more sunlight back into space than dark-colored forests) caused the ocean to freeze completely, covering it with ice all the way to the Equator. The hydrological cycle came to a halt in this state, and biological productivity all but stopped for a time of more than ten million years.

Paradoxically, this seemingly dormant state may hold the secret to the beginnings of complex biological life, and the intricate interconnections between living creatures and the composition of the Earth's atmosphere. While scientists are yet to agree on how such inhospitable conditions could give rise to complex biological forms, all theories point to an interplay of atmospheric composition and biology, serving as a chilling warning from the past of just how dependent we are on our Earth systems as a whole for survival.

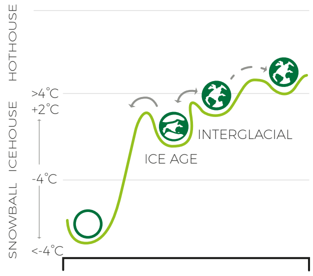
*"As far as we know, our Planet has over the past one billion years only existed in three different states; 'Snowball Earth', 'Hothouse Earth' and 'Interglacial'"*

According to one theory, as the last Snowball Earth phase ended, the seas were "fertilized" with phosphorous dust washed off the newly ice-free rocks, resulting in the release of large amounts of oxygen from well-fed microscopic plants. This sudden rise in atmospheric oxygen may have been just what was needed to foster more complex life forms.

**"Hothouse Earth" is of course the other extreme.** This state was last experienced some 56 million years ago during the Paleocene-Eocene Thermal Maximum (PETM), when global mean temperatures were more than 5-8°C higher than today. A patch of ice on Antarctica might have survived on a planet with more than 50m higher sea level and environmental conditions that were better suited to dinosaurs than humans.

**"Interglacial" is the third Earth state**, characterized by the tranquility of relatively stable climate conditions. It last began roughly 12,000 years ago, at the end of the last Ice Age. Globally, the average temperature was relatively warm and didn't waver more than 0.5°C above or below the pre-industrial average, and the concentration of $CO_2$ remained steady between 250ppm and 270ppm.

**Snowball Earth may have been the birthplace of complex life forms on the planet.**
PHOTO: ALAMY. SOURCE: HTTP://WWW.BBC.COM/EARTH/STORY/20150112-DID-SNOWBALL-EARTH-MAKE-ANIMALS

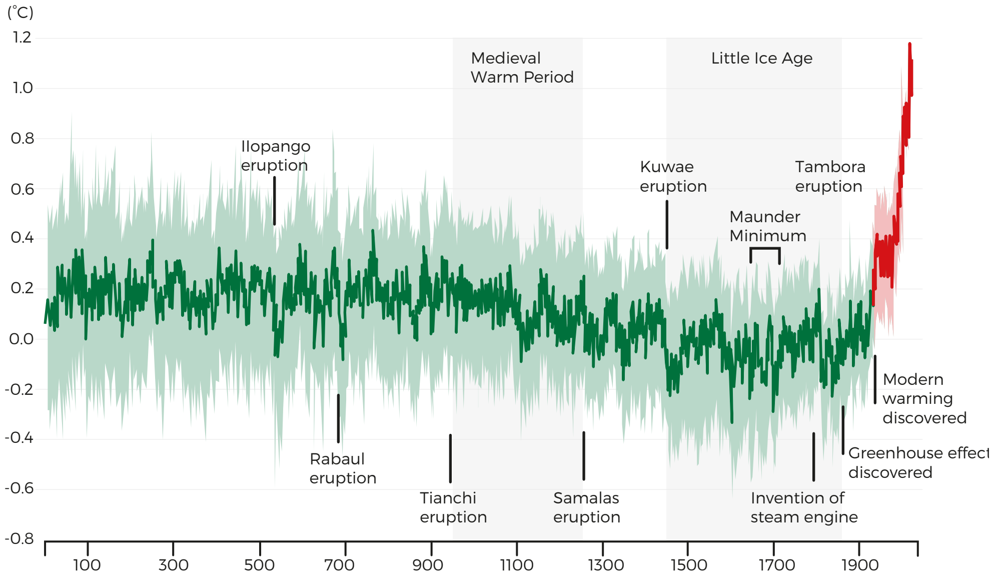



**Over the past one billion years, Planet Earth has only bounced between three different climate states.**

While Homo sapiens roamed the Earth for around 160,000 years, this interglacial period of stability, known as the Holocene, laid the foundation for modern societies by providing the conditions for human civilizations to flourish and develop sedentary agriculture.

It's now well accepted that several millennia of relatively steady climate conditions were necessary for agricultural practices to emerge. The first evidence of plant and animal domestication dates back to the early millennia of the Holocene. That agricultural practices emerged in up to nine geographically separated areas around the same time, after failing to develop over tens of thousands of years of previous human history, underlines how important the Holocene climate conditions were to the development of modern societies (source: Diamond 2002).

**Global temperature change over the last 2,000 years**




**Since the 1950s, global temperatures have been increasing at a rate faster than any time in the entire Holocene. Today, our planet is warmer than at any time during the last 11,000 years, a period in which modern human civilizations emerged.**

# The Anthropocene: humanity in the fast lane

*While the numbers behind the Great Acceleration tell a story of human development – and an escalated need for food and energy – they also tell a story of mounting human pressure on the Earth system.*

*"The onset of the Industrial Revolution marked the dawn of the paradoxical relationship between human prosperity and mounting pressure on the Earth system and the climate"*

A host of human activities began to fundamentally transform our planet already during the Holocene, the epoch that commenced after the last glacial period. By driving the extinction of megafauna – including its superstars, the mammoth and the daeodon – domesticating and taming crops and livestock, tilling land, and clear-cutting vast swathes of forest for cultivation, humans became a decisive factor in altering the appearance and function of the natural landscape.

