Title: **Civilization will Collapse (High Confidence): A Compendium of Relevant Biophysical, Political, Economic, Military, Health, and Psychological Information on Climate Change**

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All comments welcome!

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Civilization will Collapse (High Confidence[1]):

A Compendium of Relevant Biophysical, Political, Economic, Military, Health, and Psychological Information on Climate Change

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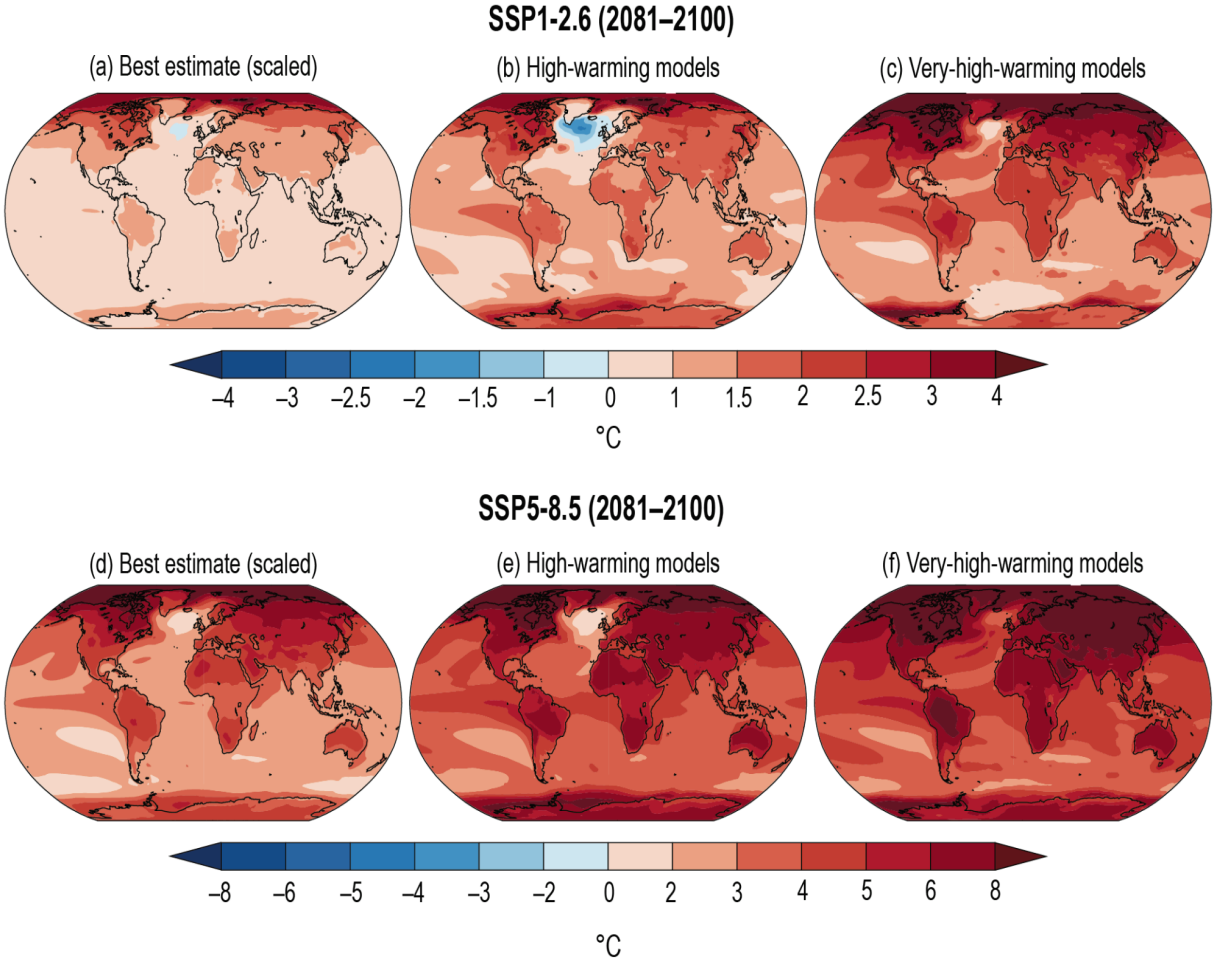
January 26, 2025[2]



[1] "High Confidence" is one of the "calibrated uncertainty" terms of the Intergovernmental Panel on Climate Change (IPCC). We should now have high confidence there is a significant probability human civilization will collapse this century, which is the thesis of this paper. However, quantifying this prediction with a high degree of certainty is impossible. See Appendix 4 for details on how the IPCC expresses uncertainty using calibrated uncertainty language.

[2] First draft, August 31, 2023

Cover Page Figure
"Box TS.3, Figure 1 in IPCC, 2021: Technical Summary. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Chen et al., 2021)"*
https://www.ipcc.ch/report/ar6/wg1/figures/technical-summary

Opinion Hope for the future: A climate conference hosted by a petrostate
By Edith Pritchett, Editorial cartoonist, December 1, 2023, Washington Post

Sultan al-Jaber was the president of COP 28. He is the chairman of Abu Dhabi National Oil Company (Adnoc), which pumped 2.7m barrels of oil a day in 2021, with plans to double that by 2027.

COP29 was held in Baku, Azerbaijan on November 11-22, 2024. Azerbaijan is also a petrostate.

Executive Summary

Human civilization will not collapse from the direct effects of climate change, but rather from the secondary effects of crop failures, infectious diseases, and armed conflict. The root cause of the climate crisis is the Earth's energy imbalance: more energy is arriving at the Earth from the sun than is being radiated back out into space. This is occurring because we have been cutting down forests and burning fossil fuels for the last 150 years at a furious rate, leading to a greenhouse effect and the consequent warming of the Earth's land, oceans, and atmosphere. There is now general agreement that continuing to burn fossil fuels will lead to catastrophic consequences for human civilization as well as thousands of other species. We know how to reduce greenhouse gas (GHG) emissions and transition to other sources of power, but we are not doing this at a rate that will prevent catastrophe. The problems at this point are not scientific or technical but rather political, which is why individuals should focus on changing policies at the national and international level rather than focusing on reducing their individual carbon footprints. For meaningful change to occur there needs to be mass mobilizations for climate action, and one critical initial prerequisite is an honest assessment of the current situation, plus predictions about what we can realistically expect in the near future. The goal here is to provide that information.

This paper reviews the latest scientific findings on our climate, and provides evidence that not only is the biophysical situation much worse than reported by most of the scientific community, but that the consequences for human societies are also much worse. In summary: the situation is already critical, and it will get much worse in the near future. Climate change mitigation (the effort to limit greenhouse gases) has failed. Risks are consistently underestimated. Rapid decarbonization is required but is unlikely to occur. Staying below the 1.5°C limit of the 2015 Paris Agreement is impossible at this point, and furthermore it is very unlikely that we will be able to stay below 2°C. A 2°C increase will be catastrophic in multiple areas and in multiple ways. Considering just ice sheets, "2°C will result in extensive, potentially rapid, irreversible sea-level rise from Earth's ice sheets" (eventually up to 20 meters), and "Many ice sheet scientists now believe that by 2°C, nearly all of Greenland, much of West Antarctica, and even vulnerable portions of East Antarctica will be triggered to very long-term, inexorable sea-level rise, even if air temperatures later decrease" (International Cryosphere Climate Initiative, 2023). In fact, we may have already crossed a point of no return for many Earth systems.

For several decades there have been a series of international meetings sponsored by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations, during which member countries have made pledges to reduce their use of fossil fuels, and specify by how much. All these efforts to reduce greenhouse gases have failed. The

only thing that really matters is how much carbon dioxide and other greenhouse gases we are pumping into the atmosphere. There have been pledges, and some reductions, but these efforts and organizations have not been effective because the amount of greenhouse gases we put into the atmosphere continues to increase. We may have reduced the rate of increase, but that doesn't matter. *The only thing that really matters is how much carbon dioxide and other greenhouse gases we are pumping into the atmosphere – and we continue to pump enormous quantities.* Pledges of future reductions are just more "blah, blah, blah" as Greta Thunberg so eloquently explains.

> Build back better. Blah, blah, blah. Green economy. Blah blah blah. Net zero by 2050. Blah, blah, blah. This is all we hear from our so-called leaders. Words that sound great but so far have not led to action. Our hopes and ambitions drown in their empty promises.[3]

As Pope Francis (2023) writes in his Apostolic Exhortation, international politics and organizations must recover their credibility by agreeing to "binding forms of energy transition that meet three conditions: that they be efficient, obligatory and readily monitored." Reaching such international agreements will be a challenge.

Unfortunately, liberal democratic states with their market economies are ill-equipped to deal with a major crisis that requires immediate actions. During World War II, the War Production Board was established to convert civilian industry to war production. The United States had, during the war years, a centrally planned economy with the federal government controlling and allocating resources, directing the conversion of factories, and even taking over some private companies. The current climate crisis is far more serious than a war, and similarly drastic actions are required, but are unlikely to occur.

Although a global mobilization is required for "deep decarbonization," political forces in many countries, as well as resistance from fossil fuel companies, are preventing the required action. As climate disasters become even more extreme than those in 2023 and 2024 and continue to multiply around the world, mass movements demanding meaningful climate action will increase, and eco-terrorism will, unfortunately, become inevitable. Eco-anxiety, already common, will increase dramatically.

The probability that there will be a global societal collapse is high because the second and third order effects of climate change, such as crop failures leading to starvation, are not fully appreciated and will lead to intra- and interstate conflict. Compound hazards and cascading effects will also increase the damage to individuals and society, and there are interconnections among risks arising from environmental, economic,

[3] Greta Thunberg's speech at the Youth4Climate summit in Milan Italy on September 28, 2021.

technological, geopolitical, and societal factors that will increase the probability of societal collapse. This is a “polycrisis.”

The direct effects of climate change will result in millions of deaths from heat waves, floods, droughts, tropical storms, wildfires, and rising sea levels, but many more will die from starvation, infectious diseases, and especially from civil unrest and regional and international conflicts. Climate change has been described as a “threat multiplier,” and it will exacerbate existing political instability via fights over water, mass migration, and from the pressures of crop failures and extreme weather events. In addition, any economic or political problems are likely to derail mitigation efforts or at a minimum make them more difficult. The extreme consequences of climate change will start first in “fragile” states, as they have less resilience and adaptive capacity, and are prone to civil unrest. Armed conflict often leads to environmental disasters and is incredibly carbon intensive, but is rarely mentioned as a contributor to climate change. The Israel-Gaza war, for example, is likely to end up emitting more GHGs than the annual emissions of over 100 countries (Neimark et al., 2024).

The rapid introduction of renewable energy will not prevent societal collapse. Planting trees will not save us, reducing methane will not save us, and removing CO_2 from the atmosphere via direct air capture will not save us. Again, the only thing that really matters is the amount of greenhouse gases we are emitting. This is a critical point that many people don’t seem to understand. The amount and price of renewable energy is basically meaningless with respect to the climate emergency if we continue to pour carbon dioxide and other greenhouse gases into the atmosphere. It is also essentially meaningless what each individual in a rich country does so long as other countries continue to build coal-fired power plants, cut down forests, and degrade other natural carbon “sinks” on our planet.

“Net zero” refers to a state in which greenhouse gases entering the atmosphere are balanced by their removal from the atmosphere. Reaching net zero will take decades – with respect to anthropogenic greenhouse gas emissions – but true net zero may be impossible to achieve. This is because a variety of biophysical processes are now emitting massive amounts of greenhouse gases as part of multiple positive feedback loops. In addition, the carbon sinks in soil, forests, and oceans are now less able to sequester carbon than in the past. And separate from the effect of greenhouse gases, there are now albedo changes (i.e., how much sunlight a surface reflects) due to changes in land use that are increasing the earth’s energy imbalance. For all these reasons, even after humans stop emitting greenhouse gases the Earth is still likely to continue warming. Recent proclamations that warming will quickly stop soon after we reach net zero are disingenuous.

Once we acknowledge that it is impossible for us to adapt to our changing climate, geoengineering via solar radiation management or other means will emerge as inevitable. In fact, some scientists now already argue that any realistic approach to the climate crisis must include “climate cooling” via geoengineering.

Not only is the biophysical situation getting much worse, but the political situation is also getting much worse. Donald Trump, a convicted felon, is now president of the United States. As climate scientist Michael Mann told an interviewer before the election, “A second Trump presidency would be more or less game over for climate action.” The United States extracts more fossil fuels than any country in history, and under Trump the extraction and exportation of fossil fuels will accelerate. Money and resources devoted to climate change mitigation will decline during a Trump presidency.

This paper just “connects the dots”: there is consensus that at 1.5°C the situation will be very bad, we are likely to cross several tipping points, and multiple feedback loops will increase the release of GHG emissions. Given the political realities in the world today, there will be no world-wide mobilization to rapidly transform our economies and power production to reduce GHG emissions. That means we will almost definitely cross 2°C, probably before 2050. The direct and indirect consequences of this increase will dramatically impact the climate around the world, leading to all the negative consequences listed above. As a result, societies around the world will start to collapse.

Given the unlikelihood of immediate and drastic actions, extreme weather events will increase and there will be major changes in the circulation of heat in the atmosphere and the oceans. With respect to our understanding of global climate and weather, it is likely that we will be entering “uncharted territory.” Several scientific organizations and initiatives are trying to sound the alarm, proclaiming, for example, that, “As of 2023, some of the very lowest emission pathways from IPCC no longer remain possible” (ICCI, 2023). More dramatically,

- “The scale of the threats to the biosphere and all its lifeforms—including humanity—is in fact so great that it is difficult to grasp for even well-informed experts” (Bradshaw et al., 2021).
- From coordinated editorials in over 200 health journals: “...climate change and biodiversity loss are one indivisible crisis and must be tackled together to preserve health and avoid catastrophe. This overall environmental crisis is now so severe as to be a global health emergency” (Abbasi et al., 2023).
- “Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (high confidence)” (IPCC, 2023).

- One to three billion people will experience “unprecedented” heat this century (Lenton et al., 2023b).
- “Earth is now well outside of the safe operating space for humanity” (Richardson et al., 2023).
- “Over the past 50 years (1970–2020), the average size of monitored wildlife populations has shrunk by 73%, as measured by the Living Planet Index (LPI)” (WWF, 2024).
- “The consequences of global heating are becoming increasingly extreme, and outcomes such as global societal collapse are plausible and dangerously underexplored” (Ripple et al., 2022).
- “...the world in which we live is collapsing and may be nearing the breaking point” (Pope Francis, 2023).

Although global societal collapse is probable, it is not inevitable, and the paper ends by describing what you as an individual should do and what we as a society should do. In the short term, political action, mass mobilization and civil resistance, plus working for a carbon tax will be the most effective actions for individuals. Only after there is agreement that a worldwide mobilization and extreme actions are required will it be worthwhile to focus on reducing one's carbon footprint.

We are now on a “Hothouse Earth” trajectory that will, if we continue on it, end human civilization as we know it. Humans are capable, however, of creating a new pathway to what Steffen et al. (2018) call “Stabilized Earth.” As a society, we must, on a global scale, rapidly reduce greenhouse gas emissions. This must be our number one priority; it is necessary but not sufficient. Simultaneously, we must protect our biosphere’s carbon sinks and actively cool the Earth using geoengineering techniques such as solar radiation management. Research and development on directly removing CO_2 from the air should continue because in the future, even after net zero is reached, it will be necessary to remove massive amounts of CO_2 from the atmosphere.

It will also be important to engage in “social-norm and social tipping interventions to promote climate action” (Constantino et al., 2022). Politicians will act when the majority of their constituents demand it, and thus it is critical that there is a change in social norms. For example,

> Collective action on climate change would benefit from a society predicated on and organized around different social norms, including the beliefs that: business as usual is unacceptable because it prioritizes the short-term economic profits of a few over the well-being of future life on this planet; global public goods, such as

> a livable climate, ultimately affect all people and are worth protecting, even if this entails immediate costs…. (Constantino et al., 2022).

Returning to the World War II analogy, it is common to describe how quickly the U.S. mobilized and transformed its economy to support the war effort. Less widely mentioned, but just as important, is that during the war an Office of War Information (OWI) was created to run a massive propaganda campaign. The goal was to unite the country behind the war effort. "...the US government waged a constant battle for the hearts and minds of the public. Persuading Americans to support the war effort became a wartime industry, just as important as producing bullets and planes."[4] Now we need an Office of Environmental Information to inform the public about the climate crisis and what actions we all should take. Persuading Americans to support the efforts to combat the climate crisis may be as important as increasing the production of solar panels and wind turbines.

Despair is not the answer or a solution. Work for change, but enjoy your life. I reject "climate doomism"; I think this document is a realistic assessment of the situation, and it is important to be realistic about the challenges that we are facing if we are to embark on effective solutions. This document paints a very pessimistic view of our collective future, but my predictions may be wrong. Many unexpected events may occur, new technologies may emerge, and the predictions of many scientists may be inaccurate. The speed with which mass movements will alter the political landscape and make rapid decarbonization possible may surprise us all. And, if the crisis does continue, geoengineering may save us. Don't give up. Join one of the many climate organizations or start your own. Read about the approach advocated by the Climate Majority Project (https://climatemajorityproject.com/). They argue for "mass mobilisation of citizens via diverse, distributed, mostly self-organising action for climate mitigation, adaptation, and protection of nature; combining to drive change at all different institutional levels" (The Climate Majority Project Theory of Change[5]). Convince your friends that we have a serious problem we need to solve. Work for a carbon fee and dividend (or tax), and work to elect politicians who are willing to take the necessary – and drastic – steps to solve the crisis.

How to Use this Document

Use this document as a resource, and as a way to find the latest research on climate change and related areas. Although I started writing what I thought would be a short paper, it has become a long compendium of relevant information from multiple disciplines. Pay special attention to the section on Solutions and then explore other

[4] https://www.nationalww2museum.org/war/articles/wwii-propaganda

[5] https://usercontent.one/wp/climatemajorityproject.com/wp-content/uploads/2023/05/ToC-Pre-Launch-Disseminate.pdf?media=1714307355

sections that interest you. If you are new to the literature on climate change, take a look at my recommendations in the section on Suggested Reading at the end of the paper. For a summary of my main arguments that collapse is likely, see the 12 points in the section, *Quantifying Collapse*.

A Note About Footnotes, References, and Quotations

Some footnotes include URLs to articles in the New York Times and Washington Post. Currently, anyone can read a limited number of free articles per month before having to pay.

Journal articles and reports from major organizations are listed in the Reference section, while citations from websites, newspapers, and magazines are included in the footnotes.

Quotations often include British spellings. Errors in the original remain without the use of "sic," and references within quotes are omitted.

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Introduction

Climate change is real, the Earth is warming, but if we reduce our consumption of fossil fuels the worst can be avoided. This is what we are told, over and over, but it is not true. Looking at all the evidence, it's clear that there is a significant probability that it is now too late to avoid catastrophe and, in fact, there is a chance that human civilization will collapse during the next 50 years, with extinction then possible. This paper includes extensive quotes from several seminal papers, as well as the major national and international organizations that collect, summarize, and disseminate the latest science on climate change. In these articles, prominent climate scientists explain how dire the current situation is. The contribution of this paper is to combine the information from the climate literature with information from the social sciences, including why the political situation makes rapid decarbonization impossible, and how the effects of even "mild" warming can have devastating impacts on society.

This paper's orientation is in accord with the Climate Majority Project's Theory of Change, which starts by advocating for a "narrative shift toward truthfulness" that includes being fully honest with the public.

> A truth that needs to be said clearly, by all those who know it, is this: we must let go of the belief that there is still time to 'fix the climate'....some valuable things are already lost, and some targets are no longer attainable. Denial of this fact props up trust that institutions can still deliver safety, when they have already failed.[6]

The truth is very disturbing, but rather than sink into climate doomism we must all act. We need to work toward a "climate majority" that involves "...mass mobilisation of citizens via diverse, distributed, mostly self-organising action for climate mitigation, adaptation, and protection of nature; combining to drive change at all different institutional levels."[7]

Here is a very simplified summary of the current situation, supported in the rest of the paper by references and quotations from the scientific literature:

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[6]Liam Kavanagh *et al.* (2023), Theory of Change*, The Climate Majority Project,* https://usercontent.one/wp/climatemajorityproject.com/wp-content/uploads/2023/05/ToC-Pre-Launch-Disseminate.pdf?media=1714307355. All research papers are included in the list of References, with links to the papers, and all quotations can be found easily by searching in the full-text documents. Newspaper articles and websites are referenced only in footnotes, as is the case with this quotation.

[7] Ibid.

The situation is already very bad. There are record-breaking heat waves, droughts, fires, floods, and hurricanes. Glaciers, ice sheets, and sea ice are melting, sea levels are rising, and there is ocean acidification. Coral reefs are bleaching and dying. Extreme weather events are becoming more common. In particular, we saw far more extreme fire and rainfall events in 2023 and 2024 than usual.[8] "The inconvenient truth is that global temperatures are already dangerously hot; that the Paris targets are not only unsafe but unachievable; and that even if NZE [net zero emissions] succeeds in stopping further temperature increases, this will not produce a safe, stable climate" (Taylor et al., 2023b).[9]

The situation will get much worse. The pace of global warming has accelerated. Positive feedback loops are now occurring, and we may be reaching multiple tipping points that will result in irreversible changes to the biosphere. The situation will inevitably get worse because even if every country meets its long-term targets of reducing greenhouse gases (targets that become increasingly difficult to meet every year), temperatures will still rise to over 2°C. We're currently at about 1.3°C as a multi-year average, and 2024 was the first year in which the average global temperature exceeded 1.5°C above pre-industrial levels. Even after greenhouse gases are reduced, the accumulated heat in the ocean will continue to melt sea ice and ice shelves and to heat the atmosphere.

Climate change mitigation, the effort to limit greenhouse gases, has failed. Carbon dioxide and other greenhouse gases continue to increase in the atmosphere. In fact, "...carbon emissions have continued soaring, and fossil fuels remain dominant, with annual coal consumption reaching a near all-time high of 161.5 exajoules in 2022" (Ripple at al. 2023a). Here is a recent headline from the Global Carbon Project: "Record high in global fossil CO_2 emissions set for 2023." Global emissions from coal, oil, and natural gas have all risen in 2023.[10] Emission records continued to be broken in 2024. Some researchers put a positive spin on this by focusing on the rate of increase: the headline from the International Energy Agency (IEA) is that the, "Major growth of clean energy limited the rise in global emissions in 2023." This is true because there was an increase in solar PV (photovoltaics), wind, and nuclear power generation, along with an increase in electric cars.[11] But emissions still increased by 410 million tonnes in 2023,

[8] See Ripple et al.'s (2023a) Table 1 for a list of climate-related disasters since the end of 2022, and Ripple et al. (2024) for climate disasters in November 2023 to August 2024.
[9] The Taylor et al. paper is a preprint and has not gone through the peer review process. Providing page numbers for quotations is difficult given the format of papers available online.
[10] https://globalcarbonbudget.org/fossil-co2-emissions-at-record-high-in-2023/
[11] https://www.iea.org/news/major-growth-of-clean-energy-limited-the-rise-in-global-emissions-in-2023

leading to a new record; although emissions are increasing less dramatically than in the past, they are still increasing.[12]

Despite all the positive aspects of the recent Inflation Reduction Act in the U.S. for creating clean energy jobs and reducing emissions, the United States, under President Biden, pumped more oil than during President Trump's first term, and more than either Saudi Arabia or Russia. In recent years, the U.S. pumped more oil than any other country in history. According to the IPCC, modeled pathways limiting warming to 2°C "are characterized by deep, rapid, and, in most cases, immediate GHG emissions reductions" (IPCC, 2023). No deep and rapid reductions are currently occurring.

Risks are consistently underestimated. The estimates and descriptions of our future world are increasingly dire, and yet scientists and scientific organizations have consistently underestimated the rate and extent of climate change. There is evidence that underestimates are continuing. As Taylor et al. (2023b) write, "...selective science communication and unrealistically optimistic assumptions are obscuring the reality that greenhouse gas emissions reduction and carbon dioxide removal will not curtail climate change in the 21st Century."

Rapid decarbonization is unlikely. A world-wide mobilization is required to rapidly reduce greenhouse gases, and although theoretically possible, it is in practice impossible given our current political environment and economic system. Consider this headline from the New York Times on November 8, 2023:

"Nations That Vowed to Halt Warming Are Expanding Fossil Fuels, Report Finds. The world remains on track to produce far more oil, gas and coal than would be consistent with relatively safe levels of heating, a new report found."

And from the New York Times on June 29, 2024:
A String of Supreme Court Decisions Hits Hard at Environmental Rules. Four cases backed by conservative activists in recent years have combined to diminish the power of the Environmental Protection Agency.

Donald Trump became president on January 20th, 2025 and is carrying out his promise to expand the extraction, use, and exporting of fossil fuels, as well as modifying or eliminating a wide variety of regulations that are currently limiting fossil fuel production.

[12] Part of the increase in 2023 is due to a reduction in hydropower in several countries as a result of extreme drought, pointing out how one of the effects of climate change can make mitigation more difficult.

Staying below 1.5°C is not possible. We are told not only that if we stay below 1.5°C the worst effects of climate change can be avoided, but that this is still feasible. As James Hansen and colleagues write in a short communication (Hansen, Sato, & Ruedy, 2023), “That is pure, unadulterated, hogwash.” In a recent paper, Hansen and over a dozen coauthors argue that, “... under the present geopolitical approach to GHG [greenhouse gas] emissions, global warming will exceed 1.5°C in the 2020s and 2°C before 2050” (Hansen et al., 2023c).[13] This view is not an outlier; for example, Taylor et al. (2023b) write, “The presumption that the global climate can be safely stabilized at 1.5°C or 2°C above pre-industrial levels in the 21st Century is the most unrealistic finding of various climate assessments.” The situation is changing rapidly, and in a January 4, 2024 newsletter, Hansen et al. write that, “By May the 12-month running-mean global temperature relative to 1880-1920 should be +1.6-1.7°C and not fall below +1.4 ± 0.1°C during the next La Nina minimum. Thus, given the planetary energy imbalance, it will be clear that the 1.5°C ceiling has been passed for all practical purposes.”[14]

Deaths will increase, and most will die from indirect effects such as starvation and armed conflict. Hundreds of thousands of people currently die every year from the direct effects of climate change, and these numbers will increase dramatically in the future, especially when there are compound hazards where multiple events interact. Most deaths, however, will not result directly from heat, floods, or storms, but rather from indirect causes, including starvation as a result of crop failures, the spread of infectious diseases, as well as armed conflict and social unrest caused by water and food scarcity and the pressures of mass migration. Regional conflicts are already breaking out over limited water resources and other impacts of climate change.

Only recently are some scientists and economists predicting realistic deaths this century: “If warming reaches or exceeds 2°C this century, mainly richer humans will be responsible for killing roughly 1 billion mainly poorer humans through anthropogenic global warming” (Pearce & Parncutt, 2023).[15]

In this report, I’ll describe what the situation looks like to a researcher who is not a climate scientist but has followed the field for the last 25 years. The proximal cause of climate change is simple: the Earth is not in energy balance, which just means that more energy is arriving at the Earth from the sun (as well as back radiation from the

[13] Reaching a particular level of warming, such as 1.5°C or 2°C, means that an average over several years has reached this point. In November, 2023, the Earth reached 2°C on a single day for the first time.
[14] https://www.columbia.edu/~jeh1/mailings/2024/Groundhog.04January2024.pdf
[15] This paper was criticized because one of the authors is an engineer and the other a musicologist. As argued in this paper, their prediction is probably an underestimate.

atmosphere and clouds) than is being radiated back out into space. The reason is well-known and universally accepted – we have been burning fossil fuels for the last 150 years at a furious rate and this has led to a greenhouse effect that traps heat within our atmosphere and leads to the warming of Earth's land, oceans and atmosphere.[16]

The Organization of this Paper

The Current Situation describes how we are already in a "Code Red" state. The following section, on *The Future*, reviews how we may be on a path toward a new trajectory away from recent glacial-interglacial cycles. The loss of biodiversity, tipping points, and feedback loops increase the probability that this will happen. In addition, compound hazards and cascading effects can lead to a polycrisis, and I also discuss the specifics of what happens when a society collapses. The section on *International Efforts* covers the IPCC, why risks have been underestimated and not communicated clearly, and why current efforts at rapid decarbonization are insufficient. *Rapid Decarbonization is Unlikely* explains further how we are falling short on what is needed, and covers the limitations of renewable energy, nuclear energy, planting trees, and direct air capture.

In the section on *Political Considerations*, I discuss why it's critical to understand the political forces preventing decarbonization. The section on *Indirect Effects: Economic Impacts, Food Production, and Migration* cover economic impacts, which will be far more extensive than most economists have predicted. There will also be major impacts on food production. Mass migration is already becoming a problem, but it will increase exponentially, leading to political instability in some countries. *Related Topics* include geoengineering, paleoclimatology, climate models, the rise of climate anxiety, and several other topics. The paper ends with a section on *Solutions*, including recommendations on what you as an individual should do, and what we as a society must do.

The Current Situation

Code Red on Planet Earth

"We are now at 'code red' on planet Earth" according to a recent report titled, "World Scientists' Warning of a Climate Emergency 2022" (Ripple et al., 2022). Bradshaw et al. (2021) title another paper, "Underestimating the Challenges of Avoiding a Ghastly Future," and write, "The scale of the threats to the biosphere and all its lifeforms—including humanity—is in fact so great that it is difficult to grasp for even well-informed experts." Richardson et al. (2023), writing within a planetary boundaries

[16] For an excellent primer on climate change, see Emanuel (2016). See the section on Suggested Reading for more information on our climate.

framework, find that we have passed six of nine planetary boundaries and that “Earth is now well outside of the safe operating space for humanity.”

In Europe, “several climate risks have already reached critical levels. If decisive action is not taken now, most climate risks identified could reach critical or catastrophic levels by the end of this century. Hundreds of thousands of people would die from heatwaves, and economic losses from coastal floods alone could exceed EUR 1 trillion per year” (European Climate Risk Assessment, 2024).

Many scientists have realized that they can’t continue in a typical academic mode, focusing on their research and writing, but must now become advocates for change to avoid catastrophe. In 1992, 1,700 scientists signed a “World Scientists’ Warning to Humanity,” but no one listened. Additional warnings followed, with more scientists realizing that they must leave the laboratory and engage with the public. A recent warning, mentioned above (Ripple et al., 2022), continues the extreme rhetoric (which is, of course, justified):

> We are now at “code red” on planet Earth. Humanity is unequivocally facing a climate emergency. The scale of untold human suffering, already immense, is rapidly growing with the escalating number of climate-related disasters. Therefore, we urge scientists, citizens, and world leaders to read this Special Report and quickly take the necessary actions to avoid the worst effects of climate change.
>
> 2022 marks the 30th anniversary of the “World Scientists’ Warning to Humanity,” signed by more than 1700 scientists in 1992. Since this original warning, there has been a roughly 40% increase in global greenhouse gas emissions. This is despite numerous written warnings from the Intergovernmental Panel on Climate Change and a recent scientists’ warning of a climate emergency with nearly 15,000 signatories from 158 countries. Current policies are taking the planet to around 3 degrees Celsius warming by 2100, a temperature level that Earth has not experienced over the past 3 million years. The consequences of global heating are becoming increasingly extreme, and outcomes such as global societal collapse are plausible and dangerously underexplored. Motivated by the moral urgency of this global crisis, here, we track recent climate-related disasters, assess planetary vital signs, and provide sweeping policy recommendations.[17] (Ripple et al., 2022)

[17] This quotation, and many of the other quotations in this paper, include references, which I have omitted for simplicity and clarity.

Note that 3 degrees by 2100 is almost certainly an underestimate. 2023 brought some of the most extreme weather events in recorded history, in part perhaps due to the confluence of both continued warming, the start of the El Niño phase of the El Niño-Southern Oscillation (ENSO), and a reduction in human-made aerosols. As one climate scientist recently wrote, "Temperatures are rising at the rate we thought they would, but the effects are more severe, more frequent, more critical. It's crazy and getting crazier."[18] As Pope Francis writes in his recent Apostolic Exhortation, "...the world in which we live is collapsing and may be nearing the breaking point" (Pope Francis, 2023).

Ripple and his colleagues now provide yearly updates, and their 2023 report indicates the situation continues to deteriorate; we are "under siege" and are now "in uncharted territory" (Ripple et al., 2023a). The 2024 update is by Ripple and 13 other prominent climate scientists. Rather than improving, the situation continues to deteriorate.

> We are on the brink of an irreversible climate disaster. This is a global emergency beyond any doubt. Much of the very fabric of life on Earth is imperiled …. Tragically, we are failing to avoid serious impacts, and we can now only hope to limit the extent of the damage …. We find ourselves amid an abrupt climate upheaval, a dire situation never before encountered in the annals of human existence. We have now brought the planet into climatic conditions never witnessed by us or our prehistoric relatives within our genus, *Homo*. (Ripple et al., 2024)

Boehm et al. (2023), in a massive report, examined historical data to track the changes in 42 indicators of efforts to mitigate climate change. Their key findings were not encouraging, as "Recent rates of change for 41 of the 42 indicators across power, buildings, industry transport, forests and land, food and agriculture, technological carbon removal, and climate finance are not on track to reach their 1.5°C-aligned targets for 2030." The only indicator on track to reach its target in 2030 is the share of electric vehicles in passenger car sales ("Increase the share of EVs to 75–95% of total annual LDV [light-duty vehicle] sales."). During 2024, however, major car manufacturers canceled some planned models and reduced their estimates for EV production, so even this indicator is no longer on track to reach the target. And, as soon as Trump became president in 2025, he started to reduce subsidies and goals for EV adoption, as well as trying to reduce states' ability to limit the sales of gas-powered cars.

[18] Michael Flannigan, a climate scientist studying the interaction of fire and climate, as reported in Serge Schmemann's article in the NYTimes, Aug. 23, 2023, "It Is No Longer Possible to Escape What We Have Done to Ourselves," https://www.nytimes.com/2023/08/23/opinion/canada-wildfires-climate-change.html

Dr. James Hansen has been at the forefront of climate science research for 50 years, and is a prime example of scientists who feel the need to speak out more forcefully. The website of the Earth Institute at Columbia University, where he now works, includes this on its website:

> …although Dr. Hansen's scientific productivity in NASA might be described as prodigious, his most important contribution to the climate discussion may be his refusal to accept the admonition that scientists should not go all the way to describing policy implications of their research. We suggest, on the contrary, that the objectivity of science is particularly effective in ferreting out the relative merits of alternative policies.[19]

In written testimony before the International Court of Justice, Hansen goes on to write the following:

> But where is scientific advice? The UN is served by a huge scientific apparatus, but we hear little scientific objection to the farcical climate "strategy" at COP meetings. Voluminous IPCC reports contain good data, but what good are data alone? Scientists are the physicians of the planet. We have a moral obligation for diagnosis and advice.[20]

Dr. Earle Williams, a research scientist at MIT studying physical meteorology, describes the problem for many scientists: "We are so preoccupied trying to figure out how the climate system works that we have been distracted from the ultimately more important issue of where the planet is heading in the longer-term."[21]

A Global Health Emergency

Over 200 health journals coordinated editorials they published on October 25, 2023 titled, "Time to treat the climate and nature crisis as one indivisible global health emergency" (Abbasi et al., 2023).

> Over 200 health journals call on the United Nations, political leaders, and health professionals to recognise that climate change and biodiversity loss are one indivisible crisis and must be tackled together to preserve health and avoid catastrophe. This overall environmental crisis is now so severe as to be a global health emergency.

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[19] https://csas.earth.columbia.edu/about/our-mission; Dr. Hansen has also been arrested at climate protests.
[20] James E. Hansen (Dec. 9, 2024), Climate Change at the International Court of Justice, https://www.columbia.edu/~jeh1/mailings/2024/ICJ.PressBriefing.09December2024.pdf
[21] Personal communication, May 26, 2024.

> The world is currently responding to the climate crisis and the nature crisis as if they were separate challenges. This is a dangerous mistake. The 28th UN Conference of the Parties (COP) on climate change is about to be held in Dubai while the 16th COP on biodiversity is due to be held in Turkey in 2024. The research communities that provide the evidence for the two COPs are unfortunately largely separate, but they were brought together for a workshop in 2020 when they concluded: "Only by considering climate and biodiversity as parts of the same complex problem … can solutions be developed that avoid maladaptation and maximize the beneficial outcomes." (Abbasi et al., 2023)

The editorial summarizes all the ways in which human health is damaged by both the climate crisis and the nature crisis, and all the interrelationships between the two. For example, "Restoring one subsystem can help another—for example, replenishing soil could help remove greenhouse gases from the atmosphere on a vast scale."

Ecological Footprint and Overshoot

The concept of our ecological footprint, and ecological overshoot, are important for understanding our current situation. The World Wildlife Fund (WWF) relied heavily on the concept of ecological footprint in their *Living Planet Report 2008*. As defined recently on the Earth Overshoot Day website:

> Humanity's demand on the planet's living resources, its Ecological Footprint, now exceeds the planet's regenerative capacity by about 30 per cent…. This global overshoot is growing [this was written 16 years ago] and, as a consequence, ecosystems are being run down and waste is accumulating in the air, land and water. The resulting deforestation, water shortages, declining biodiversity and climate change are putting the well-being and development of all nations at increasing risk.[22]

We are in trouble because we are using resources and creating waste faster than our ecosystems can replace or deal with them. This means we are now in a state of "ecological overshoot."

> Ecological overshoot occurs when human demand exceeds the regenerative capacity of a natural ecosystem. Global overshoot occurs when humanity demands more than what the biosphere can renew.

[22] https://wwfint.awsassets.panda.org/downloads/lpr_living_planet_report_2008.pdf

> Ecological overshoot is only possible for a limited time before ecosystems begin to degrade and possibly collapse. Impacts of ecological overspending are apparent already in soil erosion, desertification, reduced cropland productivity, overgrazing, deforestation, rapid species extinction, fisheries collapse and increased carbon concentration in the atmosphere.[23]

Planetary Boundaries

Richardson et al. (2023)[24] have updated the planetary boundaries framework, and for the first time define control variables for each that can be measured to determine the extent of anthropogenic influence.

> The planetary boundaries framework draws upon Earth system science. It identifies nine processes that are critical for maintaining the stability and resilience of Earth system as a whole. All are presently heavily perturbed by human activities. The framework aims to delineate and quantify levels of anthropogenic perturbation that, if respected, would allow Earth to remain in a "Holocene-like" interglacial state.
>
> The planetary boundaries framework delineates the biophysical and biochemical systems and processes known to regulate the state of the planet within ranges that are historically known and scientifically likely to maintain Earth system stability and life-support systems conducive to the human welfare and societal development experienced during the Holocene.[25] (Richardson et al., 2023)

The nine planetary boundaries are represented in Figure 1 below.

[23] https://overshoot.footprintnetwork.org/newsroom/media-backgrounder/#2
[24] There were 29 scientists from eight different countries involved in this research.
[25] From Wikipedia: "The Holocene is the current geological epoch. It began approximately 9,700 years before the Common Era. It follows the Last Glacial Period, which concluded with the Holocene glacial retreat."

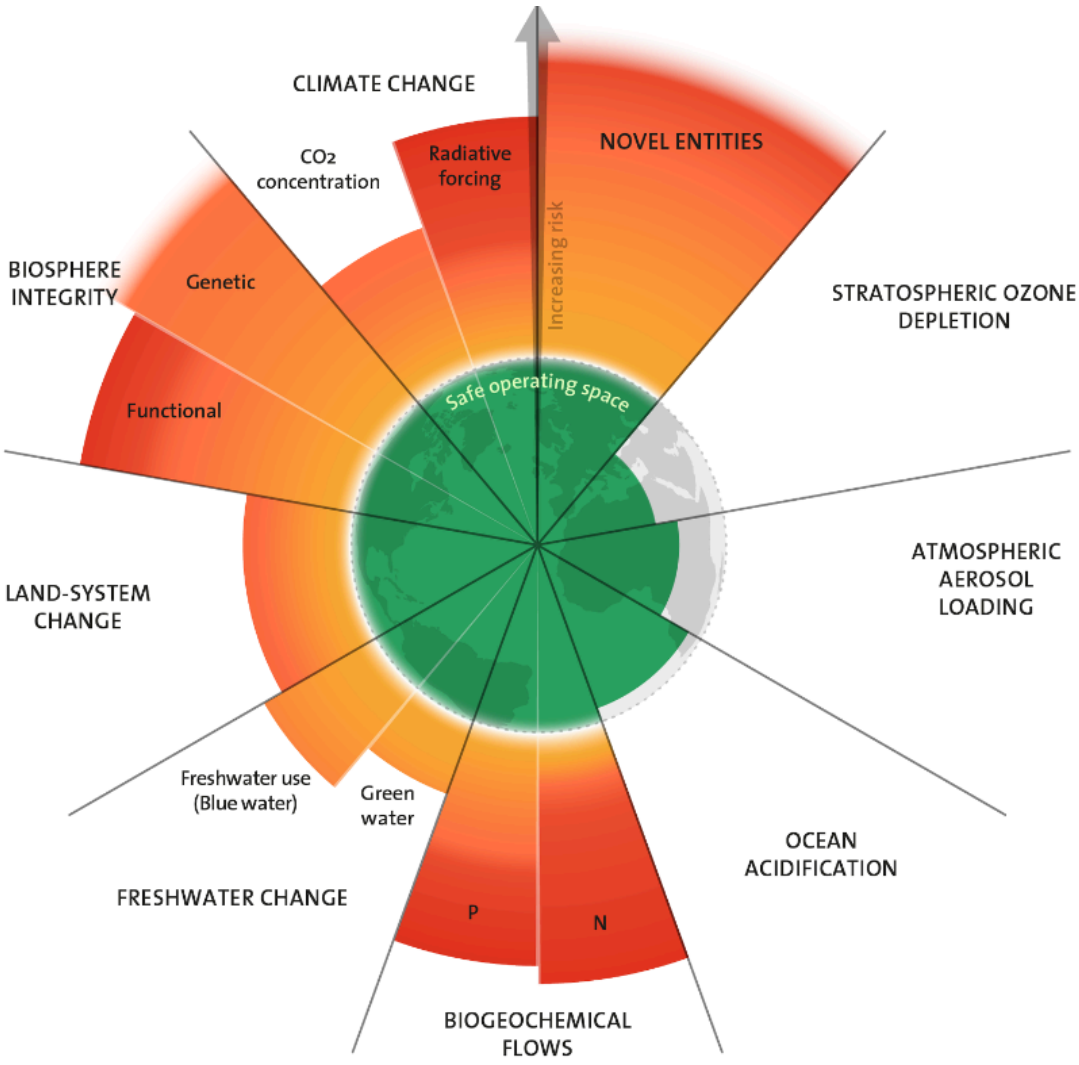

Figure 1. Planetary Boundaries: Nine Assessed, Six Crossed

"The 2023 update to the Planetary boundaries. Licensed under CC BY-NC-ND 3.0. Credit: 'Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023'." From https://www.stockholmresilience.org/research/planetary-boundaries.html, which also includes graphics from 2009 and 2015.

The six planetary boundaries that have been crossed include biosphere integrity (NPP, net primary production, a "proxy for photosynthetic energy and materials flow into the biosphere"), land system change (reduction in forest cover), biogeochemical flows of nitrogen and phosphorus, freshwater change (surface and ground water as well as soil moisture available to plants), climate change (atmospheric CO_2), and "novel entities" (synthetic chemicals released into the environment). Simulations using Earth models indicate that two of these systems (land system change and climate) had already moved out of a safe zone by about 1988. Stratospheric ozone depletion, atmospheric aerosol loading, and ocean acidification are now either in the safe zone or are at the

margin of the safe operating space. (Quotes in this paragraph are from Richardson et al., 2023.)

Passing these six boundaries is further confirmation that we are in a “code red” situation, and that we are on a trajectory to a new Earth system state in which it will be very difficult for humans to survive.

Warming is Accelerating

Global warming is steadily increasing, but is the rate actually accelerating? In a recent guest essay, Zeke Hausfather, a climate research scientist at Berkeley Earth, presents his view that, “there is increasing evidence that global warming has accelerated over the past 15 years rather than continued at a gradual, steady pace.” Although there is serious disagreement among climate scientists, Hausfather’s arguments are convincing:

> …the data we’re getting from three sources tells a worrying story about a world warming more quickly than before. First, the rate of warming we’ve measured over the world’s land and oceans over the past 15 years has been 40 percent higher than the rate since the 1970s, with the past nine years being the nine warmest years on record. Second, there has been acceleration over the past few decades in the total heat content of Earth’s oceans, where over 90 percent of the energy trapped by greenhouse gases in the atmosphere is accumulating. Third, satellite measurements of Earth’s energy imbalance — the difference between energy entering the atmosphere from the sun and the amount of heat leaving — show a strong increase in the amount of heat trapped over the past two decades. If Earth’s energy imbalance is increasing over time, it should drive an increase in the world’s rate of warming.[26]

Not only is the Earth’s energy imbalance increasing, but the effects of warming are exacerbated because there has been a “large, persistent increase of absorbed solar radiation” since 2015, probably due to a decrease in particulate air pollution.

> The only known mechanism capable of such a large forcing is a decrease of cloud albedo. Indeed, we concluded elsewhere that decreased particulate air pollution in the past decade should cause such a decrease of cloud albedo and thus an acceleration of global warming in the post-2010 period. The most distinct and probably the most effective aerosol reduction is due to limitations on the sulfur content of ship fuels imposed by the International Maritime Organization

[26]Zeke Hausfather (Oct. 13, 2023), Study Climate Change. The Data Is Telling Us Something New.,*The New York Times*, https://www.nytimes.com/2023/10/13/opinion/climate-change-excessive-heat-2023.html?smid=em-share

> (IMO) in January 2015 and strengthened in January 2020. (Hansen, Sato, & Ruedy, 2023)

There has been a decrease in the sulfur content of ship fuels, which has reduced air pollution and so is a health benefit. However, this air pollution was acting to cool the Earth, and now that it has been reduced the increase in global warming is more pronounced. (See Appendix 6 for an explanation of radiative forcing.)

All climate scientists agree that global warming will continue, but not all think that the rate of warming is increasing. Some of those who disagree don't think there is enough data to be definitive, but that within the next few years we should be able to know for sure. James Hansen and his colleagues are in the group arguing that acceleration is already occurring.

> Record global temperature in 2023 helps reveal acceleration of global warming on decadal time scales. The proximate cause of the acceleration is increase of Earth's energy imbalance, specifically a substantial darkening of the planet (decreased albedo) equivalent to a CO_2 increase of more than 100 ppm, although it is difficult to apportion the albedo change between aerosol forcing and cloud feedbacks because of limited global measurements.[27]

Hansen and his colleagues continue their arguments that warming is accelerating in a more recent communication, focusing on the change in human-made aerosols mentioned above.

> Global warming in 2010-2023 is 0.30°C/decade, 67% faster than 0.18°C/decade in 1970- 2010. The recent warming is different, peaking at 30-60°N….Such an acceleration of warming does not simply "happen" – it implies an increased climate forcing (imposed change of Earth's energy balance). Greenhouse gas (GHG) forcing growth has been steady. Solar irradiance has zero trend on decadal time scales. Forcing by volcanic eruptions has been negligible for 30 years, including water vapor from the Honga Tunga eruption. The one potentially significant change of climate forcing is change of human-made aerosols. The large warming over the North Pacific and North Atlantic coincides with regions where ship emissions dominate sulfate aerosol production.
>
> Global absorbed solar radiation (ASR) has increased dramatically since 2010, more than 1.4 W/m^2, equivalent to a CO_2 increase of more than 100 ppm. The

[27] James Hansen, Makiko Sato, and Reto Ruedy (Jan. 12, 2024), Global Warming Acceleration: Causes and Consequences, *Communication,* https://www.columbia.edu/~jeh1/mailings/2024/AnnualT2023.2024.01.12.pdf

> ASR increase is not due to a brightening Sun, it is due to a darkening Earth. Our task is to learn how much of this darkening is climate feedback (due to decreasing ice/snow and cloud albedo, i.e., reflectivity) and how much is climate forcing (due to decreasing aerosols). (Hansen et al., 2024)

In an April, 2024, commentary on whether warming is really accelerating, "Much ado about acceleration," Gavin Schmidt compares Hansen et al.'s predictions with the latest CMIPs climate models and writes that:

> Remarkably, the Hansen et al projections are basically indistinguishable from what the mean of the TCR-screened CMIP6 models are projecting [TCR: transient climate response]. Or, to put it another way, **everybody** is (or should be) expecting an acceleration of climate warming (in the absence of dramatic cuts in GHG emissions) (CarbonBrief has a similar analysis), even if we might differ on whether it is yet detectable.[28]

Greenhouse gas concentrations in the atmosphere continue their seemingly inexorable rise (see Figure 2 below; as Hansen and his colleagues write above, "Greenhouse gas (GHG) forcing growth has been steady"). The Scripps Institution of Oceanography at UC San Diego maintains a daily record of global atmospheric CO_2 concentration (the Keeling Curve), and recently reported a new record for the largest increase in a year:

> The monthly average concentration of carbon dioxide in the atmosphere measured at NOAA's Mauna Loa Observatory in March 2024 was 4.7 parts per million (ppm) higher than that recorded in March 2023, setting a new record and revealing the increasing pace of CO2 addition to the atmosphere by human activities.[29]

Scripps and the National Oceanic and Atmospheric Administration (NOAA) measure CO_2 independently, but their measurements are basically identical. Scripps calculated a May, 2024, monthly average of 426.7 ppm, while NOAA has the monthly average at 426.9 ppm.

[28] Gavin Schmidt (Apr. 4 2024), Much ado about acceleration, *RealClimate,* https://www.realclimate.org/index.php/archives/2024/04/much-ado-about-acceleration/
[29] https://keelingcurve.ucsd.edu/

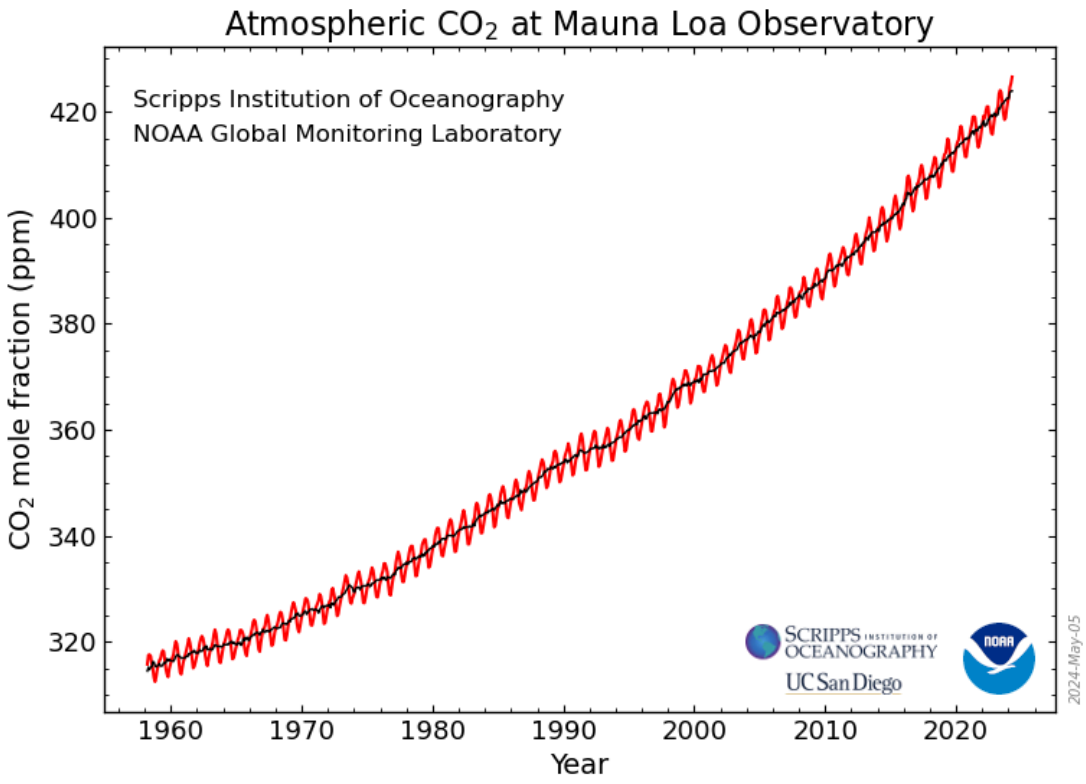

Figure 2. The Keeling Curve: Atmospheric CO_2 Measured at Mauna Loa Observatory
"This graph shows the full record of monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. The carbon dioxide data on Mauna Loa constitute the longest record of direct measurements of CO_2 in the atmosphere. They were started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958 at the NOAA Weather Station on Mauna Loa volcano. NOAA started its own CO_2 measurements in May of 1974, and they have run in parallel with those made by Scripps since. (Image credit: NOAA Global Monitoring Laboratory)"[30]

The level of CO_2 rises and falls each year with the seasons, which explains the jagged line in Figure 2 above; levels fall during the growing season in the northern hemisphere and then rise as plants die in the fall.

Earth System Sensitivity

Determining how much temperature will rise as CO_2 concentrations increase (Earth-system sensitivity) is critical for understanding the long-term temperature response to a specific change in CO_2 "forcing," and being able to model our future

[30] https://www.noaa.gov/news-release/during-year-of-extremes-carbon-dioxide-levels-surge-faster-than-ever

climate.[31] Since there are no direct measures of atmospheric CO_2 from prehistoric times, scientists use various proxies, such as ice cores, corals, fossil leaves, tree rings, ancient soil, and plant macrofossils. Scientists often refer to the global temperature increases when there is a doubling of CO_2 compared to pre-industrial levels (280 ppm in the mid 1700s up to a doubling at 560 ppm; we are currently (January, 2025) at about 427).

Witkowski et al. (2024) used a new method to examine the relationship between atmospheric CO_2 at a single site that covers the last 15 million years: "We reconstruct pCO_2 values [i.e., atmospheric CO_2] using sterane and phytane, compounds that many phytoplankton produce and then become fossilised in sediment." This new research indicates that the climate is more sensitive to atmospheric CO_2 levels than previously thought, and that temperature increases will be far greater than those predicted by the IPCC.

> The resulting ESS [Earth-system sensitivity] shows 18.8 °C (per CO_2-doubling) for NH [northern hemisphere] high latitudes, 16.0 °C for the mid-latitudes, and 11.1 °C for the tropics.
>
> Our reconstructed *p*CO2 values across the past 15 million years suggest Earth system sensitivity averages 13.9 °C per doubling of pCO_2 and equilibrium climate sensitivity averages 7.2 °C per doubling of pCO_2. Although these values are significantly higher than IPCC global warming estimations, they are consistent or higher than some recent state-of-the-art climate models and consistent with other proxy-based estimates. (Witkowski et al., 2024)

Earth system sensitivity (ESS) and equilibrium climate sensitivity (ECS) both measure the temperature response to increased CO_2. ESS is much higher than ECS because ESS takes into account long-term effects such as changes in ice sheets and vegetation, which can take thousands of years to manifest.

Gavin Schmidt, in a technical review of this paper that includes his own calculations to confirm the results, concludes by writing that "this paper usefully adds to the database for paleo-CO_2 value, but on its own does not further constrain actual global ESS and ECS estimates…." [32]

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[31] See See Zeke Hausfather (June 19, 2018), *Carbon Brief*, Explainer: How scientists estimate 'climate sensitivity', https://www.carbonbrief.org/explainer-how-scientists-estimate-climate-sensitivity/

[32] Gavin Schmidt (August 28, 2024), Oh My, Oh Miocene! *Real Climate*, https://www.realclimate.org/index.php/archives/2024/08/oh-my-oh-miocene/

Summary of the Current Situation

This paper summarizes the most recent scientific literature on climate change and then explains why the consequences for society are so much worse compared to an analysis that just takes into consideration the physical aspects alone. For more detailed reviews of the scientific literature on the physical bases of climate change, readers are directed to a short list of the most authoritative reports in the Suggested Reading section at the end of this document.

The most serious direct consequences of climate change on human civilization can be summarized succinctly: extreme heat waves and droughts, extreme rainfall and floods, extreme fires, extreme tropical cyclones, extreme sea ice and ice shelf loss, extreme loss of biodiversity, the collapse of ocean currents, ocean acidification and sea level rise, extreme shortages of fresh water, and the spread of infectious diseases. These changes will lead to crop failures and starvation, regional conflicts, and mass migration.
.
We don't need to reach the "hothouse" Earth scenario described by Steffen et al. (2018) for civilization as we know it to collapse. We just need enough climate stresses to lead to armed conflict and civil unrest, which will then make it even more difficult to adapt to a warmer world, leading to continued conflict. See the causal loop diagram in Figure 3 for a visual representation of how the different aspects of climate change connect and interrelate.

Only recently have climate scientists started writing about how serious the effects on society will be. For example, Ripple et al., 2023a, in their most recent annual report, write that,

> Conditions are going to get very distressing and potentially unmanageable for large regions of the world, with the 2.6°C warming expected over the course of the century, even if the self-proposed national emissions reduction commitments of the Paris Agreement are met. We warn of potential collapse of natural and socioeconomic systems in such a world where we will face unbearable heat, frequent extreme weather events, food and fresh water shortages, rising seas, more emerging diseases, and increased social unrest and geopolitical conflict. (Ripple et al., 2023a)

"Climate scientists say that even if the world blows past the 1.5°C target, every tenth of a degree matters, and 2.5°C of warming would be much safer than 4°C."[33] This is from a

[33]Maxine Joselow (Nov. 20 2023), Three surprising findings in the latest U.N. emissions report, *The Washington Post*,

climate newsletter, and nearly identical statements have appeared dozens of times in all types of media. It is partly true, as every tenth of a degree does matter – with respect to warming – but it is not necessarily the case that 2.5°C is safer than 4°C, because if 2.5°C is enough to destroy human civilization, then it is no different from 4°C in terms of safety. Getting shot with one bullet is generally better than getting shot with two, but if the first bullet kills you then one bullet is just as dangerous as two. One goal of this paper is to convince you of the unfortunate fact that we may now be at a point where every tenth of a degree no longer matters. Hansen and his colleagues summarize the overall situation in the title of a recent communication[34]: "'A Miracle Will Occur' is Not Sensible Climate Policy."

https://www.washingtonpost.com/politics/2023/11/20/three-surprising-findings-latest-un-emissions-report/

[34] https://www.columbia.edu/~jeh1/mailings/2023/Miracle.2023.12.07.pdf

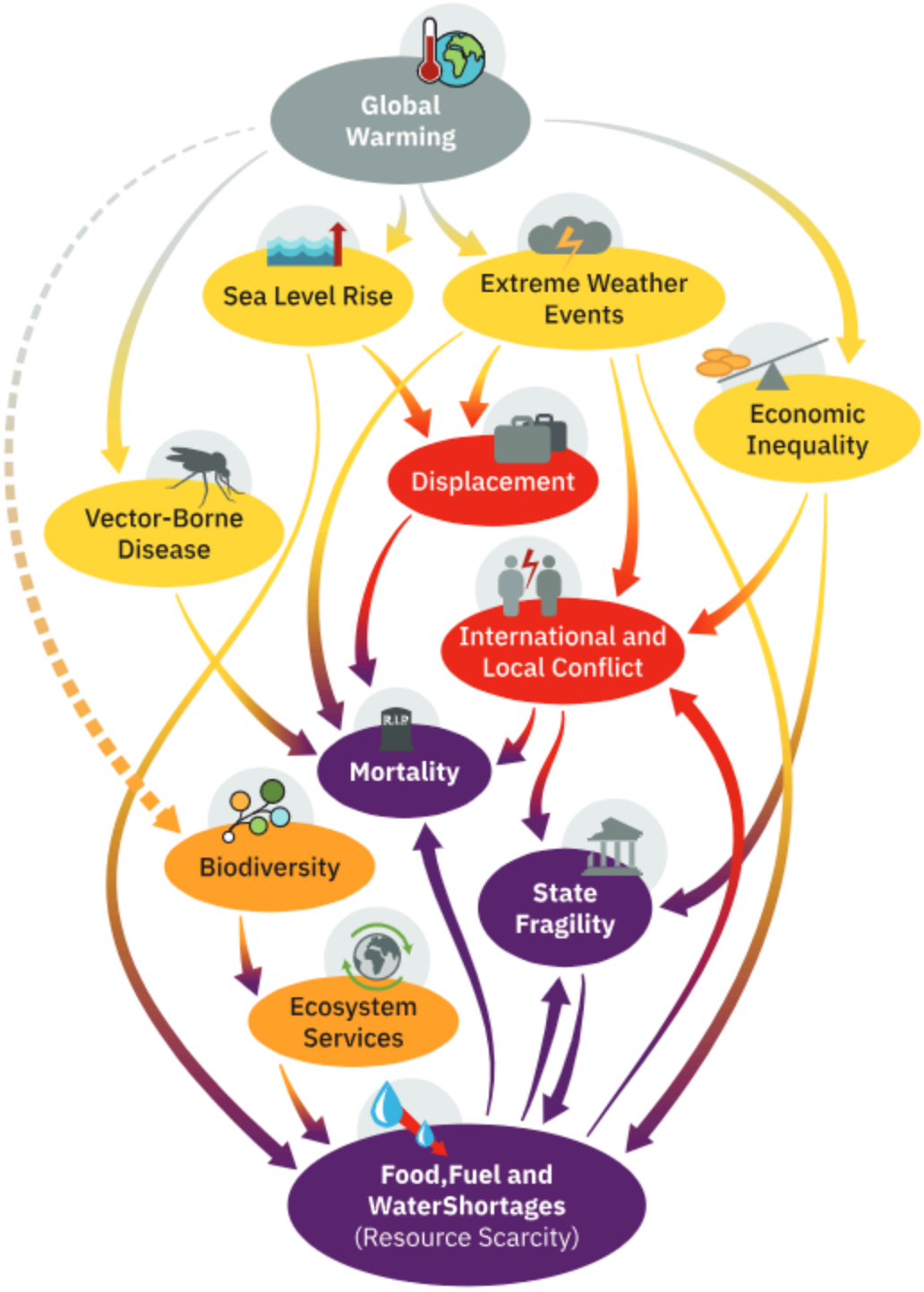

Figure 3. Cascading Global Climate Failure

(This is Fig. 3 from Kemp et al., 2022.) *"Cascading global climate failure. This is a causal loop diagram, in which a complete line represents a positive polarity (e.g., amplifying feed-back; not necessarily positive in a normative sense) and a dotted line denotes a negative polarity (meaning a dampening feedback)."*

Extreme Heat

The IPCC (2023) concludes with very high confidence that, “In all regions increases in extreme heat events have resulted in human mortality and morbidity.”

> It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with high confidence that human-caused climate change is the main driver of these changes. Marine heatwaves have approximately doubled in frequency since the 1980s (high confidence), and human influence has very likely contributed to most of them since at least 2006. (IPCC, 2023)

Lenton et al. (2023b) show that one to three billion people will experience “unprecedented” heat this century, depending on the IPCC scenario used and the rise in temperature. They also provide references linking high temperatures to “increased mortality, decreased labour productivity, decreased cognitive performance, impaired learning, adverse pregnancy outcomes, decreased crop yield potential, increased conflict, hate speech, migration and infectious disease spread.”

According to the World Meteorological Organization, the number of deaths from heat are already staggering, and will increase dramatically.

> The impacts of extreme heat and heatwaves are underestimated, as heat-related mortality could be 30 times higher than current estimates. Between 2000 and 2019, estimated deaths due to heat were approximately 489,000 per year, with a particularly high burden in Asia (45%) and Europe (36%). (WMO, 2023)

A new report on climate risk assessment by the European Environment Agency finds that extreme heat is becoming more common, and that Europe is warming faster than any other continent.

> Extreme heat is becoming increasingly common, exposing a large share of the population to heat stress, particularly in southern and western Europe. The record-hot summer of 2022 has been linked to between 60,000 and 70,000 premature deaths in Europe, despite considerable investments in heat-health action plans. Warmer temperatures also facilitate the northward movement of disease vectors and their spread to higher elevations. Southern Europe is now warm enough for mosquitoes to transmit formerly tropical diseases. (European Climate Risk Assessment, 2024)

In addition, there is new evidence that heat waves now last longer. Luo et al. (2024) reanalyzed existing datasets and, combined with model simulations, concluded that "longer-lived, longer-traveling, and slower-moving contiguous heatwaves will cause more devastating impacts on human health and the environment in the future if greenhouse gas emissions keep rising and no effective measures are taken immediately."

Focusing on children from 3 to 36 months in five West African countries, Blom et al. (2022) found that, "extreme heat exposure increases the prevalence of both chronic and acute malnutrition. We find that a 2°C rise in temperature will increase the prevalence of stunting by 7.4 percentage points, reversing the progress made on improving nutrition during our study period."

Vecellio et al. (2023), using a more accurate measure of the maximum temperatures at which a person can thermoregulate, found that "humanity is more vulnerable to moist heat stress than previously proposed….":

> A wet-bulb temperature (T_w) of 35°C has been proposed as a theoretical upper limit on human abilities to biologically thermoregulate. But, recent — empirical — research using human subjects found a significantly lower maximum T_w at which thermoregulation is possible even with minimal metabolic activity. (Vecellio et al., 2023)

Vecellio et al. (2023) used the latest coupled climate models to quantify exposure to potentially lethal heat at various global warming levels. The results are quite disturbing:

> The annual accumulation of hot-hours experienced by the world's population begins to climb substantially in worlds warmer than 2°C above the preindustrial baseline. In this study's worst-case scenario of a 4°C warmer world, around 2.7 billion persons will experience at least 1 wk of daytime (8 h) ambient conditions associated with uncompensable heat stress, 1.5 billion will experience a month under such conditions, and 363.7 million will be faced with an entire season (3 mo) of life-altering extreme heat. (Vecellio et al., 2023)

Hot-hours, and "uncompensable heat stress," means that the body is unable to maintain a thermal steady state. This will lead to heat stroke and then death unless treated immediately. Major cities in South and East Asia, the Middle East, and the equatorial and Sahel regions of Africa will start experiencing many hours per year of this high heat

even at just 1.5°C. This will increase at 2°C and then jump dramatically when 3°C is reached.

Extreme Heat and Infrastructure

Everyone understands that the human body can withstand only a certain amount of extreme heat, but most people don't understand the effect that extreme heat can have on critical infrastructure.

> A basic fact of thermodynamics is coming to haunt every foot of train track in the United States. Heat makes steel expand, moving its molecules farther apart, and as hot days become hotter and more frequent, rail lines are at risk of warping and buckling more often.[35]

There are potential problems with almost anything made with steel. Bridges can fail, roads may buckle, and there are serious problems when permafrost under roads and buildings starts to melt. Heat even reduces the amount of power that can be delivered over power lines. For an interesting article on bridges, see Coral Davenport's review, "Climate Change Can Cause Bridges to 'Fall Apart LIke Tinkertoys,' Experts say."[36]

There are, of course, engineering approaches that will reduce the negative impacts of increasing heat – as well as of extreme rain and floods, which also damage bridges and roads. Spending money proactively to strengthen infrastructure saves a tremendous amount of money in the long term. Newmann et al. (2021) estimated "impacts to railroad, roads, and coastal properties under three infrastructure management response scenarios: No Adaptation; Reactive Adaptation, and Proactive Adaptation."

> Comparing damages under each of these potential responses provides strong support for facilitating effective adaptation in these three sectors. Under a high greenhouse gas emissions scenario and without adaptation, overall costs are projected to range in the $100s of billions annually by the end of this century. The first (reactive) tier of adaptation action, however, reduces costs by a factor of 10, and the second (proactive) tier reduces total costs across all three sectors to the low $10s of billions annually. (Newmann et al., 2021)

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[35] Zoë Schlanger (August 14, 2024), America Has a Hot-Steel Problem: Railways, roads, power lines, batteries—the heat of climate change is making them all falter. *The Atlantic*, https://www.theatlantic.com/science/archive/2024/08/america-infrastructure-climate-change/679458/

[36] Coral Davenport (September 12, 2024), Climate Change Can Cause Bridges to 'Fall Apart Like Tinkertoys,' Experts Say. *The New York Times*, https://www.nytimes.com/2024/09/02/climate/climate-change-bridges.html

Extreme Drought and Aridity

Drought is temporary, while aridity is permanent, a feature of the climate. In late 2024, the United Nations Convention to Combat Desertification (UNCCD) released a major report, “The Global Threat of Drying Lands: Regional and global aridity trends and future projections” (Vicente-Serrano et al., 2024). Aridity will be a major factor in the collapse of societies in fragile states, and a new report makes clear the critical importance of aridity.

> Aridity—the relative, long-term lack of available, life-sustaining moisture in terrestrial climates—significantly affects land degradation, desertification and the overall resilience of ecosystems and human communities. Aridity-related land degradation and water scarcity have been linked to food and water insecurity, poor soil fertility, losses in crop and plant productivity, biodiversity declines, ecosystem degradation, intense sand and dust storms, wildfires, poor health and large-scale human migration. Human-caused climate change, meanwhile, is a main culprit for changing aridity around the world. (Vicente-Serrano et al., 2024)

Here are the main findings of the report:

> The report finds that rising aridity is threatening people and environments in almost every global region. More than three-quarters of all land on Earth experienced a drier climate during the three decades leading up to 2020, compared to the previous 30-year period, and global drylands expanded by about 4.3 million km2—an area equal to half the size of the continent of Australia/Oceania—to cover more than 40 per cent of global land (excluding Antarctica). If the world fails in efforts to curb greenhouse gas emissions, another 3 per cent of the world’s humid areas are projected to transform into drylands by the end of this century.
>
> Meanwhile, people living in drylands have doubled in number—to 2.3 billion, more than a quarter of the global population—over the past three decades, and models suggest as many as 5 billion could inhabit drylands by 2100 in a worst-case climate change scenario. These billions of people face even greater threats to their lives and livelihoods from climate-related increases in aridification and desertification. (Vicente-Serrano et al., 2024)

Extreme Rainfall and Floods

Extreme rainfall can lead to deaths from floods, landslides, houses collapsing, and there are multiple negative impacts on human health. It can also damage or destroy infrastructure and ruin crops. In one example from 2023, Beijing experienced the heaviest rainfall in recorded history and had to evacuate over a million people. There has also been extreme flooding recently in multiple countries, including Brazil, Pakistan, and Bangladesh. In the United States, there was extreme flooding in North Carolina as well as in Houston and other parts of southeastern Texas.

Flooding and Health Risks

Floods cause serious damage and result in multiple health problems. A special report in the New England Journal of Medicine reviews the current knowledge about both the short- and long-term health risks of floods (Wu et al., 2024). Consider this summary of flood-related effects on health (verbatim from Wu et al.'s Figure 2):

- **Drowning, electrocution, and hypothermia**: Associated with direct exposure to floodwater
- **Nonfatal injuries:** From cuts, falls, injuries from falling debris or objects in the floodwater
- **Flood-related chemical accidents:** Result of spills caused by dislodged gas cylinders and chemical-storage tanks, explosions, and fires
- **Dermatologic conditions and anaphylactic reactions:** Result from wound infections and bites and stings from arthropods and venomous animals
- **Communicable diseases:** Result from exposure to contaminated floodwater, overcrowded shelters, contaminated drinking water, and mold
- **Adverse pregnancy outcomes:** Caused by accidental injuries, physiological and mental stress, infectious diseases, decreased access to essential services, and poor hygiene
- **Mental illness:** Associated with physical and economic insecurity, heightened violence, and displacement
- **Undernutrition:** Caused by shortages of water, food, and other supplies; gastrointestinal disease; and financial loss
- **Exacerbation of preexisting conditions:** Physiological and mental stress, disruption of health care services
- **Increased mortality:** Affected by flood-related injuries and illnesses, including mental illness; exacerbation of preexisting diseases; disruption of health care services (Wu et al., 2024)

Extreme floods often destroy sources of clean water and sewage infrastructure, spread contaminants, and provide a breeding ground for insects that carry diseases. Consider the dramatic effects on human health from the flooding in Bangladesh during the summer of 2024:

> Relentless monsoon rains, coupled with an irreversible deluge from upstream, have inundated vast swathes of Bangladesh, particularly in the southeastern and northeastern districts, displacing millions and incapacitating vital infrastructure…. The flooding has compromised water and sanitation services, rendering previously potable water sources lethal vehicles for pervasive waterborne diseases. As the floodwaters combine with an array of contaminants, including human excreta and agricultural and industrial runoff, the probability of an outbreak of cholera, dysentery, hepatitis A, and other enteric diseases is large….

> The irremediable destruction of agriculture and livestock means a food security crisis of unprecedented magnitude is all but inevitable. (Yusha, 2024)

Dam Collapses

Heavy rain that leads to flooding can cause unbelievable devastation. In Sudan, rains starting in June led to flooding that affected over 300,000 people and led to over 12 million being displaced. Then, on August 25, 2024, the Arba'at Dam collapsed after heavy rain. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), the resulting flood

> [damaged] roads, electricity, and telecommunication networks, making it difficult to assess the situation…. Authorities estimate that around 50,000 people living on the western side of the dam have been severely affected, while the impact on the eastern banks is still being assessed.
>
> "The government delegation reported that about 70 villages around Arba'at Dam have reportedly been affected by the flash flooding of which 20 villages have been destroyed," OCHA said.
>
> At least 30 fatalities have been confirmed, as of Monday, but the actual number of casualties is feared to be much higher. Severe damage to infrastructure has also been reported, including the collapse of 84 borehole wells and 70 schools have been fully or partially destroyed. Over 10,000 livestock are also missing.[37]

Glacial Lake Outburst Floods

Glacial lake outburst floods, or GLOFs, occur when an avalanche in the mountains results in a lake breaking through its barriers and causing an "inland tsunami" that races down mountain valleys destroying everything in its path. There are thousands of potential GLOFs around the world, primarily in the Himalayas, Andes, Alps,and Pacific Northwest. Taylor et al. (2023a) "show that 15 million people globally are exposed to impacts from potential GLOFs. Populations in High Mountains Asia (HMA) are the most exposed and on average live closest to glacial lakes with ~1 million people living within 10 km of a glacial lake. More than half of the globally exposed population are found in just four countries: India, Pakistan, Peru, and China."

The Physics of Extreme Rainfall

Extreme rainfall is typically explained by invoking a thermodynamical explanation of increased evaporation in a warmer climate and the fact that warmer air can hold more

[37] https://www.unocha.org/publications/report/sudan/sudan-collapse-arbaat-dam-port-sudan-red-sea-state-flash-update-no-02-29-august-2024-enar

moisture. There are also dynamical aspects that can lead to extreme rainfall due to changes in winds and cloud structures.[38]

The air's capacity to hold water vapor increases by about 7% for each 1°C increase in temperature, which is a large sensitivity. This is called the Clausius-Clapeyron relationship. Since water vapor is the working substance of thunderstorms, this is one important reason why there is more rainfall and lightning in the tropics than at the poles.[39]

> As a rough rule of thumb, the equilibrium water vapor concentration e*(T) doubles for every 10°C of temperature increase. This result has much to say about the sparsity of thunderstorms in polar regions and their predominance in tropical latitudes. A change in temperature of 30°C between equatorial regions and high latitudes amounts to nearly an order of magnitude difference in available water vapor. (Williams et al., 2022)

Extreme Fire

A combination of extreme heat and drought is a deadly combination, and increases the risk of extreme fire behavior. In addition, lightning is sensitive to temperature and there will be an increase in lightning – and thus lightning-ignited forest fires – as the world warms. (There is an approximately 10% increase in lightning for each 1°C increase in temperature; see Williams et al., 2022.) In Fairbanks, Alaska, for example (at latitude 64.8N), there have been dramatic increases in both temperature and thunder day counts.

We are now seeing extreme fire behavior in North America, Europe, and Russia.

> "The number of days of high or extreme fire danger in southern Europe is already at levels we thought we wouldn't see until 2050," said Jesus San Miguel, a senior researcher at the European Commission's Joint Research Centre. "Because of climate change, we are going much faster than we thought."[40]

David Wallace-Wells, in an article in the New York Times titled, "Forests Are No Longer Our Climate Friends,"[41] starts his column like this:

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[38]Explained briefly by Rasmus Benestad (Sep. 26 2023), Old habits, *RealClimate*, https://www.realclimate.org/index.php/archives/2023/09/old-habits/

[39] I thank Dr. Earle Williams for pointing this out to me.

[40] Anthony Faiola and Elinda Labropoulou (2023), How wildfires are threatening the Mediterranean way of life, *The Washington Post*, September 2, 2023 at 4:00 a.m. EDT https://www.washingtonpost.com/world/2023/09/02/greece-fires-2023-rhodes/

[41]David Wallace-Wells (Sep. 6 2023), Forests Are No Longer Our Climate Friends, *The New York Times*, https://www.nytimes.com/2023/09/06/opinion/columnists/forest-fires-climate-change.html

> Canadian wildfires have this year [2023] burned a land area larger than 104 of the world's 195 countries. The carbon dioxide released by them so far is estimated to be nearly 1.5 billion tons — more than twice as much as Canada releases through transportation, electricity generation, heavy industry, construction and agriculture combined. In fact, it is more than the total emissions of more than 100 of the world's countries — also combined.
>
> But what is perhaps most striking about this year's fires is that despite their scale, they are merely a continuation of a dangerous trend: Every year since 2001, Canada's forests have emitted more carbon than they've absorbed. That is the central finding of a distressing analysis published last month by Barry Saxifrage in Canada's National Observer, ominously headlined "Our forests have reached a tipping point."
>
> In fact, Saxifrage suggests, the tipping point was passed two decades ago, when the country's vast boreal forests, long a reliable "sink" for carbon, became instead a carbon "source." In the 2000s, the effect was relatively small. But so far in the 2020s, Canada's forests have raised the country's total emissions by 50 percent.

The estimate of 1.5 billion tons is actually a vast underestimate. Now that scientists have had time to measure the extent of the fires more accurately, using a Landsat-based annual change detection metric, they concluded that the release of CO_2 is actually about 3 billion tons. In the paragraphs below, MacCarthy et al. (2024) provide an overall summary of the Canadian fires, followed by the results of their analysis.

> Extreme wildfires in Canada in 2023 were among the most destructive ever recorded, causing billions of dollars in property damage, and forcing hundreds of thousands of people to evacuate their homes. Health costs also spiked in Canada in 2023 due to poor air quality resulting from wildfire smoke. Farther afield, smoke from Canada's wildfires caused unhealthy levels of air pollution far away from the source, including much of the densely populated northeastern United States. Global atmospheric circulation patterns brought smoke from Canadian wildfires as far away as China and Europe, negatively impacting air quality in those areas.
>
> We found that the 2023 Canadian wildfires burned nearly 7.8 million hectares [1 hectare is 2.47 acres][42] of forest and accounted for more than a quarter of all tree

[42] For comparison, the land area of Sierra Leone is 7.22 million hectares, while Austria is 8.25 hectares.

> cover loss globally. Furthermore, forests impacted by wildfires emitted nearly 3 billion tons of CO_2 or about 25% more carbon than all primary tropical tree cover loss that year. These results have important implications for global carbon budgets because emissions from these wildfires will largely be excluded from official greenhouse gas reporting. (MacCarthy et al., 2024)

Fires Outside the Tropics are Becoming More Intense and Emitting More Carbon

Jones et al. (2024) grouped forest ecoregions into 12 pyromes (regions with similar fire activity patterns), and found that "the intensity and severity of fires is increasing in extratropical forests, which is consistent with fires affecting drier, more flammable stocks of vegetation fuels as the climate warms and as droughts become more frequent" (Jones et al., 2024). This greater intensity and severity led to increasing emissions from forest fires in extratropical pyromes, and this increase was

> …linked to climate change, [and] offset declining emissions in tropical pyromes during 2001 to 2023. Annual emissions tripled in one extratropical pyrome [primarily the boreal forests in Eurasia and North America] due to increases in fire-favorable weather, compounded by increased forest cover and productivity. This contributed to a 60% increase in forest fire carbon emissions from forest ecoregions globally." (Jones et al., 2024)

Cunningham et al. (2024) show that fires "... of extreme intensity have more than doubled in frequency and magnitude, with increases largely concentrated in the carbon-rich boreal and temperate conifer forests of the northern hemisphere." To measure fires of extreme intensity, the authors used sensors on two NASA satellites to "identify active wildfires based on thermal anomalies… Each fire observation is accompanied by a measure of FRP [fire radiative power], measuring the instantaneous fire energy (megawatts) emitted by a fire, which is known to scale to smoke plume size and has been widely used as a proxy of fire intensity." Cunningham and his coauthors summarize the situation with respect to fires, and then describe their results:

> Most fires on Earth are small, ignited by humans, and not remarkably damaging. Indeed, fire plays a crucial role in the health of most fire-adapted ecosystems. It has been widely reported that the area burned globally has decreased this century, but this trend is mostly driven by declines in low-intensity fires in African grasslands and savannas.
>
> In contrast to the majority of fires, energetically extreme wildfires are associated with extreme ecological, social and economic consequences, including emitting

vast quantities of smoke and greenhouse gases that threaten to further accelerate warming.

… we identify energetically extreme wildfire events by calculating daily clusters of summed fire radiative power using 21 years of satellite data, revealing that the frequency of extreme events (≥99.99th percentile) increased by 2.2-fold from 2003 to 2023, with the last 7 years including the 6 most extreme. Although the total area burned on Earth may be declining, our study highlights that fire behaviour is worsening in several regions—particularly the boreal and temperate conifer biomes—with substantial implications for carbon storage and human exposure to wildfire disasters. (Cunningham et al., 2024)

Fires are Growing More Rapidly

Although there has been an emphasis on the size of megafires, Balch et al. (2024) argue persuasively that more important than size is how fast fires spread (fire growth rate, FGR). They "demonstrate that fires are getting faster, particularly in the Western US…. Moreover, the frequency of fast-growing fires is predicted to increase by ~50 to 200% with projected warming" (Balch et al., 2024).

.... we define fast fires as events that grow >1620 ha on a single day (i.e., maximum FGR > 1620 ha/day). [Ha is a hectare, which is 10,000 square meters, or roughly 2.47 acres.] These fast fires represent only 2.7% of all events, yet they account for 89% of the total structures damaged or destroyed.

Using satellite data, we analyzed the daily growth rates of more than 60,000 fires from 2001 to 2020 across the contiguous US…. From 2001 to 2020, the average peak daily growth rate for these fires more than doubled (+249% relative to 2001) in the Western US.

Some of the most deadly and destructive wildfires in US history have occurred in recent years, with most having the common characteristic of extremely rapid growth. The 2018 Camp Fire in California burned >21,000 ha the day it started, killing 85 people and destroying >16,000 homes.

Fast fires matter for life safety and structure impacts; large fires matter more for ecosystems and they generate substantial smoke. The speed of a fire determines (i) whether firefighters are more focused on evacuation than home protection and (ii) how effectively they can extinguish burning firebrands and new ignitions on structures before the home becomes fully involved.

> Fast fires overall accounted for 88% of residential structures destroyed in the US from 2001 to 2020. With warming temperatures increasing the likelihood of wildfires across the US, we would expect to see more fast fire events in the future. (Balch et al., 2024)

Wildfires and Air Pollution

New research is quantifying the effect of wildfires on air pollution. Although air pollution in general has decreased in the United States over the last several decades, pollution made up of very small particulate matter ($PM_{2.5}$) is now increasing in some areas. This type of air pollution is particularly dangerous because the particles are so small they can move deeply into the lungs. Burke et al. (2023) used both ground and satellite-based measurements to study $PM_{2.5}$ concentrations from wildfire smoke.

> We find that since at least 2016, wildfire smoke has influenced trends in average annual $PM_{2.5}$ concentrations in nearly three-quarters of states in the contiguous USA, eroding about 25% of previous multi-decadal progress in reducing $PM_{2.5}$ concentrations on average in those states, equivalent to 4 years of air quality progress, and more than 50% in many western states. (Burke et al., 2023)

As the extent and prevalence of wildfires increase, so will the extent of $PM_{2.5}$ pollution.

Fire Weather

For a riveting story of how terrible our fire future will be, read John Vaillant's book, *Fire Weather: A True Story from a Hotter World*. Vaillant describes in great detail the Canadian Fort McMurray Fire of May, 2016. A week after the fire tore through Fort McMurray,

> …the fire's toll conjured images of a nuclear blast: there was not just "damage," there was total obliteration. Trying to articulate what she saw during a tour of the fire's aftermath, one official said, "you go to a place where there was a house and what do you see on the ground? Nails. Piles and piles of nails." More than 2,500 homes and other structures were destroyed, and thousands more were damaged: 2,300 square miles of forest were burned. By the time the first photos were released, the fire had already belched 100 million tons of carbon dioxide into the atmosphere, much of it from burning cars and homes. The Fort McMurray Fire…continued to burn, not for days, but for months….
>
> "No one's ever seen anything like this," Fort McMurray's exhausted and grieving fire chief said on national TV. "The way this thing happened, the way it traveled, the way it behaved – this is rewriting the book." (Vaillant, 2023)

Extreme Tropical Cyclones

There is a general consensus among climate scientists that although cyclones may not become more frequent as the climate warms, they will become more powerful.[43] In the future, we will have more major hurricanes, defined as category 3, 4, or 5, than in the historical record. Gilford et al. (2024), for example, found that "modern storms are ~8.3 $m\ s^{-1}$ (about a category) more intense, on average, than they would have been in a world without human-driven North Atlantic SST [sea surface temperature] warming." Climate Central, using Gilford et al.'s attribution methodology, found that "All eleven hurricanes in 2024 (as of November 10) intensified by 9-28 mph during the record-breaking ocean warmth of the 2024 hurricane season, strengthening over waters made as much as 2.5°F warmer because of climate change."[44] This finding is presented in Figure 4 below.

[43] "Tropical cyclone" is the term typically used by meteorologists and climate scientists, and refers to the same phenomena as "hurricanes" and "typhoons". Hurricane is used for storms in the Atlantic, while in the South Pacific and Indian Ocean, the generic term tropical cyclone is used.

[44] https://www.climatecentral.org/report/2024-hurricane-attribution

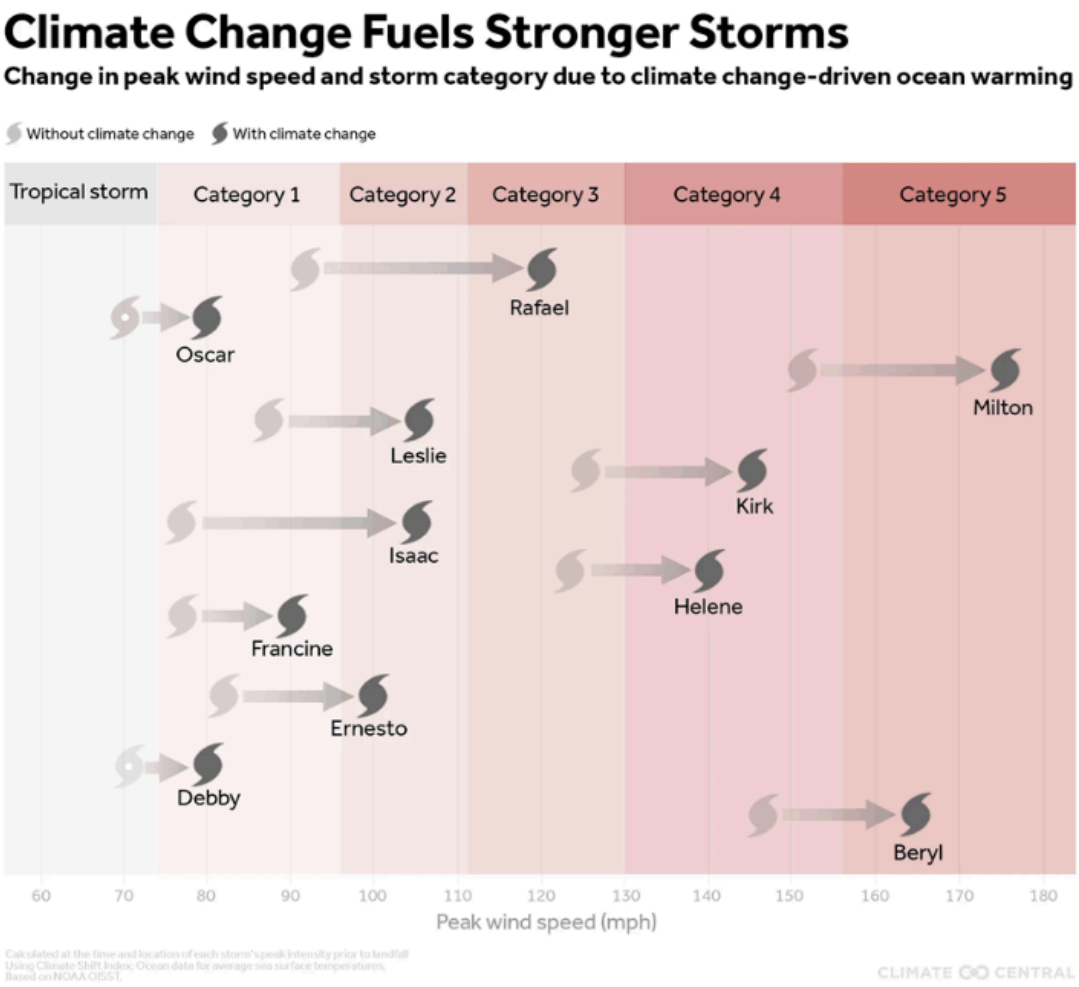


Figure 4. Climate Change Fuels Stronger Storms
"Change in wind speed for the 11 Atlantic hurricanes of 2024 from human-warmed ocean temperatures. (Image credit: Climate Central)"

Wind speed is critically important because hurricane damage increases exponentially with wind speed: "A 10% increase in winds yields about a doubling in hurricane damage,"[45] and hurricanes are more damaging than any other weather event along the U.S. Atlantic and Gulf coasts.

> From 2012 to 2022, over 160 "billion-dollar" weather and climate disasters impacted the U.S; 24 of these events were TCs [tropical cyclones], including the six costliest disasters on record during this time. Many of the most damaging TCs to impact the U.S. in recent years have been notable for the speed at which they have intensified. (Garner, 2023)

[45] https://yaleclimateconnections.org/2024/11/human-caused-ocean-warming-intensified-recent-hurricanes-including-all-11-atlantic-hurricanes-in-2024/

Garner (2023) found a significant increase in the intensification rates of North Atlantic tropical cyclones:

> An analysis of observed maximum changes in wind speed for Atlantic TCs from 1971 to 2020 indicates that TC intensification rates have already changed as anthropogenic greenhouse gas emissions have warmed the planet and oceans. Mean maximum TC intensification rates are up to 28.7% greater in a modern era (2001–2020) compared to a historical era (1971–1990).

Garner studied Atlantic cyclones, but since rapid intensification depends on a warming ocean, and in particular sea surface temperatures, it will be a global phenomena. On October 25, 2023, Hurricane Otis made landfall near Acapulco as a Category 5 hurricane with winds at 165 mph and caused catastrophic damage. It intensified by 115 mph within 24 hours, faster than any other hurricane in the eastern Pacific except Hurricane Patricia. The National Hurricane Center (NHC) had predicted it would make landfall as a tropical storm with 70 mph winds only 24-hours before it hit land – giving over a million people in Acapulco little warning or time to evacuate.