With the onset of the Industrial Revolution in the 18th century, what had been a slow burn picked up steam, marking the dawn of the paradoxical relationship between human prosperity and mounting pressure on the Earth systems and the climate.

Starting in Great Britain, and spreading through Europe, to North America, Asia and the rest of the world, humans began to tap millions of years of energy stored in coal, to feed steam engines and machinery and to systematize deforestation. Simultaneously, the Industrial Revolution revamped agricultureal practices. The transformative invention of the Haber-Bosch process in the early 1900s – producing synthetic plant fertilizer by capturing nitrogen from the air – paved the way for industrial-scale agriculture, yielding more crops, but also polluting air and waterways, and laying the very first and very heavy stone of climate interference.

**At almost eight billion today, global population is on course to almost ten billion by 2050.**
PHOTO: GETTY IMAGES

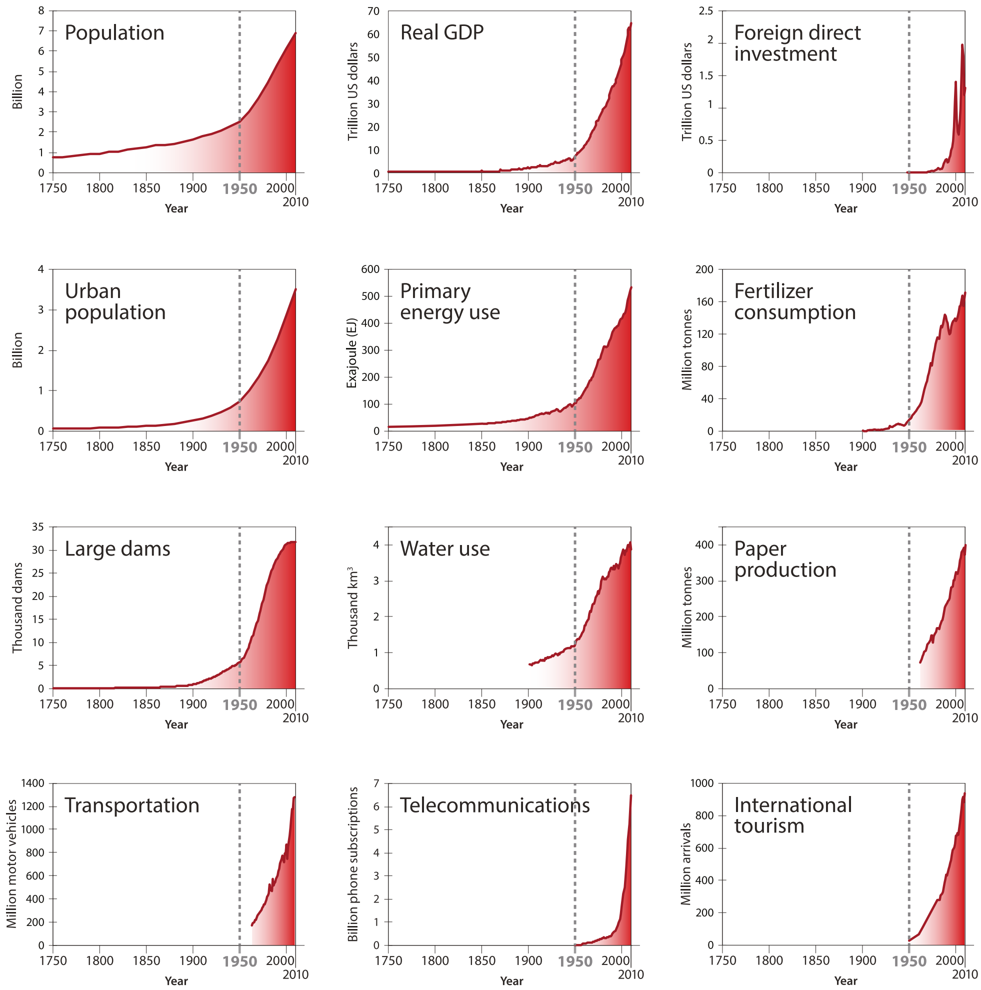
*"Between 1950 and 2020, the world's population ballooned from 2.5 billion to almost eight billion"*

By the middle of the 20th century, global agriculture entered a radical "Green Revolution" transformation. High-yielding crops and standardized techniques made it possible to multiply production, reduce hunger and increase prosperity while ramping up the pressure on the planet's resources and stability. Between 1950 and 2020, the world's population ballooned from 2.5 billion to almost eight billion.