Hurricanes are becoming more intense, they are intensifying more rapidly, and there is now also evidence that they are more likely to stall, remaining longer over an area. This can result in a category two or three hurricane causing more damage from extreme rain, flooding, and wind than a category four or five one that moves more quickly over an area. Hurricane Harvey, which hit Houston, Texas on August 25th, 2017, is often cited as an example. Although it hit as a category four, it quickly weakened, but then stalled for days as it continued dropping rain until over 50 inches had fallen in some areas, with two cities reporting over 60 inches. As Trepanier et al. (2024) explain,

> The forward movement of a tropical cyclone [TC] can influence rainfall, storm surge height, and exposure time to high wind speeds. Storms that slow down or stall can increase total damage by prolonging the exposure time to intense conditions…. A stall is defined as a TC with a track contained in a circular area (“corral”) with a radius of ≤200 km for 72 h…. The estimated annual frequency of stalls significantly increased over the satellite era (1966–2020) by 1.5% yr^{-1}, and the cumulative frequency in the number of stalls compared to all storms also increased. Stalling storms have a significantly higher frequency of major hurricane status than nonstalling storms. Storms are also more likely to stall near the coast (≤200 km).... Potential risk will increase with continued sea level rise, population migration [to the coast], and increasing sea surface temperatures in a warmer climate. (Trepanier et al., 2024)

On September 26, 2024, Hurricane Helene hit near Perry, Florida. It had transformed from a 80-mph (130 km/hr) Category 1 hurricane (“minimal” damage expected) to a 140 mph (225 km/hr) Category 4 hurricane (“devastating” damage) in 24 hours. Although its wind speed quickly lessened, it caused catastrophic damage across Florida, Georgia, North and South Carolina, and Tennessee. Asheville, in the western part of North Caroline, and surrounding areas, received 30 inches of rain or more. As the water flowed down the Blue Ridge Mountains through narrow valleys (called “hollers” or “hollows”), the streams and rivers became raging torrents that destroyed everything in their path. As a result, Helene became the deadliest hurricane to hit the U.S. since Hurricane Katrina hit New Orleans in 2005.

Recently, scientists have suggested that it is time to start discussing a new 6th category to the Saffir-Simpson scale.

> Global warming leads to more intense tropical cyclones (TCs). Three separate lines of evidence from both observations and models suggest that the open endedness of the 5th category of the Saffir–Simpson hurricane wind scale becomes increasingly problematic for conveying wind risk in a warming world. We investigate considering the extension to a 6th category of the Saffir–Simpson hurricane wind scale to communicate that climate change has caused the winds of the most intense TCs to become significantly higher. (Wehner & Kossin, 2024)

A 6th category would make it easier to identify the most extreme tropical cyclones, but there is worry that it might lead to less fear, and thus less evasive action, when a category 5 storm is predicted. A more serious criticism of the Saffir-Simpson scale is that it takes only wind speed into consideration, while most deaths are water related (e.g., via storm surge and flooding).

Rising sea levels can dramatically increase the damage from hurricanes in some areas. For example, the extensive coastal wetlands in Louisiana serve as a buffer zone for areas further inland. In a recent study examining changes at 253 monitoring sites, almost 90% “were unable to keep up with rising water levels….Under the current climate trajectory (SSP2-4.5), drowning of ~75% of Louisiana’s coastal wetlands is a plausible outcome by 2070” (Li et al., 2024).

Excess Mortality

In the United States, there are over 100 deaths every day from car accidents. And yet most sources list deaths from hurricanes at fewer than 100 per year, and for some

years fewer than 5.[46] In a country of over 330 million, this is a tiny number. Young and Hsiang (2024), however, point out that the official numbers refer only to immediate deaths that are directly observed, and they agree with those who hypothesize that "tracking only these 'direct deaths' might misrepresent the total mortality that results from disasters, since disasters trigger complex cascades of events that ultimately may cause additional future mortality" (Young & Hsiang, 2024). The authors provide examples of complex chains of events that can impact health outcomes:

> For example, individuals may use retirement savings to repair damage, reducing future healthcare spending to compensate; family members might move away, removing critical support when something unexpected occurs years later; or public budgets may change to meet the immediate post-TC needs of a community, reducing investments that would otherwise support long-run health. (Young & Hsiang, 2024)

In addition, there are also many near-term health impacts that are not typically counted. During and immediately after a hurricane people may not be able to continue with their medicine or treatments for chronic diseases, clinics and hospitals may not be open (or it may be impossible to reach them), and the stress of losing housing or possessions can lead to multiple health problems. (See the section above on flooding for a list of other negative health outcomes.)

Young & Hsiang studied all TCs in the Continental United States (CONUS) between 1930 and 2015, focusing on the long-term effects on health and mortality.

> We observe a robust increase in excess mortality that persists for 15 years after each geophysical event. We estimate that the average TC generates 7,000–11,000 excess deaths, exceeding the average of 24 immediate deaths reported in government statistics
>
> Our estimates indicate that the current TC climate of CONUS imposes an annual burden of around 55,280–88,080 excess deaths. During the period of study, we estimate that TCs contributed to more deaths in CONUS (3.6–5.2 million) than all motor vehicle accidents (2.0 million), infectious diseases (1.9 million) or US battle deaths in wars (1.3 million). These findings point to TCs as an important and understudied contributor to health in the United States, particularly for young or Black populations.

[46] For example, see https://www.statista.com/statistics/203729/fatalities-caused-by-tropical-cyclones-in-the-us/

Extreme Sea Ice and Ice Shelf Loss and Sea Level Rise

The extent of sea ice in both the arctic and around Antarctica is rapidly declining. In September, 2023, with the end of the Antarctic winter, sea ice reached a record low. From an article in the Washington Post:

> "It's not great news," said Gail Whiteman, an expert on global risks resulting from polar climate change and professor of sustainability at the University of Exeter. "Polar ice is one of the world's biggest insurance policies against runaway climate change, and we can see in both the North and the South sea ice, we've got problems and alarm bells are ringing."[47]

Not only is there albedo feedback because darker ocean waters absorb more heat than ice, but in addition, "...sea-ice acts as an insulator between air and sea. When it retreats, it opens up for more heat and moisture exchange between the ocean and the atmosphere, and the strongest warming can be found where the sea-ice has retreated."[48] For example, Josey et al. (2024) show "that the 2023 Antarctic sea-ice loss has substantially modified air–sea interaction in the Southern Ocean….the strongest winter 2023 ice-retraction regions provide an important new source of turbulent ocean heat loss to the atmosphere in wintertime. Ice concentration in these regions (located primarily in the Weddell, Bellingshausen and Ross seas) is reduced by up to 80% and is accompanied by an unprecedented doubling of mid-winter ocean heat loss" (Josey et al., 2024).

In addition to this effect of the loss of sea ice, ice shelves in the Antarctic are incredibly important. Ice shelves are the extensions of glaciers floating on the ocean. Ice shelves stabilize large parts of the Antarctic ice sheet by "buttressing" the ice sheets and slowing their speed. When ice shelves thin they can "reduce the buttressing force provided by the ice shelf, leading to an increase in the speed of the upstream grounded ice and an increase in the ice sheet contribution to global sea level rise" (Davison et al., 2023). Davison and his coauthors "make use of high-resolution satellite datasets to produce an annual record of ice shelf mass balance and its constituent components for all Antarctic ice shelves from 1997 to 2021….Out of 162 ice shelves, 71 lost mass, 29 gained mass, and 62 did not change mass significantly" (Davison et al., 2023). What is especially concerning is that not only did almost 44% of the ice shelves lose mass, but two thirds of the ice shelves that lost mass lost more than 30% of their initial mass. This

[47] Kasha Patel (Sep. 25, 2023), "Antarctica just hit a record low in sea ice — by a lot." *Washington Post*, https://www.washingtonpost.com/climate-environment/2023/09/25/antarctica-record-low-ice-arctic-climate/

[48] Rasmus Benestad (Sep. 26 2023), Old habits, *RealClimate*, https://www.realclimate.org/index.php/archives/2023/09/old-habits/

means that the buttressing force will be reduced, and also that the reduction in mass translates to approximately 67,000 gigatons of freshwater released into the Southern Ocean.

Thinning ice sheets are one problem, while another is caused by the manner in which ice shelves melt at the ocean floor. In fact, sea level rise may happen more quickly than predicted because there are feedbacks between melting and ice geometry that are not represented in current models. “There is growing evidence suggesting that ice-sheet models lack representation of important physical processes driving ice sheet retreat, rendering their projections of sea-level rise less sensitive to climatic changes than they should be” (Bradley & Hewitt, 2024). Ice sheets in Antarctica extend from the land into the sea. The ice extends to the bottom of the ocean at first (grounded ice) and then floats on the ocean. Warm salty ocean water eats away at the grounded ice and can extend into the ice shelf via channels and tunnels. Melting at the “grounding zones” is a critical factor in determining how fast ice sheets melt.

> ...as the grounding zone widens in response to melting, both temperature and flow velocity in the region increase, further enhancing melting. We find that increases in ocean temperature can lead to a tipping point being passed, beyond which ocean water intrudes in an unbounded manner beneath the ice sheet, via a process of runaway melting.
>
> Current sea-level-rise projections for Antarctica and Greenland are based on simulations that lack grounding-zone melting via intrusion and may therefore represent underestimates.
>
> Our results point towards a stronger sensitivity of ice-sheet melting, and thus higher sea-level-rise contribution in a warming climate, than has been previously understood. (Bradley & Hewitt, 2024)

Collapse of the West Antarctic Ice Sheet

Recent research from Naughten et al. (2023) has garnered a lot of attention because of their shocking conclusion – it may be too late to prevent the collapse of the West Antarctic Ice Sheet (rather than “shocking,” they write, “sobering outlook”). No matter how much we reduce greenhouse gases, ocean warming around the West Antarctic Ice Sheet will continue, and the ice sheet will continue to lose mass and contribute to sea-level rise. The authors simulate five scenarios in their model: The Paris 1.5 °C and Paris 2 °C scenarios and the RCP 4.5 (Representative Concentration Pathways) and RCP 8.5 scenarios. This is a good range, as Naughten et al. consider both the 1.5 °C

and RCP 8.5 unrealistic. (See Figure 22 on the different RCP pathways in the section on Climate Models below.)

> We find that rapid ocean warming, at approximately triple the historical rate, is likely committed over the twenty-first century, with widespread increases in ice-shelf melting, including in regions crucial for ice-sheet stability. When internal climate variability is considered, there is no significant difference between mid-range emissions scenarios and the most ambitious targets of the Paris Agreement. These results suggest that mitigation of greenhouse gases now has limited power to prevent ocean warming that could lead to the collapse of the West Antarctic Ice Sheet. (Naughten et al., 2023)

What should we do? We should consider adaptation more seriously, Naughten et al. write, because, “The opportunity to preserve the WAIS in its present-day state has probably passed, and policymakers should be prepared for several metres of sea-level rise over the coming centuries.”

Here is some background from the Introduction of the Naughten paper:

> The West Antarctic Ice Sheet (WAIS) is losing mass and is Antarctica’s largest contributor to sea-level rise . This ice loss is driven by interactions with the Southern Ocean, particularly the Amundsen Sea region of the continental shelf seas. Enhanced basal melting of ice shelves, the floating extensions of the ice sheet, has reduced their buttressing and caused upstream glaciers to accelerate their flow towards the ocean. Continued trends in ice-shelf melting have the potential to cause irreversible retreat of the WAIS glaciers, which together contain enough ice to raise global mean sea-level by 5.3 m. (Naughten et al., 2023)

The relevance to sea level rise is clear:

> Increased ice-shelf basal melting can result in a loss of buttressing, increased mass flux across the grounding line and ultimately sea-level rise. Because our ocean simulations are not coupled to an ice-sheet model, we cannot quantify the sea-level rise contribution implied by our findings. However, we can indirectly assess their importance for sea-level rise on the basis of the spatial distribution of the basal melting trends. (Naughten et al., 2023)

There is now general consensus that sea level rise is unavoidable, although there is no scientific consensus on exactly how much sea level will rise. According to the IPCC’s most recent report:

> Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (high confidence). Global mean sea level rise will continue in the 21st century (virtually certain), with projected regional relative sea level rise within 20% of the global mean along two-thirds of the global coastline (medium confidence). The magnitude, the rate, the timing of threshold exceedances, and the long-term commitment of sea level rise depend on emissions, with higher emissions leading to greater and faster rates of sea level rise. (IPCC, 2023)

Why Sea Level Differs Around the World

As ice sheets melt and water flows into the ocean, sea level rises – but the metaphor of filling a bathtub is incorrect. The water level in a bathtub is the same everywhere (unless you're splashing or moving around!). Sea level, on the other hand, differs markedly around the world for several reasons. Water expands when it warms, and the water is much warmer in some areas than others. When the land is sinking (subsidence), the level relative to the land is higher. Wind and currents can also affect sea level. Most interesting is the question of what would happen to the sea level near Greenland if all its ice melted? The answer is counterintuitive: the sea level would actually decrease. This is because the amount of ice on Greenland and Antarctica is so great that it exerts a gravitational pull on the oceans near it. As the ice on Greenland is melting, the sea levels near it are decreasing, although of course there is a compensating rise further away.

Sea Level Rise in the Gulf States and Southeast United States

In much of the coastal areas of the gulf states and southeastern U.S., the ocean has risen over six inches in just the last 15 years, a rate that is one of the most rapid in the world. When the rising sea level is combined with a high tide and rain storms, the outcome is extensive flooding, because rivers are unable to drain. The situation is even worse in areas where there is land subsidence. These flooding events are now common, and have occurred thousands of times over the last decade. They will become much worse in the near future. You can see changes in sea level at multiple cities across eight states on the Gulf of Mexico and Atlantic coasts in an analysis by the Washington Post in an article on "The Drowning South."[49]

From the Washington Post article:

[49] Chris Mooney, Brady Dennis, Kevin Crowe, and John Muyskens (Apr, 29, 2024), The Drowning South: Where Seas are Rising at Alarming Speed, *The Washington Post*, https://wapo.st/3QvTnFR

> “The phenomenon is so new, we still don’t necessarily even have the vocabulary for it,” Christopher Piecuch, a sea level scientist at Woods Hole Oceanographic Institution, said of the unrelenting nature of flooding confronting more and more communities. “This is something that quite literally didn’t happen two decades ago.”
>
> But it undoubtedly is happening now. The number of high-tide floods is rapidly increasing in the region, with incidents happening five times as often as they did in 1990, said William Sweet, an oceanographer for the National Oceanic and Atmospheric Administration.
>
> “We’re seeing flooding in a way that we haven’t seen before,” said Sweet, who leads the agency’s high-tide flooding assessments. “That is just the statistics doing the talking.”[50]

The Impact on Coastal Infrastructure

The Union of Concerned Scientists analyzed the impact on critical coastal infrastructure under three scenarios: sea level rise of 1.6 feet, 3.2 feet, and 6.5 feet. They defined critical infrastructure “as those assets and facilities that provide functions necessary to sustain daily life, which includes schools, hospitals, public and affordable housing, energy infrastructure, and wastewater treatment plants. We also include known sites of industrial contamination that, if they were to flood, could expose people to toxic or hazardous pollutants” (Dahl et al., 2024). There are already 900 critical pieces of infrastructure that flood twice a year or more. In less than 30 years the situation will be much worse.

> The nearly 90 million people living in US coastal communities depend on an array of critical infrastructure—from the schools that students attend to the power and wastewater treatment plants that provide electricity and clean water…. between now and 2050, climate change–driven sea level rise will expose more than 1,600 critical infrastructure assets coastwide to disruptive flooding at least twice per year [under the medium scenario of 3.2 feet sea level rise by 2100]. Future flooding particularly threatens public and affordable housing. (Dahl et al., 2024)

Salt Water Intrusion

“Saltwater intrusion is the movement of saline seawater into coastal freshwater areas due to rising seas and changing coastal hydrology” (Adams et al., 2024). Saltwater intrusion is a serious problem for a wide variety of reason, including the following: it can

[50] Ibid.

contaminate drinking water, reduce agricultural productivity, lead to a loss of biodiversity and ecosystem degradation, and when water is not treated, high levels of salt can lead to hypertension, heart disease, kidney problems, and other health issues.

Adams et al. (2024) estimated “future saltwater intrusion vulnerability across 60,638 coastal watershed locations spanning the global coastline” using a global analytical modeling framework. Recharge rates refer to water entering an aquifer from surface water coming from rain, floods, or other sources. Figure 5 below shows how changes in recharge rates brought about by climate change and sea level rise work together to salinize fresh groundwater. It is an excellent schematic diagram and I recommend reading the figure caption carefully. Adams et al. (2024) summarize their findings, showing that

> … nearly 77% of global coastal areas below 60° north will undergo saltwater intrusion by 2100, with different dominant drivers. Climate-driven changes in subsurface water replenishment (recharge) is responsible for the high-magnitude cases of saltwater intrusion, whereas sea level rise and coastline migration are responsible for the global pervasiveness of saltwater intrusion and have a greater effect on low-lying areas. (Adams et al., 2024)

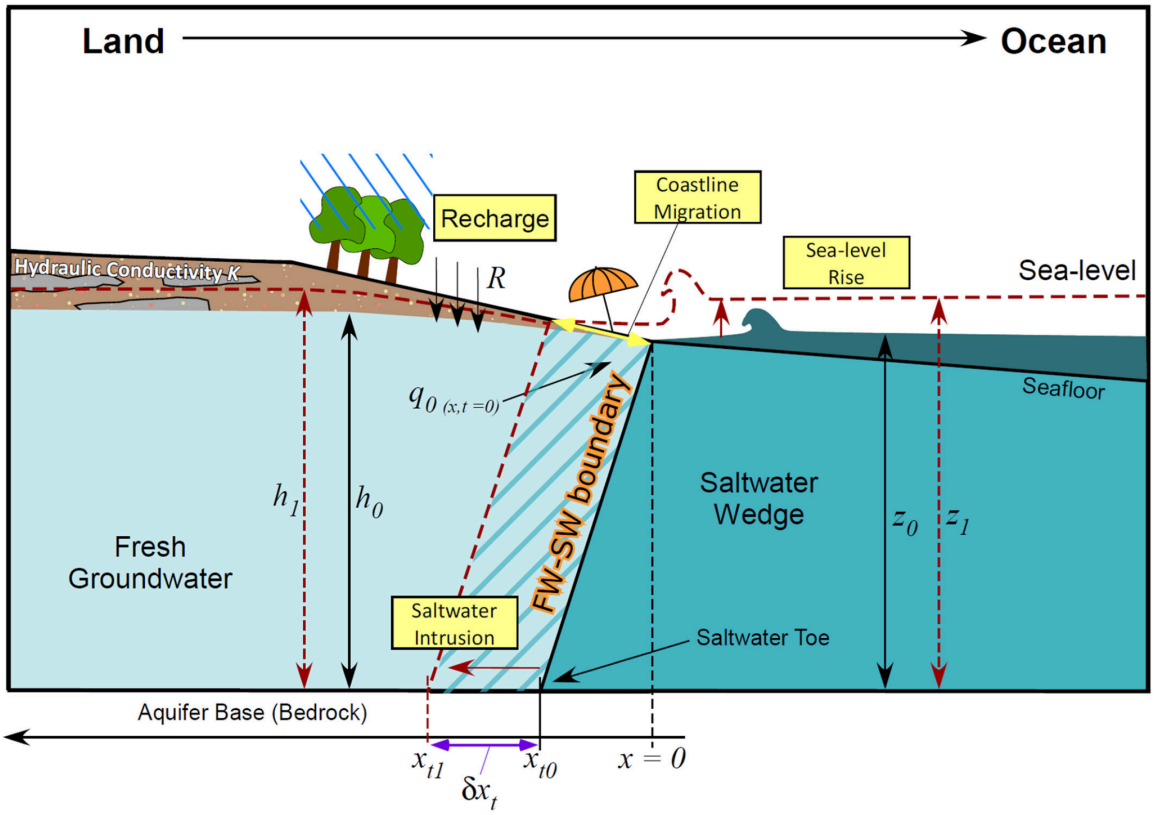


Figure 5. A Coastal Aquifer Undergoing Saltwater Intrusion

"Cross-sectional schematic diagram of a coastal aquifer undergoing saltwater intrusion. Aquifer base (bedrock) is the bottom of the figure. The aquifer is recharged onshore at a rate *R*. Fresh groundwater discharges directly to the ocean with a flux of *q*0, pushing against the saltwater wedge and defending against salinization. FW-SW (freshwater-saline water) boundary denotes the fresh-saline groundwater interface. The most landward point of the FW-SW boundary along the aquifer base is the saltwater toe (*xt*0; under script *t*0 denotes "toe" at time = 0). This toe moves from *xt*0 to *xt*1 (δ*xt*) with sea-level rise (red dotted line, *z*0 to *z*1), salinizing fresh groundwater (dashed areas) and migrating the coastline (yellow line). If given topographic space (i.e., a thick unsaturated zone), hydraulic head will also rise (*h*0 to *h*1…)." (Adams et al., 2024)

The Collapse of Ocean Currents

The gulf stream feeds into the Atlantic Meridional Overturning Circulation, or AMOC, which brings warm water from the tropics to the North Atlantic and cold water south (and is part of what is referred to as a global conveyor belt). The wind is a factor in surface currents (up to 100 meters), but there are much slower currents that occur due to thermohaline circulation, which occurs due to changes in the saltiness and temperature of the ocean, and results in changes to the water's density.

> In the Earth's polar regions ocean water gets very cold, forming sea ice. As a consequence the surrounding seawater gets saltier, because when sea ice forms, the salt is left behind. As the seawater gets saltier, its density increases, and it starts to sink. Surface water is pulled in to replace the sinking water, which in turn eventually becomes cold and salty enough to sink. This initiates the deep-ocean currents driving the global conveyer belt.[51]

A new paper predicts that there is a high probability that the AMOC will cross a tipping point and collapse this century, perhaps as soon as 2050 (Ditlevsen & Ditlevsen, 2023). In a response to the paper, Rahmstorf (2023) answers some of the criticisms and clearly lays out the consequences:

> An AMOC collapse would be a massive, planetary-scale disaster. Some of the consequences: Cooling and increased storminess in northwestern Europe, major additional sea level rise especially along the American Atlantic coast, a southward shift of tropical rainfall belts (causing drought in some regions and flooding in others), reduced ocean carbon dioxide uptake, greatly reduced oxygen supply to the deep ocean, likely ecosystem collapse in the northern Atlantic, and others. (Rahmstorf, 2023)

[51] https://oceanservice.noaa.gov/education/tutorial_currents/05conveyor1.html

Scientific predictions get more accurate over time as we collect more evidence and refine models. Rahmstorf continues his commentary, pointing out that we need to keep risks of serious collapses like this at a minimum:

> In other words: we are talking about risk analysis and disaster prevention. This is not about being 100% sure that the AMOC will pass its tipping point this century; it is that we'd like to be 100% sure that it won't. Even if there were just (say) a 40% chance that the Ditlevsen study is correct in the tipping point being reached between 2025 and 2095, that's a major change to the previous IPCC assessment that the risk is less than 10%. Even a <10% chance as of IPCC (for which there is only "medium confidence" that it's so small) is in my view a massive concern. That concern has increased greatly with the Ditlevsen study – that is the point, and not whether it's 100% correct and certain. (Rahmstorf, 2023)

van Western et al. (2024) provide additional strong evidence that the AMOC "is on tipping course" using different data and methods. The AMOC can collapse due to freshwater forcing from ice melt from the Greenland Ice Sheet, precipitation, and runoff from rivers. With respect to the Ditlevsen & Ditlevsen (2023) study mentioned above, van Western et al. suggest that, "...their estimate of the tipping point (2025 to 2095, 95% confidence level) could be accurate." The effects on the climate would be extreme, and happen very quickly.

> The AMOC collapse dramatically changes the redistribution of heat (and salt) and results in a cooling of the Northern Hemisphere, while the Southern Hemisphere slightly warms. Atmospheric and sea-ice feedbacks, which were not considered in idealized climate models studies, further amplify the AMOC-induced changes, resulting in a very strong and rapid cooling of the European climate with temperature trends of more than 3°C per decade. In comparison with the present-day global mean surface temperature trend (due to climate change) of about 0.2°C per decade, no realistic adaptation measures can deal with such rapid temperature changes under an AMOC collapse. (van Western et al., 2024).

For an excellent review of whether the AMOC is approaching a tipping point, see Ramstorf's (2024) paper in Oceanography, where he reviews paleoclimatic data, the predictions from multiple different climate models, as well as recent observational data.

Ocean Heating: Effects on Fish, Shellfish, and Coral Reefs

Over 90% of the excess heat from the greenhouse effect is absorbed by the oceans, and the effects are, and will be, devastating. Many fish species and shellfish are

impacted (including salmon, scallops, tuna, mackerel, and herring), there is ocean acidification and changes in ocean health and biochemistry, and a warming ocean, along with large quantities of fresh water from melting glaciers, will cause major changes to ocean currents. Coral reefs are where we are seeing some of the first devastating effects of climate change.

Climate Council is an independent organization in Australia focused on climate policies and solutions (https://www.climatecouncil.org.au/). In a briefing paper on the Great Barrier Reef, they summarize the situation, which is now critical:

- Thursday 14 March, 2024 marks 365 non-stop days of global ocean temperature records falling.
- Ocean heating has led to devastating bleaching of coral reefs world-wide, with widespread bleaching now occurring across the Great Barrier Reef.
- It took around 8,000 years for the Great Barrier Reef to develop. Following seven mass bleaching events, including five in the past nine years, that have repeatedly damaged this complex ecosystem, the Great Barrier Reef has most likely crossed a tipping point and is fading into a new, 'shadow state'.[52]

Continued Loss of Biodiversity

There has already been a catastrophic loss of biodiversity, and the rate of loss is accelerating. The loss of biodiversity means "reduced carbon sequestration, reduced pollination, soil degradation, poorer water and air quality, more frequent and intense flooding and fires, and compromised human health" (Bradshaw et al., 2021). Bradshaw and his coauthors make clear the enormous biodiversity loss resulting from climate change and the increase in human population:

> Since the start of agriculture around 11,000 years ago, the biomass of terrestrial vegetation has been halved, with a corresponding loss of >20% of its original biodiversity, together denoting that >70% of the Earth's land surface has been altered by *Homo sapiens*.…Population sizes of vertebrate species that have been monitored across years have declined by an average of 68% over the last five decades, with certain population clusters in extreme decline, thus presaging the imminent extinction of their species. Overall, perhaps 1 million species are threatened with extinction in the near future out of an estimated 7–10 million eukaryotic species on the planet, with around 40% of plants alone considered endangered. Today, the global biomass of wild mammals is <25% of that

[52] Verbatim from https://www.climatecouncil.org.au/wp-content/uploads/2024/03/Briefing-Paper-Underwater-Bushfire-14-March-2024-FINAL-1.pdf

> estimated for the Late Pleistocene, while insects are also disappearing rapidly in many regions.
> …
> As telling indicators of how much biomass humanity has transferred from natural ecosystems to our own use, of the estimated 0.17 Gt of living biomass of terrestrial vertebrates on Earth today, most is represented by livestock (59%) and human beings (36%) — only ~5% of this total biomass is made up by wild mammals, birds, reptiles, and amphibians. As of 2020, the overall material output of human endeavor exceeds the sum of all living biomass on Earth. (Bradshaw et al., 2021)

In a major new report by the World Wildlife Fund and the Zoological Society of London, the subtitle is, “A System in Peril” and the title of the Executive Summary is “Nature is being lost – with huge implications for us all.” It starts off with amazingly depressing statistics on the loss of wildlife populations:

> Biodiversity sustains human life and underpins our societies. Yet every indicator that tracks the state of nature on a global scale shows a decline. Over the past 50 years (1970–2020), the average size of monitored wildlife populations has shrunk by 73%, as measured by the Living Planet Index (LPI). This is based on almost 35,000 population trends and 5,495 species of amphibians, birds, fish, mammals and reptiles. Freshwater populations have suffered the heaviest declines, falling by 85%, followed by terrestrial (69%) and marine populations (56%). (WWF, 2024)

The population of wildlife species is critical for our ecosystems. “When a population falls below a certain level, that species may not be able to perform its usual role within the ecosystem – whether that’s seed dispersal, pollination, grazing, nutrient cycling or the many other processes that keep ecosystems functioning” (WWF, 2024).

Consider how a loss of seed dispersal can have a dramatic impact on carbon storage. As shown in Figure 6 below, hunting and poaching of large fruit-eating animals in the Atlantic forests in Brazil led to a change in tree species that resulted in a reduction of carbon storage.

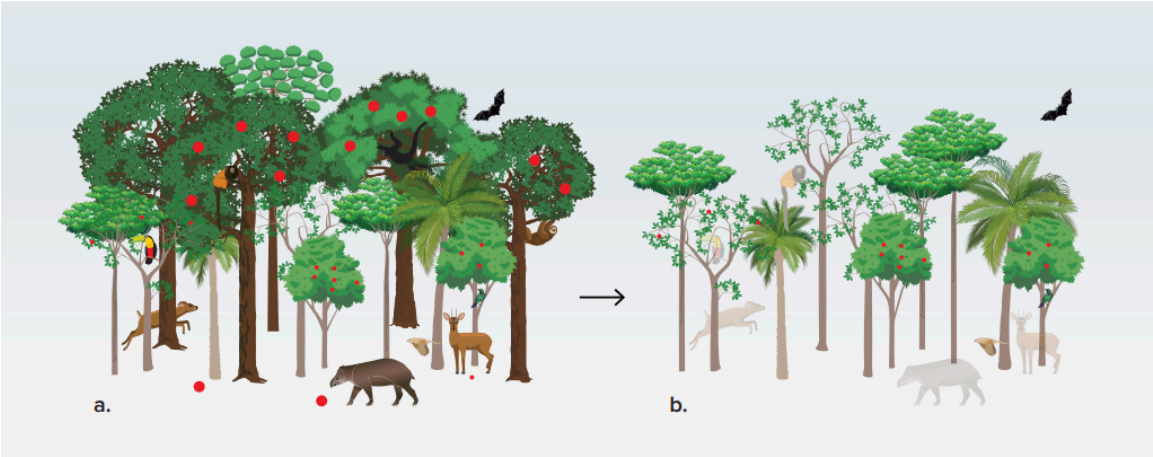


Figure 6. Hunting Can Lead to a Loss of Carbon Storage

(This is Figure 1.2 from WWF, 2024) "Losses of populations of large fruit-eating animals by hunting in tropical forests lead to a decline in forest carbon storage, exacerbating climate change. (a) When large animals such as the Brazilian tapir, the green-billed toucan, the black-faced lion tamarin, and the grey brocket deer that eat large fruit (indicated by red dots) are hunted and their populations decline, the large fruits and seeds that they eat are no longer dispersed throughout the forest. Since the trees in this forest that store more carbon also have larger fruits and seeds, the forest loses the carbon-dense, hardwood tree species over time (indicated in dark brown trunks). (b) The resulting forest is dominated by carbon-poor, softwood tree species with small fruits and seeds that store less carbon (indicated in light brown trunks). Figure adapted from Bello et al. 2015."

It is obvious that we are altering or destroying natural ecosystems by clear cutting, strip mining, damming rivers, draining marshlands, expanding agricultural land, and especially by expanding urban and suburban areas. The example above shows, in contrast, how even relatively subtle changes can have dramatic impacts.

The Spread of Infectious Diseases

Many factors contribute to the distribution and frequency of vectorborne diseases, but climate change is certainly important, primarily by increasing temperatures at moderate latitudes and higher elevations. The IPCC has already concluded that vectorborne diseases have increased, and that malaria, dengue, Lyme disease, and West Nile virus will continue to increase in the future. As Thomson et al. (2022) conclude in an article in the New England Journal of Medicine,

> Climate change has substantial effects on pathogens, vectors, and reservoir hosts, with implications for the health sector worldwide. Many vectors are already expanding their latitude and altitude ranges, and the length of season during which they are active is increasing; these trends are expected to continue as the climate continues to warm. (Thomson et al., 2022)

In a recent meta-analysis examining risks of infectious disease, Mahon et al. (2024) conclude that many anthropogenic changes, and not just those associated directly with climate change, are contributing to the increase in infectious diseases. “Studies have shown,” they write, “that infectious disease risk is modified by changes to biodiversity, climate change, chemical pollution, landscape transformations and species introductions” (Mahon et al., 2024).

Biodiversity loss in the oceans will be just as severe as on the land. Consider just acidification: The current rates of ocean acidification are faster now than in the last 300 million years, and the effects will be dramatic, and relatively swift. A 2°C increase will lead to acidification levels in polar oceans that will likely be devastating to marine organisms.

> All 2°C emissions pathways lead to CO_2 levels in the atmosphere well above 450 ppm, the critical level for polar oceans identified decades ago by marine scientists. The Arctic and Southern Oceans are bearing the brunt of acidification impacts because they absorb CO_2 faster. At these CO_2 levels, peaking near 500 ppm in the atmosphere, the near-polar oceans, especially the Barents, North and Baltic seas, also would have acidification levels rivaling that of the poles. Shell-building animals, and commercial fisheries that rely on them in the food chain – valuable species such as krill, cod, salmon, lobsters, king crab, to name just a few – may not survive in the wild or even in fish farms …. These “overshoot” corrosive conditions, set by peak atmospheric CO_2 levels, are essentially irreversible, lasting tens of thousands of years. (ICCI, 2023)

Extreme Shortages of Fresh Water

Water is critical for food and meat production, producing electricity, industrial production, and of course basic human needs. When a country is in extreme water stress, it is using at least 80% of its supply, which can lead to a crisis when there is a drought or the population increases. Here is the key finding from a new data analysis from the Aqueduct™ 4.0 water risk framework:

> The world is facing an unprecedented water crisis. New data from WRI’s Aqueduct Water Risk Atlas finds that 25 countries – one-quarter of the world’s population - are currently exposed to extremely high water stress annually. Globally, around 4 billion people, half the world’s population are exposed to water stress for at least one month a year. By 2050, that number could be closer to 60%. (Kuzma et al., 2023)

Many serious water problems are caused by mismanagement and then exacerbated by climate change. The Aral Sea is a prime example, as it was once the fourth-largest lake in the world, but started drying up after the Soviet Union began diverting water from the rivers that fed it. Most of the lake is now gone, and what used to be the eastern basin is now the Aralkum Desert. The effects on the ecology and economy of the region have been devastating.[53]

Current predictions with respect to mountain glaciers and snow cover will lead to dramatic negative effects on freshwater supplies.

> 2°C will result in extensive, long-term, essentially irreversible ice loss from many of the world's glaciers in many major river basins, with some disappearing entirely. Snow cover also will greatly diminish.
>
> If 2°C warming is reached, projections show that nearly all tropical glaciers (north Andes, Africa) and most mid-latitude glaciers outside the Himalayas and polar regions will disappear, some as early as 2050. Others are large enough to delay complete loss until the next century, but have already passed a point of no return. Even the Himalayas are projected to lose around 50% of today's ice at 2°C.
>
> Losses in both snowpack and glacier ice will have dramatic impacts on downstream dry season water availability for agriculture, power generation, and drinking. Impacts may be extreme in especially vulnerable river basins, such as the Tarim in northwest China and the Indus. (ICCI, 2023).

Greenhouse Gases

The three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[54]

> The latest analysis of observations from the WMO [World Meteorological Organization] Global Atmosphere Watch (GAW) in situ observational network shows that the globally averaged surface concentrations for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2022, with CO_2 at 417.9±0.2 ppm, CH_4 at 1923±2 ppb and N_2O at 335.8±0.1 ppb. These values constitute, respectively, increases of 150%, 264% and 124% relative to pre-industrial (before 1750) levels. (WMO Greenhouse Gas Bulletin, 2023)

[53] Search for "Aral sea ecological disaster" or something similar to find a variety of articles.
[54] There are four other greenhouse gases covered by the Kyoto Protocol: Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6), and Nitrogen trifluoride (NF_3).

Note that water vapor is also a greenhouse gas, because it absorbs long-wavelength infrared radiation from the Earth and radiates some of it back to the Earth. As temperature rises, the amount of water vapor also rises, which results in one of the most important positive feedback loops. For an article on "The History of Carbon Dioxide Emissions" by the World Resources Institute, including excellent visualizations, see https://www.wri.org/insights/history-carbon-dioxide-emissions.

Carbon dioxide emissions continued to rise in 2023 and then in 2024. According to Carbon Brief,

> Carbon dioxide (CO_2) emissions from fossil fuels and cement will rise around 0.8% in 2024, reaching a record 37.4bn tonnes of CO_2 ($GtCO_2$), according to the 2024 Global Carbon Budget report by the Global Carbon Project.
>
> Total CO_2 emissions, which include land-use change, are also expected to reach record highs at 41.6$GtCO_2$, or 2.0% above the previous record set in 2023.
>
> This large increase was driven both by consistent growth in fossil-fuel emissions and abnormally high land-use emissions in 2024 – due in part to wildfires in South America exacerbated by a strong El Niño event and high temperatures.
>
> Global land-use emissions stem from deforestation, degradation, loss of peatlands and harvesting trees for wood.[55]

Carbon dioxide remains in the atmosphere for hundreds of years, so it's important to look at both historical and current emissions. Historically, the United States has emitted more CO_2 than any other country, and is responsible for almost a quarter of the CO_2 currently in the atmosphere. China comes in second in the total amount, and is currently the largest polluter by far, emitting twice as much as any other country. This is evident from Figure 7 below.

[55] https://www.carbonbrief.org/analysis-global-co2-emissions-will-reach-new-high-in-2024-despite-slower-growth/

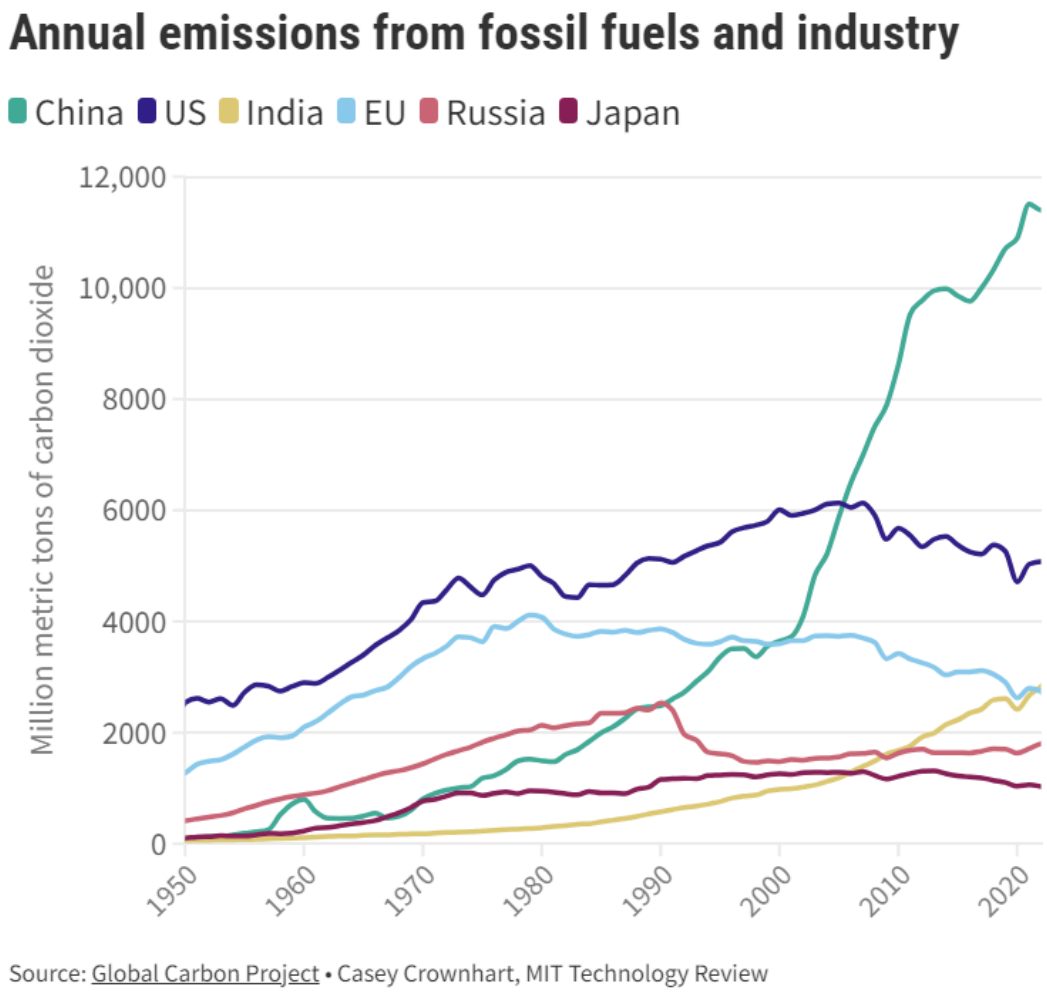


Figure 7. Annual Emissions from Fossil Fuels and Industry[56]

Coal

Burning coal is the worst thing we can do with respect to greenhouse gas emissions, air pollution, and environmental damage, and much has been made of the transition in some areas from burning coal to natural gas. Coal power plants, however, are still being built at an increasing rate in China, currently the world's largest greenhouse gas emitter. Here are the disturbing results from a recent report by the Centre for Research on Energy and Clean Air (CREA) and the Heinrich Böll Foundation:

> Investments in coal-based power capacity have accelerated. Since the start of 2022, Chinese authorities have granted permits to 152 gigawatts (GW) and started construction on 92 GW of new coal power capacity. Even if we assume existing coal capacity will be retired at an accelerated pace, China's coal-fired

[56] https://www.technologyreview.com/2024/11/20/1107015/global-climate-emissions/

> power capacity is still on track to increase 23% by 2030 from existing levels. (Myllyvirta et al., 2023)

To put the 152 gigawatt figure in perspective, the average nuclear power plant produces 1 gigawatt, while most power plants in the United States generate less than half a gigawatt.

On a (slightly) positive note, some new coal-fired power plants in China are being designed to make it easy to replace them with small modular nuclear reactors in the future. Xu et al. (2022) also present research that "...provides the technical and economic foundation for retrofit decarbonization of coal plants by nuclear reactors (specifically HTR-PM) to major public utilities in China that are currently operating or constructing coal plants."[57]

None of This is New

Many point to James Hansen's testimony before congress on June 23, 1988 as the first significant warning about the dangers of climate change,[58] but five years earlier, in 1983 (40 years ago!) Seidel (1983), an EPA scientist, published a long, detailed report with the title, "Can we delay greenhouse warming?"[59] In the early 1980s the relationship between greenhouse gases and climate change was clear, but scientists were warning of negative consequences in the 1950s. For example, the physical oceanographer Roger Revelle testified before congress in 1956 and 1957. During his second appearance he said,

> The last time that I was here I talked about the responsibility of climatic changes due to the changing carbon dioxide content of the atmosphere and you will remember that I mentioned the fact that during the last 100 years there apparently has been a slight increase in the carbon dioxide because of the burning of coal and oil and natural gas….in the future… southern California and a

[57] From Wikipedia: "The HTR-PM… is a Chinese small modular nuclear reactor. It is a high-temperature gas-cooled (HTGR) pebble-bed generation IV reactor evolved from the HTR-10 prototype. The technology is intended to replace coal-fired power plants in China's interior, in line with the country's plan to reach carbon neutrality by 2060."

[58] From Wikipedia, quoting the NYTimes article published the day after the testimony: "Hansen testified that 'Global warming has reached a level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and observed warming...It is already happening now'." (https://en.wikipedia.org/wiki/James_Hansen#:~:text=Climate%20change%20activism-,US%20Senate%20committee%20testimony.Resources%20on%20June%2023%2C%201988)

[59] The abstract, with warnings similar to those we still hear today, is included in Appendix 4. As an interesting aside, Seidel thanks Hansen for his assistance in the acknowledgments of his paper.

good part of Texas, instead of being just barely livable as they are now, would become real deserts.[60]

As far back as the 1880s there were newspaper articles about how the “pollution of the air” from the burning of coal and the carbon dioxide it produced would produce a “marked change on the climate of the world”. You can find copies of these newspaper articles, and much more, in Brad Johnson’s, “A Timeline of Climate Science and Policy,” which starts with an entry from 1856.[61]

The Future

The climate in our future will depend on how quickly we can reduce our use of fossil fuels, but many changes are already irreversible. Whatever we do, the oceans, which currently absorb most of the excess heat energy in our Earth system, will continue to influence climate for hundreds of years because there are extreme thermal lags, and “The heat energy eventually re-enters the rest of the Earth system by melting ice shelves, evaporating water, or directly reheating the atmosphere.”[62]

Glacial-interglacial cycles are a natural part of Earth’s climate, but we may now be leaving the past cycles and heading toward a new, and dangerous, pathway to a “Hothouse Earth” climate. Our continued use of fossil fuels is an important driver of this potential change to a new trajectory, but when we cross a number of tipping points, and feedback loops become more important, the Earth will then continue to heat even if we are able to reduce our use of fossil fuels. The continued loss of biodiversity is also critical, and all of these topics will be discussed in this section on the future. Cascading effects and compound hazards can make the situation even worse, leading to armed conflict and the eventual collapse of human societies.

Ocean Heat Content

Over 90% of the extra energy from global warming is taken up by the oceans. Although heat mixes rapidly down to about 150 feet, it can take over a thousand years for heat to mix completely throughout the ocean. This creates a long thermal lag. Even if we completely eliminate all greenhouse gas emissions and remove millions of tons of carbon dioxide from the atmosphere, sea level will continue to rise, probably for hundreds of years, as the oceans will continue to release the heat they have been accumulating. Glaciers and ice sheets will continue to melt, while land and atmospheric

[60] https://www.hillheat.com/articles/2020/09/10/in-1957-climate-scientist-warned-congress-the-continued-burning-fossil-fuels-could-turn-california-into-a-desert
[61] https://climatebrad.medium.com/climate-hearings-af27a3886a43
[62] https://www.climate.gov/news-features/understanding-climate/climate-change-ocean-heat-content

temperature will drop only slightly during this time. We can prevent the world from heating up to an extreme state via rapid decarbonization, but the Earth will not cool by itself after we stop burning fossil fuels. We can cool the Earth via geoengineering, but without additional research and testing, this may have devastating consequences, as described in a separate section below.