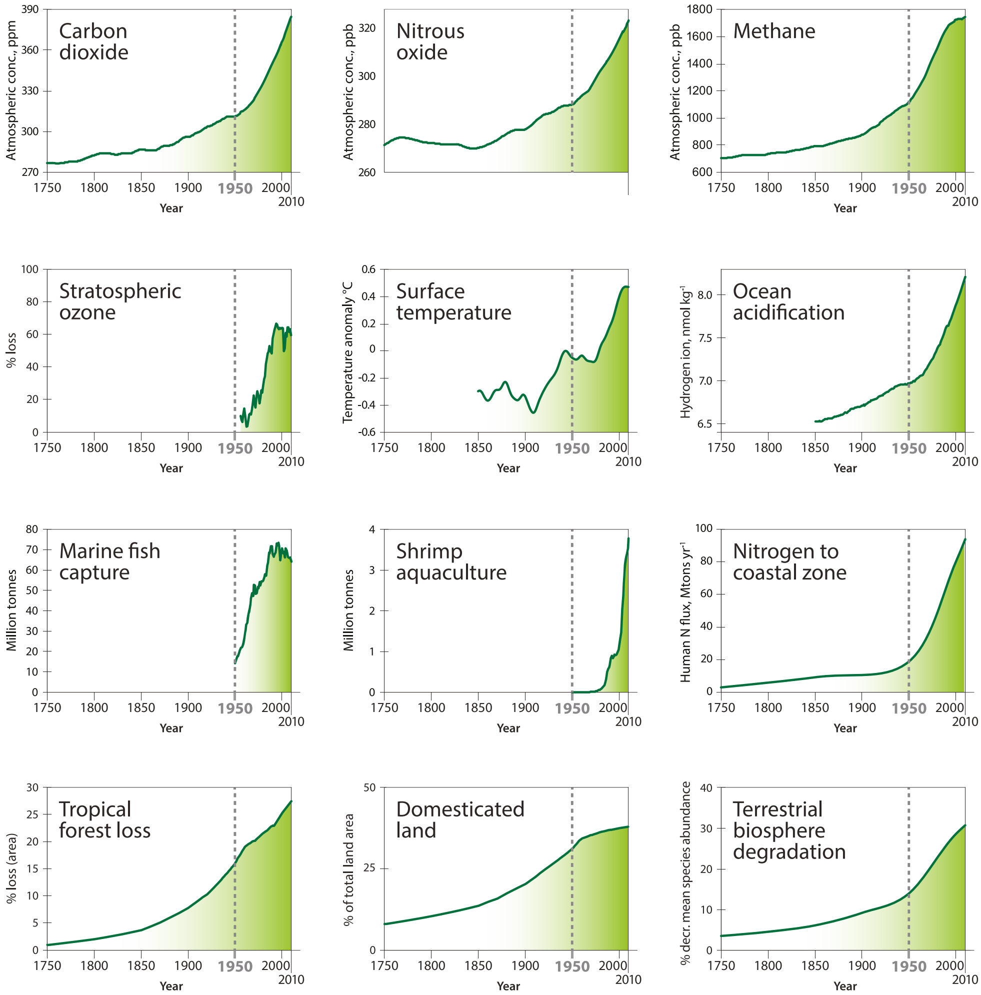
**The "Great Acceleration"** is conspicuously evident in all measures of human activity, be it economic growth or trade volumes, fertilizer or land use, water consumption or transportation – as well as greenhouse gas emissions and rising mean air and ocean temperatures. Scientists concede that these precipitous changes define the beginning of a new geological era: the "Anthropocene", in which humans have become a global force for geological change.

## Runaway statistics. As our population and prosperity grow, so does our imprint on the planet

**SOCIOECONOMIC TRENDS**



**EARTH SYSTEM TRENDS**




*"The transformative invention of the Haber-Bosch process in the early 1900s paved the way for industrial-scale agriculture"*

While the runaway numbers behind the Great Acceleration tell a story of human success – and an exponentially growing need for food and energy – they also tell a story of mounting human pressure on the Earth systems.

In the face of a changing climate, diminishing natural resources, and frightening transformations of previously steadfast phenomena in the natural world, scientists ask themselves if there is a threshold at which this accumulated pressure will exceed our planet's ability to absorb it. The "human project" is at stake.

# Approaching the tipping points

*When average global temperatures reach around 1.5°C higher than pre-industrial levels, we run the risk of activating up to five of the "tipping elements", which could make pushing the "stop" button on climate change almost impossible.*

**Rogue icebergs near Uummannaq, Greenland, illustrate the vulnerability of the climate-regulating Greenland ice sheet.** PHOTO: S-E ARNDT/AZOTE

*"The Antarctic and Greenland ice sheets regulate the temperature of the water and air around them, driving circulation patterns that determine weather conditions across the planet"*

It has become easier than ever to identify how human-driven global warming is causing dramatic changes in weather patterns and the natural environment. Some cases are even exceeding pessimistic predictions, and we already see signs that some critical elements in our Earth system are on the verge of collapsing.

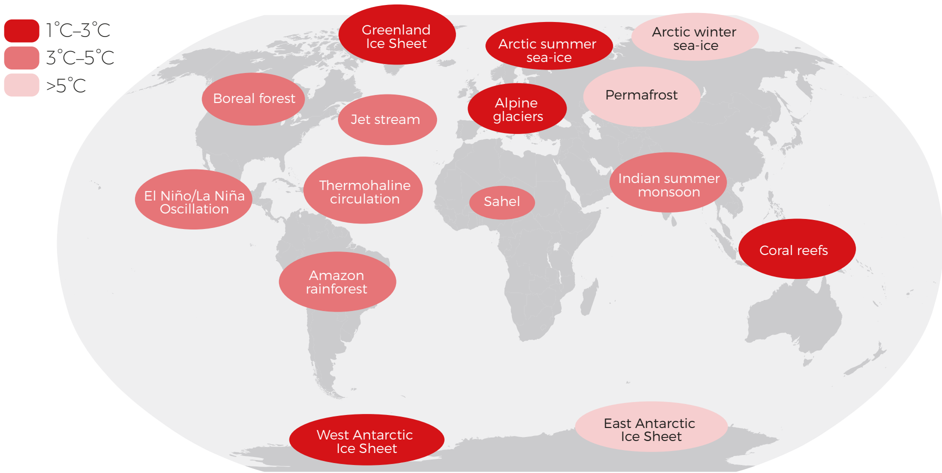
Since the early 2000s, a set of processes, patterns, ecosystems, and large-scale entities in the Earth system have been identified as "tipping elements". (source: Schellnhuber et al. 2002, Lenton et al. (2008)) Driven beyond critical thresholds, these factors could trigger a domino effect of climate calamities. The risk of activating one of these tipping elements increases with rising global temperatures, and their activation would wreak havoc on the Earth system.

Sometimes referred to as the Achilles heels of the Earth systems, tipping elements are perhaps best understood with a few examples.

**Red alerts. A cluster of tipping elements, spread across the world, could cause a domino effect of climate calamity.**

SOURCE: (LEFT) SCHELLNHUBER ET AL. NATURE CLIMATE CHANGE (2016); (RIGHT) STEFFEN ET AL. (2018), PNAS.