Consider the recent projections on sea-level rise:

> The most recent projections show a slow, but continuing pattern of sea-level rise (SLR) for many centuries even with “low emissions” (SSP1-2.6). This is an emissions pathway that peaks at 1.8°C and returns close to 1.6°C by 2100; yet the models show SLR continuing at this slow pace, indicating some level of ice loss has been irreversibly triggered even by this brief period of overshoot. (International Cryosphere Climate Initiative, ICCI, 2023)

Our inability to act decisively on a global scale means that this low emission pathway is already out of our reach.

Glacial-Interglacial Cycles and Possible Future Trajectories

During the last million years, the Earth has gone through multiple glacial-interglacial cycles following similar “trajectories.” We may now be headed on a new, dangerous, and unprecedented trajectory. In the following passages, Steffen et al. (2018) describe our future in terms of this new trajectory (which is illustrated in Figures 8 and 9 below).

> Earth System dynamics can be described, studied, and understood in terms of trajectories between alternate states separated by thresholds that are controlled by nonlinear processes, interactions, and feedbacks. Based on this framework, we argue that social and technological trends and decisions occurring over the next decade or two could significantly influence the trajectory of the Earth System for tens to hundreds of thousands of years and potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be inhospitable to current human societies and to many other contemporary species.
>
> The Anthropocene represents the beginning of a very rapid human-driven trajectory of the Earth System away from the glacial–interglacial limit cycle toward new, hotter climatic conditions and a profoundly different biosphere.
>
> In the future, the Earth System could potentially follow many trajectories, often represented by the large range of global temperature rises simulated by climate

> models. In most analyses, these trajectories are largely driven by the amount of greenhouse gases that human activities have already emitted and will continue to emit into the atmosphere over the rest of this century and beyond—with a presumed quasilinear relationship between cumulative carbon dioxide emissions and global temperature rise. ***However, here we suggest that biogeophysical feedback processes within the Earth System coupled with direct human degradation of the biosphere may play a more important role than normally assumed, limiting the range of potential future trajectories and potentially eliminating the possibility of the intermediate trajectories.*** [Emphasis added]
>
> Beyond this threshold [2°C], intrinsic biogeophysical feedbacks in the Earth System could become the dominant processes controlling the system's trajectory. Precisely where a potential planetary threshold might be is uncertain. We suggest 2°C because of the risk that a 2°C warming could activate important tipping elements, raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures. Such cascades comprise, in essence, the dynamical process that leads to thresholds in complex systems.
>
> This analysis implies that, even if the Paris Accord target of a 1.5°C to 2.0°C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly onto a "Hothouse Earth" pathway. (Steffen et al., 2018)

Note that the "next decade or two" will be critical, and we have already gone through more than half a decade since this paper was published. Also note that many scientists now suggest that it is unlikely we can stay below 2°C, a potential threshold that, once crossed, may lead to the "Hothouse Earth" pathway. In the rest of this paper, I'll explore some of the biogeophysical feedbacks mentioned above, and support the claim that we're now on a trajectory toward a new and dangerous state. Unfortunately, it is likely that we are about to cross – or have already crossed – the "planetary threshold" that Steffen et al. mention.

Consider Figures 8 and 9 below: These two figures, from Steffen et al. (2018), may seem intimidating at first, but I encourage you to take the time to read the notes under them and study them for a few minutes. They really provide an excellent framework for thinking about our current environmental crisis. Another informative way to describe future temperature risks and trajectories is in Figure 10 below.

Possible Future Pathways

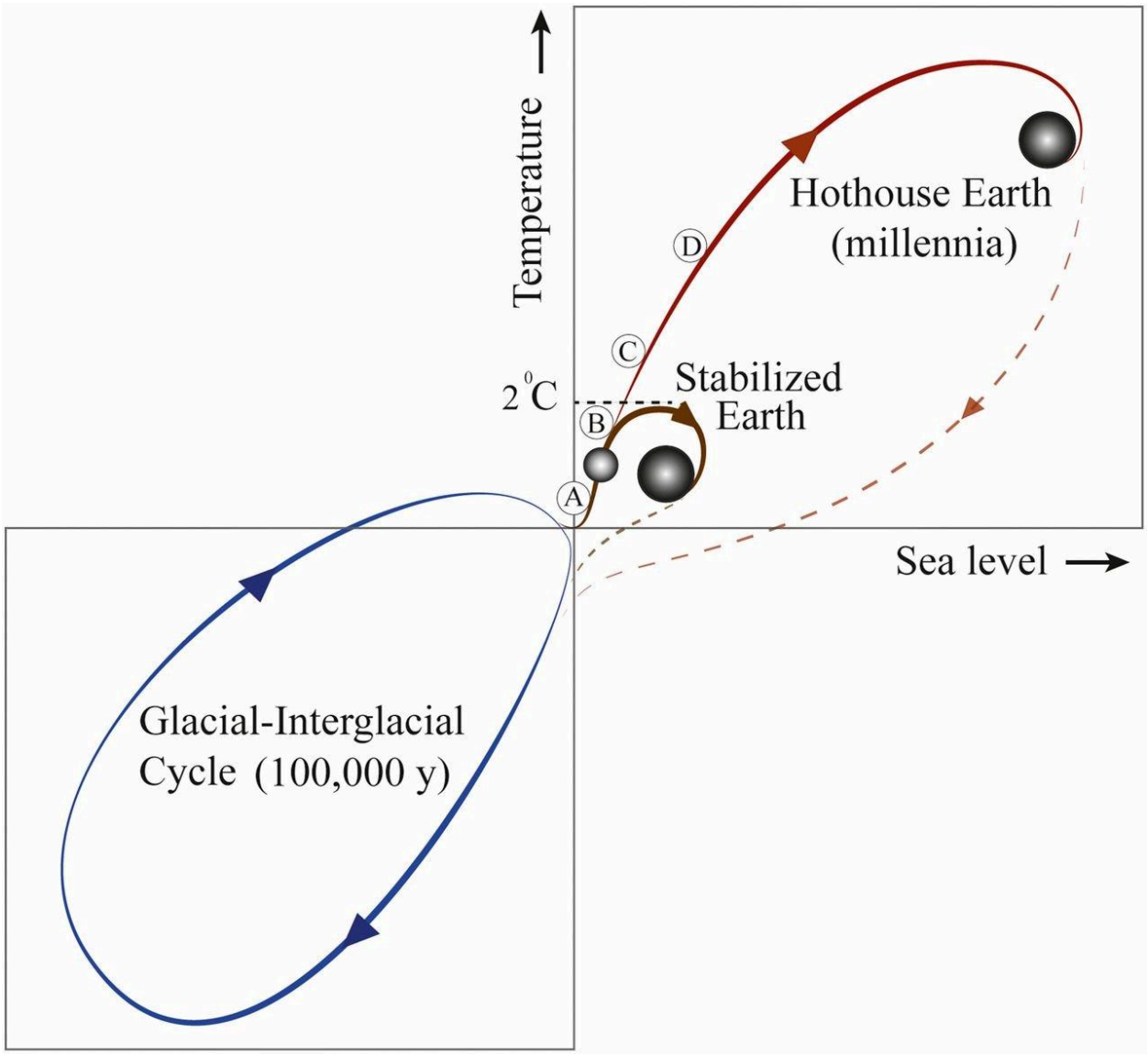


Figure 8. Possible Future Pathways

(Figure 1 from Steffen et al., 2018.) *"A schematic illustration of possible future pathways of the climate against the background of the typical glacial–interglacial cycles (Lower Left). The interglacial state of the Earth System is at the top of the glacial–interglacial cycle, while the glacial state is at the bottom. Sea level follows temperature change relatively slowly through thermal expansion and the melting of glaciers and ice caps. The horizontal line in the middle of the figure represents the preindustrial temperature level, and the current position of the Earth System is shown by the small sphere on the red line close to the divergence between the Stabilized Earth and Hothouse Earth pathways. The proposed planetary threshold at ~2 °C above the preindustrial level is also shown. The letters along the Stabilized Earth/Hothouse Earth pathways represent four time periods in Earth's recent past that may give insights into positions along these pathways: A, Mid-Holocene; B, Eemian; C, Mid-Pliocene; and D, Mid-Miocene. Their positions on the pathway are approximate only. Their temperature ranges relative to preindustrial are given in SI Appendix, Table S1."*

Pathways of the Earth System out of the Holocene

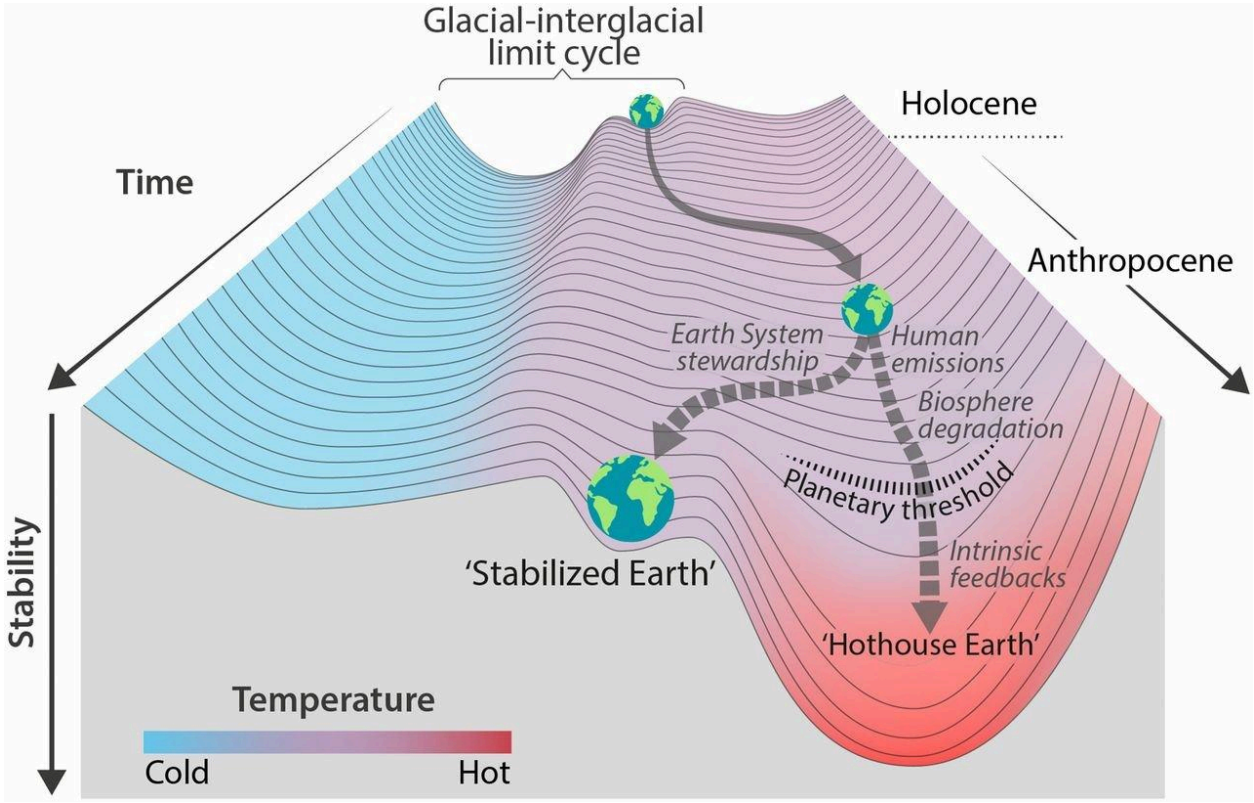


Figure 9. Pathways of the Earth System Out of the Holocene

(Figure 2 from Steffen et al., 2018.) *"Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 [Figure 2 above in this paper] is shown here as the two divergent pathways of the Earth System in the future (broken arrows). Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ~2 °C (horizontal broken line at 2 °C in Fig. 1), beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have low potential energy, and considerable energy is required to move them out of this stable state. Systems in an unstable state (top of a hill) have high potential energy, and they require only a little additional energy to push them off the hill and down toward a valley of lower potential energy."*

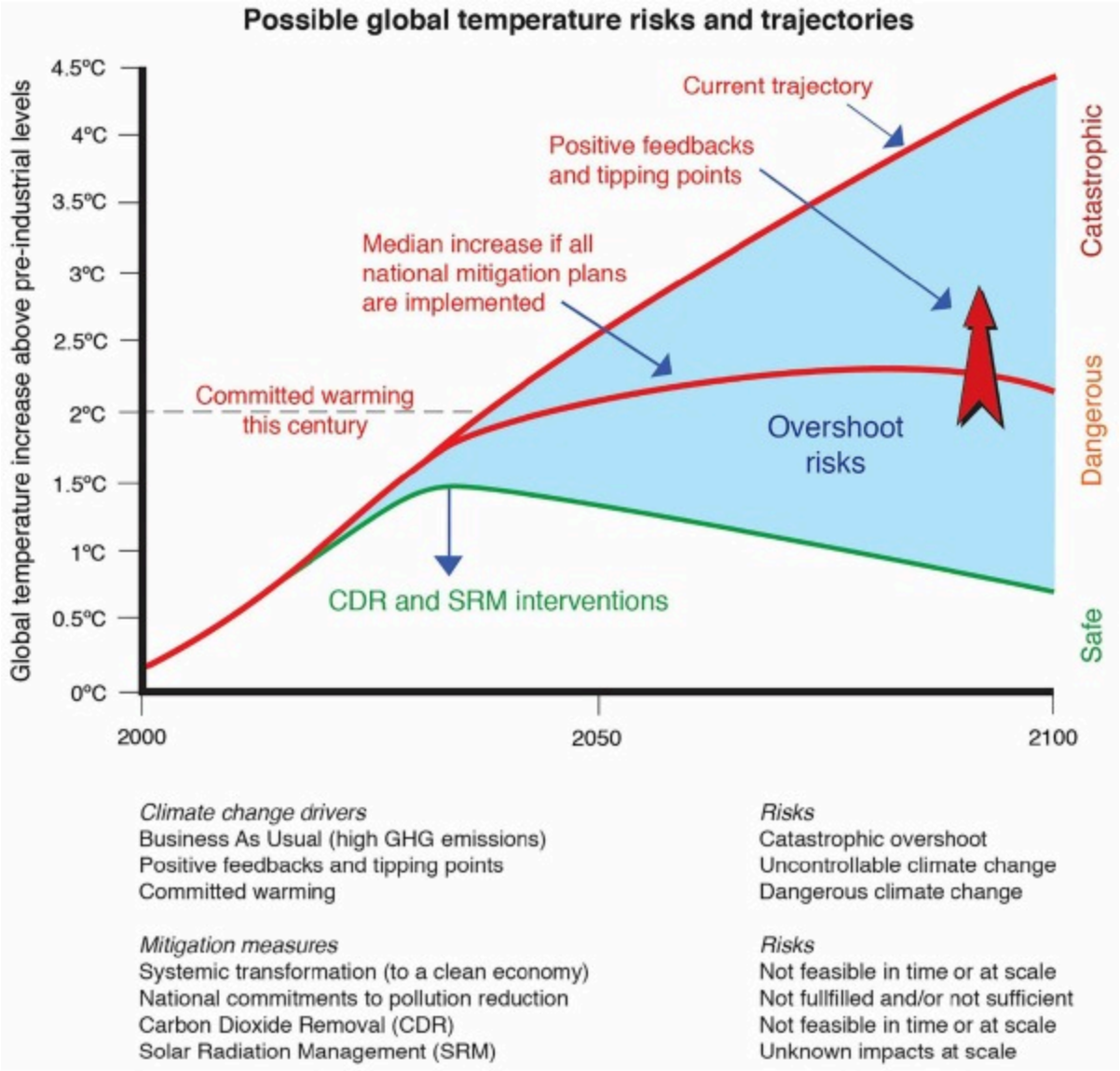


Figure 10. Possible Global Temperature Risks and Trajectories

(Figure 1 from Taylor et al. (2023b.) *"Possible global temperature risks and trajectories. Taylor and Vink, 2021.")*

The only way to prevent disaster and enter a safe state, according to Taylor et al. (2023b), is via CDR and SRM (carbon dioxide removal and solar radiation management, which are described later in this paper).

Tipping Points and Feedback Loops

Climate "tipping points" (CTP) are "critical thresholds where a certain degree of change triggers self-accelerating and potentially irreversible cascades of changes" (WMO Greenhouse Gas Bulletin, 2023). Tipping points are accelerated by positive feedback, and, "This type of behaviour in which the system gets into a phase of self-reinforcing

(runaway) change is often referred to as 'critical transition'" (Flores et al., 2024). What makes tipping points so dangerous is that when one is crossed a system can flip from one state to another, and there may be no way to return to the previous state. For example, after permafrost thaws it continues emitting CO_2 and methane even when the temperature drops below zero. In fact, when "These emissions are irreversibly set in motion," they "will not slow for 1–2 centuries, meaning that future generations must offset them (draw down carbon) at scales the size of a major emitter" (ICCI, 2023). In another example, when deforestation in a part of the Amazon rainforest reaches a certain threshold, it may transform into a dry savannah and this, in turn, can have profound effects on global weather patterns. As described by an editorial in the Washington Post on December 6, 2023:

> Today, roughly 17 percent of the Amazon is gone and more than 75 percent of what remains has been weakened. As trees disappear, the Amazon's ability to return moisture to the atmosphere declines, leading to less rainfall, higher temperatures and a dry forest. Unless levels of deforestation drop dramatically, this feedback loop could transform over half of the Amazon into savanna within decades.[63]

Flores et al. (2024) explain how critical the Amazon is for our climate.

> The Amazon forest holds more than 10% of Earth's terrestrial biodiversity, stores an amount of carbon equivalent to 15–20 years of global CO_2 emissions (150–200 Pg C), and has a net cooling effect (from evapotranspiration) that helps to stabilize the Earth's climate. The forest contributes up to 50% of rainfall in the region and is crucial for moisture supply across South America…. (Flores et al., 2024)

Flores et al. (2024) examine five critical drivers of water stress: global warming (with a critical threshold of 2 ºC), annual rainfall (1,000 mm), rainfall seasonality intensity (–450 mm), dry season length (eight months), and accumulated deforestation (20% deforested).

> By combining spatial information on various disturbances, we estimate that by 2050, 10% to 47% of Amazonian forests will be exposed to compounding disturbances that may trigger unexpected ecosystem transitions and potentially exacerbate regional climate change….Although most recent models agree that a large-scale collapse of the Amazon forest is unlikely within the twenty-first

[63] Editorial Board (Dec. 7 2023), Here's a realistic path to protecting the Amazon rainforest, *The Washington Post,* https://wapo.st/47V4Fd0

> century, our findings suggest that interactions and synergies among different disturbances (for example, frequent extreme hot droughts and forest fires) could trigger unexpected ecosystem transitions even in remote and central parts of the system. (Flores et al., 2024)

The Amazon is amazing, but it's certainly not the only region under threat. Changes in large parts of the climate system are now occurring that could lead to the crossing of up to 15 tipping points, and it's possible that the West Antarctic ice sheet may have already passed a tipping point. "Current global warming of ~1.1°C above pre-industrial already lies within the lower end of five CTP uncertainty ranges. Six CTPs become likely (with a further four possible) within the Paris Agreement range of 1.5 to <2°C warming, including collapse of the Greenland and West Antarctic ice sheets, die-off of low-latitude coral reefs, and widespread abrupt permafrost thaw" (McKay et al., 2022). In addition, "Crossing these CTPs can generate positive feedbacks that increase the likelihood of crossing other CTPs." Cascading tipping points are discussed in a section below (Compound Hazard Analyses and Cascading Effects).

Randers & Goluke (2020), using the ESCIMO[64] climate model, report that

> …the world is *already* past a point-of-no-return for global warming. In ESCIMO we observe self-sustained thawing of the permafrost for hundreds of years, even if global society stops all emissions of man-made GHGs immediately.… The thawing (in ESCIMO) is the result of a continuing self-sustained rise in the global temperature. This warming is the combined effect of three physical processes: (1) declining surface albedo (driven by melting of the Arctic ice cover), (2) increasing amounts of water vapour in the atmosphere (driven by higher temperatures), and (3) changes in the concentrations of the GHG in the atmosphere (driven by the absorption of CO_2 in biomass and oceans, and emission of carbon (CH_4 and CO_2) from thawing permafrost). This self-sustained, in the sense of no further GHG emissions, thawing process (in ESCIMO) is a causally determined, physical process that evolves over time. It starts with the man-made warming up to the 1950s, leading to a rise in the amount of water vapour in the atmosphere—further lifting the temperature, causing increasing release of carbon from thawing permafrost, and simultaneously a decline in the surface albedo as the ice and snow covers melts. To stop the self-sustained warming in ESCIMO, enormous amounts of CO_2 have to be extracted from the atmosphere.

[64] ESCIMO: Earth System Climate Interpretable Model

In a major review of tipping elements, Wang et al.(2023) come to a somewhat less pessimistic view, arguing that most tipping elements will not lead to abrupt changes to the climate within the very near future.[65] However, they also write that "Overall, even considering remaining scientific uncertainties, tipping elements will influence future climate change and may involve major impacts on ecosystems, climate patterns, and the carbon cycle starting later this century" (Wang et al., 2023).

As reported above, Canadian forests have already crossed a tipping point, now being a source for carbon rather than a "sink" (a sink would mean that they absorb more carbon than they release). Details from a new paper on the Atlantic Meridional Overturning Circulation, or AMOC, are also included above; the AMOC brings warm water from the tropics to the North Atlantic and cold water south. It now seems possible that the AMOC may cross a tipping point and collapse as soon as 2050, with devastating consequences.

McKay, the lead author on the influential 2022 study cited above, has recently been working as part of a large team, led by Tim Lenton, from the University of Exeter, to summarize the literature on tipping points (Lenton et al., 2023a). The project is funded by the Bezos Earth Fund, and was released during COP28. It is aimed at a non-academic audience, and is an excellent and comprehensive summary of the existing literature, filled with interesting charts and figures. The report spends significant space describing all the positive tipping points in social, political, and economic systems that can still save us, but is very Pollyannaish in its overall outlook.[66]

Feedback Loops

Amplifying climatic feedback loops are one of the main reasons why pessimism is warranted.[67] "An amplifying, or positive, feedback on global warming is a process whereby an initial change that causes warming brings about another change that results in even more warming. Thus, it amplifies the effects of climate forcings — outside influences on the climate system such as changes in greenhouse gas concentrations. In part because of positive climate feedbacks, a very rapid drawdown in emissions will be required to limit future warming" (Ripple et al., 2023b). As discussed later in this paper, a rapid drawdown is theoretically possible but extremely unlikely to happen in the near future. Ripple et al. (2023b) discuss 27 positive (reinforcing) feedback loops. The most

[65] Although published in 2023, given publication lags, the Wang et al. paper does not review the most recent 2023 Ditlevsen paper on the collapse of the AMOC, although it does cite an older paper by Lohmann & Ditlevsen, 2021.

[66] The authors obviously focused on trying to make the report readable and visually interesting to non-scientists, but there are so many introductions and summaries and main points and key messages that the overall organization lacks cohesion.

[67] The IPCC publishes papers titled, *Reasons for Concern*, but it would be more apt to call these, *Reasons for Pessimism*.

commonly reported physical feedback is the melting of sea ice in the Arctic as the climate warms. Water has a lower albedo (reflectivity) than ice, so when sea ice melts more energy is absorbed by the ocean rather than being reflected back into space. In addition, as the Arctic warms there is a biological feedback as permafrost thaws, releasing carbon dioxide and methane into the atmosphere, which leads to further warming. At some point – and no one knows when this point will be reached – even if humans stop releasing greenhouse gases, these amplifying feedback loops will result in the crossing of one or more tipping points and there will be increased warming independent of human activities.

Loss of sea ice results in one of the most powerful feedback effects, and is resulting in the loss of our “global refrigerator.” This is why the Arctic and Antarctic are warming twice as fast as the rest of the planet.

> Why 2°C is Too High for Sea Ice: By 2°C, the Arctic Ocean will be sea ice-free in summer not occasionally, but almost every year; and for periods of up to four months (July-October).... Open water in the Arctic for several months will absorb more heat from polar 24-hour sunlight conditions. A warmer Arctic will increase coastal permafrost thaw – adding more carbon to the atmosphere – and speed Greenland Ice Sheet melt and resulting sea-level rise.
>
> Arctic sea ice serves as a “global refrigerator” and is an important regulator of the Earth’s temperature. This large area of ice-covered ocean — the size of the U.S. and Russia combined — reflects most of the sun’s rays back into space during the entire 6-month polar summer “day,” cooling the planet. In contrast to reflective sea ice and snow, the darker open ocean water absorbs heat, amplifying Arctic and overall global warming. Sea ice has served this cooling role in the climate system almost continuously for at least the past 125,000 years. (ICCI, 2023)

Although Ripple et al. (2023b) provide a comprehensive list of feedback loops, including 27 positive ones, new positive feedback loops are still being discovered or predicted. For example, de Vrese et al. (2024) postulate that there is a permafrost cloud feedback that may amplify climate change. In the Arctic and subarctic, when there is a thawing of frozen soils, water can move through the ground more easily and the ground then becomes drier.

> While rising temperatures in the continuous permafrost zone may lead to an initial increase in thaw lakes, moisture storage capacity, runoff and evapotranspiration, advanced permafrost thaw ultimately facilitates the drying of the landscape.

> [De Vrese et al.] show that such a drying increases regional temperatures via an atmospheric feedback: During the warm season, dryer conditions at the surface reduce the moisture transport into the atmosphere. This decreases the relative humidity in the boundary layer and the low-altitude cloud cover. Since clouds reflect more sunlight than the snow-free land surface, the reduced cloudiness increases the available energy, hence, temperatures and advances the thawing of the ground. (de Vrese et al., 2024)

The reasoning here is straightforward and makes sense, but note that this feedback is based on an Earth System model simulation, and has not been directly observed or measured. Although permafrost covers only a small percentage of the Earth's surface, the results "strongly suggest" that this feedback "may exert a substantial impact on global climate."

Scientists currently have little detailed knowledge of many feedback loops, which is another reason, discussed below, that current predictions are an underestimate of future warming. Note that the Arctic is warming much faster than the rest of the planet, and when the Earth reaches 2°C above pre-industrial levels the Arctic will reach somewhere between 4° and 8°C (ICCI, 2023).

> There are even more uncertain feedbacks, which, in a very worst case, might amplify to an irreversible transition into a "Hothouse Earth" state …. In particular, poorly understood cloud feedbacks might trigger sudden and irreversible global warming....For instance, recent simulations suggest that stratocumulus cloud decks might abruptly be lost at CO_2 concentrations that could be approached by the end of the century, causing an additional ~8°C global warming. (Kemp et al., 2022)

Although the three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), water vapor is also a greenhouse gas, and as temperature rises, the amount of water vapor also rises, which results in one of the most important positive feedback loops. There are other ways that water vapor can enter the atmosphere. The Hunga Tonga-Hunga Ha'apai underwater volcano erupted on January 15, 2022 with tremendous force, ejecting 146 million tons of water into the stratosphere. The water vapor released will contribute to warming for up to 10 years.[68]

[68] Wikipedia, https://en.wikipedia.org/wiki/2022_Hunga_Tonga%E2%80%93Hunga_Ha%CA%BBapai_eruption_and_tsunami#cite_note-OCallaghan-60

Compound Hazard Analyses and Cascading Effects

Risk assessments rarely focus on what might happen when events interact and risks cascade and spread dramatically.

> A thorough risk assessment would need to consider how risks spread, interact, amplify, and are aggravated by human responses, but even simpler "compound hazard" analyses of interacting climate hazards and drivers are underused. Yet this is how risk unfolds in the real world. For example, a cyclone destroys electrical infrastructure, leaving a population vulnerable to an ensuing deadly heat wave. (Kemp et al., 2022)

See the causal loop diagram in Figure 3 above on a cascading global climate failure. When tipping elements interact, compound hazards for human populations and infrastructure become more likely. As Klose et al. (2021) write, there are several ways in which multiple tipping elements may interact (some causal and some not),[69] but the troubling outcome is that cascading effects are a "possible mechanism for creating a potential planetary-scale tipping point (of the biosphere)...we may approach a global cascade of tipping points via the progressive activation of tipping point clusters through the increase of global mean temperature. This could potentially lead to undesirable hothouse climate trajectories" (Klose et al., 2021).[70] "Undesirable" indeed, when "hothouse" Earth scenarios involve large regions of the Earth becoming uninhabitable.

Tipping elements at risk at low levels of warming may trigger elements that are normally at risk only at higher levels of warming. "For example, tipping (loss) of the Greenland Ice Sheet [at risk at only 1-3°C] could trigger a critical transition in the Atlantic Meridional Ocean Circulation (AMOC) [at risk at 3-5 °C], which could together, by causing sea-level rise and Southern Ocean heat accumulation, accelerate ice loss from the East Antarctic Ice Sheet [at risk at >5°C]…." (Steffen et al., 2018)

Compound events "refer to the combination of multiple drivers and/or hazards that contribute to societal and/or environmental risk" (IPCC, 2023).

> With every increment of warming, climate change impacts and risks will become increasingly complex and more difficult to manage. Many regions are projected to experience an increase in the probability of compound events with higher global warming, such as concurrent heatwaves and droughts, compound flooding and

[69] Klose et al. (2021) identify three types of tipping dynamics: two phase cascades, domino cascades, and joint cascades.

[70] Tipping points and tipping cascades are an active research area, and much is unknown, including the exact conditions under which they will start, the temperatures required, and the possible outcomes.

> fire weather. In addition, multiple climatic and non-climatic risk drivers such as biodiversity loss or violent conflict will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Furthermore, risks can arise from some responses that are intended to reduce the risks of climate change, e.g., adverse side effects of some emission reduction and carbon dioxide removal (CDR) measures. (high confidence) (IPCC, 2023)

See Appendix 3 for a figure from IPCC (2023) of a relatively simple example. The figure is titled, “Complex risk, where impacts from climate extreme events have cascading effects on food, nutrition, livelihoods and well-being of smallholder farmers.”

A “Polycrisis”

One of the goals of this paper is to argue that climate change should not be considered separately from other crises we are facing. In military terms, it is a “threat multiplier” that can exacerbate existing political instability, which will then make mitigation efforts more difficult. The causal loop diagram above in Figure 3 shows how there can be a cascading series of events caused by climate change, but of course it is an oversimplification. The World Economic Forum focuses primarily on economic activity, but nevertheless takes a broad view of risks; all risks, after all, can impact economic activity. Over the last several years, the concept of a “polycrisis” has emerged at the World Economic Forum’s Annual Meeting in Davos, and has been described in several reports on global risks. A polycrisis is “a cluster of related global risks with compounding effects, such that the overall impact exceeds the sum of each part” (Global Risks Report 2023, 2023). Figure 11, on the next page, presents global risks in five categories: economic, environmental, geopolitical, societal, and technological.

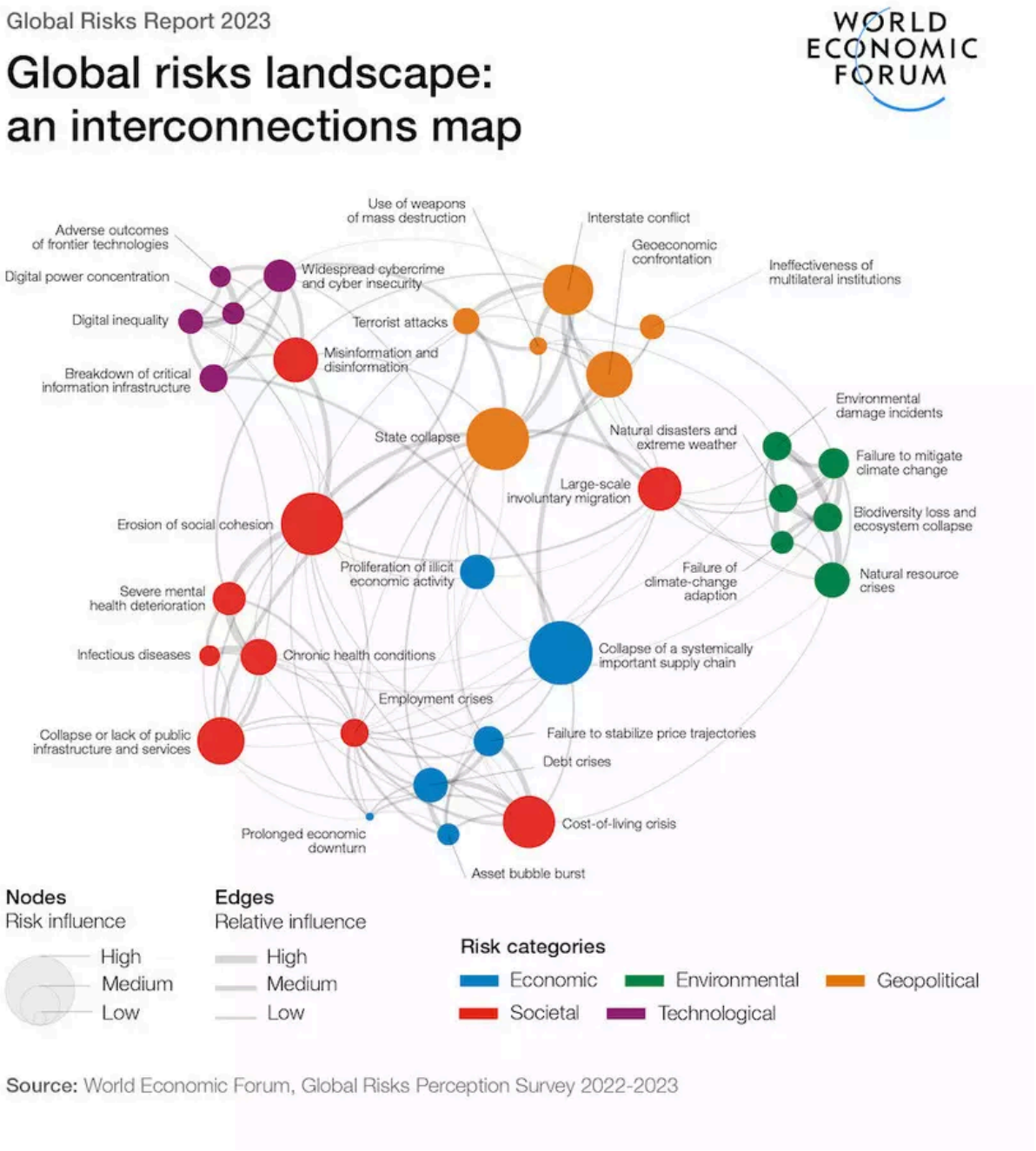


Figure 11. Global Risks Landscape: An Interconnections Map

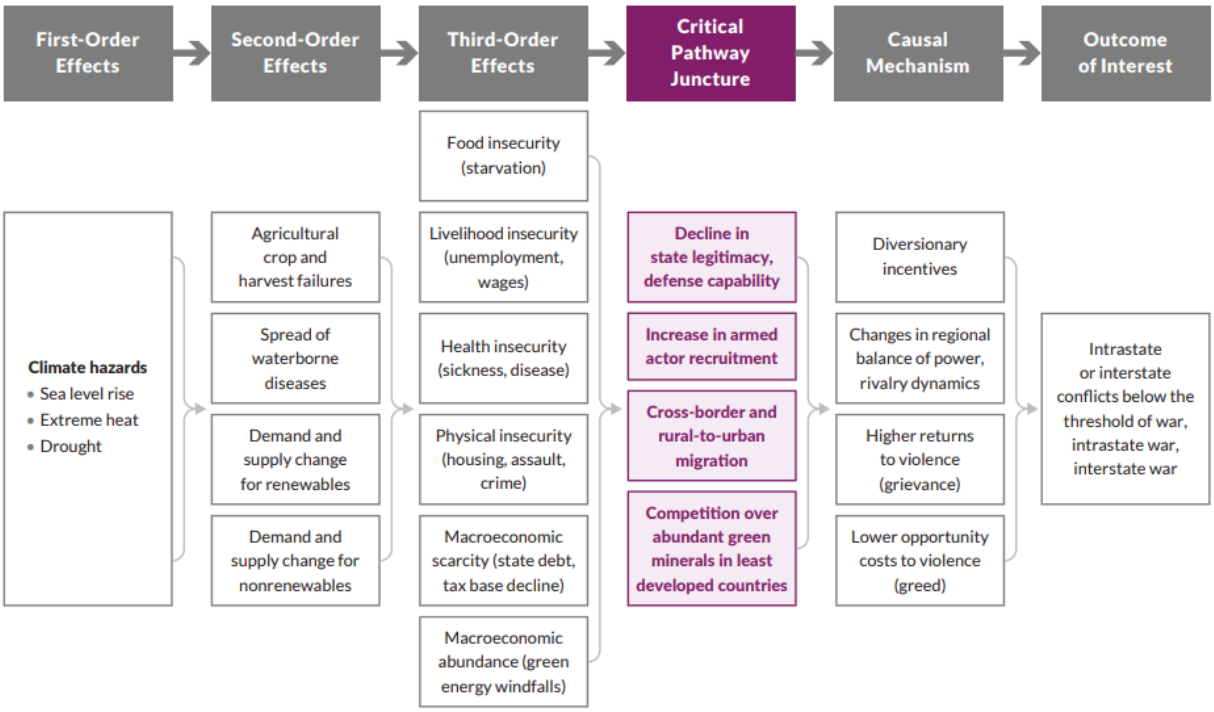
Armed Conflict and Standing Armies

The U.S. military was one of the first governmental organizations to take seriously the security threats introduced by climate change, and started writing reports and identifying risks from climate change over 30 years ago. The Center for Naval Analyses' (CNA) Military Advisory Board on Climate Change and National Security was founded in 2006, and in 2007 published a report on the national security implications of climate change.

In 2023, The Center for Climate & Security prepared a report on "Climate Change as a 'Threat Multiplier': History, Uses and Future of the Concept." In this report, they quote the opening letter of the 2007 CNA report that "climate change can act as a threat multiplier for instability in some of the most volatile regions of the world, and it presents significant national security challenges for the United States." This recent report on the history of the term "threat multiplier" goes on to describe it as "a key concept in the debate on climate change and its connections to national security, with substantial influence on U.S. and international security policy."[71]

The military recently contracted with the Rand Corporation to survey the literature and produce reports for the U.S. Central Command. These are described in Appendix 5, with a focus on the second report, titled "*Pathways from Climate Change to Conflict in U.S. Central Command"* (Chandler et al., 2023). This report provides details on the various "causal pathways from climate change to conflict." See Figure 12 below for a simplified conceptualization of the six step process from climate hazard to conflict.

Figure 1.2. Simplified Conceptualization of the Six-Step Process from Climate Hazard to Conflict



NOTE: This figure does not depict all the potential interactive effects across factors.

[71] Sherri Goodman and Pauline Baudu (Jan. 3 2023), Climate Change as a "Threat Multiplier": History, Uses and Future of the Concept, *Center for Climate Security Briefer* (*No. 38),* https://councilonstrategicrisks.org/wp-content/uploads/2023/01/38-CCThreatMultiplier.pdf

Figure 12. The Six-Step Process from Climate Hazard to Conflict
This figure is from the second Rand Corporation report for the U.S. Military, *Pathways from Climate Change to Conflict in U.S. Central Command* (Chandler et al., 2023).

The Rand Reports conclude that although climate hazards may directly lead to violence, it is more often a multistep process. They summarize the causal pathways like this:

> The causal pathways from climate hazard to conflict vary but often begin with a hazard that results from a form of insecurity (such as food, livelihood, physical, or health insecurity) that then combines with climate impacts on state capacity, population flows, and other factors. When filtered through individuals' and armed groups' incentives to mobilize around greed or grievance, the impacts of these hazards culminate in conflict. (Chandler et al., 2023)

Not only can climate change lead to conflict, but armed conflict, and even the maintenance of armies, have an enormous impact on greenhouse gas emissions. Military jets, ships, tanks, trucks and other transport vehicles consume a huge amount of fossil fuels, while armed conflict often has devastating effects on wildlife and biodiversity. Each bomb or missile detonation releases greenhouse gases, as do any fires that they start. Bombs also degrade natural carbon sinks, especially soil, trees, and other vegetation. Some researchers refer to this impact as a “carbon war boot-print.”[72] Cement, used in large quantities to rebuild after military conflict, is responsible for up to 8% of global greenhouse gas emissions.[73] There are also typically many secondary effects, from ships traveling thousands of miles out of their way to avoid the Suez canal during the Israel-Gaza war, to additional fossil fuel subsidies after the Russian invasion of Ukraine.

> The world’s militaries combined, and the industries that provide their equipment, are estimated to create 6% of all global emissions, according to Scientists for Global Responsibility (SGR). Owing to what they describe as a “large loophole” in the Paris agreement, governments are not required to provide full data on greenhouse gases being emitted by armed forces.[74]

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[72] See “The ‘carbon boot-print’”, https://www.ipb.org/wp-content/uploads/2019/11/IPB-Information-Paper-the-carbon-boot-print-1.pdf

[73] https://www.nrdc.org/bio/veena-singla/cut-carbon-and-toxic-pollution-make-cement-clean-and-green

[74] Tom Ambrose, (Nov. 11 2021) World’s militaries avoiding scrutiny over emissions, scientists say, *The Guardian*, https://www.theguardian.com/environment/2021/nov/11/worlds-militaries-avoiding-scrutiny-over-emissions

Conflict can Exacerbate Fossil Fuel Use

During wars or regional conflicts, attention is focused on military operations, and ongoing mitigation strategies may be put on hold. There may also be more direct consequences. The Ukraine war was not precipitated by climate change, but is having a negative effect. After the war started, Europe accelerated its move to renewable energy to reduce dependence on Russian gas, but other regions switched from Russian gas to coal. The conflict has also led to a more than doubling of fossil fuel subsidies in order to reduce price increases for consumers.

All military action is incredibly carbon intensive. Consider the fighting between Israel and Hamas in Gaza.

> In the first two months of the war, the total emissions from the activities we calculate here run to 281,315 tCO_2e. This includes combined emissions of bombs, rockets and artillery, flight time for bomb raids, and the delivery of materiel (for Israel) via cargo jet. This is roughly the equivalent of 75 coal-fired power plants operating for a year. (Neimark et al., 2024)

GHG emissions from military activity are rarely reported, and there are few requirements to even monitor this significant element of our emissions. Consider the highlights from the Neimark et al. study (verbatim, but typos corrected):

- The projected emissions from the first 60 days of the Israel-Gaza war were greater than the annual emissions of 20 individual countries and territories.
- If we include war infrastructure built by both Israel and Hamas, including the Hamas' tunnel network and Israel's protective fence or 'Iron Wall,' the total emissions increase to more than over 33 individual countries and territories.
- The carbon costs of reconstructing Gaza are enormous. Rebuilding Gaza will entail total annual emissions figures higher than over 130 countries, putting them on par with that of New Zealand.
- The ad-hoc nature of these calculations point to the urgent need for mandatory military emissions reporting for both war and peacetime through the UN Framework Convention on Climate Change (UNFCCC) (Neimark et al., 2024)

In addition, there are secondary effects that have tremendous GHG implications. In support of the Palestinians, the Houthis in Yemen started attacking shipping in the Red Sea in late 2023 and into 2024. Thousands of container ships were diverted around the

southern tip of Africa to avoid the Red Sea, rather than going through the Suez Canal. This added several weeks of extra travel time, and a single large container ship can burn several hundred tons of fuel per day.[75]

Climate Change and Human Health

The World Economic Forum, in collaboration with Oliver Wyman, used a "middle of the road" scenario (SSP2-RCP6) to study the health impacts of six weather-related events by 2050. The six events were:

- Floods
- Droughts
- Heat waves
- Tropical storms
- Wildfires
- Sea level rise

For each of these events, the researchers modeled the health impacts using disability adjusted life years (DALY), a technique "used by the WHO and other organizations to measure years of life lost to premature mortality associated to a specific cause as well as years of healthy life lost to disability or reduced health." The following possible health outcomes were mapped to each of the weather events (not all outcomes are associated with each weather event):

- Fatalities and injuries (the only direct and immediate outcome)
- Infectious disease
- Mental health issues
- Malnutrition
- Respiratory disease
- Cardiovascular disease
- Heat-related disease

From the report:

> The current analysis conducted indicates that 14.5 million deaths worldwide could be prevented by 2050….The escalating frequency of floods is anticipated to take the highest toll, with an estimated 8.5 million deaths[76]….The second-highest mortality rate will be from droughts, with an estimated 3.2 million associated deaths worldwide….Heat waves are expected to claim approximately 1.6 million lives by 2050, with those aged 65 and older being the most susceptible to the prolonged extreme temperatures….The projected impact of

[75] https://transportgeography.org/contents/chapter4/transportation-and-energy/fuel-consumption-containerships/ from https://transportgeography.org/

[76] Most analyses conclude that heat will lead to the most deaths from climate change. I'm not sure why heat waves are number three in this analysis.

> tropical storms is expected to result in an additional one-half million deaths by 2050, while the devastating spread of wildfires is predicted to claim another 300,000 lives. Finally, rising sea levels will result in 100,000 more lives lost.
>
> The impact of climate events on health outcomes is primarily driven by morbidity rather than mortality. It is projected that only 21% of the overall health impact will be attributable to mortality, while a concerning 79% is due to long-term disabilities and health conditions that developed subsequent to the climate event.
>
> Health outcomes involve both direct and indirect consequences of these events – some of which only appear months, and even years, after the event. Immediate impacts include deaths, physical injuries, malnutrition, respiratory and cardiovascular ailments and exposure to infectious diseases, such as cholera, dysentery and typhoid, which result from drinking contaminated water or eating contaminated food. The stress, trauma and displacement caused by climate-related disasters can be expected to produce a surge in mental health illnesses, including anxiety, depression and post-traumatic stress disorder (PTSD). In fact, a rise in mental health conditions is an outcome that all six climate events share. (Quantifying the Impact of Climate Change on Human Health, 2024)

Children are especially vulnerable to many of the consequences of climate change, including higher temperatures, infectious diseases, and extreme weather events. Respiratory problems are especially severe. Respiratory infections already lead to over 900,000 deaths per year in children under five, and as Bignier et al. write,

> Rising temperatures and extreme weather events increase children's exposure to allergens, mould, and air pollutants. Children are particularly vulnerable to these airborne particles due to their higher ventilation per unit of body weight, more frequent mouth breathing, and outdoor activities. Children with asthma and cystic fibrosis are at particularly high risk, with increased risks of exacerbation, but the effects of climate change could also be observed in the general population, with a risk of impaired lung development and growth. (Bignier et al., 2024)

Warmer air can hold more moisture, and with increased rainfall and flooding there is an increase in humidity, which leads to mold. Exposure to mold increases the probability of developing asthma. "The successive hurricanes Katrina and Rita in the Gulf of Mexico illustrate the impact of these phenomena on the risk of mould exposure: after 80% of New Orleans was flooded for more than six weeks, over 100,000 homes experienced significant mould growth" (Bignier et al., 2024).