## Tipping elements at risk




*"The Amazon rain-forest might transform into a seasonal forest or grassland, adapted to drier conditions"*

**The Amazon** basin is one of the planet's key tipping elements, it regulates the climate and regional rainfall, and is one of the most biodiverse regions on the planet. Some 25% of the flow of carbon between the atmosphere and biosphere takes place here, making it essential for the global carbon cycle. These lungs play a momentous role in the climate change story. The Amazon is so immense that it's partly responsible for its own weather: Most of the rainfall in the Amazon basin originates from water evaporating and transpiring over the rainforest.

The lush and self-irrigated Amazon rainforest could become a savannah, leaving just a few trees and wide expanses of grassland.

PHOTO: GETTY IMAGES

*"The tipping point to the complete loss of the Greenland ice sheet in the long term could be already reached if the global temperature rises by slightly less than 2°C"*

A combination of a warmer global climate, declining regional precipitation, deforestation (mainly to create more agricultural land) and forest fires could push the rainforest toward a critical threshold (source: Zemp et al. Nature Communications 2016), beyond which it might transform into a seasonal forest or grassland, adapted to drier conditions. This would mean the loss of one of the world's most important terrestrial carbon sinks, as well as loss of the forest's own tools for a possible recovery. Unparalleled biodiversity would also be a casualty of this scenario (source: Sakschewski et al. Nature Climate Change 2016).

**Even though a retreat** of continental-scale ice sheets is a hallmark of the Holocene, ice still plays an essential role in the Earth systems today. The Antarctic and Greenland ice sheets regulate the temperature of the water and air around them, driving circulation patterns that determine weather conditions across the planet.

*"Deep basins under the ocean's surface are funneling warm water toward the glacier's edge and accelerating the melting process"*

With average temperatures in the Arctic warming almost twice as fast as the rest of the planet, ice loss from the Greenland ice sheet has increased considerably in recent years. As a consequence, the ice sheet (three kilometers thick in some places) is becoming thinner. When the ice sheet's surface – which today still reaches into high, cold air layers – sinks, it will be progressively exposed to lower and warmer layers of air, in turn leading to more melting. The tipping point to a complete and irreversible loss of the Greenland ice sheet in the long term could already be reached if the global temperature rises by slightly less than 2°C (source: Robinson et al. Nature Climate Change (2012)). If the Greenland ice sheet collapses completely, the sea level would rise up to seven meters over hundreds to thousands of years (source: Ashwandan et al. Science Advances 2019).

The tipping of the Greenland ice sheet would inject massive amounts of freshwater into the ocean around it, possibly leading to a complete shutdown of one of the Earth's most powerful ocean circulation patterns. Usually, warm water travels up the North American Atlantic coast, driven by the Gulf Stream. Upon reaching northern latitudes, this water becomes cooler, saltier and denser, and sinks to the depths of the ocean to be transported back toward the Equator. This giant conveyor belt, known as the Atlantic Meridional Ocean Circulation, isn't just a key to regulating temperatures, it's essential for redistributing nutrients, salt and other gases across all oceans. The increasing amounts of freshwater coming off the Greenland ice sheet interrupt this process by diluting the salty water. Scientists have already observed a 15% slowdown of this Atlantic Meridional Ocean Circulation since the middle of the 20th century, attributing it to melt water from Greenland (source: Caesar, Rahmstorf et al., Nature (2018)). A complete shutdown of this circulation system is now plausible.

Melting rapidly, dumping billions of tons of ice every year, and raising the global sea-level, "The Twaites" has been labeled "the Doomsday Glacier".

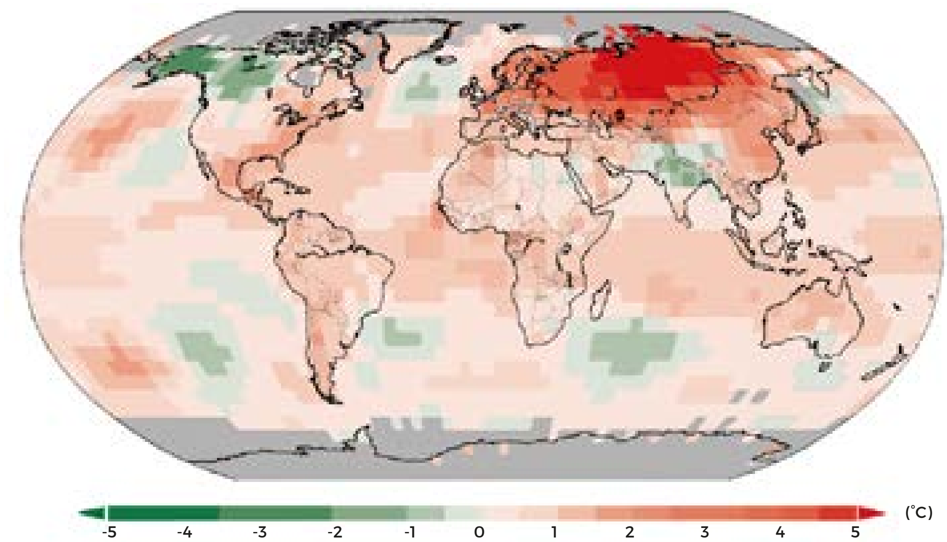
PHOTO: ALEKSANDRA MAZUR

The Thwaites Glacier in the West Antarctic is melting faster than first anticipated. Shedding around 80 billion tons of water yearly, it's already responsible for 4% of annual sea level rise, globally. The Thwaites is the largest of the glaciers draining into the West Antarctic Ice Sheet, and it plays a key role in the potential tipping of the ice sheet – when the glacier melts, the rate of ice flowing upstream, from the ice sheet into the glacier, increases, which leads to further melting. If this process continues unabated and provokes the glacier's complete collapse – a fate that is not expected in the near future, but could be the result of an unstoppable process that has already begun – global sea levels will rise 65 cm. To make matters worse, deep basins under the ocean's surface are funneling warm water toward the glacier's edge and accelerating the melting process.