For a comprehensive report on how climate change impacts the health and safety of workers, see the International Labour Organization's recent global report (Ensuring Safety and Health at Work in a Changing Climate, 2024). For example, it reports that over 2.4 billion workers are exposed to excessive heat each year, and the health impacts include, "Heat stress, heatstroke, heat exhaustion, rhabdomyolysis, heat syncope, heat cramps, heat rash, cardiovascular disease, acute kidney injury, chronic kidney disease, physical injury."

What Does it Mean to Say that Civilization, or Society, Will Collapse?

Widespread collapse will not happen all at once, but will build up after multiple local and regional collapses. It will happen first in fragile countries (as defined later in this paper), and even within wealthy industrialized countries it will happen sporadically at first, and in some regions before others. The process may start when there is a series of events, often interrelated, and often involving extreme weather and crop failures. Even fragile countries will be able to recover from one or two, but when multiple extreme events continue – droughts, floods, storms, fires, and heat waves, there will not be enough resources to help the affected regions – not just food and water, but also emergency shelters, medical supplies, construction equipment to clear roads and debris, and so on. Some of these extreme weather events will cause serious damage to critical infrastructure, including dams, roads, water and sewage treatment plants, and the electrical grid.

Consider what happened in Libya during the summer of 2023. It is a fragile country divided by civil war with poor maintenance of infrastructure and a weak central government. When extreme rainfall led to the collapse of two dams, a large part of the city of Derna was swept away and over 10,000 people died. Roads were washed out and fresh water and food were almost immediately in short supply. International aid arrived, as did aid from the regional government, but not enough, and slowly, and more people died. What if no international aid had arrived and other climate emergencies were sapping the limited resources of the government? Then there would be an almost immediate regional societal collapse as described below.

The flooding in southern Brazil in May, 2024 was an even more extensive and far worse disaster. While reading the description below, think about how terrible this situation would be if no outside aid arrived. Brazil will recover this time, but what will happen when this is just one of many disasters twenty or thirty years from now, and Brazil has been weakened by repeated environmental disasters, such as droughts in São Paulo and extensive fires in the Amazon?

> With landslides, destroyed roads, and collapsed bridges, almost a million people do not have access to drinking water. Many cities are unreachable, or even worse, completely submerged. The state of Rio Grande do Sul in south Brazil and 265 cities have declared a state of calamity. The disaster becomes more evident with each passing day. On May 3, 2024, the ongoing rain affected hundreds of thousands of inhabitants and damaged crucial civilian infrastructure, including homes, schools, hospitals, and water and electrical supplies. Hospitals in affected areas needed to transfer many critically ill patients by helicopter or boats. In many cities, people are facing major shortages of food, water, and life-saving medicines, which are increasingly difficult to deliver due to the blockade of roads trying to reach the region with supplies. In the middle of this humanitarian crisis, restricted access to essential health resources for people living with health conditions is worrisome. Access to health-care services such as dialysis or consultations has been affected. (Machado, 2024)

In the United States, consider what would have happened to the mountainous areas of North Carolina and abutting states after Hurricane Helene hit in late September, 2024 if there had not been an immediate and coordinated response. There was extreme rainfall, flash floods, mudslides, thousands of toppled trees, and many towns were completely isolated when hundreds of roads were closed. Entire towns were leveled, water systems destroyed, wells contaminated, and cellphone service and electrical power was down. Thousands of emergency medical and fire personnel, search and rescue teams, the National Guard, along with teams with heavy equipment to clear roads and restore services arrived quickly. More than a thousand people from FEMA (Federal Emergency Management Agency) alone arrived, and FEMA sent millions of meals, millions of liters of water, and over 150 generators. What would have happened if FEMA and emergency responders were stretched thin with other disasters, or no money was available, or dozens of helicopters were not available to send in aid?

Collapse is likely to occur when extreme or unusual weather continues for years. Consider the collapse of the Ming dynasty in China in the 1640s (see Brook, 2023). This was during the Little Ice Age, and when there was a combination of both very cold weather and drought, crops failed and chaos erupted. If the extreme weather had lasted only a few years, societal disruption would have been minimized, but when it continued for seven years, there was no way for the society to cope.

Climate disasters can lead to political instability and regime change, which can make ongoing efforts on adaptation and mitigation more difficult. Mass migration can often lead to political upheavals and instability, but dissatisfaction with a government's failure to address climate calamities and provide expected services will be a more serious and

universal problem. Brechin and Lee (2023) explore the possibility that "...democracy, already under threat, does not survive the realities of climate change. Governments' failure to provide adequate relief to their citizens becomes the last straw that topples democratic institutions."

Consider the situation during the summer of 2024, when dissatisfaction with the Egyptian government was growing due to its inability to provide uninterrupted electrical power during a long stretch of weeks with temperatures over 100° F. The heat inside apartment buildings can become deadly at times, but will always make life miserable. It is difficult to operate most businesses without electricity, so there will be immediate economic impacts. Egypt has experienced rolling blackouts for over a year. Climate change, resulting in increased demands for electricity, is only one of several factors. There is also an ongoing economic crisis with high inflation and a large national debt. The war in Gaza resulted in a reduction in gas supplies from Israel, and a reduction in revenue because fewer ships are traveling through the Suez Canal, fearing attacks from Yemen's Houthi. At the same time, the war in Ukraine was leading to dramatic increases in wheat prices, which is serious because Egypt needs to import half of its grain and Ukraine is a major supplier. Wheat prices are critically important in Egypt because bread is highly subsidized and feeds more than half of Egyptians daily; price increases can lead to food riots. "To the governing regime, the maintenance of Egypt's bread subsidy is a matter of national security."[77] The current situation in Egypt is another example of a polycrisis, and involves the interrelationships among climate change, economic problems, political instability, disruptions in the food supply, and the major disruptions caused by armed conflict.

The difficulty governments have in providing expected services will become a global problem. In most large cities, citizens expect clean water, sewage disposal, reliable electricity, gas, and fuel deliveries, garbage pickup, emergency medical assistance, plus phone and Internet service. When these services become unavailable or degraded over a long period of time, dissatisfaction will grow and many people will be drawn to extreme political parties that offer solutions, even when the solutions are unlikely to be effective or even possible.

During societal collapse, there will be serious disruptions or dysfunction of the political system, and city, state, and national services will be disrupted or cease to exist, including state and regional policing; water, oil, and gas delivery to businesses, homes and apartments; garbage pickup; and even mail delivery and other more "minor" services. Food production and distribution will be disrupted or collapse, leading to

[77] Jessica Barnes (Feb. 22, 2023), The Ukraine War, Grain Trade and Bread in Egypt, *Middle East Research and Information Project: Critical Coverage of the Middle East Since 1971*, https://merip.org/2023/02/the-ukraine-war-grain-trade-and-bread-in-egypt/

hunger and starvation. Supply chains will be disrupted or collapse, leading to the difficulty (or the impossibility) of obtaining gasoline, clothing, and household supplies, as well as components for manufacturing. The financial system will be severely disrupted or collapse. Mass transit and airplane travel will be disrupted or collapse. Hospitals and medical care will deteriorate and then collapse. Deaths will accelerate due to starvation, disease and lack of medical care, plus violence.[78]

Climate change risks will "increasingly compound and cascade" according to the IPCC. Appendix 3 provides an example "of a compound heat wave and a drought event striking an agricultural region [and] shows how multiple risks are interconnected and lead to cascading biophysical, economic, and societal impacts even in distant regions…" (IPCC, 2023, Figure 4.3).

Collapse in the United States

There are 26 years until 2050, and they will be difficult ones. According to the latest National Climate Assessment (Crimmins et al., 2023), there is now, on average, a one billion-dollar weather or climate disaster in the U.S. every three weeks (see Appendix 2). This number will increase. During the next 26 years, rising sea levels along the U.S. coasts will force many thousands to migrate inland. There will be extreme droughts and heat waves, with major crop losses in some years. There will be floods, hurricanes, and a variety of extreme weather events; the insurance and banking industry may have trouble staying solvent while dealing with all of these disasters. There will be serious disruptions to global supply chains as other less resilient countries have trouble recovering from repeated climate-related disasters and the political instability and armed conflict that often follow. There will need to be massive infusions of money to the Federal Emergency Management Agency (FEMA) and various social welfare programs including Medicaid, food stamps (Supplemental Nutrition Assistance Program, or SNAP), Supplemental Security Income (SSI), Temporary Assistance for Needy Families (TANF), the Earned Income Tax Credit (EITC), and several others. Unemployment will increase, tax revenues will decrease, and budget deficits will explode and become unmanageable. A major economic depression will ensue. The federal and state assistance programs will be unable to even remotely assist all those in need, and tent cities and homeless encampments will proliferate.

Now, given this background, collapse could accelerate when the extreme weather events cluster and happen in rapid succession. Consider a speculative scenario during

[78] Violence will be worse in countries and regions where guns are easy to acquire. Consider the United States. Although it's hard to know exactly how many guns are in circulation within the U.S., examining figures of gun production and then subtracting the number that are broken, destroyed or illegally exported each year, a reasonable estimate is over 400 million (https://www.thetrace.org/2023/03/guns-america-data-atf-total/).

a one-year period starting in mid 2050 during which hurricanes strike Texas and Louisiana during the summer and fall. In the winter there is then extreme rainfall and flooding in California, devastating food production in the Central Valley. Starting in the spring of 2051 there are extreme forest fires lasting for months, and during the summer there is a heatwave and electrical grid failure in Phoenix that leaves over 200,000 dead. This is followed by crop failures in the midwest. Then in the fall another major hurricane strikes Miami. Many millions across the country are now homeless, unemployment is extreme, food riots are breaking out in all the major cities, and the financial and health systems are near collapse. Armed gangs prowl the cities and countryside, fighting skirmishes with what is left of the police and national guard. At this point there are very limited resources to come to the aid of communities when additional natural disasters occur. Parts of the country may become armed encampments, setting up their own rules and trying to become self-reliant, while in many areas there will be no civil authority left. Infectious diseases and starvation will kill an increasing number of people. Parts of the country that still function will try to return to an agrarian and barter-based lifestyle reminiscent of the 17th and 18th century, but continuing heat, drought, and extreme weather events will make it impossible for these communities to exist for more than a few decades. This is just one of many possible scenarios, and let's consider it in even more detail.

First, hurricanes. Although hurricanes are not becoming more frequent, there is now consensus that they are getting stronger, and some have even suggested adding a Category 6 to the Saffir-Simpson Hurricane Wind Scale. During the summer of 2050, a Category 5 hurricane hits Houston and moves up the coast, disabling much of the oil refinery capability there and destroying infrastructure and homes. Then another Category 5 hurricane hits Louisiana early in the fall. Texas and Louisiana have about 30% of the oil refining capability in the country, and when a significant percentage of that goes offline there are widespread fuel shortages (of gasoline, diesel, and jet fuel) that lead to massive disruptions in transportation. These refineries also produce propane that is used for generating electricity, which leads to some power outages. Prices spike and there is panic buying. Refinery shutdowns cripple regional economies and lead to mass unemployment. The fuel shortages seriously disrupt transportation; although more than half the cars on the road are now electric, the vast majority of trucks still run on diesel. The slow rollout of charging stations across the country reduced the demand for electric cars, and their adoption never came close to predictions made in the mid 2020s.

Then extreme rain and floods. Several months later, during the winter of 2050-2051, a series of atmospheric rivers dumps enormous amounts of water on California, equal or surpassing the rain during the Great Flood of 1861-1862. Entire towns were swept away

during that flood, and the Central Valley was submerged under more than 10 feet of water.[79] Now, in early 2051, roads, bridges, dams, water treatment plants and other infrastructure suffer massive damage, and millions of people are displaced. Almost half of the fruits, nuts, and vegetables in the entire country are grown in the Central Valley of California, which is now underwater, and a large percentage of these crops are wiped out. California also refines over 10% of the country's oil, and when some of these plants go offline, it exacerbates the already dire national situation with respect to gasoline and diesel fuel.

Followed by extreme heat and forest fires. With all the rain in California, grasses and other vegetation grow rapidly. Then, during the spring and summer of 2051, extreme heat arrives over the entire southwest and up all the way through Oregon and Washington. Forest fires rage in California, given all the extra fuel on the ground, and continue all the way into Canada. Extreme wildfires destroy entire cities. Air pollution from the smoke is so bad that millions are instructed to stay indoors. The situation is far worse than the extreme fire year of 2023.

It was also in 2023 that Phoenix went for over a month with temperatures above 110 F. Now, in 2051, there is a month of days with temperatures above 120. The burden on the electrical grid from extra air conditioning, along with propane shortages due to the closed refineries, plus some lightning strikes, a tornado, and human error lead to a massive failure of the electrical grid. With a population of over 2.5 million (up from 1.6 in 2024) generators that are brought in make little difference, and although many try to evacuate, this just isn't possible. Over 200,000 people die from the extreme heat.

Heat and drought leading to crop failures. The extreme heat extends to the midwest, along with a severe drought, which has a devastating impact on multiple crops, including corn, soybean, wheat, and oats. Given that stored grains have already been depleted from prior disasters and aid to starving millions overseas, there are few backup supplies to rely upon. In addition, the drought also leads to extremely low water levels in the Mississippi, making it difficult to transport the grain that is grown.

Given the loss of fruits and vegetables in California and the difficulty of transportation due to fuel shortages, the loss of midwestern grains leads to extreme food shortages throughout the country. Prices skyrocket and many stores are not able to obtain food at any price. Food riots break out in all the major cities. When the national guard can't

[79] From the Wikipedia article on The Great Flood of 1862: "An area about 300 miles (480 km) long, averaging 20 miles (32 km) in width, and covering 5,000 to 6,000 square miles (13,000 to 16,000 km^2) was under water. The water flooding the Central Valley reached depths up to 30 feet (9.1 m), completely submerging telegraph poles that had just been installed between San Francisco and New York."

handle the situation, a national emergency is declared and the army is brought in. Armed gangs prowl the cities and suburbs looking for food and looting.

And then, another hurricane. At the end of summer in 2051 it has been a year since the hurricanes hit Texas and Louisiana. Now another major Category 5 hurricane hits Miami. Hurricane Camille in 1969 had a storm surge of 24 feet, but this new monster hurricane has a storm surge of over 30 feet. Miami Beach and Key Biscayne, two barrier islands immediately adjacent to Miami, are now totally underwater, as are low lying areas for over 150 miles up the Florida coast. 100,000 people live on these two islands alone, which have very few evacuation routes, and since this hurricane intensified rapidly, as is becoming more common, tens of thousands of people are trapped and perish. The economic consequences are astronomical. The value of the residential and commercial real estate in the greater Miami area is now over a trillion dollars, and many of these buildings are destroyed. This devastates the financial and insurance industries, already reeling from losses due to the floods and forest fires in the West and hurricanes along the Gulf coast. Even with their reinsurance, many insurance companies go bankrupt, as do many banks holding mortgages on those properties.

During the previous decade, global supply chains had already been disrupted, and now many collapse altogether. Along with infrastructure damage, high unemployment, and social unrest, regional economies across the country start to collapse. Complex infrastructure, including communications and the Internet, start failing. Both local and regional governments become unable to provide basic services and social cohesion erodes.

Glimpses of a Future Collapse in South America

After only two years of drought, much of South America is in a water crisis and, as a result, a power crisis. Drought is extreme in Brazil, Bolivia, Columbia, Ecuador, Peru, and Venezuela. The water level of the Amazon River, and multiple tributaries, has fallen so far that essential travel on many rivers is now impossible, and it is difficult to reach many remote communities. Brazil gets over 60% of its electricity from hydropower,[80] and the drought has slashed hydropower output in Brazil, Ecuador, and Columbia. The drought has also led to extreme wildfires in multiple countries, and in Brazil smoke from wildfires have spread over almost 80% of the country, leading to extreme respiratory problems.

[80] https://www.statista.com/statistics/985665/brazil-electricity-generation-source/#:~:text=Hydropower

Hydropower produces more electricity than any other source of renewable energy, but is susceptible to droughts, which have been exacerbated by climate change. Consider the situation in Ecuador and Columbia during spring and summer of 2024.

> A drought fueled by the El Nino weather phenomenon has reduced reservoir water levels in hydropower plants, which both countries rely on for most of their electricity. This led Ecuador to declare a state of emergency earlier in the year and to institute power cuts. In neighboring Colombia, rainfall levels are 80% below seasonal averages, with the country halting electricity exports to Ecuador. Amazon River levels in Colombia have also dropped by as much as 90%.[81]

The lead paragraph in a recent NY Times article paints an extreme scenario:

> Electricity cuts across an entire nation. A capital rationing water. A mayor encouraging people to shower together to save precious drops. The world's largest river system, the Amazon, which sustains some 30 million people across eight countries, is drying up.[82]

And from NASA's Earth Observatory:

> Rivers in the Amazon basin fell to record-low levels in October 2024 as drought gripped vast areas of South America. Months of diminished rains have amplified fires, parched crops, disrupted transportation networks, and interrupted hydroelectric power generation in parts of Brazil, Bolivia, Colombia, Ecuador, Peru, and Venezuela.[83]

Even without a drought, a warmer world will cause serious problems for many South American cities. Glaciers and snowpack in the Andes provide water for drinking and agriculture in several countries. Melting of snowpack and glaciers during the summer provides a significant percentage of the water for many cities. Consider La Paz, Bolivia, with a greater metropolitan population of over two million. It relies on meltwater for about 15% of its water on average, but over 50% during dry months. All South American glaciers will disappear this century, with most disappearing within the next 30 years.

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[81] https://www.dw.com/en/can-hydropower-hold-its-own-against-weather-extremes/a-68929058
[82] Julie Turkewitz, Ana Ionova, & José María León Cabrera (Oct. 19, 2024), An alarming glimpse into a future of historic droughts, The New York Times, https://www.nytimes.com/2024/10/19/world/americas/south-america-drought-amazon-river.html.
[83] https://earthobservatory.nasa.gov/images/153447/intense-widespread-drought-grips-south-america

What will happen when drought and fires lead to even more extreme levels of water shortages, power cuts, rivers where navigation is impossible, medical emergencies from wildfire smoke, and a reduction of agricultural output?

Entering Uncharted Territory?

The real danger, in the immediate future, is entering uncharted territory – a climate system that deviates so dramatically from the recent past, and our climate models, that scientists will be unable to predict what will happen next. Gavin Schmidt, a climatologist and director of NASA's Goddard Institute for Space Studies, wrote in a personal reflection in the journal Nature in March, 2024, about why he and other scientists are worried.

> For the past nine months, mean land and sea surface temperatures have overshot previous records each month by up to 0.2 °C — a huge margin at the planetary scale. A general warming trend is expected because of rising greenhouse-gas emissions, but this sudden heat spike greatly exceeds predictions made by statistical climate models that rely on past observations….the 2023 temperature anomaly has come out of the blue, revealing an unprecedented knowledge gap perhaps for the first time since about 40 years ago, when satellite data began offering modellers an unparalleled, real-time view of Earth's climate system. If the anomaly does not stabilize by August — a reasonable expectation based on previous El Niño events — then the world will be in uncharted territory. It could imply that a warming planet is already fundamentally altering how the climate system operates, much sooner than scientists had anticipated. It could also mean that statistical inferences based on past events are less reliable than we thought, adding more uncertainty to seasonal predictions of droughts and rainfall patterns. (Schmidt, 2024)

International Efforts: Extensive but Ineffective

There are multiple efforts and organizations focusing on climate change; the largest is the Intergovernmental Panel on Climate Change (IPCC).[84] Another major effort, by the U.S. Global Change Research Program, is the National Climate Assessment (USGCRP, 2018; USGCRP, 2023; the full reports are over 1,500 pages), which focuses on the effects of climate change on the United States. These organizations survey the literature and provide excellent technical summaries, although they are overly conservative, as will be explained below. Their summaries for policy makers and the public are also problematic because they neglect to present the risks of extreme outcomes accurately.

[84] The IPCC produces multiple reports. I suggest starting with the "Summary for Policymakers" in IPCC (2023).

The IPCC, and Why the Risks of Climate Change are Underestimated

The IPCC's primary mandate is to present the consensus on climate change and advise policy makers (see Appendix 4 for a brief history of IPCC conferences). Thousands of scientists and editors are involved in reviewing the literature and writing reports, and with 195 governments required to approve the results, the IPCC is inherently conservative in nature.[85] In addition, Brysse et al. (2012) make a compelling case that the scientists involved, "...are biased not toward alarmism but rather the reverse: toward cautious estimates, where we define caution as erring on the side of less rather than more alarming predictions." This conservative bias likely results from the "...adherence to the scientific norms of restraint, objectivity, skepticism, rationality, dispassion, and moderation." In many areas, the IPCC has underestimated both the impacts and rate of climate change, including in sea level rise, temperature rise, CO_2 emissions, and both continental ice-sheet melt and arctic sea ice decline.[86] Even the way in which the IPCC uses calibrated qualifiers (confidence and likelihood) have led to problems in conveying results to non-scientists, and the "tone" is "remarkably conservative" (Herrando-Pérez et al., 2019).

The IPCC reports also do not include the latest research, as they include in their analyses only well-established and peer-reviewed scientific papers. They are, in effect, several years behind the state of the art.

The Paris Agreement

Alan (2019) argues that the Paris Agreement was really a form of "dangerous incrementalism."

> The Paris Agreement is a form of dangerous incrementalism in two ways. First, it repackages existing rules that have so far proved to be an inadequate response to climate change …. Second, the Paris Agreement is dangerously incremental because of its widespread legitimation, leading many to assert that the solution to climate change is now at hand. (Alan, 2019)

But why then did every country sign, and why was it hailed as such a success? Alan goes on to write:

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[85] "About 830 Authors and Review Editors from over 80 countries were selected to form the Author teams that produced the Fifth Assessment Report (AR5).They in turn drew on the work of over 1,000 Contributing Authors and about 2,000 expert reviewers who provided over 140,000 review comments." From https://archive.ipcc.ch/organization/organization_structure.shtml

[86] For details on the underestimation of sea level rise, see Garner et al. (2018), Oppenheimer & Alley (2016), in addition to Brysse et al. (2012).

> Many understood in Paris that the treaty would not constitute a solution to climate change, and yet they publicly supported it. After Copenhagen, there was a palpable sense that the UNFCCC could not survive another such failure. Developing countries, like many others, wanted above all to avoid failure and to end negotiations that detract from implementation. They therefore consented to an agreement that is not in their interests. Beyond the binary choice that any agreement is better than no agreement, I suggest that other factors constrained developing countries' decisions to legitimize the Paris Agreement: primarily that it builds on a series of existing institutions that had their own legitimacy and that aligned with US demands. (Alan, 2019)

Reasons for Concern

The IPCC has presented a "reasons for concern" synthesis in its reports for over 20 years. There are five primary concerns, and over the last several IPCC reports, greater risks were found at lower global mean temperatures in each successive report. At 1.2°C to 4.5°C, only two of the five were rated as a very high concern in the Fifth Assessment Report, but all five were rated as very high in the Sixth (most recent) report. Clearly, the IPCC has underestimated the dangers of climate change in the past.[87] Recent IPCC reports do note that risks are now higher and have increased dramatically from the fifth to the sixth report:

> For a given level of warming, many climate-related risks are assessed to be higher than in AR5 (high confidence). Levels of risk for all Reasons for Concern (RFCs) are assessed to become high to very high at lower global warming levels compared to what was assessed in AR5 (high confidence). This is based upon recent evidence of observed impacts, improved process understanding, and new knowledge on exposure and vulnerability of human and natural systems, including limits to adaptation. Depending on the level of global warming, the assessed long-term impacts will be up to multiple times higher than currently observed (high confidence) for 127 identified key risks, e.g., in terms of the number of affected people and species. Risks, including cascading risks… and risks from overshoot …, are projected to become increasingly severe with every increment of global warming (very high confidence). (IPCC, 2023)

For a discussion of the conceptual basis of RFCs, and the associated "Burning Embers" diagram that presents risk judgments, see O'Neill et al. (2017).

[87] Despite these criticisms of the IPCC, it has done extremely valuable work over the last 35 years.

Not only is the IPCC conservative in its estimates, but it has not studied extreme outcomes. From Kemp et al. (2022):

> As noted by the Intergovernmental Panel on Climate Change (IPCC), there have been few quantitative estimates of global aggregate impacts from warming of 3°C or above. Text mining of IPCC reports similarly found that coverage of temperature rises of 3°C or higher is underrepresented relative to their likelihood. Text-mining analysis also suggests that over time the coverage of IPCC reports has shifted towards temperature rise of 2°C and below. Research has focused on the impacts of 1.5°C and 2°C, and studies of how climate impacts could cascade or trigger larger crises are sparse.

Kemp et al. (2022) suggest this focus on the lower bounds of warming is related, in part, to the IPCC working by consensus. Kemp et al. also point out that the damages and negative consequences of climate change are likely to be nonlinear and have “fat tails” of “low probability, high-impact extreme outcomes.” In 2023 we started to see some of these low probability but high-impact outcomes in terms of extreme weather events, especially extreme rainfall leading to catastrophic flooding, as well as extreme forest fires.

The Effectiveness of the IPCC

The effectiveness of the IPCC and international organizations in leading to reductions in GHGs can be seen in Figure 13 below. As meetings continue, and warnings become more dire, atmospheric CO_2 and global temperatures continue to climb. However, in defense of the IPCC, their charter is to advise policymakers, and not to reduce GHGs. Nevertheless, they have been ineffective in convincing policymakers of the severity of the climate crisis.

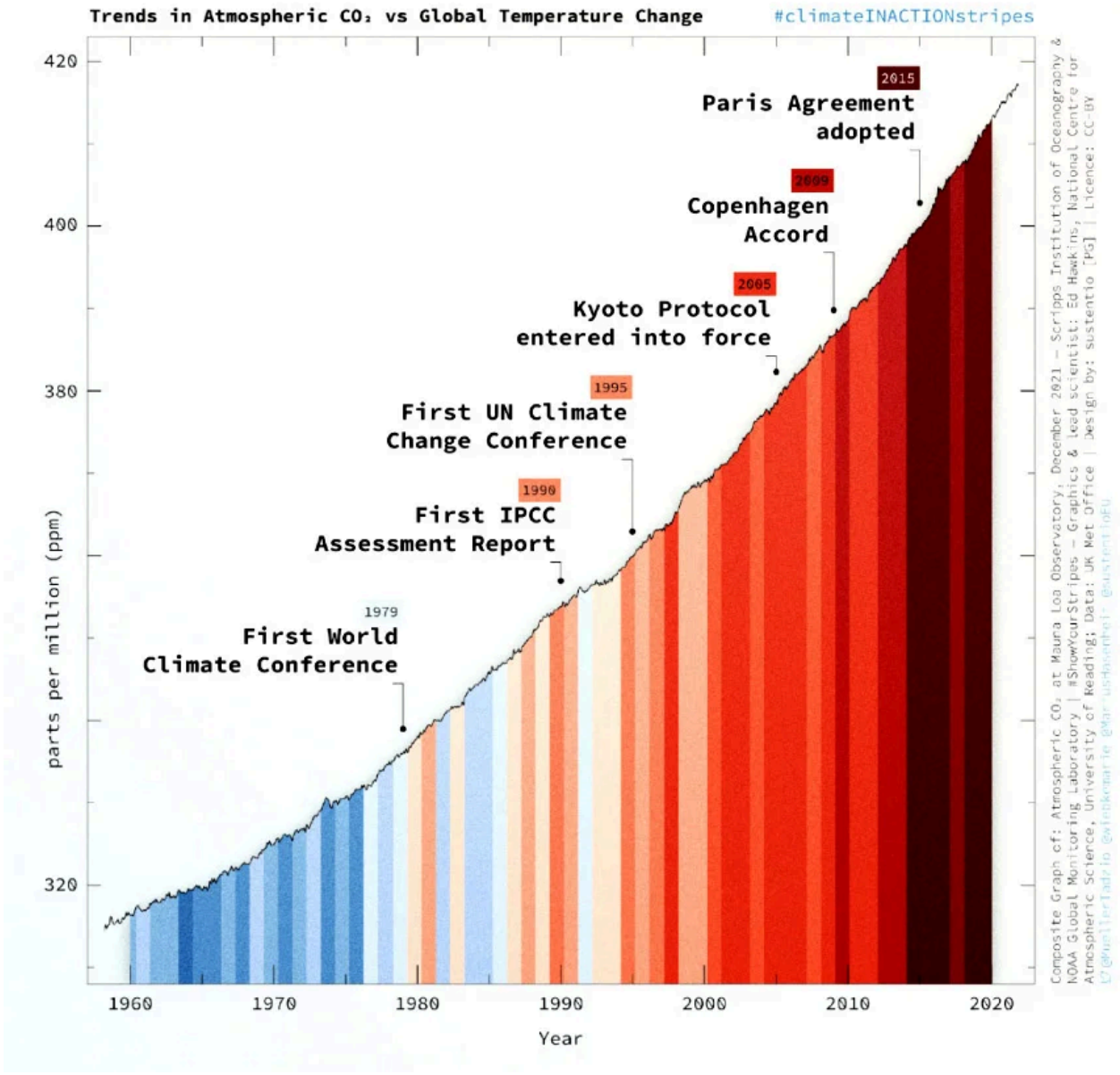

Figure 13. Trends in Atmospheric CO_2 vs Global Temperature Change
(From Scientist Rebellion, https://scientistrebellion.org/)

COP28

The United Nations Framework Convention on Climate Change (UNFCCC) has a yearly Conference of the Parties (COP).[88] COP28, the 28th meeting, ended on December 12, 2023. There was a big breakthrough at COP28 (I'm being sarcastic, of course). For the

[88] Every year, in preparation for the COP, the UNFCCC hosts a meeting of the "Subsidiary Bodies" (SB) in Bonn, Germany. For an informative discussion of the difference between the COP and SB meetings, see https://drawdown.org/insights/what-is-the-bonn-climate-conference-and-why-you-should-care

first time in 28 years the final document mentioned “fossil fuels.” Even more amazing, the final document included a statement that we should transition away from fossil fuels – but in an “orderly and equitable manner.” Most countries wanted the stronger terms of “phasing out” rather than “transitioning away” but that was too radical for the petrostates. Of course, nothing in any of the agreements are in any way legally binding, and there are no enforcement mechanisms for any of the goals that are mentioned. And there are many loopholes. The stock price of major oil and gas producers went up immediately after the conference released its final report. Continuing the unreality of the moment, attendees kept talking throughout the conference about the magical goal of remaining below 1.5°C. A resolution calling for the transition away from fossil fuels should have been adopted during the first COP in 1995.

Rupert Read, one of the founders of the Climate Majority Project, suggested (in the title of an article published immediately after COP28), that we “End COP: Aren’t we all fed up with this vapid, self-congratulatory farce?”[89]

On December 13th, 2024, the International Court of Justice concluded public hearings on the *Obligations of States in respect of Climate Change*. James Hansen, in a brief for the Court, wrote the following:

> Nations of the world meet at annual COP meetings (Conferences of the Parties), where they promise to reduce emissions to “net zero” at some distant date, an almost meaningless pledge. There is no plan to actually stabilize climate. Instead, there is dickering over potential payments to the most affected nations. Such illusory payments seem more immediate than long-term climate change, so they are dangled out front, like a carrot, as a bribe to continue business-as-usual. Meanwhile, real world emissions remain at a level driving climate inexorably toward conditions out of humanity’s control, leaving a global community increasingly unjust and ungovernable.[90]

When will we reach 1.5°C above pre-industrial levels?

First, we need to define the “pre-industrial” reference period. Different ranges are used, but the period from 1850 to 1900 is perhaps the most commonly used range of years to define the “pre-industrial period.” 1850 is chosen because it is the earliest date at which there were widespread and consistent temperature records. 1.5°C is a threshold that is defined as a long-term (multi-year) average; a period of 20 or even 30 years is often

[89] https://climatemajorityproject.com/rupert-read-end-cop-arent-we-all-fed-up-with-this-vapid-self-congratulatory-farce-brave-new-europe/

[90] James E. Hansen (Dec. 9, 2024), Climate Change at the International Court of Justice, https://www.columbia.edu/~jeh1/mailings/2024/ICJ.PressBriefing.09December2024.pdf

used, though the Paris Agreement didn't explicitly define how to determine when the threshold has been crossed.

Although the monthly global surface temperature reached or exceeded 1.5°C over a recent twelve month period, it will take many more years until scientists agree that we've exceeded 1.5°C. But it is definitely coming, and soon. According to the Copernicus Climate Change Service (C3S; https://climate.copernicus.eu/) we reached 1.28° C in June 2024. If the 30-year trend continues, we will reach 1.5°C in less than a decade, by March of 2033. Some scientists think that when we look back fifty years from now, it will be clear that we crossed the 1.5°C threshold before 2030.

Figure 14 below shows how striking the temperatures of the last year have been.

> The thresholds of 1.5°C and 2°C above the pre-industrial average global temperature have been temporarily exceeded several times in recent months. For the first time in the ERA5 dataset, the global surface temperature reached or exceeded 1.5 °C above the 1850-1900 average, for 12 consecutive months [July 2023 – June 2024].
>
> Considering that the previous longest streak above 1.5°C was three months long in 2016, the current sequence is unusual, and it has shown larger anomalies than ever before, for example the monthly average surface temperature of 1.78°C above preindustrial recorded in December 2023. Marked by an unprecedented streak of records, the year ended up as the warmest ever observed.[91]

Note that there are multiple different land and sea surface temperature data sets and there are minor differences among them. Temperature can be measured at the ground surface or two meters above it, while over the oceans water temperature can be measured directly or the air temperature can be measured two meters above the water. There are also variations in how different organizations combine observations into a global dataset. Despite these differences, all data sets show a similar long-term warming trend.

[91] https://climate.copernicus.eu/why-do-we-keep-talking-about-15degc-and-2degc-above-pre-industrial-era

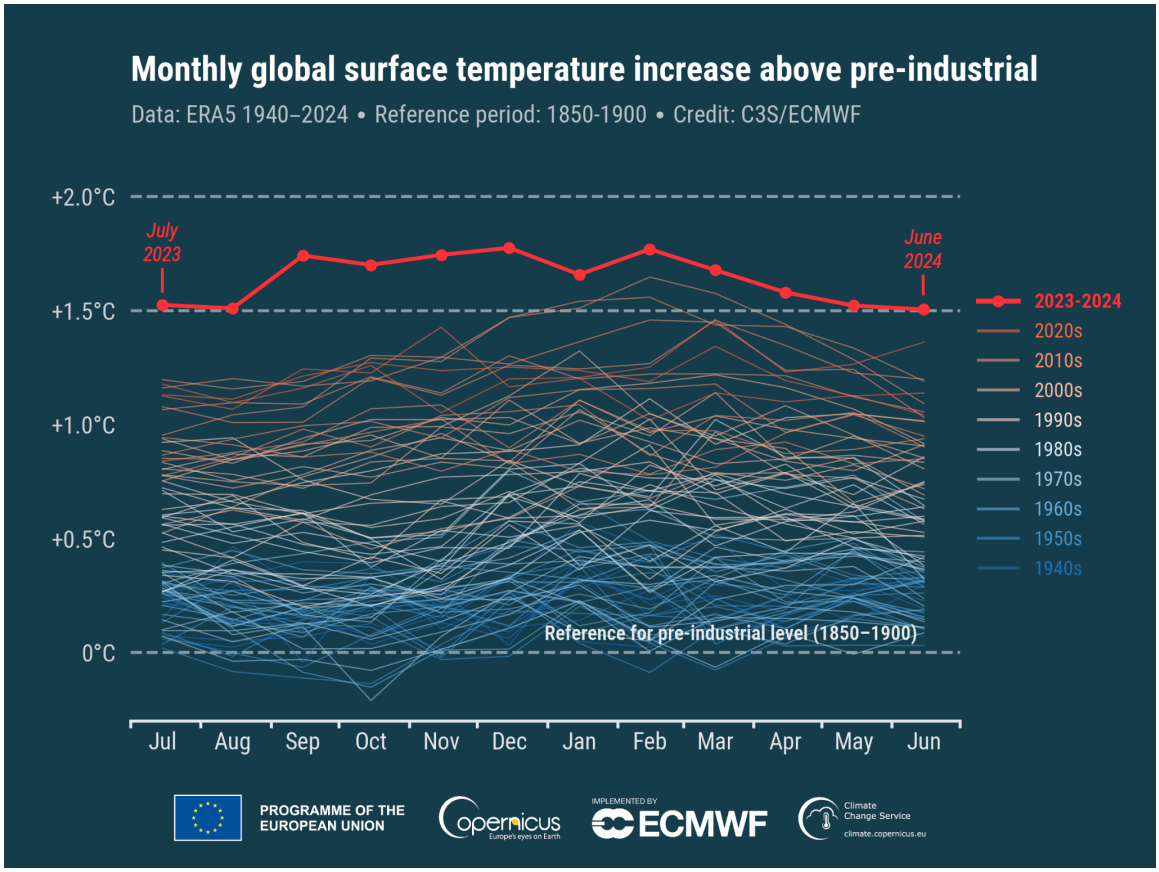

Figure 14. Monthly Global Surface Air Temperature Increases Above Pre-industrial Levels

"*Monthly global surface air temperature anomalies (°C) relative to 1850–1900 from January 1940 to June 2024, plotted as time series for all 12-month periods spanning July to June of the following year. The 12 months from July 2023 to June 2024 are shown with a thick red line, while all other 12-month periods are shown with thin lines shaded according to the decade, from blue (1940s) to brick red (2020s). Data source: ERA5. Credit: Copernicus Climate Change Service /ECMWF*"[92]

2024 Will be the First Year Above 1.5C

In a recent assessment of global surface temperature records, Zeke Hausfather from the website CarbonBrief analyzed data from five research groups that track global temperatures. Figure 15 below shows the estimates made in November for all of 2024.

> In all cases, the projected global average temperature for 2024 is virtually certain to exceed the prior record set in 2023.
>
> Three of the five groups (Hadley, Berkeley and Copernicus/ECMWF) are very likely to show annual temperatures exceeding 1.5C above pre-industrial levels

[92] Ibid.

(defined here as the 1850-1900 period), while the NASA record has a roughly 40% chance of exceeding 1.5C. Only NOAA's record is unlikely to show global temperatures above 1.5C this year.[93]

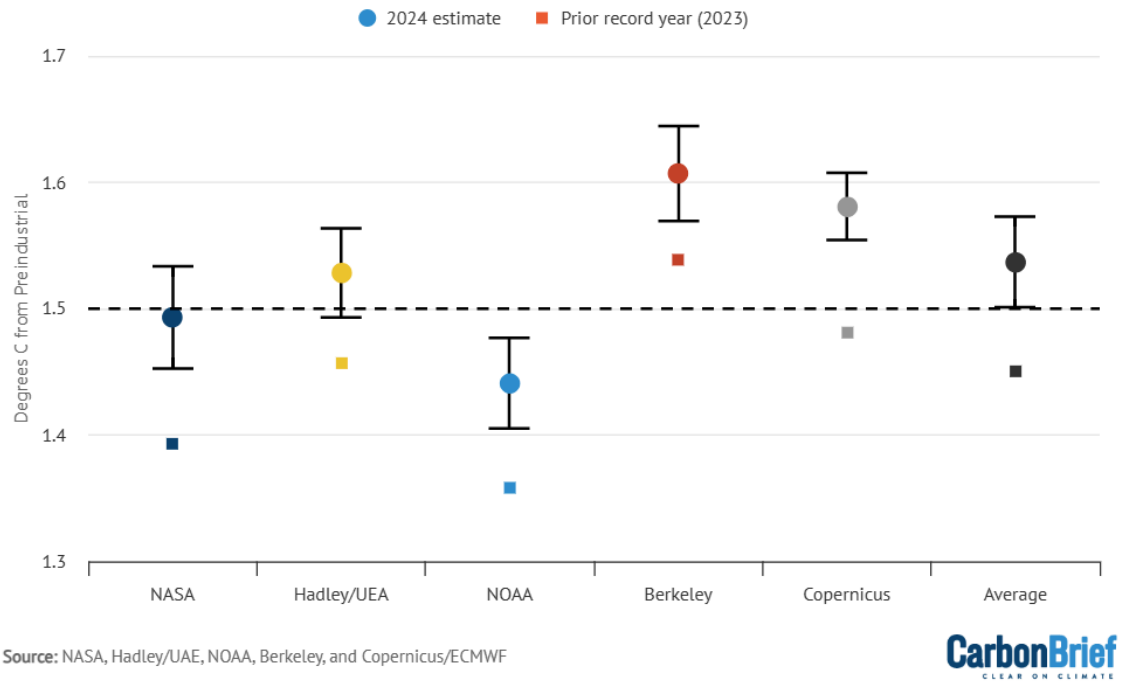

Figure 15. Estimates of 2024 Temperatures

"Carbon Brief's project of 2024 annual global average surface temperatures for each group, along with 95% confidence intervals and prior record (2023) values. 1.5C above pre-industrial (1850-1900) levels is shown by a dashed line. The average projection represents a composite of all five records following the WMO approach. Chart by Carbon Brief.)"[94]

The 1.5°C Method of Evaluation

When you read or hear something to the effect that we must do X or Y to remain below the Paris agreement limit of 1.5°C, then you know that the paper or speaker is not being serious. They are either ignorant or dishonest. Many scientists and public figures probably have what they consider good reasons for being dishonest, or perhaps don't consider themselves dishonest. Perhaps they believe it will be too upsetting to tell the truth, or that the truth will lead to defeatism. My position is that only the truth will convince us to take the drastic measures necessary.

[93] Zeke Hausfather (Nov. 11, 2024), State of the Climate: 2024 Will be the First Year Above 1.5C of Global Warming. *CarbonBrief*, https://www.carbonbrief.org/state-of-the-climate-2024-will-be-first-year-above-1-5c-of-global-warming/.

[94] Ibid.

Climate scientists are now speaking out more frequently about their pessimism. The British newspaper The Guardian recently ran a survey in which all the respondents had been involved in writing or reviewing the IPCC reports, which means they were all experts in climate science. The results were sobering, and in accord with the views in this paper.

> …the Guardian contacted every available lead author or review editor of all IPCC reports since 2018. Almost half replied – 380 out of 843, a very high response rate.
>
> Almost 80% of the respondents, all from the authoritative Intergovernmental Panel on Climate Change (IPCC), foresee at least 2.5C of global heating, while almost half anticipate at least 3C (5.4F). Only 6% thought the internationally agreed 1.5C (2.7F) limit would be met.
>
> The experts were clear on why the world is failing to tackle the climate crisis. A lack of political will was cited by almost three-quarters of the respondents, while 60% also blamed vested corporate interests, such as the fossil fuel industry.
>
> Many of the scientists envisage a "semi-dystopian" future, with famines, conflicts and mass migration, driven by heatwaves, wildfires, floods and storms of an intensity and frequency far beyond those that have already struck.[95]

Views of a "semi-dystopian" future explain the subtitle of the article: "'Hopeless and broken': Why the world's top climate scientists are in despair."

A Fundamentally Flawed Approach?

Not only is the IPCC conservative, but some now argue that the approach of the IPCC and practically every other national and international organization is fundamentally flawed. Taylor et al. (2023b) describe the situation in a preprint that is getting a lot of attention.

> The current narrow approach to managing climate change risks is fundamentally flawed because the risks and costs of failure are both likely and catastrophic.

[95]Damian Carrington (May 8 2024), World's top climate scientists expect global heating to blast past 1.5C target, *The Guardian* https://www.theguardian.com/environment/article/2024/may/08/world-scientists-climate-failure-survey-global-temperature. See also https://www.theguardian.com/environment/ng-interactive/2024/may/08/hopeless-and-broken-why-the-worlds-top-climate-scientists-are-in-despair

> The IPCC has done indispensable work in collating peer-reviewed studies and identifying key issues and trends for consideration by policymakers. Still, due to serious errors and omissions, the summary reports fail to convey the reality and severity of the climate crisis and urgent need to act. Because reports are arrived at by consensus—a process that allows self-interested governments to moderate or veto the final wording—many key issues have been ignored or downplayed. These include the dangers of passing climate tipping points, the role of fossil fuel interests in obstructing mitigation efforts, and the need for humanity to shift away from meat-based diets. (Taylor et al., 2023b)

Taylor et al. (2023b) present a summary of fallacies and facts. Here is the fallacy about IPCC assessments and the facts they present:[96]

> Fallacy: Climate models represent all possible future risks from climate change, and IPCC assessments and international agreements are objective and accurate.
>
> Fact 1: The Paris Agreement has created confusion by focusing on maximum acceptable temperatures, rather than on the need to reduce the EEI [Earth energy imbalance].
>
> Fact 2: Most models do not include long-term feedbacks identified in paleoclimate research, and thus do not simulate the full climatic responses evident in the Earth's climatic history.
>
> Fact 3: Models incorrectly assume that rising temperatures will have incremental impacts, and that overshoot can be managed with adaptive measures and reversed within decades.
>
> Fact 4: Analyses tend to minimize the likelihood and risks of high-temperature scenarios, although these are already occurring and are the most dangerous.
>
> Fact 5: Because IPCC reports are developed through a political process requiring consensus, many key issues are downplayed or ignored.
>
> Fact 6: Risk assessments need to be informed by reality as evidenced by current and past data.