*"Average surface temperatures in May were up to 10°C higher than normal in some parts of the Arctic Siberia. Statistically, such conditions are only expected about once in 100,000 years"*

**At the opposite end of the globe,** this past summer's heat wave in Siberia brought balmy, Mediterranean-like breezes to the tundra, signaling that another critical tipping element is at risk of being activated. Average surface temperatures in May were up to 10°C higher than normal in some parts of the region. Statistically such conditions are only expected about once in 100,000 years. Besides pushing 2020 toward the hottest year on record globally, this heat wave has been implicated in wildfires, an oil spill, a moth plague, and the spectacular growth of the Batagaika Crater. In the longer term, warmer temperatures in Siberia would cause millions of tons of carbon to escape from the thawing permafrost into the atmosphere, in turn sparking further warming.

**Land & Ocean temperature departure from average Jan–April 2020**




National Centers for Environmental Information
GHCNM v.4.0.1.20200507.qfe

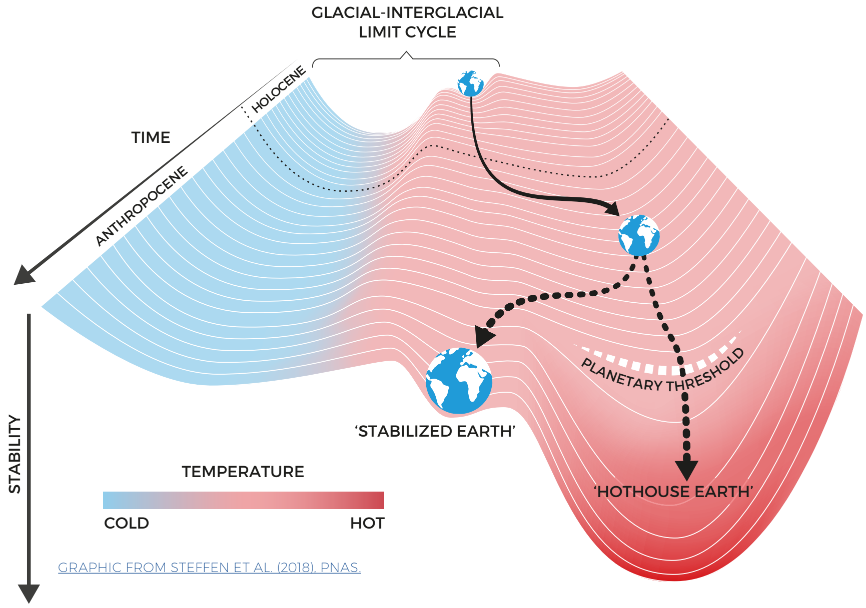
Please Note: Gray areas represent missing data

In June 2020, temperatures reached 38°C in Verkhoyansk – the highest temperature ever recorded in one of the coldest inhabited places on Earth. Between January and April 2020, the Arctic parts of Siberia witnessed the world's biggest deviation from average temperatures.

MAP BY NOAA HTTPS://THEBARENTSOBSERVER.COM/EN/ARCTIC-ECOLOGY/2020/05/RED-ALERT-NORTHERN-SIBERIA-HEAT-SHOCKS-THREATEN-LIFE-TUNDRA

*"If global temperatures continue to rise, the Earth System could be on course to a Hothouse Earth, crossing a planetary point of no return"*

**The interconnectedness of these tipping elements** points to an even stronger knock-on effect, and an even greater risk of permanently leaving the Holocene climate conditions if one or more of these tipping elements are triggered. When the average global temperature reaches around 1.5°C higher than pre-industrial levels, we run the risk of activating up to five of these tipping elements, which could make pushing the "stop" button on climate change almost impossible. Soon we might not be able to halt global warming by solely limiting human emissions of greenhouse gases. At this point, cascading tipping elements could thrust us on a path toward a Hothouse Earth.




No thanks, we don't want to slide into that abyss! This stability model shows the pathway our Earth System is currently on–out of the glacial-interglacial cycle, to its present position in the hotter Anthropocene, at risk of crossing the planetary point of no return toward a Hothouse Earth. Once there, we will have great difficulty to move back. If we humans take control of our Earth System, we could steward it toward Stabilized Earth in which our life-support systems are conserved and runaway feedback effects between different parts of the Earth System are kept in check.

The consequences could be dire: Rising sea levels, increased ice loss in Antarctica, severe heat and extreme storms in North America and Europe, and even increased drought in the Sahel region, south of the Sahara Desert. Within a longer time frame, this might lead to destabilization of ice sheets in the Northern Hemisphere and further warming, which could, in turn, trigger tipping elements such as melting of the artic permafrost and loss of Arctic sea ice.

These cataclysmic domino effects would, needless to say, pose a huge threat to agricultural activity and widespread loss of arable lands, not just in subsistence-dominated regions, but also in industrialized countries (source: Ritchie et al, Nature Food (2020)).

# The global carbon cycle is powering life as we know it

*The oceans, atmosphere and land act as long-term storage centers for vast amounts of carbon, while flows of carbon between these components are mediated by plants, chemical processes in soils, rocks and ocean water, and increasingly, human activity. We all run on carbon.*

We are "the carbon planet", and carbon is the basic building block of life as we know it. The carbon cycle and its interaction with other dynamic planetary processes is the magnificent narrative of planet Earth.