What Should be Done?

Because the IPCC has been so ineffective, Taylor et al. (2023b) suggest a two-track approach.

> Ambitious change is being obstructed by the UNFCCC's requirement for consensus. To accelerate change, a two-track approach could be used, with UNFCCC agreements complemented by climate "coalitions of the willing": e.g.,

[96] This is Fallacy 4 and the facts are 4.1, 4.2, and so on. I've removed the "4"s for clarity.

> agreements among nations willing to impose meaningful internal carbon taxes matched by tariffs on all imported goods and services. A two-track approach will allow the simultaneous application of both the Paris Agreement and a supplemental plan for managing overshoot risks.

An alternative to a two-track approach is to remove the requirement for consensus. There are 198 participating countries in COP, and all must consent to any agreement, which is why it is so difficult to agree to anything of substance. Why not require only a super majority for agreements (75-80%)? This would prevent a handful of countries from vetoing meaningful action.

Magical Thinking

Greenhouse gases have been accumulating in the atmosphere for decades, and climate scientists warned continuously that the situation was serious. Both scientists and public officials often write, “If we act soon to reduce our consumption of fossil fuels, the worst can be avoided” (my words). After decades with no meaningful action it becomes difficult – and illogical – to continue with this refrain and keep saying that we must act soon; “soon” can’t last forever. The IPCC, the most prestigious climate organization in the world, presents a way out of this problem by adding in a fudge factor, “negative emissions,” or the removal of carbon from the atmosphere. However, as one prominent scientist has written, this is magical thinking, because there is no economical way to do this at the scale needed.

> These models [of the IPCC] present pathways to carbon reductions that may permit us to keep climate change below two degrees Celsius. They rely heavily on technologies that don't yet exist, such as ways to store carbon in the ground safely, permanently and affordably.
>
> Stop and think about this for a moment. Science — that is to say, Euro-American science — has long been held as our model for rationality. Scientists frequently accuse those who reject their findings of being irrational. Yet depending on technologies that do not yet exist is irrational, a kind of magical thinking. That is a developmental stage kids are expected to outgrow. Imagine if I said I planned to build a home with materials that had not yet been invented or build a civilization on Mars without first figuring out how to get even one human being there. You'd likely consider me irrational, perhaps delusional. Yet this kind of thinking pervades plans for future decarbonization. (Oreskes, 2022)

Long-term global emission scenarios are critical for research in climate change and for modeling different future outcomes. Within the IPCC there were extensive discussions

and critiques of how to define different scenarios. Pedersen et al. (2022) discuss the different scenarios adopted by the IPCC and how they evolved over the last 30 years. The IPCC didn't just cavalierly introduce Negative Emissions Technologies (NETs) into their scenarios, but wanted to create low-emission scenarios in alignment with the Paris Agreements of 2015. Nevertheless, including NETs was unrealistic, and in retrospect was immensely damaging, because when examining scenarios it is easy to forget that the low-emission scenarios are not at all realistic. The Paris Agreement's goal of 2°C (with an aspirational goal of 1.5°C) is best thought of as an outcome of magical thinking.

The IPCC and Carbon Dioxide Removal

A recent paper in Science argues persuasively that the IPCC estimates of carbon dioxide removal (CDR) are wildly optimistic, unrealistic, and not sustainable (Deprez et al., 2024). The IPCC analyses focus on technical constraints and economic considerations, but fail to take into account ecological, biophysical, socioeconomic, and feasibility constraints. Consequently, many of the IPCC scenarios rely on risky and unsustainable levels of CDR.

Deprez et al. (2024), "assess risks to biodiversity and other impacts of land-use change arising from bioenergy with carbon capture and storage (BECCS)[97] and afforestation and reforestation (A/R), the two CDR approaches most used in climate mitigation scenarios; and 'nature-based' CDR (which includes various ecosystem restoration approaches)."

The IPCC technical mitigation potentials in the models may be theoretically possible but are clearly impossible practically and would have disastrous consequences, as the following passage makes clear:

> The latest IPCC Working Group III (WGIII) report estimates the upper "technical mitigation potential" of BECCS and A/R at 11.3 and 10 gigatonnes of CO_2 per year ($GtCO_2$/year), respectively. Together, this could require converting up to 29 million km^2 of land—over three times the area of the United States—to bioenergy crops or trees, and potentially push over 300 million people into food insecurity. (Deprez et al., 2024)

Now that the IPCC's seventh assessment cycle is starting, Deprez et al. (2024) describe how they propose the IPCC should develop a realistic and sustainable CDR budget:

[97] Bioenergy with carbon capture and storage (BECCS) is a negative emissions technology. The bioenergy part involves converting biomass (e.g., wood chips) into electricity or other forms of energy by using it as a fuel, then capturing the CO_2 produced and storing it (perhaps underground, or by turning it into stable carbonate compounds).

> This sustainable CDR budget should (i) assess ecological and biophysical risks and limits, as well as social feasibility constraints; (ii) account for competing land-use demands (food production, the bioeconomy, biodiversity protection); (iii) safeguard human rights and sustainable development priorities (food security, respecting land tenure); (iv) determine realistic timescales for deployment and climatic benefits; (v) address concerns regarding the permanence of nongeological storage; and (vi) scrutinize bioenergy accounting rules and capture rate assumptions. (Deprez et al., 2024)

The IPCC is Not Tracking Carbon Accurately

Carbon released from “unmanaged” land does not have to be reported under IPCC guidelines, and as a result progress toward the goals of the Paris agreement will be overstated. MacCarthy et al. (2024) explain why this is now a serious problem given the increase in wildfires, and propose a simple and obvious solution: track and report GHGs released from all forest land.

> Tree cover loss from fires in Canada emitted nearly 3.0 billion tons of carbon dioxide in 2023 — roughly six times the annual average and 25% higher than emissions from all primary tropical tree cover loss in 2023.
>
> These emissions will largely be excluded from official greenhouse gas (GHG) reporting to the United Nations (UN). Under guidelines from the Intergovernmental Panel on Climate Change, countries can designate a portion of their lands as “unmanaged,” under the assumption that they are not subject to direct human influence and are thus not the focus of Paris Agreement goals to limit human-induced greenhouse gas emissions. While not all countries apply this “managed land proxy,” Canada designates roughly 30% of its forest area as unmanaged and is not subject to reporting. Furthermore, despite tracking GHG fluxes from forest fires and other natural disturbances in managed forests in their inventory, Canada does not officially report them to the UN based on the logic that carbon emissions from forest fires are eventually balanced by carbon removals as forests regrow post-fire. Therefore, neither carbon emissions nor removals are reported for managed forests impacted by natural disturbances. Only when managed forests fully recover the carbon lost during a natural disturbance are they returned to the official accounting ledger. As a result, GHG emissions from wildfires in all unmanaged forests and nearly a quarter of managed forests were excluded from Canada's official GHG reporting in 2019.
>
> We advocate for a more comprehensive reporting mechanism wherein countries not only track, but also report GHG fluxes across all forest land—both managed and unmanaged. Under the current frame-work, nearly a billion tons of carbon

> dioxide emitted by wildfires in Canada's unmanaged forests in 2023 will not be tracked or reported to the UN. As such, GHG inventories and nationally determined contributions in their current form may overstate progress towards global climate change mitigation. (MacCarthy et al., 2024)

Rapid and Deep Decarbonization is Unlikely

A World-Wide Mobilization is Required

The Earth will continue to warm, but how much it warms will depend in large part on the amount of additional carbon dioxide and other greenhouse gases we pump into the atmosphere. There is universal consensus that this is true. The argument in this paper is that all our current plans to reduce greenhouse gases are far from sufficient, and the most likely outcome is insufficient decarbonization to prevent societal collapse. Not only are our plans lacking, but our current reality is that fossil-fuel subsidies are actually increasing worldwide![98] "Fossil fuel subsidies from G20 countries in 2022 amounted to at least USD $1 trillion, more than four times the annual average in the previous decade, driven by vast consumption subsidies in response to the energy crisis."[99]

Theoretically, we could limit warming enough to prevent catastrophe by very rapidly decreasing our use of fossil fuels. This would require a world-wide mobilization similar to what the US did during WWII, when industry focused exclusively on supporting the war effort. During the war it was impossible to buy a new car or refrigerator, but hundreds of thousands of planes, ships, tanks, trucks, rifles, bombs and other armaments were produced. This required the government to take control of the economy and allocate resources to industry.

This didn't happen by chance, and factory owners didn't all suddenly agree to radically alter their businesses to support the war effort. The War Production Board (WPB), a federal agency, was created in 1942, and took control of the economy. It allocated resources, paid subsidies for plant construction, forced factories to convert to produce military equipment, and even took over some private companies.

> The WPB and the nation's factories effected a great turnaround. Military aircraft production, which totaled 6,000 in 1940, jumped to 85,000 in 1943. Factories that made silk ribbons now produced parachutes, automobile factories built tanks, typewriter companies converted to rifles, undergarment manufacturers sewed

[98] "Fossil-fuel subsidies surged to a record $7 trillion last year [2022]…. subsidies for oil, coal and natural gas are costing the equivalent of 7.1 percent of global gross domestic product. That's more than governments spend annually on education (4.3 percent of global income) and about two thirds of what they spend on healthcare (10.9 percent)." Simon Black, Ian Parry, Nate Vernon (Aug. 24 2023), Fossil Fuel Subsidies Surged to Record $7 Trillion, *IMF Blog,* https://www.imf.org/en/Blogs/Articles/2023/08/24/fossil-fuel-subsidies-surged-to-record-7-trillion

[99] https://www.energypolicytracker.org/G20-fossil-fuel-support

> mosquito netting, and a rollercoaster manufacturer converted to the production of bomber repair platforms. The WPB ensured that each factory received the materials it needed to produce the most war goods in the shortest time.[100]

Consider the likelihood of something similar to the War Production Board being created today, when major segments of the population, and our elected representatives, don't believe climate change is a serious threat, believe that the government is the problem, and want to defund major government agencies. There are still many elected officials who deny the science of climate change and there are organizations (some supported by the fossil fuel industry) that are actively trying to stop the transition to renewable energy. In addition to these difficulties in the U.S., consider the increased difficulty of making something like this work on a global scale; our atmosphere respects no national boundaries, so solutions must be global to be effective.

International cooperation will be required to reduce the use of fossil fuels. "Absent international coordination, constraining supply from some countries can increase economic incentives for others to increase production" (van Asselt & Newell, 2022). Van Asselt & Newell discuss different types of international cooperation, including an International Coal Elimination Treaty and a Fossil Fuel Non-Proliferation Treaty. (See the section below, as well as Burke and Fishel, 2020, for details on a Coal Elimination Treaty.)

There will continue to be incremental improvements, but no quick and radical decarbonization. A tax on carbon is probably the most effective way to rapidly reduce fossil fuel use, but despite efforts by some politicians and several organizations, this is very unlikely to happen in the near future.

Transforming Society and the Economy

This paper focuses on our current situation, from the perspective of several disciplines, and how multiple factors lead to the conclusion that societal collapse is likely later this century. We need to reduce greenhouse gases and protect the biosphere, and if that isn't sufficient, actively cool the Earth. We need to transform multiple aspects of our current civilization, including the following areas: energy production, land use, urban organization and infrastructure (including transportation), and industrial systems. Exactly how we should transform our society and economy in order to quickly reduce greenhouse gases and sequester carbon (using both biological and geological methods) is outside the scope of this paper, but there are multiple groups and organizations that have been focusing on how such a transformation could occur. Consider the proposals of the Drawdown Project.

[100] https://en.wikipedia.org/wiki/War_Production_Board

“Project Drawdown’s world-class network of scientists, researchers, and fellows has characterized a set of 93 technologies and practices that together can dramatically reduce concentrations of greenhouse gases in the atmosphere.”[101] The Drawdown Project provides 93 solutions for transformations in the following sectors (example solutions are provided for each sector):

- Electricity (distributed energy storage, micro wind turbines)
- Food, agriculture and land use (farm irrigation efficiency, seafloor protection)
- Industry (alternative cement, reduced plastics)
- Transportation (efficient ocean shipping, high-speed rail)
- Buildings (clean cooking, high-performance glass)
- Land sinks (multistrata agroforestry, tropical forest restoration)
- Coastal and ocean sinks (coastal wetland restoration, seaweed farming); engineered sinks (biochar production)
- Health and education (family planning and education)[102]

For most solutions there are extensive details, including a summary of the impact, methodology, total addressable market, adoption scenarios, financial model, results, discussion, and references.

> Our scientific analysis shows that the world can reach drawdown—the point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline—by mid-century if we make the best use of all existing climate solutions. Each solution presented here reduces greenhouse gases by avoiding emissions and/or by sequestering carbon dioxide already in the atmosphere.[103]

Project Drawdown’s research and solutions are wonderful. Note that drawdown, as they define it, is a step beyond net zero because it reflects a point at which greenhouse gases in the atmosphere actually start declining. We can reach this state by mid-century, “if we make the best use of all existing climate solutions.” Unfortunately, we are not making the best use of all of these existing solutions and, as argued in this paper, to speed the transition we need decisive actions at the national and international levels.

The problem with Project Drawdown is that it assumes we have time for all the transitions they propose, and this is just not true. Rather than radically reducing meat production, they propose regenerative grazing, “to raise grass-fed cattle while building

[101] https://drawdown.org/
[102] https://drawdown.org/solutions/table-of-solutions
[103] https://drawdown.org/solutions

up organic matter in the soil." Rather than banning most air travel, they propose "fuel-efficient aircraft; retrofitting existing aircraft with winglets, newer engines, and lighter interiors; and retiring older aircraft early." And developing alternatives to cement will be very difficult and time consuming. "If the cement industry were a country it would rank as the world's fourth largest GHG emitter, just behind China, the U.S., and India, responsible for roughly 7-8% of global CO2 pollution."[104] We should work to implement all 93 of Project Drawdown's proposed solutions, but this is not enough; we need to move much more quickly than these solutions allow.

It's also essential to consider the problems of the developing world, where "Over 770 million people still lack access to electricity and nearly 3 billion people still burn kerosene, coal, wood or other biomass for cooking" (WWF, 2024). Those 3 billion people will need to start using non-polluting forms of energy as part of the transformation that we must undertake.

Low-Carbon Transitions for Deep Decarbonization

Many people and groups have laid out plans for how to achieve deep decarbonization. For example, David Victor and his colleagues Frank Geels and Simon Sharpe released a study arguing that to make more rapid progress requires "...new methods of industrial production and agriculture with radically lower emissions – so that key countries will be willing to do more and powerful groups and companies can mobilize around systemic decarbonization".[105]

> For accelerating deep decarbonization…. Our core argument is that getting serious about decarbonization requires a new approach to industrial policy — one that is organized sector-by-sector and coordinated internationally to create progressively larger markets and stronger incentives for decarbonized industries.
>
> Decarbonization requires a string of technological revolutions in each of the major emitting sectors. We count 10 sectors that matter most, including electricity generation, cars, buildings, shipping, agriculture, aviation, and steel. These 10 sectors account for about 80 percent of world emissions.[106]

The figure below shows the penetration of low-carbon technologies into markets. The figure, and quotation above, are both from more than five years ago. Although there has been rapid low-carbon transitions in power and cars, progress in the other sectors is

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[104] https://www.nrdc.org/bio/veena-singla/cut-carbon-and-toxic-pollution-make-cement-clean-and-green

[105] https://e360.yale.edu/features/deep-decarbonization-a-realistic-way-forward-on-climate-change

[106] Ibid.

limited; as usual, we know what to do (in most cases), there have been technological advances, but in most sectors there has been no meaningful progress. Deep decarbonization can't happen unless it is "coordinated internationally" and there is no such coordination now, nor hope of any in the near future.

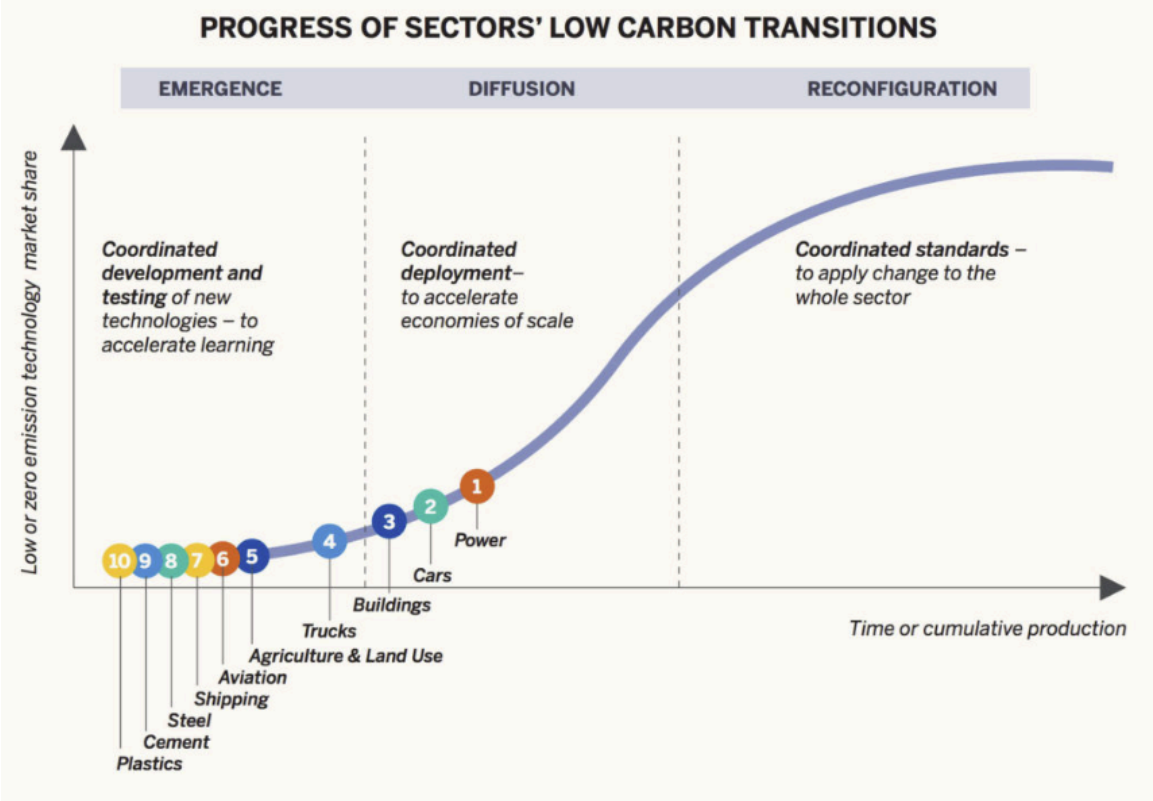

Figure 16. Progress of Sectors' Low Carbon Transitions

"The penetration of low-carbon technologies into markets follows a familiar S-shaped curve, with the emergence of a new technological system, its diffusion into widespread use, and then reconfiguration of whole markets around the new system. The decarbonization of 10 key economic sectors, shown here, is still in the early phases of this transition. Courtesy of Frank Geels."
[107]

Effective Climate Policies

In order to meet climate goals, countries pledge to reduce their greenhouse gas emissions via nationally determined contributions (NDCs). Countries take a number of different approaches, and Stechemesser et al. (2024) ask the "fundamental question as to which types of policy measures are successfully causing meaningful emission reductions. Despite more than two decades of experience with thousands of diverse climate policy measures gained around the world, there is consensus in neither science

[107] Ibid.

nor policy on this question." One problem is that it is rare that there is only one type of climate policy implemented at a time, and it is difficult to evaluate various mixes of policies. Stechemesser et al. (2024) developed machine learning techniques to evaluate policies that led to large emission reductions by examining the effects of 1,500 climate policies implemented between 1998 and 2022 across 41 countries.

Policies were assigned to four sectors and examined separately for developed and developing economies. The sectors were buildings, electricity, industry, and transport. Examples of policies include the following (many of these occurred in more than one sector): carbon taxes, fuel taxes, emission trading schemes, building codes, bans and phase outs (e.g., fossil heating in buildings), air pollution standards, energy efficiency mandates, various subsidies, performance standards (e.g., for electric motors, cars, and trucks), public expenditures for rail, labels on appliances, and many more.

This is important new research for policy makers, but needs to be confirmed. Stechemesser et al.'s (2024) policy data are publicly available, so others should be able to replicate and extend their research. Some of the results are not surprising, such as the "consistent increase in the number of implemented climate policies across all sectors between 1998 and 2022." Other results include the following:

- There were large emission reductions in only 63 out of 1,500 policies. However, it's not clear whether the authors categorized the different policies on the basis of implementation effort, cost, and how pervasive they were across the economy. That is, it's very different to require labels on appliances compared with increasing public expenditures for commuter rail or setting up an emission trading scheme or carbon taxes. However, Stechemesser et al. (2024) do acknowledge that they were "...unable to quantify the effect of policies with minor effects."
- Seventy percent of the time that emission reductions were detected there were two or more policies in place, and effect sizes were larger for policies that were part of a mix.
- The authors combined carbon and fuel taxes and emission trading into a category they called "taxation," and found that taxation policies worked well alone rather than in a mix. "...taxation is a notable exception in effectively causing large emission breaks [i.e., reductions] alone. It stands out as the only policy instrument that achieves near equal or larger effect size as a stand-alone policy across all sectors." This reinforces the argument in this paper that carbon taxes (or a fee and dividend) are one of the most effective policies.
- The most effective policy mixes varied across sectors and between developed and developing countries.

This research is incredibly important because to reduce emissions quickly and most effectively we must implement the policies, or mix of policies, that will result in the greatest reduction of GHG emissions. Currently, there is a huge "emission gap" between what is required to meet the Paris Agreement's objectives and what countries have pledged to do via their nationally determined contributions. The results here are "sobering" according to the authors. "...even if all countries in our sample were able to replicate past success, more than four times…the effort witnessed so far would have to be exerted to close the emissions gap" (Stechemesser et al., 2024). A review in Nature quotes Xu Chi, an ecologist from Nanjing University: "This study provides a warning to countries around the world that their climate policies have had very limited effects so far. Existing policies will need to be re-evaluated, and changes will need to be made."[108]

A Fossil Fuel Non-Proliferation Treaty

Thirteen small primarily island nation-states are calling for a Fossil Fuel Non-Proliferation Treaty that has three components (verbatim):

> Non-Proliferation
> Stop building out the problem by ending the expansion of coal, oil and gas production.
>
> A Fair Phase-Out
> An equitable plan for the wind down of existing fossil fuel production, where nations with the capacity and historical responsibility for emissions transition fastest, providing support to others around the world.
>
> Just Transition
> Fast track the adoption of renewable energy and economic diversification away from fossil fuels so that no worker, community or country is left behind.[109]

This makes perfect sense and is fair. The world still needs oil, and during the phase-out we'll still need to pump oil. Saudi Arabia, Russia, the United States and other countries have been pumping oil for many decades, while Guyana, where huge oil and gas fields were recently discovered in the Guyana-Suriname Basin, has just started extracting oil and gas. If there is a fair phase-out, countries like Guyana should be able to extract oil and gas while the traditional large producers should scale back rapidly. The treaty has been endorsed by thousands of academics, over 100 Nobel Laureates, faith leaders, the Vatican, the World Health Initiative, and even the European Parliament. It's easy for individuals and organizations to sign on to the initiative, but incredibly difficult for

[108] Xiaoying You (August 23, 2024), AI analysed 1,500 policies to cut emissions. These ones worked, Nature, https://www.nature.com/articles/d41586-024-02717-7
[109] https://fossilfueltreaty.org/

politicians to agree to reduce a significant source of revenue. For this reason, there is little chance that the major oil producers will agree to such a phase-out. The chances of signing the treaty go down even further for countries with economic problems. Just consider Iran, Venezuela, and Russia. They are all among the top ten countries in the world in terms of oil reserves, and oil is one of their main sources of revenue. Their economies have been decimated by sanctions, corruption, and the war in Ukraine. They need every penny of their oil revenue, and there is no chance they will reduce their output in order to combat climate change.

A Gedankenexperiment

Consider the following Gedankenexperiment, or thought experiment: if there were no individual nations and one supreme leader for the entire Earth, and everyone followed that leader religiously, how quickly could the world reduce its use of fossil fuels and deal with the climate emergency? The answer: very quickly compared to the current rate. A high fee and dividend would be imposed on fossil fuels, and it would rise rapidly over the next 20 years. Most meat would be banned, air travel would be drastically curtailed, renewable and nuclear energy would be expanded dramatically, and fossil-fuel run vehicles would be phased out rapidly. Deforestation and the destruction of natural carbon sinks would cease. For example, it would be easy to stop deforestation in the Amazon by cutting off the main roads into the Amazon and destroying unofficial roads, which are also spreading deforestation. Tourism and the airline industry would collapse, as would the fossil fuel industry and the meat industry, but millions of new jobs would be created to complete the transition to renewable energy and a plant-based diet, to expand mass transit, increase building insulation, and so on. Millions of existing jobs would be lost, but millions of new jobs would be created.

Natural Carbon Sinks

Oceans and forests help tremendously with mitigation by capturing more than half of annual CO_2 emissions, which they can store for thousands of years. Carbon dioxide is released naturally from venting volcanoes, outgassing from the ocean, decomposing vegetation, and other sources. The natural carbon cycle involves the release and absorption of about ten times as much carbon as is emitted by humans. The problem is that the carbon humans are now emitting has, “tipped out of equilibrium what was once a balanced cycle …. Human activities tip the scales by adding carbon to the air faster than the planet’s sinks can absorb it.”[110] Wildfires, droughts, and deforestation now reduce the amount of CO_2 that forests can sequester, and the physical properties of how a gas dissolves in water are reducing the ability of oceans to remove CO_2 from the atmosphere.

[110] Andrew Moseman (January 26, 2024), How much carbon dioxide does the Earth naturally absorb? *MIT Climate Portal*, https://climate.mit.edu/ask-mit/how-much-carbon-dioxide-does-earth-naturally-absorb

The oceans act as a carbon sink, and as anthropogenic CO_2 emissions have increased the amount taken up by the oceans has also increased, and is now at about 25% of all emissions. Carbon dioxide is taken up by the oceans due to both pressure differences between the air and ocean, leading to carbon dioxide dissolving in water, and due to photosynthesis by algae and phytoplankton.

However, as water temperature increases, its ability to dissolve carbon dioxide decreases, because temperature affects solubility and warmer water can hold less dissolved gas. This means that in the future the oceans will be less effective at removing CO_2 from the atmosphere. Winds also influence the amount of CO_2 taken up by the ocean: "...winds set the ocean in motion, drive ocean currents and thus control the transport of dissolved forms of CO_2 with ocean circulation. In particular, winds drive the exchange between the surface ocean and the deep ocean, where the bigger part of the ocean's carbon is stored" (Bunsen et al., 2024). As explained on a NASA website:

> The warmer the surface water becomes, the harder it is for winds to mix the surface layers with the deeper layers. The ocean settles into layers, or stratifies. Without an infusion of fresh carbonate-rich water from below, the surface water saturates with carbon dioxide. The stagnant water also supports fewer phytoplankton, and carbon dioxide uptake from photosynthesis slows. In short, stratification cuts down the amount of carbon the ocean can take up.[111]

As a recent study concludes,

> In recent decades, changes in winds and global warming have reduced the capacity of the ocean to remove CO_2 from the atmosphere. Yet, this climate effect is not well understood. Here, we use computer simulations from 1958 to 2019 to quantify the climate effect and find that climate change reduced the oceanic CO_2 uptake of the last two decades by 13%, with winds having more of an effect than sea surface warming. The effect of warming increases over time. (Bunsen et al., 2024)

The oceans are simultaneously dissolving CO_2 from the atmosphere while outgassing CO_2 into the atmosphere (and doing a lot more dissolving than outgassing). "For eons, the world's oceans have been sucking carbon dioxide out of the atmosphere and releasing it again in a steady inhale and exhale."[112]

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[111]Holli Riebeek (July 1, 2008), The Ocean's Carbon Balance, *Earth Observatory* https://earthobservatory.nasa.gov/features/OceanCarbon

[112] Ibid.

Unfortunately, even when we reduce CO_2 emissions the oceans will continue to release CO_2.

> If anthropogenic CO_2 emissions abate in the future, the anthropogenic component of the air-sea CO_2 flux directed into the ocean is expected to stop growing. In contrast, the trend in the air-sea CO_2 flux toward more outgassing of natural CO_2 driven by climate change is expected to persist longer. (Bunsen et al., 2024)

Forests and Carbon Sinks

Hubau et al. (2020) studied structurally intact tropical forests (i.e., those that had not been logged) in Africa and the Amazon, and examined how changes in CO_2 concentration, air temperature, and water availability will affect photosynthesis and respiration in the future, and how this in turn will determine how much carbon these forests can store. Since there is a CO_2 fertilization effect, the ability to store carbon increases as CO_2 increases. However, any such increase is more than offset by increases in temperature and the frequency of droughts, which reduce carbon assimilation.

> In summary, our results indicate that although intact tropical forests remain major stores of carbon and are key centres of biodiversity, their ability to sequester additional carbon in trees is waning. In the 1990s intact forests removed 17% of anthropogenic CO_2 emissions. This declined to an estimated 6% in the 2010s, because the pan-tropical weighted average per unit area sink strength declined by 33%, forest area decreased by 19% and anthropogenic CO_2 emissions increased by 46%. Although tropical forests are more immediately threatened by deforestation and degradation, and the future carbon balance will also depend on secondary forest dynamics and forest restoration plans, our analyses show that they are also affected by atmospheric chemistry and climatic changes. Given that the intact tropical forest carbon sink is set to end sooner than even the most pessimistic climate driven vegetation models predict, our analyses suggest that climate change impacts in the tropics may become more severe than predicted. Furthermore, the carbon balance of intact tropical forests will only stabilize once CO_2 concentrations and the climate stabilizes. (Hubau et al., 2020)

Hubau et al. (2020) highlight the divergence in the carbon sink responses of the tropical forests in Africa and the Amazon; the African forests are declining slowly, whereas there is a rapid weakening of the Amazonian carbon sink.

> Overall, the larger modelled increase in carbon gains in Africa relative to Amazonia appear to be driven by slower warming, fewer or less extreme droughts, lower forest sensitivity to droughts, and overall lower temperatures (African forests are on average ~1.1 °C cooler than Amazonian forests, because they typically grow at higher elevations of ~200 metres above sea level).

Land Areas May Absorb Less CO_2 in the Future

Between 2022 and 2023 global fossil fuel CO_2 emissions increased only slightly, whereas atmospheric CO_2 increased dramatically, up 86% from 2022 to 2023. "The CO_2 growth rate in the decade 2013-2022 has averaged at 2.42 ± 0.08 ppm yr^{-1}. In 2023, it increased to a record high value of 3.37 ± 0.11 ppm yr^{-1} at the Mauna Loa station…" (Ke et al., 2024). Using several global vegetation models and satellite data, Ke et al. (2024) concluded that this "implies an unprecedented weakening of land and ocean sinks…." They go on to write, "Land regions exposed to extreme heat in 2023 contributed a gross carbon loss of 1.73 GtC yr^{-1}, indicating that record warming in 2023 had a strong negative impact on the capacity of terrestrial ecosystems to mitigate climate change" (Ke et al., 2024).

This is from an unreviewed preprint, but if the relationship between warming and the capacity of terrestrial ecosystems to sequester carbon is confirmed, this is very bad news, because land areas currently sequester a large percentage of the CO_2 we emit. In addition, since this relationship is not coded into current Earth system models, the outputs of these models will be overly optimistic. As Ke et al. (2024) explain,

> The observation that 2023 had an exceptionally weak land sink despite being only a moderate El Niño constitutes a test bed for Earth System models which lack processes causing rapid carbon losses, such as extreme fires and climate-induced tree mortality in their projections, and may thus be too optimistic for estimating remaining carbon budgets. If very high warming rates continue in the next decade and negatively impact the land sink as they did in 2023, it calls for urgent action to enhance carbon sequestration and reduce greenhouse gasses emissions to net zero before reaching a dangerous level of warming at which natural CO_2 sinks may no longer provide to humanity the mitigation service they have offered so far by absorbing half of human induced CO_2 emissions. (Ke et al., 2024)

Note, however, that atmospheric CO_2 can increase not only because less is being sequestered by the land, but also because more is being released from non-anthropogenic sources such as thawing permafrost. Although Ke et al. (2024) based their work on vegetation models and satellite data to estimate land and ocean

sinks, the results would have been clearer had they also tried to estimate the CO_2 released from permafrost and other non-anthropogenic sources.

The Oceans as Carbon Sinks: More Bad News

Oceans around the world have taken up about one-quarter of anthropogenic CO_2 emissions. Zhong et al. (2024) examined the surface ocean partial pressure of CO_2 (pCO_2) in winter and summer and at different latitudes. It has been difficult to measure pCO_2 accurately due to both the variability of pCO_2 and insufficient observations. Using a new neural network approach, Zhong et al. (2024) "identified an underestimation of the surface Southern Ocean pCO_2 due to notably uneven density of pCO_2 measurements between summer and winter, which resulted in about 16% overestimating of Southern Ocean carbon sink over the past three decades. In particular, the Southern Ocean carbon sink since 2010 was notably overestimated by approximately 29%" (Zhong et al., 2024). Any reduction in natural carbon sinks is very bad news. In addition, Zhong et al. (2024) conclude that if Antarctic sea ice completely melts, a large amount of CO_2 will be released into the air.

Benefits of Decarbonization

Decarbonization can have near-term benefits by reducing particulate matter air pollution, and this can be cost effective. Using projections from multiple climate models, Shindell et al. (2024) show how rapid decarbonization can help developing countries even in the near term. They report that, "...in South and East Asia, the $PM_{2.5}$-related benefits are largest throughout the century [larger than reduced heat exposure], and their valuation exceeds the cost of decarbonization, especially in China, over the next 30 y[ears].... Aggressive decarbonization, access to clean energy, and strong air quality policies…avert millions of premature deaths annually..." (Shindell et al., 2024).

Renewable Energy and Nuclear Power Alone are Insufficient

Increasing renewable energy by itself is meaningless unless it replaces fossil fuels. Renewable energy is being rolled out much more quickly than expected and the prices have fallen dramatically over the last 15 years – up to 90% by some estimates. For much of the world, solar power is now the cheapest form of electricity. This is impressive, and wonderful. However, people forget that it doesn't really matter how much renewable energy we install or how cheap it is. All that matters is the amount of greenhouse gases that we inject into the atmosphere, and that has been going up, not down.

We could increase power generated from renewables by a factor of ten, and it wouldn't matter if demand were also to increase and the amount of fossil fuels we burned remained the same. We could generate 90% of our power from renewables and it really

wouldn't matter if we also kept burning fossil fuels at the same rate. Yes, the world will warm less with 90% renewables compared to 10%, but with respect to catastrophic consequences for human civilization, the percentage of renewables doesn't matter if we continue to pump significant quantities of greenhouse gases into the atmosphere.

It's quite amazing how the rapid introduction of renewable energy has blinded people to the realities of climate change. In the International Energy Agency's (IEA) recent report, they emphasize that, "The path to 1.5°C has narrowed, but clean energy growth is keeping it open" (Net Zero Roadmap, 2023).[113] The path has not narrowed, it has closed. To say otherwise is to be dishonest.

Yes, there has been tremendous progress, but not enough. As Climate Action Tracker (2024) points out in Figure 17 below, "two opposing trends are balancing out." Renewable growth has been phenomenal, but demand for electricity has increased, and rather than putting a tax on carbon, fossil fuel subsidies remain.

> … fossil fuel subsidies remain at record high levels and funding for fossil fuel-prolonging projects quadrupled in a single year (between 2021 and 2022). While renewable energy is expanding rapidly, its positive climate impact is being offset by the growth of fossil fuel subsidies, which continue to anchor fossil fuel use in the global economy…. For the trend in renewables to truly make a difference, they need to displace fossil fuels, not simply coexist with them. So far, these trends translate into emissions projections peaking and plateauing by the end of the decade, but lack the steep decline necessary in that period to reach the Paris Agreement goal.

[113] The IEA does, however, do an excellent job in tracking all the subsidies for fossil fuels.

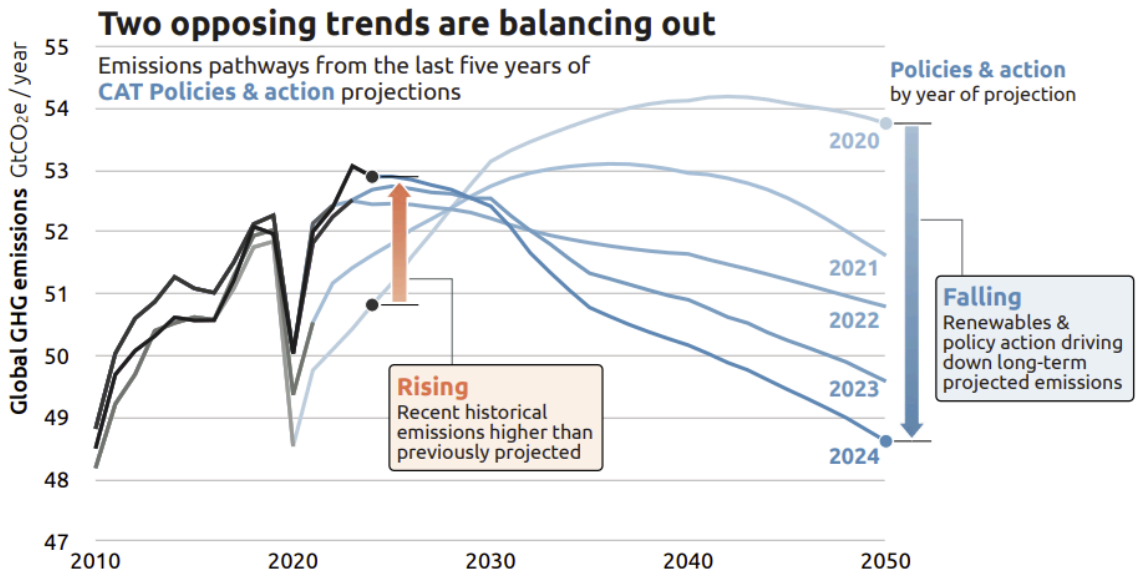

Figure 17. Two Opposing Trends are Balancing Out

"Two opposing trends are balancing each other out: while renewables and policy action are driving down emissions, those emissions are at a higher level than projected." (Figure 2 from Climate Action Tracker, 2024).

Price is Just One Factor

Ted Nordhaus reviews Brett Christophers's new book, *The Price Is Wrong: Why Capitalism Won't Save the Planet* (Christopher, 2024). Here is how Nordhaus explains Christopher's views:

> Christophers, a geographer at Sweden's Uppsala University, argues that getting prices right, whether by making fossil fuels expensive through pricing carbon or making clean energy cheap through subsidies and technological innovation, is entirely insufficient to drive the rapid deployment of renewable energy. Much heavier-handed intervention will be necessary, Christophers argues, including government price guarantees or even public ownership of electricity generation and distribution.[114]

Many have pointed out that utilities have incentives to build capital intensive fossil fuel plants because most public utilities commissions allow utilities to earn a profit as a percentage of costs, so large projects bring in more profits. The unbundling of power generation, distribution, and sale also brings up other problems for renewable energy. Nordhaus continues:

[114] https://foreignpolicy.com/2024/04/21/christophers-price-is-wrong-book-review-climate-change-policy-renewable-energy-wind-solar/

> The drive to break up regulated, vertically integrated utilities and create competitive wholesale electricity markets, he argues, has disadvantaged renewable energy developers, because it forces developers to sell the electricity that they produce much of the time at fire-sale prices, as wind and solar installations often produce lots of electricity at times when it is difficult to sell it for very much. So even though the cost of producing electricity with solar and wind is often very low, it's not profitable enough for private developers because they can't sell it for enough to make a return on their investment.
>
> A consumer-facing utility—as opposed to a mere power producer—must consider the overall cost and complexity of operating an electrical grid that delivers power to users all the time. And from this perspective, the business case for introducing lots of capital-intensive wind and solar that often produce electricity at times when it isn't needed has never been a strong one.
>
> The result, Christophers argues, is that nobody can make money on wind and solar despite their low installation cost without sustained public subsidies.[115]

There is no question that more "heavier-handed intervention will be necessary," because we need to move quickly. In the United States, both public utility commissions and the federal government need to exert more control over the way electrical utilities operate and the type of power plants they build. The government also needs to streamline upgrading the distribution system, as described below.

Nuclear Energy

Nuclear energy is also a clean option, but very few nuclear plants are being constructed, even though they are much safer than fossil fuel and far cheaper. Although most people think that nuclear power is very expensive, this is not true if you consider the costs to society from burning fossil fuels (the term in economics is "externality"). The burning of fossil fuels kills millions every year from air pollution, so not only is nuclear power cheaper than fossil fuels, but it is also much safer. Nuclear power is comparable to solar and wind, which are not perfectly safe because there can be accidents (e.g., helicopters crashing into wind turbines). Nuclear energy "...results in 99.9% fewer deaths than brown coal [i.e., lignite]; 99.8% fewer than coal; 99.7% fewer than oil; and 97.6% fewer than gas. Wind and solar are just as safe".[116] There is still a problem in

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[115] https://foreignpolicy.com/2024/04/21/christophers-price-is-wrong-book-review-climate-change-policy-renewable-energy-wind-solar/

[116] Hannah Ritchie and Pablo Rosado (2020) - "Nuclear Energy" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/nuclear-energy' [Online Resource]

dealing with nuclear waste, but it is minor when compared to the possibility of global societal collapse.

Nuclear plants are most efficient when they run constantly, yet to complement solar and wind power, which fluctuates with the sun and wind, they should be able to vary their output. This is why nuclear plants should be paired with energy storage, which is already happening in some areas. When all the electricity the plant produces is not needed, some can be used to pump water uphill, generating electricity later when it is released downhill through a hydroelectric dam. This is only possible in some areas, but there are other options. For example, tanks of molten salt can also be used to store energy, and nuclear designs that use molten salt tanks are now under development. The molten salt can hold heat for days, and is used to generate electricity when needed.

The technology of most existing nuclear plants in the U.S. is from 50 years ago. Research on nuclear technology is now advancing on multiple fronts, but even more needs to be done. Although rarely acknowledged, the development of small modular nuclear reactors is incredibly important, and one could argue that they could become almost as important as solar and wind turbine technologies. Microreactors offer one very encouraging new technology. Along with small modular reactors, they can be composed of modules constructed in factories, which can dramatically reduce costs. As Black et al. (2023) write in their comprehensive review,

> This technology has disruptive potential as an alternative to carbon-intensive energy technologies based on its mobility and transportability, resilience, and independence from the grid, as well as its capacity for long refueling intervals and low-carbon emissions. Microreactors may extend nuclear energy to a new set of international customers, many of which are located where energy is at a price premium and/or limited to fossil sources. Developers are creating designs geared toward factory production where quality and costs may be optimized. (Black et al., 2023)

A good example is Radiant's Kaleidos (https://www.radiantnuclear.com/), a 1.2 MW high-temperature, gas-cooled nuclear microreactor that is assembled, fueled, and tested in the factory and can be delivered by truck one day and be running at full power the next day (but yes, this is currently just marketing hype). It can also generate up to 1.9 MW of thermal power. Kaleidos could replace diesel generators for both the military and commercial users and can be used in remote locations without site preparation. After five years of operation, when the fuel is depleted, the entire container can be shipped back to the factory for refueling. It is one of three microreactor designs funded in part by the US Department of Energy, and Radiant is supposedly on track to submit

the design for regulatory review in 2024 and demonstrate the first fueled operation by 2027. There is no information about the cost of the unit, but Radiant's intention is that it be cheaper than diesel generators. I have not been able to find any independent assessments of the technology, and all the information above about its performance and ease of use are just marketing claims at this point. Can it really be delivered by truck one day and be running at full power the next day?

Power Usage IS Increasing, and Electricity Transmission IS a Bottleneck

Power use in the U.S. is increasing much more than expected, in part from a dramatic increase in data centers and manufacturing, but also from the increase in electricity use from heat pumps, air conditioning, and electric vehicles. In response, utilities in multiple states are now planning to build many new natural gas power plants to keep up with the demand. The NERC (North American Energy Reliability Corporation), in a recent report on long-term reliability assessment, concludes that, "Natural-gas-fired generators are essential for meeting demand."[117]

A project sponsored by the Clean Grid Initiative comes to the same conclusion in their recent report (2023), "The Era of Flat Power Demand is Over." Here is their summary (verbatim):

- Over the past year, grid planners nearly doubled the 5-year load growth forecast.
    - The nationwide forecast of electricity demand shot up from 2.6% to 4.7% growth over the next five years, as reflected in 2023 FERC [Federal Regulatory Energy Commission] filings.
    - Grid planners forecast peak demand growth of 38 gigawatts (GW) through 2028, requiring rapid planning and construction of new generation and transmission.
- The main drivers are investment in new manufacturing, industrial, and data center facilities.
- The U.S. electric grid is not prepared for significant load growth.
    - The U.S. installed 1,700 miles of new high-voltage transmission miles per year on average in the first half of the 2010s but dropped to only 645 miles per year on average in the second half of the 2010s.[118]

[117] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2023.pdf
[118] John D. Wilson and Zach Zimmerman (Dec. 2024), The Era of Flat Power Demand is Over, *Grid Strategies*, https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

A major problem with the rapid rollout of renewable energy is that there needs to be significant upgrades to our electrical grid. Even if money were not an issue, this is incredibly difficult to do quickly given all the approvals from both state and local officials that are required, plus delays imposed by electrical utilities because they often have to upgrade equipment before allowing new interconnections with solar and wind farms. Obtaining right-of-way easements to put up new transmission lines is also very time consuming.

Here's an interesting, and unfortunate, unintended consequence of expanding the electrical grid – it can increase the release of sulfur hexafluoride (SF_6), one of the most powerful greenhouse gases, which has a global warming potential 24,300 times that of CO_2 and can last for 1,000 years![119] This is happening because sulfur hexafluoride is used in high-voltage electrical switching gear. As electrical power demand has increased, atmospheric concentrations of SF_6 have also increased. Most SF_6 emissions come from China, and between 2011 and 2021, SF_6 emissions doubled in China as it dramatically expanded its electrical grid (An et al., 2024). There are now plans to minimize SF_6 leakage rates and use SF_6-free equipment and SF_6 substitutes.

The Inflation Reduction Act (IRA) was an incredible achievement with far-reaching and very positive impacts. In fact, "The IRA has made renewable electricity cost-competitive with coal and natural gas …. The biggest barriers to deployment between now and 2030 are non-cost in nature—like siting and permitting delays, backlogged grid interconnect queues, and supply chain challenges."[120] (There are many reasons why selecting a geographic site can take extra time, and these all fall within the category of siting delays.)

The Zero Lab at Princeton University[121] focuses its research on improving decision-making to aid in the transition to net-zero carbon energy systems. The title of a recent report summarizes their main conclusion: "Electricity Transmission is Key to Unlock the Full Potential of the Inflation Reduction Act." Here is the summary of their findings (verbatim):

- Failing to accelerate transmission expansion beyond the recent historical pace (~1%/year) increases 2030 U.S. greenhouse emissions by ~800 million tons per

[119] See the IPCC report, "The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity Supplementary Material," https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf. See Appendix 6 for information about Global Warming Potential, or GWP.
[120] Clean Investment in 2023: Assessing Progress in Electricity and Transport (Feb 21 2024), *Clean Investment Monitor,* https://repeatproject.org/docs/Clean_Investment_in_2023_02-21-24.pdf
[121] "Zero" stands for the Zero carbon Energy systems Research and Optimization Laboratory.

year, relative to estimated reductions in an unconstrained IRA case. Emissions are 200 million tons higher if transmission growth is limited to 1.5%/year.

- Over 80% of the potential emissions reductions delivered by IRA in 2030 are lost if transmission expansion is constrained to 1%/year, and roughly 25% are lost if growth is limited to 1.5%/year.
- To unlock the full emissions reduction potential of the Inflation Reduction Act, the pace of transmission expansion must more than double the rate over the last decade to reach an average of ~2.3%/year. That rate of expansion is comparable to the long-term average rate of transmission additions from 1978-2020.
- To achieve IRA's full emissions reduction potential, new clean electricity must be rapidly added to both meet growing demand from electrification and reduce fossil fuel use in the power sector. Constraining transmission growth severely limits the expansion of wind and solar power.
- If electricity transmission cannot be expanded fast enough, power sector emissions and associated pollution and public health impacts could increase significantly as gas and coal-fired power plants produce more to meet growing demand from electric vehicles and other electrification spurred by IRA.[122]

The electricity transmission bottleneck is now well understood. It has been getting a lot of press, and there are many encouraging signs of progress.[123] If control were removed from state and local officials and put in the hands of a new federal licensing agency that also had the power to force utilities to speed interconnection, it would be much easier to accelerate transmission expansion. In the United States, the political and legal difficulties of establishing such a new federal agency are immense, and without new legislation there is no chance of this happening. Even if the president declares a climate emergency and invokes the National Emergencies Act and the Defense Production Act, this is unlikely to provide all the powers necessary for rapid grid expansion.

Planting Trees

Some of the current plans to plant trees stem from a 2019 study in the journal Science that drew immediate scientific rebuttals, and the first author of that study, Thomas Crowther, now says, "If no one had ever said, 'Plant a trillion trees,' I think we'd have been in a lot better space."[124] In the original study, Brastin et al. (2019; Crowther was

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[122] https://repeatproject.org/docs/REPEAT_IRA_Transmission_2022-09-22.pdf

[123] For example, FERC established a new rule, Order No. 1920, in May of 2024 that requires utilities to "update long-term transmission planning over a 20-year time horizon to anticipate future needs" (https://www.ferc.gov/news-events/news/ferc-takes-long-term-planning-historic-transmission-rule).

[124] Alex Luhn (Dec. 13 2023), Stop Planting Trees, Says Guy Who Inspired World to Plant a Trillion Trees, *Wired*, https://www.wired.com/story/stop-planting-trees-thomas-crowther/. See also Catrin Einhorn (Nov. 13 2023), How Much Can Trees Fight Climate Change? Massively. But not Alone, Studies Find, *The New York Times*,

the last author) calculated that there was room for over two billion acres of additional tree canopy cover, which could store over 200 gigatonnes of carbon. That original article (and an earlier 2015 paper) led to the United Nation's Trillion Trees Campaign and many other initiatives to plant trees. Crowther now points out, in an excellent section of his lab's website ("What's the potential of a trillion trees"[125]) that planting a trillion trees is not even theoretically possible. "While tree planting can play a role in certain restoration projects," Crowther writes on his website, "the tree potential paper is not a prescription for tree planting. Instead, it points to the tremendous capacity the Earth has for forested ecosystems and to the benefits we would see if we created the conditions where a trillion more trees could naturally flourish." He goes on to write, "Tree restoration is not a quick fix for climate change. Restored trees will accumulate carbon slowly over the rest of this century and beyond."

There are both positive and negative impacts of planting trees, especially in naturally treeless ecosystems. Moyano et al. (2024) write that although trees can be critical for climate change mitigation,

> …considering other impacts such as reductions in soil carbon or albedo and increased fire severity (through increases in fuel loads and connectivity) reduces the effectiveness of afforestation strategies for climate change amelioration. Additional negative impacts of afforestation are also likely, such as the reduction of native biodiversity and productivity, substantial water yield losses, and changes in nutrient cycles, which can exacerbate other global change drivers. (Moyano et al., 2024)

In a current study, which is much more rigorous than the 2019 study cited above, Mo et al. (2023; Crowther is the last of over 150 authors) conclude:

> At present, global forest carbon storage is markedly under the natural potential, with a total deficit of 226 Gt (model range = 151–363 Gt) in areas with low human footprint. Most (61%, 139 Gt C) of this potential is in areas with existing forests, in which ecosystem protection can allow forests to recover to maturity. The remaining 39% (87 Gt C) of potential lies in regions in which forests have been removed or fragmented (Mo et al., 2023).

Therefore, it's better to preserve existing forests than to plant new trees, and mass plantings or monoculture plantations are definitely not the way to proceed, because "...almost half of global forest production can be directly or indirectly attributed to the

https://www.nytimes.com/2023/11/13/climate/trillion-trees-research.html

[125] https://crowtherlab.com/whats-the-potential-of-a-trillion-trees/

role of biodiversity, highlighting that the full carbon potential cannot be achieved without a healthy diversity of species. Ecologically responsible forest restoration does not include the conversion of other natural ecosystem types, such as grasslands, peatlands and wetlands, that are equally essential" (Mo et al., 2023).

Unfortunately, even these revised estimates of the positive contributions of forests for carbon mitigation are probably overly optimistic, because they depend on reductions of fossil fuel emissions. If emissions continue – as they most certainly will in the near future – then rising temperatures, drought, and fire will reduce the ability of forests to store carbon. In summary, it has been a fantasy to think that planting trees can save us, and the misinterpretation of the research on trees and carbon reduction has set back mitigation efforts by many years.

But We're Still Cutting Down Forests

The World Resources Institute has a Global Forest Watch that collects data on forests around the world. Brazil, under its new president Lula da Silva, has decreased the destruction of forests in the Amazon, but the loss of forests has increased in other countries.

> Between 2022 and 2023, Brazil and Colombia experienced a remarkable 36% and 49% decrease in primary forest loss, respectively. Yet despite these dramatic reductions, the rate of tropical primary forest loss in 2023 remained stubbornly consistent with recent years, according to new data from the University of Maryland's GLAD lab and available on WRI's Global Forest Watch platform.
>
> As some countries show political will to reduce forest loss and others do not, the frontiers of forest loss are shifting: the notable reductions in Brazil and Colombia were counteracted by sharp increases in forest loss in Bolivia, Laos and Nicaragua, and more modest increases in other countries.
>
> Total tropical primary forest loss in 2023 totaled 3.7 million hectares, the equivalent of losing almost 10 football (soccer) fields of forest per minute. While this represents a 9% decrease from 2022, the rate in 2023 was nearly identical to that of 2019 and 2021. All this forest loss produced 2.4 gigatonnes (Gt) of carbon dioxide emissions in 2023, equivalent to almost half of the annual fossil fuel emissions of the United States.[126]

Note that although Brazil lost less forest in 2023 than in 2022, it is still losing a tremendous amount of primary (i.e., old growth) forest.

[126] https://research.wri.org/gfr/latest-analysis-deforestation-trends

Mass Delusion: Reducing Methane

Methane can trap more heat in the atmosphere than CO_2 because of the way it interacts with infrared light leaving the Earth. “Methane has more bonds between atoms than CO_2, and that means it can twist and vibrate in more ways that absorb infrared light on its way out of the Earth’s atmosphere.”[127] There are, however, common misinterpretations about the relative importance of methane versus carbon dioxide, and how it’s misleading to describe methane as 80 times as powerful as carbon dioxide. Jessica McKenzie, an editor of the Bulletin of the Atomic Scientists, interviewed Raymond Pierrehumbert, a professor of physics at the University of Oxford about this common but misleading view.

> **Pierrehumbert:** The 80 times figure comes from the standard Global Warming Potential framework, which was introduced in the very first IPCC (Intergovernmental Panel on Climate Change) report, but what everybody forgot was that it was introduced as an example of how to do a comparison, and not as something people should actually use to make decisions. Nonetheless it stuck.
>
> The main thing is that there is no true equivalence between carbon dioxide emissions and methane emissions, because the climate responds in different ways to a short-lived gas than to a long-lived gas….There is a way to compare them, which is to compare the actual amount of warming produced by different strategies.
>
> **McKenzie:** I sat in on a press call with some of the congressional representatives who have gone to COP, and [US Senator] Sheldon Whitehouse said his number one priority was methane. What’s your message for the politicians who have taken methane as their guiding star, and the journalists who are supporting this narrative, that methane is the big thing that we should be focusing on?
>
> **Pierrehumbert:** It’s a mass delusion and wishful thinking, based on a fundamental failure to understand the different ways that a short-lived gas like methane affects the climate versus a long-lived gas like carbon dioxide. The basis of the fallacy is the total amount of warming you can avoid by any likely amount of methane reduction is small, compared to what needs to be done. And it just comes from a fundamental lack of understanding of basic climate physics.

[127] https://climate.mit.edu/ask-mit/what-makes-methane-more-potent-greenhouse-gas-carbon-dioxide

> It is useful to reduce methane, but it's not going to really help us towards net zero. The only real solution to the climate crisis is to get carbon dioxide emissions down to as close to zero as we can.
> …
> They [politicians and journalists] can easily be seduced by statistics like methane is responsible for 30 percent of the warming now, which implies that we can get rid of that much warming by aggressively acting on methane. But that ignores how much methane is due to natural sources we can't control. It is a mass delusion. Even the IPCC has been very resistant to moving away from this false global warming potential equivalence, which goes back to the very first IPCC report.[128]

Reducing methane will not save us.

Direct Air Capture and Other Types of CO_2 Removal

Removing CO_2 directly from the atmosphere, called direct air capture (DAC), can be done anywhere on the planet, and receives a lot of attention, especially since some plants are already running and removing CO_2 from the atmosphere (although at only demonstration scales). This will probably be necessary (and carbon dioxide removal is assumed in IPCC models), but is not a solution to our problems. DAC is currently extremely expensive, costing over $600 per ton of CO_2:

> IPCC models now indicate that CDR [carbon dioxide removal] must be coupled with NZE [net zero emissions] to reduce total atmospheric GHG concentrations. Present estimated costs of this removal are $100 to $200 per tonne of CO_2. With estimates of how much CO_2 must be removed every year ranging from 5-16 Gt per year, this represents a multi-trillion dollar per year unfunded problem that the world's nations will have to manage. (Taylor et al., 2023b)

The enormous practical problems of removing carbon dioxide at a meaningful global scale are rarely mentioned.

> All of the CO_2 captured by traditional CCS [carbon capture and storage] on coal and gas power plants—plus the CO_2 captured from BECCS [bioenergy with carbon capture and storage] and DACCS [direct air capture with carbon storage]—has to be stored somewhere permanently. The scale of this challenge

[128] Jessica McKenzie (Dec. 18, 2023), 'Mass delusion and wishful thinking': Why everything you think you know about methane is probably wrong, *Bulletin of the Atomic Scientists* https://thebulletin.org/2023/12/mass-delusion-and-wishful-thinking-why-everything-you-think-you-know-about-methane-is-probably-wrong/

> is enormous. Annual global greenhouse gas emissions have soared to 50 billion tons of CO_2 equivalent. Sequestering just 3 billion tons per year works out to 8 million tons per day. Permanently storing it would mean capturing, transporting, and storing a volume of compressed CO_2 greater than the more than 90 million barrels of petroleum a day extracted by the global oil industry, the infrastructure of which took a century to develop. As one expert said, “Needless to say, such a technical feat could not be accomplished within a single generation.” (Romm, 2024)

Even if we can scale up DAC by a factor of 100 in the next few decades, that isn’t enough. It needs to scale up by a factor greater than a million! With respect to carbon dioxide capture and storage, the physicist Pierrehumbert says (in the same interview quoted from above):

> Just about everybody agrees we’ll need a certain amount of that, once we’ve gotten carbon dioxide emissions down to nearly zero, but right now, as Pierre Friedlingstein has said recently, the existing air capture projects are capturing one-one-millionth of what they would need to, and even under outrageously optimistic projections, where they improve by a factor of 1,000, or even 10,000, that’s still not going to do the job of decarbonization.
>
> The role of carbon dioxide air capture, or capture and sequestration, is in dealing with the last 10 percent or so of emissions that we can’t easily avoid. That would include things like hard-to-decarbonize sectors, maybe aircraft, it would include rogue nations; you know, North Korea isn’t likely to sign on to emission reductions. Whether you call it a phase-down or a phase-out, the fact is that we have to get emissions down by about 90 percent before we can even think about a possible role of air capture in sopping up the rest. So while it is useful to have another entity putting money in to develop the technology, because we will need some of it, it’s not the game changer. It only becomes an important part of the strategy once we get down to within shouting distance of net zero.

Romm (2024) emphasizes the point that direct air capture is not something that we should be focusing on now (although I think that research and demonstration systems should continue). Direct air capture with carbon storage (DACCS) requires an enormous amount of renewable energy, and this energy could be much more efficiently used to directly reduce our use of fossil fuels.

> The bottom line is that right now, for every ton of CO_2 removed by a DACCS system, we effectively raise ambient CO_2 levels by 10 to 20 tons since that’s how

> much emissions we could have reduced if we had not misallocated the renewable energy along with all of the money and effort needed for DACCS. (Romm, 2024)

Direct air capture and other types of CO_2 removal will not save us.

New Carbon Capture Technologies

There are many new direct air capture techniques and companies. Consider Heirloom, which claims to be the most cost effective technique, and uses limestone to remove CO_2:

> Limestone is made up of calcium oxide and CO_2. When CO_2 is removed from limestone, the remaining calcium oxide acts like a sponge – absorbing CO_2 so it can return to its natural limestone state. Our technology accelerates this natural property of limestone, reducing the time it takes to absorb CO_2 from years to just 3 days.
>
> We heat limestone mineral powder in a renewable-energy powered kiln to remove the CO_2. Our partners then permanently and safely sequester this CO_2 in deep geological reservoirs, or in long-lasting materials like concrete.
>
> Once the CO_2 is removed, we spread this mineral powder onto vertically-stacked trays and "treat" it to optimize its ability to uptake CO_2 in different environmental conditions.
>
> Like repeatedly wringing a sponge, we loop this limestone mineral powder through our system to continuously suck CO_2 from the atmosphere – a cyclic process that not only lowers costs but also reduces how much limestone must be mined.[129]

Although direct air capture will not save us in the short term, it is probably part of the long-term solution. Even after we reach net zero, there will still be far too much CO_2 in the atmosphere, and direct air capture will be required to remove some and return us to a safe level.

Not only will direct air capture not save us, but doing more than refining the technology and building demonstration systems is misguided, for the reason stated above, which is worth repeating for emphasis: Direct air capture with carbon storage (DACCS) requires

[129] https://www.heirloomcarbon.com/technology

an enormous amount of renewable energy, and this energy could be much more efficiently used to directly reduce our use of fossil fuels.

Shaming the Superrich

Joe Fraser, in an opinion piece in the NYTimes, talks about how carbon shaming and taxes on the ultra-wealthy can have dramatic impacts, both psychologically and with respect to rapidly reducing emissions.[130]

> On an individual basis, the superrich pollute far more than the rest of us, and travel is one of the biggest parts of that footprint. Take, for instance, Rising Sun, the 454-foot, 82-room megaship owned by the DreamWorks co-founder David Geffen. According to a 2021 analysis in the journal Sustainability, the diesel fuel powering Mr. Geffen's boating habit spews an estimated 16,320 tons of carbon-dioxide-equivalent gases into the atmosphere annually, almost 800 times what the average American generates in a year.[131]

The five thousand superyachts on the seas today pollute as much as entire nations, Fraser writes, and private jets are even worse. This can discourage ordinary people from taking small steps to reduce their carbon footprints. From the Fraser article:

> Research in economics and psychology suggests humans are willing to behave altruistically — but only when they believe everyone is being asked to contribute. People "stop cooperating when they see that some are not doing their part," the cognitive scientists Nicolas Baumard and Coralie Chevallier wrote last year in Le Monde.[132]

There are tens of thousands of private jets. Here's the headline from a NYTimes article from February 7, 2024:

"It's a Big Weekend for Football. And for Fancy Jets.
Around 1,000 private aircraft are expected at Las Vegas airports for the Super Bowl. It matters for climate change, and maybe for Taylor Swift, too."
(In actuality, about 900 showed up.)

Carbon shaming can work, both on the ultrarich, and on government officials. "Change can happen — and quickly. French officials are exploring curbing private plane travel.

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[130] Joe Frassier (April 10, 2023). The Superyachts of billionaires are starting to look a lot like theft, *The New York Times*, https://www.nytimes.com/2023/04/10/opinion/superyachts-private-plane-climate-change.html
[131] Ibid.
[132] Ibid.

And just last week — after sustained pressure from activists — Schiphol Airport in Amsterdam announced it would ban private jets as a climate-saving measure."[133]

Unbridled Optimism: Just Flip the Switch!

Former Vice President Al Gore has probably done more than anyone else to warn of the dangers of climate change, deservedly winning the Nobel Peace Prize, along with the IPCC, in 2007. In a recent New Yorker interview, he explains many of the serious problems facing us, but then misrepresents recent climate research. Gore is a brilliant man, and I can only assume that he believes his dishonesty is warranted in this situation to prevent despair and spur people to action. In the interview, Gore says,

> I've used the metaphor of flipping a switch, and some people have objected to that. But, really, we have a switch we can flip. The climate crisis is really a fossil-fuel crisis. There are other components of it, for sure, but eighty per cent of it is the burning of fossil fuels. And scientists now know—and this is a relatively new finding, a very firm understanding—that, once we stop net additions to the overburden of greenhouse gases, once we reach so-called net zero, then temperatures on Earth will stop going up almost immediately. The lag time is as little as three to five years. They used to think that temperatures would keep on worsening because of positive-feedback loops—and some things, tragically, will. The melting of the ice, for example, will continue, though we can moderate the pace of that; the extinction crisis will continue without other major changes. But we can stop temperatures from going up almost immediately, and that's the switch we need to flip.[134]

According to most of the models in the new research, warming will stop within a few decades after net zero, not three to five years, and some models suggest it may take even longer. There are many problems with the passage above, but the main problem is that Gore implies it will be easy to reach net zero. The major MIT study described below, for example, actually concludes that there will be only modest reductions in GHG emissions by 2050. Joseph Romm, who formerly ran the Department of Energy's efficiency and renewables office, summarizes the situation in the subtitle to a recent article, "'Net zero' emissions depends on a dangerous myth. Proposals now center on three prominent strategies for CO_2 removal—tree planting, bioenergy with carbon capture and storage, and direct air capture—but they are not scalable, and could make things worse" (Romm, 2024).

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[133] Ibid.; private jets will be banned starting in 2025.

[134] David Remnick (Oct. 6 2023), Al Gore doesn't say I told you so, *The New Yorker,* https://www.newyorker.com/news/q-and-a/al-gore-doesnt-say-i-told-you-so

The new finding (a “very firm understanding”) that Gore mentions is also based in part on computer models that examine the effects of zero-emission scenarios assuming that were to happen today. Even the most optimistic estimates put zero emissions at least 30 years out, at which point we will almost certainly have passed multiple tipping points and locked in several carbon-cycle feedback processes. Other estimates, described below, indicate that even 30 years from now we will be nowhere near net zero. The metaphor of flipping a switch is based on pure conjecture at this point, and in my opinion is dishonest. Whether it is warranted as a way to prevent climate despair and inaction is an open question.

Unfortunately, even if Gore is correct and warming were to stop immediately at net zero, we would still be in an extremely undesirable state, because after the temperature stops going up it will not come down, based on natural processes, for at least several hundred years. As Le Page (2023) writes, contradicting Gore’s very firm understanding, “The longer it takes to reach net zero, the greater the risk that global warming will continue for decades or millennia even after we have cut greenhouse gas emissions, according to an assessment by climate researchers.” Since we are on track to exceed 2°C, continued warming after net zero is inevitable. Consider one of the many pessimistic conclusions of the International Cryosphere Initiative (ICCI, 2023):

> 2°C – and even 1.5°C – is too high to prevent extensive permafrost thaw and resulting CO_2 and methane emissions that will cause temperatures to continue to rise, even once human emissions reach zero, unless offset by extensive negative emissions/carbon drawdown…. (ICCI, 2023)

Others continue in this vein of unbridled optimism, and unfortunately receive a lot of attention in the press. See, for example, Hannah Ritchie’s recent book, *Not the End of the World: How We Can Be the First Generation to Build a Sustainable Planet* (2024). The blurb on Amazon.com includes this: “...in this bold, radically hopeful book, data scientist Hannah Ritchie argues that if we zoom out, a very different picture emerges. In fact, the data shows we’ve made so much progress on these problems that we could be on track to achieve true sustainability for the first time in human history. Did you know that: carbon emissions per capita are actually down ….” Note that carbon emissions per capita is a misleading metric; if the population increases (which it is), then emissions per capita can go down while total emissions increase, and the only thing that really matters at this point is total emissions. Despite what Richie writes, we are certainly not on a path to achieving true sustainability.

Net Zero by 2050?

MIT has a Joint Program on the Science and Policy of Global Change, and recently released a major report, the 2023 Global Change Outlook (Paltsev et al., 2023). In their Current Trends scenario, which assumes the Paris Agreement NDCs (Nationally Determined Contributions) are implemented through 2030 (which is very unlikely to happen), they predict that global greenhouse gas emissions will stay relatively constant for the next decade and then decrease slightly by 2050. Greenhouse gas emissions will go from 47 gigatonnes of CO_2 equivalent (Gt CO_2e) in 2020 to about 48 Gt CO_2e in 2030, and then decrease to 45 Gt CO_2e in 2050. So rather than net zero, there will be very little change from 2020 to 2050!

As Taylor et al. (2023b) explain, reaching net zero is exceedingly difficult.

> Achieving NZE [net zero emissions] is an extremely difficult and complex challenge. It is unlikely that this goal will be reached by 2050, let alone 2030, due to different national commitments, political resistance (particularly from fossil fuel producers), structural inertia from existing institutions, infrastructure and technologies, and because the technologies do not yet exist to allow the rapid decarbonization of the global economy in many sectors, e.g., agriculture and aviation.

Establishing Budgets for Carbon Dioxide Removal

Removing carbon dioxide from the atmosphere is critical for achieving net zero, but is limited by our current technology and the costs. For this reason, some have suggested creating a Carbon Removal Budget (CRB) to complement carbon budgets. Carbon budgets are used to measure how much carbon we are producing and to calculate how much emissions must be cut in the future; they are used extensively and are part of all planning activities.

Caldecott and Johnstone (2024) distinguish between what they call “conventional” and “novel” carbon dioxide removal (CDR) techniques. Conventional CDR includes reforestation and the restoration of peatlands and other carbon sinks, while novel CDR includes technologies that remove and store carbon such as direct air carbon capture and storage (DACCS). They write that carbon budgets have “been a vital concept to model the relationship between cumulative emissions and temperature increase,” and then go on to argue that a Carbon Removal Budget should be employed in parallel with carbon budgets. A Carbon Removal Budget is “a conceptual tool that can be used to estimate, allocate and manage the finite global potential of CDR” (Caldecott & Johnstone, 2024). A CRB would help in “revealing the necessary near-term investments in CDR supply needed today to offset tomorrow’s residual emissions.”

Caldecott and Johnstone (2024) discuss a variety of issues, including various constraints, and the issue of reversibility – some techniques are able to store carbon for only relatively short time periods and so the positive effects are reversible. After analyzing IPCC scenarios, Caldecott & Johnstone (2024) conclude, as argued above, that these scenarios are based on more carbon dioxide removal than now seems possible. A detailed analysis of both carbon budgets and carbon removal budgets should make clear exactly how much more effort we need to put into carbon dioxide removal.

Political Considerations

Political Problems in the United States

In the first U.S. Republican presidential debate (August 23, 2023), the eight candidates (Trump was absent) were asked if they believed that "human behavior is causing climate change." Most candidates refused to answer, but one, Vivek Ramaswamy, said that, "The climate change agenda is a hoax" and that we should "unlock American energy, drill, frack, burn coal."[135] Ramaswamy's poll numbers went up after the debate. All the candidates believed that we should continue expanding the extraction of fossil fuels. When this is the view of one of the two major political parties in the United States, how likely is rapid decarbonization? The candidates reflect the views of most Republicans, as 58% say we should prioritize expanding the production of oil, coal, and natural gas rather than prioritizing alternative energy sources (Tyson et al., 2023). Even though many in the U.S. now realize that climate change should be a top priority, it is far down the list of national issues: "Overall, 37% of Americans say addressing climate change should be a top priority for the president and Congress in 2023, and another 34% say it's an important but lower priority. This ranks climate change 17th out of 21 national issues included in a [Pew] Center survey from January [2023]" (Tyson et al., 2023).

Recent surveys and interviews make clear how difficult it will be to move quickly on climate change. "Overall, 46% of Americans say human activity is the primary reason why the Earth is warming. By contrast, 26% say warming is mostly caused by natural patterns in the environment and another 14% do not believe there's evidence the Earth is warming at all" (Pasquini et al., 2023). Pasquini and his colleagues at the Pew Research Center conducted in-depth interviews with people who do not think there is a climate crisis. These interviews provided insights into their thought processes: although they are in agreement that the Earth's climate is changing, they think this is due to natural patterns and variability. Although most of these people trust climate scientists, they are concerned that some scientists may have political or personal biases. In

[135] Ramaswamy has a page on his website called, "Truth." (https://www.vivek2024.com/truths/). Number three is, "Human flourishing requires fossil fuels."

contrast, most do not believe what they hear from the national news media, and are especially skeptical when told there is a crisis and we must take immediate action. Most stress the importance of individual freedom, so do not want to be told, for example, that gas-powered vehicles must be phased out. If there are transitions from fossil fuels, these people say, they should be gradual.

It seems reasonable to assume that Republicans in congress should be more responsible than presidential candidates, who may need to make outrageous statements to get attention. Unfortunately, this is not the case, and here is just one example: On September 14th, 2023, the US House of Representatives voted 222-190 to pass a Republican-led bill, H.R. 1435, "To amend the Clean Air Act to prevent the elimination of the sale of internal combustion engines." This bill would prohibit states from banning the sale of gas-powered cars. It did not become law, given opposition in the Senate and a certain presidential veto, but it illustrates the view among House Republicans about fossil fuel and climate change.[136]

After a month of chaos in the US House of Representatives, the Republicans finally chose a new speaker. Here is a headline from the NYTimes from October 26, 2023 that summarizes some of his views:

"New House Speaker Champions Fossil Fuels and Dismisses Climate Concerns
Representative Mike Johnson comes from Louisiana oil country and has said he does not believe burning fossil fuels is changing the climate."

In 2024, Republican opposition to any actions that limit fossil fuels continued, and emblematic of the attitudes of many Republicans was Florida Governor Ron DeSantis, who signed legislation (HB 1645) that prohibits the construction of offshore wind energy facilities, prohibits any political subdivision of the state from limiting the types of fuel sources that can be used, and even removes the words "climate change" from state statutes. The law took effect on July 1, 2024. Meanwhile, ex-president Trump, at a fundraising dinner with oil executives, said he would help them to drill and export fossil fuels if he were elected – provided they donated a billion dollars to his campaign.

The 2024 Republican Party Platform
In July, 2024, the Republican party released their platform. It begins with twenty "promises" including these two: #4, "Make America the dominant energy producer in the world, by far!," and #15, "Cancel the electric vehicle mandate and cut costly and burdensome regulations."[137]

[136] https://www.congress.gov/bill/118th-congress/house-bill/1435/text
[137] https://www.presidency.ucsb.edu/documents/2024-republican-party-platform

The Preamble is titled, “America First: A Return to Common Sense.”

> Common Sense tells us clearly that we must unleash American Energy if we want to destroy Inflation and rapidly bring down prices….We will DRILL, BABY, DRILL and we will become Energy Independent, and even Dominant again. The United States has more liquid gold under our feet than any other Nation, and it's not even close. The Republican Party will harness that potential to power our future.[138]

Chapter Three is titled, “Reliable and Abundant Low Cost Energy.”

> Republicans will increase Energy Production across the board, streamline permitting, and end market-distorting restrictions on Oil, Natural Gas, and Coal. The Republican Party will once again make America Energy Independent, and then Energy Dominant, lowering Energy prices even below the record lows achieved during President Trump's first term.[139]

Throughout the platform there are also a variety of statements about slashing and cutting burdensome regulations, many of which were passed to reduce the use of fossil fuels, promote renewable energy, and protect the environment. “Climate,” “climate change,” or “greenhouse gases” never appear in the document. As climate scientist Michael Mann said in an interview with Ali Velshi for MSNBC, “A second Trump presidency would be more or less game over for climate action.”[140] Now that Trump has won the election, Mann writes that, “...the United States is now poised to become an authoritarian state ruled by plutocrats and fossil fuel interests. It is now, in short, a petrostate.”[141] Given this state of affairs, it is worth asking the question once again: how likely is a worldwide mobilization to eliminate the use of fossil fuels when this is how one of the two major political parties in the U.S. is acting – and that party is now in control of the country?

President Trump’s First Actions on the Environment

On Trump’s first day in office (January 20, 2025) he signed an executive order withdrawing the U.S. from the Paris deal, suspended new offshore wind leasing from all parts of the U.S. continental shelf, revoked Biden’s order that 50% of new vehicles sold in the U.S. by 2030 should be electric, halted unspent money for charging stations, and also reversed Biden’s executive order blocking Arctic

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[138] Ibid.
[139] Ibid
[140] https://www.msnbc.com/ali-velshi/watch/-game-over-for-climate-action-top-climate-scientist-on-2nd-trump-term-213522501609
[141] Michael E. Mann (November 7, 2024), Welcome to the American petrostate, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2024/11/welcome-to-the-american-petrostate/

drilling. He restarted the processing of export permit applications for new liquified natural gas projects (primarily in Louisiana and Texas), reduced environmental regulations, and declared a national energy emergency, which will enable Trump to streamline projects involved in the extraction and distribution of fossil fuels. It is hard to imagine a more effective set of actions to aggravate the climate crisis and accelerate our path toward societal collapse.

Not Just the U.S.

In Australia, Tranter et al. (2023) studied a nationally representative sample and found that "only a slim majority (approximately 55%) of Australians trust two operationalised projections from the IPCC. The IPCC projections we model refer to estimates of 1.5° warming occurring between 2030 and 2052, and that coral reefs will decline in size by between 70% and 90% at 1.5° warming."

> Over a third of those who had little or no trust in these IPCC projections [20% of the total sample] believe scientists stand to benefit by overstating the impact of climate change, while close to one third claimed climate models were not reliable enough to predict the climate of the future. A further 17% of those with low trust believed human activities do not cause global warming or that global warming does not cause climate change." (Tranter et al., 2023)

Note that one of the "operationalised projections" involved the decline of coral reefs between 70% and 90% at 1.5° warming. We're not yet at 1.5°, but during the first several months of 2024 coral reefs around the world experienced their fourth mass bleaching event since 1998, and over half the world's coral experienced bleaching-level heat stress during the last year. In effect, respondents in the Tranter survey were asked about whether they believed something would happen in the future when it was already in the process of happening!

Economic Power to Political Power

Former Vice President Gore explains succinctly how economic power in a capitalist society translates to political power:

> The banks and the other large lenders, and associated industries, have, for more than a hundred years, built up a legacy network of political and economic influence. Shockingly, they have managed to convert their economic power into political power with lobbying, and campaign contributions, and the revolving-door phenomenon — where fossil-fuel executives go into the government.

> I mean, the last President of the United States made the C.E.O. of ExxonMobil the Secretary of State. It's almost hard to believe, but that is a symbol of how fossil-fuel companies have penetrated governments around the world.
> …
> The polluters have gained a high degree of control over the processes of self-government. I've often said that, in order to solve the crisis, we have to pay a lot of attention to the democracy crisis. Our representative democracy is not working very well. We have a dual hegemonic ideology called democratic capitalism, and the democracy part of our ideology has been cannibalized, to some extent, by economic actors, who have found ways to convert wealth into political influence. Wealth has always had its usefulness in the political sphere, but much more so in an era in which the candidate who raises the most money, and can buy the most media presence, almost always wins the election.
> …
> They [the fossil-fuel industry] have taken over one of our two major political parties, lock, stock, and oil barrel. It's really quite shocking.
> …
> This year [2023], the annual United Nations Climate Conference is in the United Arab Emirates, and they have named the head of their national oil company, Sultan al-Jaber, as the president of the conference.
> …
> It's absurd to put the C.E.O. of one of the largest and, by many measures, least responsible oil and gas companies in the world in charge of the climate conference. At last year's conference, in Sharm el-Sheikh, Egypt, the delegates from oil and gas companies outnumbered the combined delegations of the ten most climate-affected nations. The year before, in Glasgow, the fossil-fuel delegates outnumbered the largest national delegation. They have dominated this U.N. process the same way they've dominated so many state governments in the U.S., and the national government much of the time.[142]

COP28 was no different, and many news outlets reported that the fossil fuel industry was sending more delegates than any single country. Kick Big Polluters Out is a coalition trying to eliminate the influence of fossil fuel companies and their associated industry organizations. They recently reported their analysis of COP attendance:

> Disclosed delegates tied to the world's biggest polluting oil and gas firms and their trade groups have attended UN-led climate talks at least 7200 times over

[142] https://www.newyorker.com/news/q-and-a/al-gore-doesnt-say-i-told-you-so. Also, see https://www.ted.com/talks/al_gore_what_the_fossil_fuel_industry_doesn_t_want_you_to_know for a TED talk in which Gore rails against fossil fuel companies for 25 minutes.

> the last 20 years, according to a new analysis from the Kick Big Polluters Out (KBPO) coalition.
>
> "The UN has no conflict-of-interest rules for COPs," said George Carew-Jones, from the YOUNGO youth constituency at the UNFCC.[143] "This unbelievable fact has allowed fossil fuel lobbyists to undermine talks for years, weakening the process that we are all relying on to secure our futures.[144]

Is Capitalism to Blame?

There is little disagreement among scientists about the seriousness of our situation. There is disagreement, however, about what led to the current crisis. Bradshaw et al. (2021) focus on the negative effects of population and economic growth more than others. In their conclusion they write,

> The gravity of the situation requires fundamental changes to global capitalism, education, and equality, which include *inter alia* the abolition of perpetual economic growth, properly pricing externalities, a rapid exit from fossil-fuel use, strict regulation of markets and property acquisition, reigning in corporate lobbying, and the empowerment of women.

These all make sense, and are probably necessary, except for "the abolition of perpetual economic growth." Growth has been destructive in the past, but there is no logical reason why economic growth can't be sustainable and decoupled from negative environmental impacts. Growth cannot continue as in the past, of course, and perhaps the definition of "economic growth" may need to change.

Blustein et al. (2021), in their critique of the Bradshaw et al. paper, write that they have no disagreement with the "diagnosis of the severity of the crises," but argue that Bradshaw et al. "focus on the role of human population growth as a central driver" of the crises they elaborate, rather than emphasizing "the role of European colonization and fossil capitalism." Blustein et al. argue that there should be more focus on inequality and the role of capitalism, and scientists "should help expose the structural causes and drivers of inequality, overproduction and overconsumption."

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[143] "YOUNGO is the official children and youth constituency of the United Nations Framework Convention on Climate Change (UNFCCC). YOUNGO is a vibrant, global network of children and youth activists (up to 35 years) as well as youth NGOs, who contribute to shaping the intergovernmental climate change policies and strive to empower youth to formally bring their voices to the UNFCCC processes." https://unfccc.int/topics/education-youth/youth/youngo

[144] https://kickbigpollutersout.org/articles/release-fossil-fuel-lobbyists-attend-un-climate-talks-more-7000-times

For a book-length exploration of the role of capitalism, read Naomi Klein (2014), *This Changes Everything: Capitalism vs The Climate*. A more recent book is Akshat Rathi's *Climate Capitalism: Winning the Race to Zero Emissions and Solving the Crisis of our Age* (2024) which is about "how we tackle climate change within the world's dominant economic system…." The book goes through all the new technologies and positive changes currently happening, but doesn't address the fact that we are now moving too slowly to prevent catastrophe. For a short treatise on how the "ethical decadence" of the power of the "technocratic paradigm" has led to the current crisis, read Pope Francis' (2023) recent Apostolic Exhortation.

Can Democracy Survive?

Brechin and Lee (2023) explore the possibility that "...democracy, already under threat, does not survive the realities of climate change. Governments' failure to provide adequate relief to their citizens becomes the last straw that topples democratic institutions." Brechin and Lee refer to the writings of Ophuls from over 50 years ago, who suggested "that the failure of our democratic politics and economic systems to protect people and nature will lead to the unfortunate but necessary decision to empower an ecological dictator to address our environmental ills with the ruthlessness required to save us all from our worst impulses" (Brechin & Lee, 2023).

We are unlikely to be saved by an "ecological dictator," although the climate crisis may be one important factor leading to authoritarian rule; "...authoritarianism today hardly seems environmentally focused. Rather, climate change is used as a pretext for manufactured, deeply divided politics that punctuate the inadequacies of democratic practice and allow authoritarians to acquire political power for their own gain" (Brechin & Lee, 2023).

Climate Change, "Fragile" Countries, and Armed Conflict

Unfortunately, some countries that are politically vulnerable and fragile are also states that will see extreme warming in the near future. Some of these will become "failed" states that can no longer deliver basic public services such as healthcare and education, can no longer enforce laws and provide security, and can no longer maintain infrastructure such as water and sewage treatment plants, roads, bridges, and communication. One measure of politically vulnerable states is measured by the Fragile States Index,[145] which examines economic, political, and social indicators as well as

[145] "The Fragile States Index is based on a conflict assessment framework – known as "CAST" – that was developed by FFP [The Fund for Peace] nearly a quarter-century ago for assessing the vulnerability of states to collapse. The CAST framework was originally designed to measure this vulnerability and assess how it might affect projects in the field, and continues to be used widely by policy makers, field practitioners, and local community networks. The methodology uses both qualitative and quantitative indicators, relies on public source data, and produces quantifiable results. Twelve conflict risk indicators are used to measure the condition of a state at any given

cohesion indicators based on the security apparatus in a country, factionalized elites, and group grievances. Kemp et al. (2022) presents a figure showing the "striking overlap" between state fragility and extreme heat. Many of these fragile countries are less wealthy countries without industrialized economies and with less resiliency than most rich countries, and they will likely be the first to experience catastrophic effects of climate change.

The World Bank also has a Fragile States Index, and categorizes states under two categories: Conflict, and Institutional and Social Fragility. In 2024, 19 states are listed in the Conflict category while 20 are listed as suffering from Institutional and Social Fragility.[146]

Sofuoğlu & Ay (2020) examined the relationship between climate change and political instability in 18 Middle East and North African (MENA) countries between 1985 and 2016. From their abstract:

> For empirical analysis, temperature and precipitation data representing climate change, political instability, and conflict data are employed. According to the findings, there is a causal relationship from climate change to political instability in 16 countries and to conflict in 15 countries. In addition to this, at least one causal relationship is determined from climate change to political instability or conflict in all MENA countries. Therefore, empirical results support the assumption that climate change acts as a threat multiplier in MENA countries since it triggers, accelerates, and deepens the current instabilities.

Climate change will be a factor in increasing political instability, and fragile countries will not have the infrastructure and resources to deal effectively with extreme weather and climate change. Consider what happened in Libya in September, 2023 – which was just one of multiple extreme weather events during the year.[147] The background: "Libya's infrastructure has suffered repeated blows during a civil war that broke out after the fall of Muammar Gaddafi in 2011. The country now remains divided between rival governments in the east and the west."[148]

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moment. The indicators provide a snapshot in time that can be measured against other snapshots in a time series to determine whether conditions are improving or worsening" (https://fragilestatesindex.org/indicators/).

[146] https://www.worldbank.org/en/topic/fragilityconflictviolence/brief/harmonized-list-of-fragile-situations

[147] Libya is classified as a fragile state by the World Bank, listed in the category of Institutional and Social Fragility.

[148] Sarah Dadouch (Sept. 12, 2023), Thousands missing and feared dead after floods submerge eastern Libya, *Washington Post* https://wapo.st/44SkTl4

> Thousands are feared to have died in floods that engulfed Libya's east after Storm Daniel smashed into the North African country, swallowing whole neighborhoods and, with them, an unknown number of residents. The city of Derna has been most acutely affected, after raging torrents of water tore through two dams and swept entire buildings into the sea…."I expect numbers of dead will rise to 10,000," he [Othman Abdul Jalil, the health minister] told the [local television] channel early on Tuesday.[149]

What happened in Libya will, unfortunately, happen in many other countries: political instability leads to poor planning and a deterioration of already weak infrastructure. Limited maintenance leads to poor roads and weak dams, and then when a major storm arrives (Storm Daniel, in this case) and 16 inches of rain fall within 24 hours, with most falling within a six-hour period, dams collapse and there is catastrophic flooding in low-lying vulnerable areas. Then, as in other fragile states, there are not enough search and rescue teams, good communication systems, trucks that can drive through deep water, helicopters, ambulances, bulldozers, backhoes and other heavy equipment, and stockpiles of emergency supplies. There was also catastrophic flooding in Greece and Turkey from Storm Daniel, but with effective central governments and the ability to react quickly to disasters, only a few dozen people died.

Conflict Over Water

There are three types of water-related conflicts. First, and the type we are most concerned with here, is when a water source triggers a violent conflict. Second, water systems can become a target or a casualty and be destroyed or damaged during an armed conflict; and third, water can be used as a weapon; e.g., by destroying dams or cutting off or poisoning water supplies.[150] The Pacific Institute has cataloged over 2,000 water conflict incidents from 2500 BCE to 2023.[151]

There has been a sharp increase in violence over water resources during the last decade, and Dr. Gleick, co-founder of the Pacific Institute, summarizes the current situation.

> "The significant upswing in violence over water resources reflects continuing disputes over control and access to scarce water resources, the importance of water for modern society, growing pressures on water due to population growth and extreme climate change, and ongoing attacks on water systems where war and violence are widespread,

[149] Ibid.
[150] Morgan Shimabuku (July 15, 2024), 4,000 years of conflict over water: A timeline. *Bulletin of the Atomic Scientists*, https://thebulletin.org/premium/2024-07/water-and-war/
[151] https://pacinst.org/water-conflict-chronology/ and https://worldwater.org/conflict/list/

> especially in the Middle East and Ukraine," said Dr. Peter Gleick, Senior Fellow and co-founder of the Pacific Institute.[152]

As the world warms, some areas will experience extreme droughts, and conflict over water will increase. In addition, when armed conflict breaks out for other reasons, damage to water infrastructure is common. For some examples of recent conflicts over water, see Appendix 1.

The Rise of Nationalism and Right-wing Populist Leaders

It is likely, as several political scientists and sociologists have pointed out, that mass migration and resource scarcity will lead to nationalistic and authoritarian political regimes. Brechin and Lee (2023), for example, write that, "With the expected movement of massive numbers of climate refugees, rising food prices from rapid climatic change, and the inability of governments, democratic, or otherwise, to respond effectively to the cascading set of disasters will make the populace of nations, even democratic ones, gravitate to authoritarian rule."

This is very problematic with respect to climate change because, as Conversi (2023) writes, "...nationalism remains a key impediment to successful climate action, since a global calamity such as the climate emergency can only be comprehended and tackled on a world-wide basis and through synchronised global action."

Over the last decade, right-wing populist leaders with anti-environmental views and policies have gained power in the U.S., Brazil, Australia, Hungary, and several other countries. Now we can add Argentina to the list, for in November, 2023, Javier Milei, an admirer of Donald Trump, became Argentina's president.