*"The planet's capacity to keep carbon stocks intact and all biophysical systems in good health is also what makes it so resilient"*

The new problematic chapter for our climate and air was written by us all and dictated by our meddling in the global carbon cycle – the exchanges of carbon within and between three major reservoirs: The atmosphere, the oceans, and land (including fossil-fuel reserves). The cycle describes the mechanisms and pathways by which carbon moves through and is stored in the Earth system, incorporating every part of our natural world (see illustration). The oceans, atmosphere and land act as long-term storage centers for vast amounts of carbon, while flows of carbon between these components are mediated by plants, chemical processes in soils, rocks and ocean water, and, increasingly, human activity. The planet's capacity to keep carbon stocks intact (in soils, biomass, oceans), and all biophysical systems like forests, ice, freshwater systems and oceans in good health, is also what makes it so resilient.

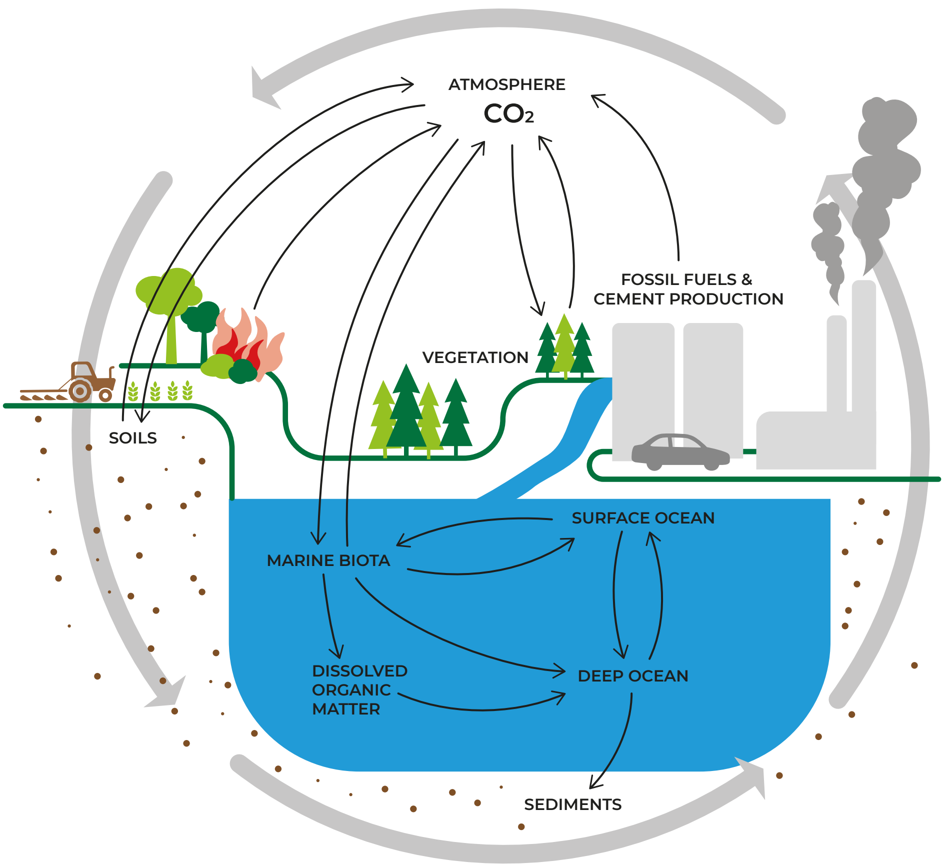
**Out in the open, the coal layer in a former sandstone quarry in Mutten Valley, Germany, reflects life in a bygone era.**

PHOTO: GETTY IMAGES

*"In a contract to keep life running, animals and plants exchange molecules of carbon and oxygen in various combinations"*

**Since the concentration of carbon** in the atmosphere regulates how much of the Sun's rays reach the Earth's surface, it's a key determinant of the warmth of the Earth described by the greenhouse effect. This effect describes how gases in the atmosphere absorb heat from the Earth's surface, then radiate it out in all directions. In this way, not all the heat from the Earth's surface is transferred out of the atmosphere back out to space, but rather, is reflected back down to Earth, resulting in warmer temperatures than if these greenhouse gases weren't there.

**Carbon cycle**




The carbon cycle is the cycle of life–as we know it. In a life-affirming cycle, plants, animals, soils and oceans exchange water, carbon, oxygen, and other elements. Since the onset of the Anthropocene, human activity has played an increasingly disruptive and dominant role in this cycle.
SOURCE: HTTPS://WWW.MPG.DE/19314/CARBON_CYCLE

The most powerful greenhouse gases include $CO_2$, aerosols (such as soot and water vapor), methane, ozone and nitrous oxides (also called NOx gases), which all result in heat being trapped in the atmosphere for different lengths of time. $CO_2$ has the most long-lasting effects, remaining in the atmosphere for hundreds to thousands of years.

*"Unfettered emissions have resulted in a massive shift of carbon from land and ocean into the atmosphere. The current concentration of $CO_2$ is higher than any time in the Holocene"*

For this reason, to understand the impact of human activity on our atmosphere and climate, we need to sum emissions from the entire history of relevant human activities. This is a particularly contentious issue in international negotiations on reducing greenhouse gas emissions, since a fair distribution of "emission rights" means considering what was emitted in the past (overwhelmingly from the world's most developed countries), not just what is still to come (increasingly from developing countries).

**Since the beginning** of the Industrial Revolution, we have pumped the equivalent of an additional 2,200 gigatons (2,200 thousand million tons) of $CO_2$ into the atmosphere, and the annual rate of emissions has increased more than seven-fold since 1950 (source: Global Carbon Project). Close to 40 gigatons were released in 2019 alone. Around a quarter of the greenhouse gases created by humans come from fossil-fuel-based energy generation, though agriculture, transport, industry, and forestry are also to blame.

The amount of $CO_2$ that we release into the atmosphere every year is almost unimaginable. The 40 gigatons of $CO_2$ we released in 2019 alone amounts to the weight of four billion African Elephants, 6.8 metric tons each. Thus, since the Industrial Revolution, we unleashed 220 billion elephants into the air. No wonder skies are sometimes dark and heavy. Clearly, the elephant is no longer in the room.

PHOTO: GETTY IMAGES

In 2019, $CO_2$ emissions per person ranged from less than 1 ton (in much of sub-Saharan Africa and Southeast Asia), to over 20 tons in the United Arab Emirates and Kuwait. China's per capita emissions rose from just over 0.1 ton to around 7 tons between 1950 and today, whereas in the United States, per capita emissions peaked in the 1970s and are currently back at the same level as in 1950 (~16 tons of $CO_2$).

*"Since the beginning of the Industrial Revolution, we have pumped the equivalent of an additional 2,200 gigatons (2,200 thousand million tons) of $CO_2$ into the atmosphere"*

These unfettered emissions have resulted in a massive shift of carbon from land and ocean into the atmosphere. The current concentration of $CO_2$ (>410 parts per million (ppm)) is higher than any time in the Holocene.

**Our oceans are absorbing most of** the of the $CO_2$ onslaught, reducing their pH (becoming more acidic) by around 30% (source: Steffen et al. 2015). Coral reefs are bleaching into oblivion, fish are dying en masse, and by extension, our food supply is diminishing. Roughly 90% of the excess heat trapped in the atmosphere by greenhouse gases is stored within the world's oceans, which reaching record-breaking levels of heat in 2019 (source: Cheng et al. 2020).

As you read this, wildfires are still blazing and glaciers continue melting, vicious hurricanes are demolishing whole communities and our once-rich biodiversity is inching its way to genetic conformity. Siberian locals are comparing tan lines to the tunes of thawing permafrost and polar bears are scrounging for their next meal while floating out to sea on errant ice sheets. Very soon, we might also be desperately seeking sustenance as our dysfunctional food system is increasingly underperforming or even breaking down.

We must recognize that our food is a big part of the problem. It has to become a big part of the solution.

# "90% of the excess heat trapped in the atmosphere by greenhouse gases is stored within the world's oceans"

Thirsty planet – agricultural practices and regional climate changes are creating big challenges for farmers, especially in the world's most vulnerable regions.
PHOTO: GETTY IMAGES

# Taking the reins of the 21st century

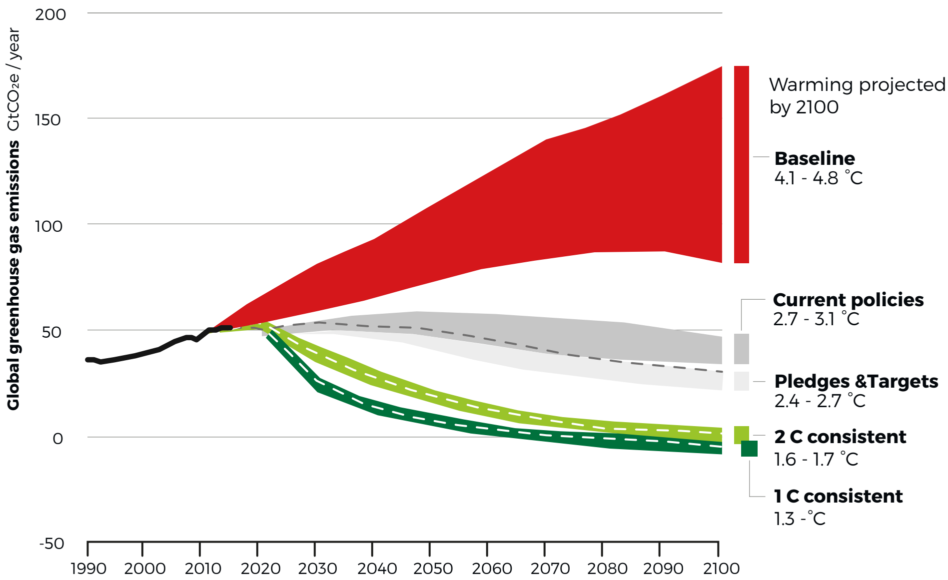
*We're heading toward a warmer world and as little as 2°C will significantly change the climatic experience for most people on Earth. When we zoom in on regional effects, the changes will be far more drastic.*

From our current perspective, deep in the Anthropocene, we are bestowed with both an unprecedented urgency to act to stabilize our Earth system, and unprecedented knowledge of the potential consequences, should we fail to act.

We can get a sense of what the future might have in store by looking at how much $CO_2$ and other greenhouse gases are likely to be emitted over the coming decades – this is a good indicator of the possible rise in average global temperature. Taking into account the pledges that have been made by most nations to reduce emissions, we are on track for a global temperature rise of between 2.8°C and 3.2°C by the end of the century.

## 2100 warming projections

Emissions and expected warming based on pledges and current policies




Pledges and targets indicate a projected warming of 2.5-2.8 ˚C by 2100, while current policies would result in 2.8-3.2 ˚C.

SOURCE: CLIMATE ACTION TRACKER

*"Each degree of global warming will put downward pressure on agricultural yields worldwide"*

**When we zoom** in on the implications of warming projections on regional weather patterns, the associated changes look far more drastic. A 2°C warmer world will significantly change the climatic experience for most people on Earth. Overall, 2°C warming compared to 1.5°C (the "nice to have" target defined in Paris), would mean an additional 2 billion people (around 20% of the world's population) would be exposed to extreme heat waves at least once every 20 years by 2100. Monsoons, on which almost a quarter of the world's population depend, are likely to become more erratic, not just due to climate change, but also in part due to air pollution from soot.

**When it comes to food production**, each degree of global warming will put downward pressure on agricultural yields worldwide. And just as in the past, the losses will vary greatly from region to region, with already vulnerable areas enduring the worst of it.

The United Nations recently surveyed the most advanced scientific research (source: IPCC Special Report on Climate Change and Land) and found that global maize yields could drop by up to 7.4% for each degree of global warming. For wheat, rice and soybeans the picture also looks fairly grim, with yields dropping by between 3% and 6% per degree of global warming.

Though they haven't yet received the same attention from the scientific community, fruits and vegetables will likely not fare much better, with heat stress leading to yield loss, reduced quality and thereby increased food waste (source: Bisbis et al. 2018). Fruits and vegetables that grow in already warm areas will be most affected. To make matters worse, additional factors associated with climate change, such as ozone concentration and salination, can lead to a reduced nutritional quality, posing further risks to human health (source: Scheelbeek et al. 2018).

While heat stress is the most direct link between rising temperatures and reduced food production, other climate changes are likely to prove just as damaging. Extreme weather, flooding and drought will contribute to soil degradation, either drying it out or washing it away.

Climate change does actually create more hospitable conditions for certain types of weeds, insects and other pests, however, the Earth's "natural helpers" for pollination and pest control suffer adversely.

**Understanding how plants react** to an increased concentration of $CO_2$ in the air is a major challenge for scientists predicting how climate change will affect food production. Together with sunlight and chlorophyll, plants absorb $CO_2$ to fuel their growth: Increased amounts of $CO_2$ act as a fertilizer, promoting growth.

*"More worrying is how $CO_2$ leads to a reduction in the nutritional quality of food, as increases in the amount of starch come at the cost of protein"*

While one might think this puts a positive spin on the climate-change debacle, using computer models and on-the-ground experiments, scientists have found that in many cases the negative results of climate change (increased heat, reduced rainfall and extreme weather) exceed the positive effects of increased $CO_2$: By the time global warming reaches 2°C, the yield gains boosted by $CO_2$ will be practically wiped out (source: Asseng et al. 2019). At this stage, however, it's more worrying that $CO_2$ "fertilization" reduces the nutritional quality of food, as increases in starch come at the cost of protein (Asseng et al. 2018).

**A sharply focused field experiment: Cultivation of winter wheat under elevated atmospheric $CO_2$ concentration and different nitrogen fertilization.**

PHOTO: THÜENEN INSTITUT, REMIGIUS MANDERSCHEID

**What levers do we have** to significantly reduce agricultural emissions and increase food production by 50 – 60% for a world population that will reach nine to ten billion by 2050? A whole menu of strategies has been proposed to transform the food system to bring about more environmental sustainability and higher food security (sources: EAT Lancet Commission. 2019, World Resources Institute 2019, Roe et al. 2019).

Science suggests that the land sector is crucial in achieving the 1.5°C target. A recently published roadmap for the land sector argues that it must deliver roughly 30% of greenhouse gas mitigation (or 15 Gt $CO_2$-equivalent) if the 1.5°C target is to be met in 2050 (source: Roe et al. 2019). This could be achieved by a combination of practices to actively remove $CO_2$ from the atmosphere and strategies to reduce emissions through curbed deforestation and degradation, conversion of coastal wetlands, and peatland burning. The food system has an important role to play here, with the potential to deliver around one quarter, or 4 Gt $CO_2$-equivalent per year of the required emissions reductions.

*"The food system has an important role in achieving the 1.5° target, with the potential to deliver around one quarter – or 4 Gt $CO_2$-equivalents per year – of the required emissions reductions."*

One of the biggest windows of opportunity is reducing non-$CO_2$ greenhouse gases, such as methane and nitrous oxide, with four main starting points having the potential to deliver equally. Changes in agricultural management practices can secure greenhouse gas savings of up to 1 Gt $CO_2$-equivalent. These changes include synthetic fertilizers, manure management, water and residue management of rice fields and livestock supervision, including changed grazing practices and feed additives which reduce the effects of rumination – enteric fermentation and carbon sequestration, i.e. burps and farts (source: Herrero and colleagues discuss this in great detail).

A similar contribution could come from changes to land management practices, increasing the uptake and storage of carbon in vegetation and soils. These include growing plants with larger roots, reducing tillage and using cover cropping. Restoration of degraded soils, application of Biochar and erosion control measures would also be part of this scheme.

Beyond the farm there are yet more significant contributions to be made. As mentioned before, if around half the world's population shifts to a plant-based diet, yet another ~1 Gt $CO_2$-equivalent could be saved, both by reducing the production of greenhouse-gas and land-intensive foods, and through the development of alternative foods. Cutting food waste and loss by half could deliver the final 1 Gt $CO_2$-equivalent in emissions reductions.

**The food sector provides** a fundamental platform for the interaction between health, climate and air. A 2018 report from a commission of 37 leading international scientists (source: EAT-Lancet report) concluded that a sustainable transformation of the food sector – both in terms of production and consumption – could massively reduce pressure on the Earth system. We don't have an alternative. It's an existential issue.

THE
CURT BERGFORS
FOOD
PLANET
PRIZE

**The Curt Bergfors Food Planet Prize** aims to identify and reward initiatives and projects that can contribute to reshaping the food system all around the world.

Two prizes of $1 million each will be awarded annually, starting in 2020. One prize will go to an existing solution that can be scaled quickly for a global impact. The second prize will go to a radically innovative project that can sustainably transform parts of the food system. The nomination for 2021 is currently open.

**The Curt Bergfors Foundation** was founded in 2019 to support the transition to resilient food systems that protect both people and the environment.

To ensure free and independent research in the field, the foundation is funding a new professorship at the Stockholm Resilience Centre, Stockholm University: *"The Curt Bergfors professorship in sustainability science with a focus on sustainable food systems."* The funding over ten years corresponds to a donation of SEK 20 million.

The foundation is capitalized with half a billion SEK from Curt Bergfors' private assets. It will continuously take new initiatives to contribute to resilient food sourcing and a responsible food culture.

foodplanetprize.org
secretariat@foodplanetprize.org

**Editorial and Executive Board Director** Lars Peder Hedberg
**Art Director** Anders Schmidt, Uniform
**Editor-at-large** Argot Murelius