> A far-right economist and television pundit with no governing experience, Milei has called climate change a "socialist lie" and has claimed that "all the policies that blame humans for climate change are false." He has also said companies should be allowed to pollute rivers "as much as they want to."[153]

Some commentators are now even talking about the possibility of a far-right European Union, because the center right and far right are coming together in some countries, especially on issues of immigration, religion, and cultural identity. The EU is already

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[152] https://pacinst.org/announcement/2023-was-a-record-year-for-violence-over-water-resources-across-the-globe/

[153] Maxine Joselow (Nov. 21, 2023), Here's how many fossil fuel lobbyists have attended U.N. climate talks, *The Washington Post* https://www.washingtonpost.com/politics/2023/11/21/heres-how-many-fossil-fuel-lobbyists-have-attended-un-climate-talks/

treating the Mediterranean as a Trumpian wall, and basically paying other countries to stop migrants from getting to Europe. Marine Le Pen's far-right National Rally is gaining surprising support in France, and is the party in France least concerned with the climate crisis. In fact, the party platform argues that, "environmental standards penalise economic growth."[154]

Authoritarian Environmentalism

Nationalistic and authoritarian leaders currently tend to scoff at the climate crisis, in part because solutions require multilateral cooperation and agreements that limit national choices with respect to energy generation. Limiting "freedom" and being forced to follow rules devised by international committees does not fit with the modus operandi of most current authoritarian leaders. "Authoritarian environmentalism," however, is already here, and may expand in the future. Mittiga (2021) defines authoritarian environmentalism as follows[155]:

> This mode of governance, typically associated with China, is often juxtaposed to the "democratic environmentalism" of wealthy, postindustrial states like the United States, Australia, Germany, and Japan. The essential idea behind these encomiums is that, while authoritarianism is in general lamentable, having a government unencumbered by democratic procedures or constitutional limits on power could be advantageous when it comes to implementing urgently needed climate action. (Mittiga, 2021)

When serious problems arise, whether economic, social, or political, many people find the simplistic solutions of a strong leader appealing, and this is also true for environmental problems. In fact, there can be an "allure of authoritarian environmentalism: for if, as many now contend, liberal democratic norms, principles, and institutions impede urgently needed climate action, then legitimacy may permit—or even require—relaxing or abandoning those constraints" (Mittiga, 2021). Mittiga advances some compelling arguments in discussing when an authoritarian regime could be considered legitimate.

> In times of war, for instance, authoritarian impositions of power, including those that curtail democratic processes or basic rights, are often thought legitimate to

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[154] Multiple Authors (June 25, 2024). France election 2024: What the manifestos say on energy and climate. *Carbon Brief*, https://www.carbonbrief.org/france-election-2024-what-the-manifestos-say-on-energy-and-climate/

[155] Mittiga's definition: "I use 'authoritarian' in a fairly generic and expansive sense throughout to refer to political arrangements or modes of governance that are illiberal (i.e., rights- and freedom-constraining), undemocratic, and characterized by a concentration of executive power."

> the extent they are necessary for protecting citizens and restoring normal conditions. Likewise, as those who have survived COVID-19 can attest, during a health emergency, severe and enduring limitations of rights to free movement, association, and speech can become legitimate techniques of government, even in robustly liberal-democratic states. As these examples suggest, in crisis moments, political legitimacy may not only be compatible with authoritarian governance but actually require it. Conversely, stringent adherence to liberal democratic constraints may diminish legitimacy insofar as it inhibits effectively addressing credible security threats. (Mittiga, 2021)

If an existential threat to a nation state by a belligerent neighbor justifies abandoning some democratic principles and norms, and the same applies to a deadly pandemic, why not also for the climate crisis, which is an existential threat to all humankind? The allure of authoritarian environmentalism may be strong if you believe that "liberal democratic norms, principles, and institutions impede urgently needed climate action." In that case, then, "legitimacy may permit—or even require—relaxing or abandoning those constraints." Consider nuclear power, where the Nuclear Regulatory Commission in the U.S. can take up to five years to approve a new license. The process is much quicker in China, and there is also a very limited ability for citizens or local municipalities to stall large projects via lawsuits.[156] When climate change becomes even more extreme, it is authoritarian leaders who will be more likely to decide unilaterally to start geoengineering. As described below, a single country can start effective geoengineering, but some of the regional consequences may be disastrous.

Mittiga also discusses how the climate crisis may "precipitate a more substantial and enduring shift in what counts as an 'acceptable' use of political power…. Imagine, for instance, if democratic representation came to be understood in intergenerational terms, such that only those governments that awarded formal standing to future people were considered legitimate; or, if individual human rights were thought to be predicated on, and therefore limited by, a more basic biotic right to continued existence, shared by all living beings."

Indirect Effects: Economic Impacts, Food Production, and Migration

Climate scientists have done amazing work over the last 50 years, but climate scientists are not experts in predicting the consequences of global warming on human societies. For that you need scientists from multiple other disciplines, including biology, medicine, psychology, sociology, anthropology, economics, and political science, as well as city planners and military strategists. One goal of this paper is to collect research from all of

[156] China currently has over 20 nuclear power plants under construction, far more than the United States or any other country.

these disciplines. In this section, I cover relevant research from economics, biology (both botany and human health), as well as the politics, sociology, and the psychology of migration.

Economic Impacts

Economic impacts will manifest in multiple areas, yet most economic analyses are relatively modest in their predictions of future losses. Rising et al. (2022), in a paper titled, “The Missing Risks of Climate Change,” explains why this is so.

> There is overwhelming evidence that the risks and impacts from increasing concentrations of greenhouse gases in the atmosphere are very significant, will impact nearly every aspect of human life and the environment, and could ultimately prove to be devastating. An apparent incongruity exists between the pervasiveness of anticipated physical changes and the relatively modest total losses often estimated in economic evaluations. Part of the explanation for this mismatch comes from ‘missing risks’: the risks that are not currently included in economic evaluations because of their uncertainty, because of our limited understanding of them or because existing economic models do not capture them in sufficient detail. (Rising et al., 2022)

$38,000,000,000,000

Kotz et al. (2024) get around this problem of “missing risks” by examining the near-term damages to which we are already committed. The results from this study have been reported extensively in the mainstream media, in part because they found enormous negative impacts from climate change over the next 25 years, *independent of the actions we are likely to take.* Using both empirical models and climate simulations (CMIP-6), Kotz et al. (2024) found

> “...that projected global damages are statistically indistinguishable across the two most extreme emission scenarios until 2049 …. As such, the climate damages occurring before this time constitute those to which the world is already committed owing to the combination of past emissions and the range of future emission scenarios that are considered socio-economically plausible. These committed damages comprise a permanent income reduction of 19% on average globally (population-weighted average) in comparison with a baseline without climate-change impacts…. this corresponds to global annual damages in 2049 of 38 trillion in 2005 international dollars. (Kotz et al., 2024)

Kotz et al. (2024) studied over 1,600 regions worldwide over the last 40 years in order “to project sub-national damages” from multiple climate variables on labor productivity

and agricultural yields, flood damages, and so on. The climate variables included annual mean temperature, daily temperature variability, total annual precipitation, annual number of wet days, and extreme daily rainfall.

An income reduction of 19% and total annual damages of 38 trillion dollars in the next 25 years is significant, but it is a vast underestimate of the real costs of climate change, because the authors do not consider major disruptions to socio-economic systems such as the effects from major supply chain problems, failed states, and regional and international conflicts. The authors also use models assuming more "level" effects (instantaneous rather than persistent) rather than "growth" effects. As the authors themselves point out, their analysis is certainly not comprehensive, because

> Important channels such as impacts from heatwaves, sea-level rise, tropical cyclones and tipping points, as well as non-market damages such as those to ecosystems and human health, are not considered in these estimates [plus wildfires, which they don't mention] ….Moreover, our main empirical analysis does not explicitly evaluate the potential for impacts in local regions to produce effects that 'spill over' into other regions. Such effects may further mitigate or amplify the impacts we estimate…. (Kotz et al., 2024)

Damages over the second half of this century will be much greater than those Kotz et al. predict for the next 26 years.

In general, econometric models are absolutely worthless in predicting the future economic consequences of climate change. There will be disruptions to socio-economic systems, as described above, and as we enter "uncharted" territory both climate models and econometric models will fail. We will experience severe disruptions to the climate system not represented in climate models, and we will experience a breakdown in international trade and economic activity that we have never experienced before and with which we have no experience – and no models.

Despite our inability to predict future economic activity within various climate scenarios, conventional analyses continue to find that even without entering "uncharted" territory early analyses were far too conservative. Bilal and Känzig (2024), for example, find that a 1°C temperature shock could lower world GDP by up to 12% rather than the 1-3% found by previous researchers. Previous researchers examined variations in country-level local temperatures, whereas Bilal and Känzig use global mean temperature. This is much more accurate, because

> Global temperature shocks predict a large and persistent rise in extreme climatic events that cause economic damage: extreme temperature, extreme wind, and extreme precipitation. By contrast, local temperature shocks predict a much weaker rise in extreme temperature, and barely any rise in extreme wind speed and precipitation. (Bilal and Känzig, 2024)

To use their time series approach and dynamic model, Bilal and Känzig created a dataset covering 173 countries for the last 120 years.[157] Note that nothing in the last 120 years is remotely similar to what will happen in the next 120 years. The situation is also extremely complicated because no country or region is now self-sufficient; there are global flows of goods, services, capital, and data. Bilal and Känzig's (2024) model results in a Social Cost of Carbon of $1,056, which is far more realistic than the official EPA estimate, which follows recommendations made by the National Academies of Science, Engineering, and Medicine, and is $190 per ton in 2020 and $310 in 2050 (Environmental Protection Agency, 2023).[158]

Banking Losses

Predicting future banking losses from major climate-related disasters is exceedingly difficult, in part because the large banks have not spent the time and effort required to collect the required datasets and develop appropriate methodologies. This is clear from The Federal Reserve's pilot climate scenario analysis that it conducted in 2023 with six large banks. The goal was "...to learn about large banking organizations' climate risk-management practices and challenges and to enhance the ability of large banking organizations and supervisors to identify, estimate, monitor, and manage climate-related financial risks" (Pilot Climate Scenario Analysis Exercise, 2024).

In one part of the exercise, the banks had to model the impacts from a severe hurricane in 2050 in the Northeast region. In another they had to choose an "idiosyncratic shock" – an event that would be significant for their particular portfolio. There were many uncertainties, but the number of defaults to both commercial and residential real estate loans was significant. Note that even the impacts from a severe hurricane is a trivial risk

[157] Bilal and Känzig used a climate dataset with information from 1901-2019 on temperature, wind speed and precipitation, and used economic information on GDP, population, consumption, investment, and productivity. They computed indices of extreme weather "by recording the fraction of days within a country that experience extreme weather. We define extreme weather of each category as a realization above a fixed percentile of the daily weather distribution in 1901-1930."

[158] The social cost of carbon added to the social cost of methane and nitrous oxide equals the social cost of greenhouse gases (SC-GHG). "The SC-GHG is the monetary value of the future stream of net damages associated with adding one ton of that GHG to the atmosphere in a given year" (Environmental Protection Agency, 2023).

compared with the reality of compound hazards and cascading effects that will be the reality by 2050.

Insurance Losses

Home and business owners are already experiencing increased home insurance costs or outright cancellation. Hurricanes and wildfires have been causing extreme damages for many years, and now storms with extremely high winds are also a problem. Insurers are losing money in many states, and in the last decade are having more bad years than good ones. In response, insurance companies are increasing their premiums and leaving some states altogether. Inability to obtain insurance can have dramatic and extensive impacts on local economies, because banks will not underwrite mortgages unless buyers can obtain home insurance.

The green line in Figure 18 below shows the average US multifamily insurance cost per unit from 2003 through 2023, along with natural disasters costing more than a billion dollars. Insurance costs in 2023 are over 50% higher than in 2018 and 5.7% higher than in 2022. Although the green line is for multifamily real estate insurance, the cost trend is similar for other types of commercial real estate, including retail, office, industrial, and hotels. For homeowner's insurance the increases are similar, with increases of up to 60% in some areas from 2018 to 2023, and yearly increases of almost 20% in some states. The highest annual home insurance costs in 2023 are in Florida, Louisiana, Oklahoma, Texas, Mississippi, and Colorado.

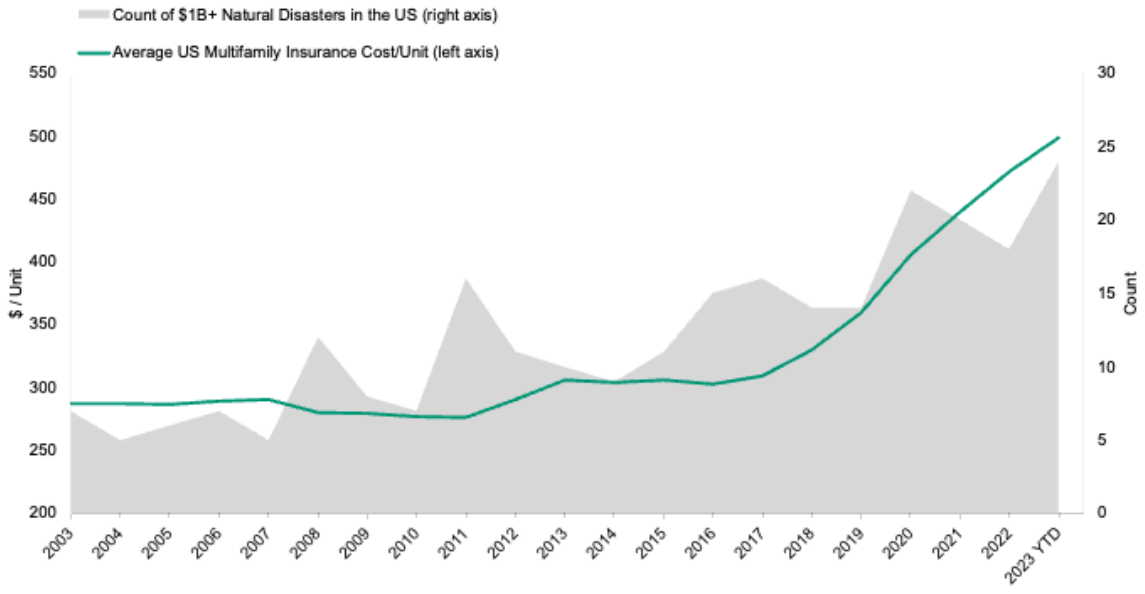

Figure 18: Average US Multifamily Insurance Costs and US Weather-related Disasters[159]

Effects on Individuals

On an individual level, a recent report by the U.S. Department of Treasury focused on the effects of flooding, wildfire, and extreme heat because these three hazards account for the greatest costs to individual households in the United States (The Impact of Climate Change on American Household Finances, 2023) . According to the report, half of U.S. counties "face heightened future exposure to at least one" of these climate hazards. In terms of household finances:

> Some climate hazards cause widespread physical damage and force interruptions and closures of normal operations of businesses, governments, and other critical services. As a result, households could face significant financial strain from lost employment income due to job loss, reduced working hours, or from interruptions in access to income supports or other public benefits. (The Impact of Climate Change on American Household Finances, 2023)

Direct property damages can be devastating, and in 2021, 10% of homes in the United States were affected by climate hazards. Hurricanes can be especially damaging, and they are getting stronger and intensifying more rapidly. "Hurricane Katrina damaged about 70 percent of all Louisiana properties, with approximately 17 percent remaining unrepaired and about 8 percent uninhabitable five years later" (The Impact of Climate Change on American Household Finances, 2023). Flooding and wildfires can not only damage homes, but can damage businesses and key infrastructure, including power systems, roads, and Internet service. See Appendix 2 for a figure showing Damages by State from Billion-Dollar Disasters from 2018-2022.

For those who work outdoors, "future heat conditions could place approximately $55 billion, or about $1,700 per worker, of annual earnings at risk due to reduced working hours" (The Impact of Climate Change on American Household Finances, 2023). Already, some farmers are working at night to escape the heat, because working during the day under extreme heat significantly reduces productivity.

[159] Natalie Ambrosio Preudhomme, Kevin Fagan, Caglar Demir, & Keith Fischer (November 7, 2023). New data for 2023 show costs of insurance and weather events continue to surge to record highs. *Moody's*, https://cre.moodysanalytics.com/insights/cre-news/new-data-for-2023-show-costs-of-insurance-and-weather-events-continue-to-surge-to-record-highs/

Disruptions to Transportation

Disruptions to transportation can have a major impact on commerce and industry. Consider what happened when drought reduced shipping routes during 2023, as reported by Sengupta in the New York Times:

> Drought, aggravated by the burning of fossil fuels, is slowing down the ship traffic that carries goods in and out of the United States through the slender and vital Panama Canal, while heat and drought in the Midwest are threatening to dry out the Mississippi River, a crucial artery for American corn and wheat exports, in the months ahead.
> …
> Last year [2022], for instance, as Europe faced its worst dry spell in 500 years, ships carried a fraction of the cargo they normally do along the Rhine in Germany, one of the continent's most important thoroughfares. The Rhine's water levels are better this year, but the river faces a longer-term climate risk: The mountain snow and ice that feeds the Rhine is declining.
>
> Last year, drought also slowed down ships on China's most important river route, along the Yangtze, forcing companies to move their goods to Chinese ports by road, which is costlier. The Mississippi River shut down briefly in some parts last fall, too, because river levels were so low.
>
> Exceptionally hot, dry conditions across the middle of the country this summer [2023] means that could happen again this fall. That's bad news for American agriculture. Grains, grown in the Midwest, make their way down the Mississippi River by barge before being shipped through the Panama Canal and then transported across the ocean.
> …
> The area around the Panama Canal is experiencing an exceptionally dry year. That's bad for the canal, because every ship that goes through needs millions of gallons of freshwater to float on, depending on how many containers it's carrying and how heavy it is.
> …
> Ships have had to watch their weight this year, which means reducing cargo volumes. Fewer ships are going through each day; the Panama Canal Authority, which runs the waterway, has restricted the number to 32 per day now, compared with 36 to 38 at other points.[160]

[160] Somini Sengupta (Aug. 25, 2023), Climate Risks Loom over Panama Canal, a Vital Global Trade Link., *(The New York Times,* https://www.nytimes.com/2023/08/25/climate/panama-canal-drought-global-trade.html

In South America, severe drought in parts of the Amazon region in 2023 led to extremely low water levels in some rivers and disrupted shipping (especially around Manaus), with boats running aground.[161] Modeling now predicts that headwater regions of the Amazon will experience increased flooding, while there will be decreases in water flow downstream during the dry season.

Health Care

Health care costs will go up due to climate related hospitalizations, medical care, and drugs. Two sections above describe many of the health consequences related to climate change: The Spread of Infectious Disease, and Climate Change and Human Health. Consider one example: the wildfire smoke from Canadian fires spread throughout large parts of the United States during 2023. This smoke can lead to coughing, asthma attacks, headaches, and chest pain. The fine particulate air pollution (PM2.5) from wildfire smoke can also lead to COVID-19 complications, increases in deaths from heart disease, and multiple other effects.

Global Food Production

Rising temperatures, droughts, floods, extreme storms and other weather events can cause serious damage to crops and dramatically reduce yields. When this happens, disruptions to food supplies in major cities can lead to severe shortages and civil unrest. Just imagine what would happen in a city of many millions if grocery stores ran out of food due to a breakdown of the distribution system, with food trucks failing to arrive at stores to restock shelves. Getting food into consumers hands in large cities is a complex process, from crop production, transportation, processing, and distribution into retail outlets. Climate change is likely to cause problems at several stages of this process, and it's clear that food scarcity and price increases can lead to conflict.

> When the price of staple crops like wheat, maize, and rice rose substantially between 2007 and 2008, it sparked unrest in many countries. In Bangladesh, thousands of workers rioted near Dhaka, smashing vehicles and vandalising factories, while expressing their anger at rising food prices and low wages. At the time, there were instances of protests in 15 countries across Africa, South America and Asia owing to food price hikes. In Burkina Faso, soaring prices led to riots in several parts of the country before thousands of demonstrators

[161]Bruno Kelly and Ana Mano, (Oct. 12, 2023), Amazon drought stalls shipping as boats run aground in low rivers, *Reuters*, https://www.reuters.com/world/americas/amazon-drought-stalls-shipping-boats-run-aground-low-rivers-2023-10-11/

> marched to Ouagadougou, the capital, to force the government to subsidise the cost of some cereals.[162]

Major crops such as wheat, maize, soybeans, and rice are grown in multiple regions around the world, so if there is shortage in one region another can often pick up the slack. But what if there are simultaneous failures across regions? Gaupp et al. (2020), "...combine region-specific data on agricultural production with spatial statistics of climatic extremes[163] to quantify the changing risk of low production for the major food-producing regions (breadbaskets) over time….We show an increasing risk of simultaneous failure of wheat, maize and soybean crops across the breadbaskets analysed." There was not, however, an increase in simultaneous failures of rice production across different breadbaskets.

Rezaei et al. (2023) review the literature on crop yields in response to warmer temperatures, elevated carbon dioxide, and water availability for major cereal crops. Note that climate skeptics often make the point that climate change will be good for crops, trees and other plants because the extra CO_2 will aid photosynthesis and thus improve growth rates. Although it's true that CO_2 can improve growth rates, the evidence is clear that climate change will result in lower crop yields because the positive effect of CO_2 is more than offset by the negative effects of drought, heat, and excessive rain in some areas. As usual, the situation in the real world is much more complex than the skeptics acknowledge. From Rezaei et al.'s (2023) abstract:

> Elevated CO_2 can have a compensatory effect on crop yield for C3 crops (wheat and rice), but it can be offset by heat and drought. In contrast, elevated CO_2 only benefits C4 plants (maize, millet and sorghum) under drought stress. Under the most severe climate change scenario and without adaptation, simulated crop yield losses range from 7% to 23%. The adverse effects in higher latitudes could potentially be offset or reversed by CO_2 fertilization and adaptation options, but lower latitudes, where C4 crops are the primary crops, benefit less from CO_2 fertilization. Irrigation and nutrient management are likely to be the most effective adaptation options (up to 40% in wheat yield for higher latitudes compared with baseline) but require substantial investments and might not be universally applicable, for example where there are water resource constraints.

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[162] C40: Food Security, https://www.c40.org/what-we-do/scaling-up-climate-action/adaptation-water/the-future-we-dont-want/food-security/

[163] The climate extremes vary by crop and region. As one example, "for soybean in China, the critical climate indicator is the number of days above 30°C during the growing season."

A review of the literature confirms these findings, as well as noting the impacts on economic indicators such as gross domestic product (GDP). Adom (2024), for example, examined the effects of climate change on socioeconomic indicators in developing countries by reviewing 139 studies published between 1992 and 2023 (with most published since 2017). Here are the highlights:

1. "Economic loss due to climate change will be significant in the long term in developing countries." Economic losses will be as much as -25% of GDP for some countries, and the negative effects will become more pronounced at 2°C.
2. "Food insecurity and declining farmland value are major future concerns under climate change scenarios." Reductions in crop yields will be as much as -18% by 2050 in Africa. Again, by 2°C warming, "the risk of climate-caused food insecurity would be severe…."
3. "Millions of people are at risk of extreme hunger and undernourishment under climate change scenarios."
4. "Poverty is likely to deepen in Africa in the future."
5. "The numbers of water-distressed areas and areas at risk of flood are likely to increase in the future due to climate change."
6. "Energy security is likely to suffer in the future under climate change scenarios. Climate change affects the energy system." (Adom, 2024)

These are certainly significant negative impacts on socioeconomic indicators, but the thesis of this paper is that all such predictions are almost certainly underestimates, given the feedback loops missing from most climate models, cascading effects, and our inability to curtail greenhouse gas emissions.

As the Earth heats up, and droughts and floods become more common, worldwide food production will decrease, which will make an already dire situation in many countries much worse, for there is already extreme hunger and famine in the world today. This is often caused by conflict; "about two thirds of the people who are facing hunger live in war or violence zones." In the future, continuing conflict, along with the negative effects of climate change, will dramatically increase famine. "The list of countries at risk of famine now includes Afghanistan, Syria and Mali…. North Korea may be nearing a famine. And Gaza...is at risk." In addition, "About 90 million people are facing severe hunger in Ethiopia, Somalia, South Sudan, Sudan and Yemen."[164] See also the World Food Programme review.[165]

[164] Alex de Waal (March 9, 2024), *I Said the Era of Famines Might Be Ending. I Was Wrong., The New York Times*, https://www.nytimes.com/2024/03/09/opinion/famine-war-gaza.html?unlocked_article_code=1.hk0.3vOm.NK13tebovh3d&smid=url-share

[165] https://www.wfp.org/global-hunger-crisis

Unfortunately, given future crop failures, it will be important to understand the definitions of food security and famine:

> The United Nations uses a five-phase scale known as the Integrated Food Security Phase Classification (IPC) to assess a country's food security situation. A famine classification is the highest on the IPC scale (Phase 5) and occurs when at least 20 percent of the population face extreme food shortages, acute malnutrition rates exceed 30 percent – meaning that people experience the most extreme and visible form of undernutrition – and two out of 1,000 people die from starvation on a daily basis.[166]

Transforming the Food System

Eating less meat is one of the best (and easiest) things we can do to protect biodiversit and reduce greenhouse gas emissions.

> The global food system is inherently illogical. It is destroying biodiversity, depleting the world's water resources and changing the climate, but isn't delivering the nutrition people need …. Food production is one of the main drivers of nature's decline: it uses 40% of all habitable land, is the leading cause of habitat loss, accounts for 70% of water use and is responsible for over a quarter of greenhouse gas emissions. (WWF, 2024)

Food waste is an enormous problem. "...today, an estimated 30–40% of all food produced is never eaten, representing around a quarter of total global calories, one-fifth of agricultural land and water use, and 4.4% of global greenhouse gas emissions" (WWF, 2024).

Mass Migration and Climate Refugees

When there is not enough food and water to survive, or it is too hot, or the rising ocean makes towns and cities unlivable, or storms destroy homes and livelihoods, people will migrate. Migration is a complex issue with political, economic, social, and demographic factors in addition to climate (there is even an interdisciplinary academic field called Migration Studies). Consider the impact of devastating hurricanes on Honduras, a fragile state, as reported by Miriam Jordan in the NYTimes[167]:

> First came the hurricanes — two storms, two weeks apart in 2020 — that devastated Honduras and left the country's most vulnerable in dire need. In

[166] https://www.unrefugees.org/news/famine-explained-definition-causes-and-facts/

[167] Miriam Jordan (Nov 28, 2023), They Fled Climate Chaos. Asylum Law Made Decades Ago Might Not Help, *The New York Times*, https://www.nytimes.com/2023/11/28/us/climate-migrants-asylum.html

> distant villages inhabited by Indigenous people known as the Miskito, homes were leveled and growing fields were ravaged.
>
> Then came the drug cartels, who stepped into the vacuum left by the Honduran government, ill-equipped to respond to the catastrophe. Violence soon followed.
>
> “Everything changed after the hurricanes, and we need protection,” Cosmi, a 36-year-old father of two, said, adding that his uncle was killed after being ordered to abandon the family plot.
>
> Cosmi, who asked to be identified only by his first name out of concern for his family’s safety and that of relatives left behind, was staying at a squalid encampment on a spit of dirt along the river that separates Mexico and Texas. Hundreds of other Miskito were alongside him in tiny tents, all hoping to claim asylum.
>
> The story of the Miskito who have left their ancestral home to come 2,500 miles to the U.S.-Mexico border is in many ways familiar. Like others coming from Central and South America, they are fleeing failed states and street violence.

A briefing to the European parliament about climate refugees in 2023 presented statistics about displaced people that made clear the magnitude of the problem.

> According to recent statistics published by the Internal Displacement Monitoring Centre, over 376 million people around the world have been forcibly displaced by floods, windstorms, earthquakes or droughts since 2008, with a record 32.6 million in 2022 alone. Since 2020, there has been an annual increase in the total number of displaced people due to disaster compared with the previous decade of 41% on average. The upward trend is alarmingly clear. With climate change as the driving catalyst, the number of 'climate refugees' will continue to rise. The Institute for Economics and Peace predicts that in the worst-case scenario, 1.2 billion people could be displaced by 2050 due to natural disasters and other ecological threats. (The Concept of “Climate Refugee”, 2023)[168]

As described above in the section on Extreme Drought and Aridification, “More than three-quarters of all land on Earth experienced a drier climate during the three decades leading up to 2020, compared to the previous 30-year period” (Vicente-Serrano et al., 2024). Climate change is leading to an increase in aridity, which will have serious impacts on many fragile countries. As Figure 19 below

[168] The briefing mentioned other terms that have been used to describe people displaced due to climate change, including “environmental refugee,” “environmental migrant,” and “environmentally/climate displaced person.”

shows, aridification leads to soil erosion, sand and dust storms, food insecurity, and these factors all lead to an increase in migration.

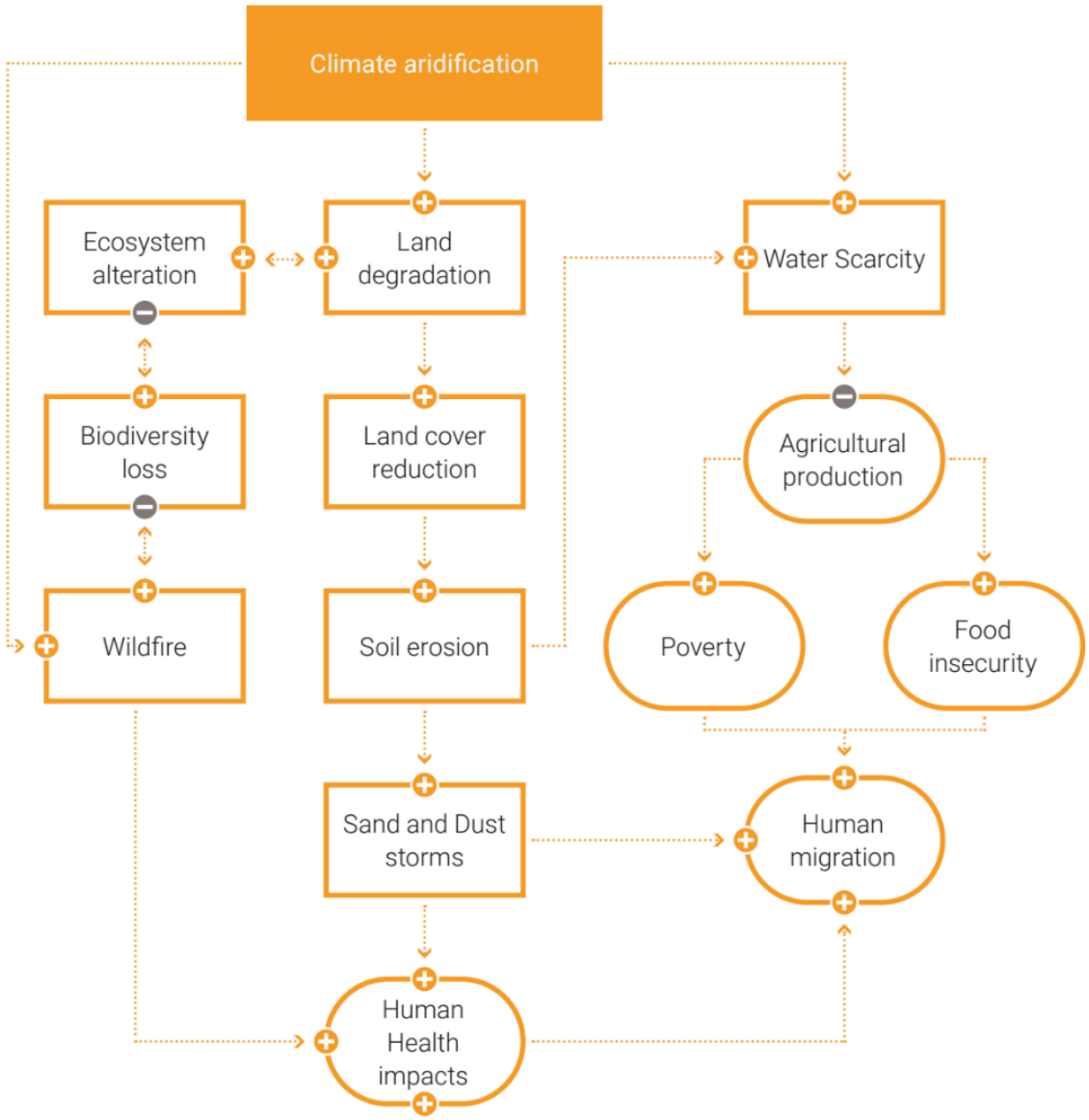

Figure 19. Climate Aridification

"A diagram of cascading impacts and interactions among different socioeconomic and environmental processes affected by aridity. Arrows indicate the direction of the effect, and plus and minus symbols reflect whether the effect on these processes is increasing or decreasing in severity" (Figure 16 from Vicente-Serrano et al., 2024).

Climate, Conflict, and Migration

There is now research that examines the relationship between climate, conflict and migration. Abel et al. (2019) examined applications for asylum for 157 countries between 2006 and 2015. "Our results indicate that climatic conditions, by affecting drought severity and the likelihood of armed conflict, played a significant role as an explanatory factor for asylum seeking in the period 2011–2015. The effect of climate on

conflict occurrence is particularly relevant for countries in Western Asia in the period 2010–2012 during when many countries were undergoing political transformation."

It is inevitable that migration across borders will accelerate due both to environmental problems caused by climate change and political instability. It is unlikely that these migrants will be welcome, but likely that uncontrolled migration will become a major political issue, as it has in both the U.S. and the EU. In June (2023), Florida governor Ron DeSantis suggested using "deadly force" against migrants entering the U.S. who were smuggling drugs, but didn't explain how to tell who was a smuggler. As migration increases, its effects on politics will increase. "The influx of migrants into a country often raises public resentment, leading to the success of more conservative political leaders and politics that use the populist fear of "the other" as a tool to motivate and manipulate voters" (Brechin & Lee, 2023).

Right wing parties often stir up resentment against immigrants, especially when the economy slows, jobs are scarce, and prices are high. This is what happened in England during the summer of 2024, when anti-immigrant riots and violent protests led to rioters attacking hotels and mosques housing asylum seekers. Some of the protesters were upset that the government was paying to house immigrants while they were suffering economically.

The Miskito, described in the quote above, are fleeing central America primarily due to economic and safety reasons. Even if their asylum requests are weak, they will be allowed to stay in the United States until their cases are heard, which can take years given the current backlogs. As the number of migrants increases even further, and as extreme climate events in the United States negatively impact the economy, it is inevitable that these rules will be changed. Just as Europe is already taking extreme actions to keep out migrants, so will the United States.

Human Rights Watch documented the killing of hundreds of Ethiopian migrants and asylum seekers who were trying to cross into Saudi Arabia from Yemen in March and June of 2023 (see Appendix 1 for more details). Greek authorities failed to prevent a ship filled with 700 migrants in the Mediterranean from sinking and hundreds were drowned or missing. In the future, when even wealthy western countries are struggling to deal with climate change, it is inevitable that killings at the borders and on the high seas will increase. As Lydia Polgreen wrote in a NYTimes opinion article:

> Despite the many international agreements and norms around the movement of people, everything from wanton disregard for the lives of migrants right up to deliberate, maximum deadly force seems to be on the table.

> …
> Indeed, the moral standard in how we treat those seeking safety and freedom across borders has unquestionably been set by the West. It was the European Union that decided to open its coffers to the murderous Libyan Coast Guard to prevent migrants from crossing the Mediterranean. Europe has paid Turkey's government billions of euro in exchange for keeping millions of Syrian refugees out of Europe. Britain's Conservative government is trying to send asylum seekers to Rwanda, of all places, rather than accept its obligation under international law to admit refugees.[169]

The European Union (EU) has worked with multiple countries to prevent migrants from reaching Europe. Over the course of a year, the Washington Post, Lighthouse Reports, and a consortium of international media outlets collected data on how the EU supported and financed forces in Tunisia, Morocco, and Mauritania. These countries, using EU funds, training, and equipment, detained tens of thousands of migrants, often busing and dumping them in remote areas. The reporting includes videos from migrant's phones, individual stories, and maps with reconstructions of their travels using coordinates from phone GPS data. The suffering and abusive treatment of the migrants is horrifying.[170]

Our "Climate Niche," Unprecedented Heat, and Mass Migration

Heat will be one of the primary drivers of migration, from its effect on humans, crops, and livestock. Under even a "middle of the road" climate scenario billions will need to migrate this century. Although people can live in extreme environments, the vast majority of people live in a relatively narrow range of temperatures. Lenton et al. (2023b) analyze human population densities around the world with respect to a "human climate niche," defined with reference to mean annual temperature (MAT). They show that there is "a primary peak of population density at a mean annual temperature (MAT) of ~13 °C [55.4 °F] and a secondary peak at ~27 °C [80.6 °F] (associated with monsoon climates principally in South Asia)."

When people depend on raising crops or livestock for their livelihood, then the climate niches for those crops and animals are also critical, and precipitation and temperature

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[169] Polgreen, L. (Aug. 24, 2023), In a report from a distant border, I glimpsed our brutal future, *The New York Times*, https://www.nytimes.com/2023/08/24/opinion/saudi-arabia-ethiopians-border-politics.html. Update: the British courts ruled against the plan to send migrants to Rwanda, and when Mr. Starmer became Prime Minister he abandoned the plan.

[170] Anthony Faiola, Imogen Piper, Joyce Sohyun Lee, Klaas van Dijken, Maud Jullien, & May Bulman (May 20, 2024). With Europe's support, North African nations push migrants to the desert. *The Washington Post*, https://wapo.st/45BvKSn

extremes are also clearly important in addition to temperature. Lenton et al. (2023b) “estimate that global warming since 1960–1990 has put more than 600 million people outside the temperature niche,” and “Above the present level of ~1.2 °C global warming, exposure to unprecedented average temperatures (MAT ≥29 °C) is predicted to increase markedly.” In fact, using a “middle of the road” pathway (SSP2-4.5), there will be over a billion people suffering from extreme heat in 2030 and near 3 billion in 2090.

Figure 20 presents country-level exposure to unprecedented heat (MAT ≥29 °C) at 2.7 °C and 1.5 °C global warming. (29°C is 84.2°F, which may not seem very hot, but this is the averaged annual temperature across seasons and day and night.) Tens of millions of people in dozens of countries listed in Figure 20 will need to migrate as the temperature increases.

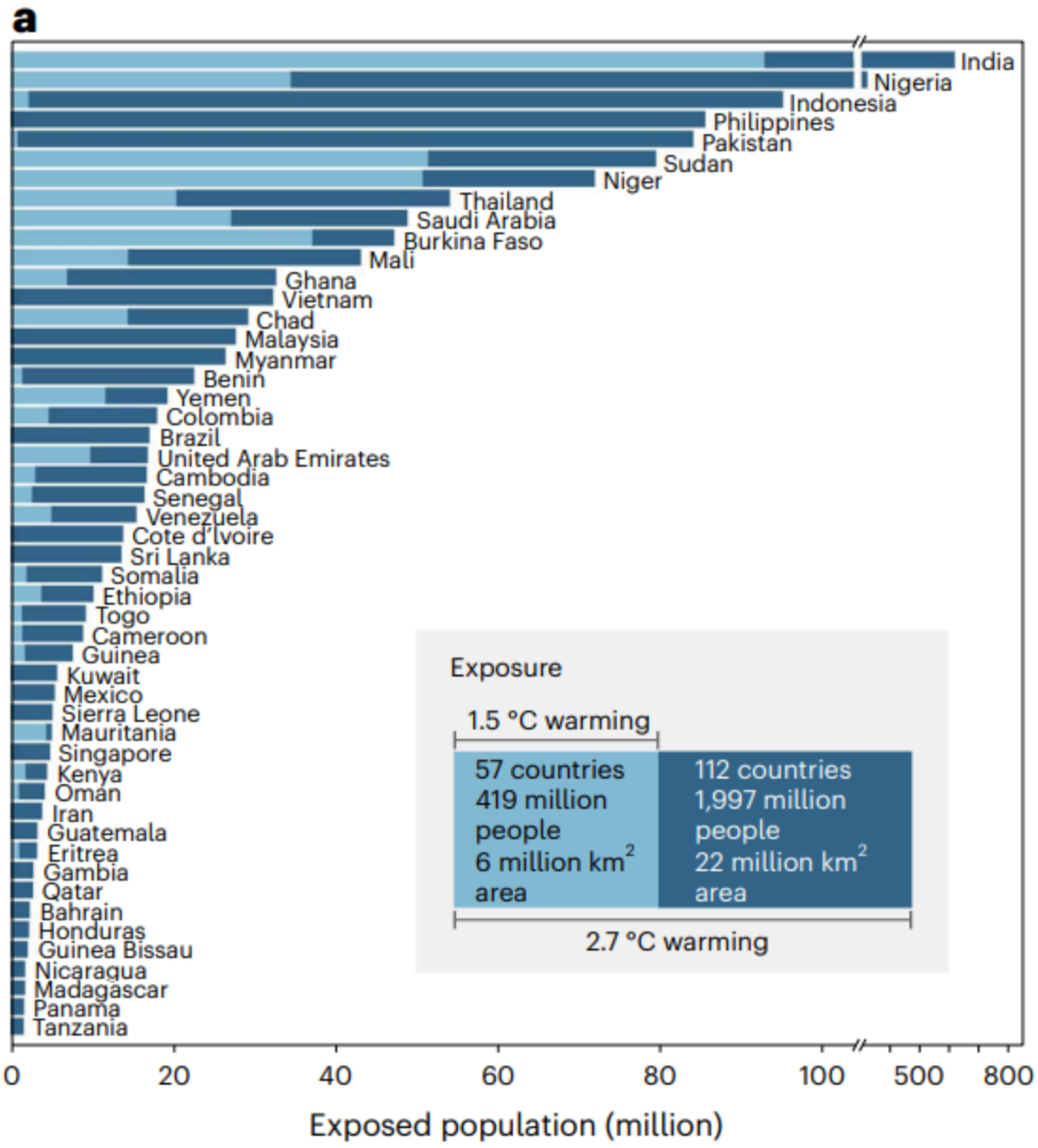

Figure 20. Country-level Exposure to Unprecedented Heat

(Fig. 5a from Lenton et al., 2023b). "Country-level exposure to unprecedented heat (MAT ≥29 °C) at 2.7 °C and 1.5 °C global warming in a world of 9.5 billion people (around 2070 under SSP2). a, Population exposed for the top 50 countries ranked under 2.7 °C global warming (dark blue) with exposure at 1.5 °C global warming overlaid (pale blue). Note the break in the x axis for the top two countries."

See Extreme Heat in the section on The Current Situation, above, for more research on the effects and prevalence of extreme heat in the future.

Migration in the U.S.

Abrahm Lustgarten, a climate reporter, just published a book focused on how climate change will lead to the migration of tens of millions of people within the United States ("On the Move: The Overheating Earth and the Uprooting of America," Lustgarten, 2024). He discusses the impact of compound disasters, such as extreme fire risk, drought, and heat.

> What they will all generally mean is that the population of the United States is likely to shift towards cities and generally towards the North and the Northeast in a long-term climate migration pattern. That doesn't necessarily mean that the American Southwest is going to empty out. It's probably a lot more likely that rural areas empty out and cities in that region become bigger…. I wouldn't be surprised to see a lot of, you know, West Texas begin to empty out but Texan cities continue to grow. Atlanta, for example, might be a, as far as the South goes, a magnet city for a lot of people coming from further south on the Gulf Coast where there's different compounding threats, where those threats include sea level rise and extreme heat, as well. But people will begin gravitating towards more urban economies and more urban infrastructure and the support network that comes with - you know, with an urban community….Some of the research that I based my reporting on suggests that there are about 13 million people who currently live in places that are projected to be underwater by later this century. So that's sort of the low end of, you know, the climate migration that we would expect might be driven from sea level rise alone.[171]

Lustgarten recounts stories from people who were forced to move as the result of wildfires and other climate events, or decided to move as their quality of life deteriorated. An early reader of this paper sent me her own story.

> I am a climate refugee. I lived in a mountain community for 34 years bordering the Cleveland National Forest in Orange County, CA. The past 10 years, we had horrific wildfires and had to evacuate several times a year. We finally left three years ago...a wildfire had broken out in the community from someone turning on a generator improperly about 10 pm. In previous years, the sheriff's department sent patrol cars up and down the canyon roads with loudspeakers telling people to get out NOW. But there were no cars. They had switched their notification system over to computers and cell phones. But all the power was out. A friend who had a landline called me at midnight and told me to get out. I still had a landline. My husband and I packed our bags quickly and left. We never got to go

[171] From an NPR interview, https://www.npr.org/2024/03/26/1239904742/how-climate-driven-migration-could-change-the-face-of-the-u-s

> back. We were trying to sell our house and had already bought another house in North Carolina. The Sheriff wouldn't let anyone back in the canyon for several days and my husband had very serious respiratory problems from the wildfire smoke. So we just threw our overnight bags in the car and drove cross country, coughing all the way. (Personal communication, March 3, 2024)

Related Topics

Changing an Individual's Views on the Climate Crisis

The words we use and the stories we tell can be critical in influencing how we think about an issue, especially complex social and environmental issues. Although this paper attempts to "connect the dots" among a diverse set of research findings, it relies on the reader to assimilate all of this information. The goal here is to collect all the relevant information about climate change in one place, provide suggestions for individual and societal actions, but also to force the reader to confront the reality of our current climate crisis and to come to their own decisions on how to respond. If the goal were to simplify and provide general, high-level approaches, then there are perhaps more effective strategies, especially when the focus is on mass communication. Consider the approach of the FrameWork Institute,[172] and their advice in an article on climate change titled, "Climate Stories that Work: Six Ways to Change Hearts and Minds about Climate Change."

> What we say about climate change and how we say it matters. It affects how people think, feel and act. The right story can build the public appetite needed to catalyse change. Decades of research and experience shows how stories can shift how people think and feel. They can make important actions feel right, normal and inevitable.
>
> Extensive research has shown that facts alone are rarely sufficient for changing minds or encouraging action — for science-based issues generally, as well as for environmental issues specifically. Facts alone aren't motivating. To motivate, reasoning must be linked to emotion, identity, and values - the things that we hold dear. When facts conflict with other powerful subconscious influences, people are likely to reject the new information.[173]

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[172] The FrameWorks Institute helps organizations communicate effectively about social issues by telling stories and framing the issues in particular ways. "Framing is the choices we make in what we say and how we say it: What we emphasize; How and what we explain; What we leave unsaid." https://www.frameworksinstitute.org/tools-and-resources/framing-101/

[173] https://www.frameworksinstitute.org/wp-content/uploads/2023/02/Six-ways-to-change-hearts-and-minds-about-climate-change.pdf

The article discusses six ways to frame climate change to increase the probability that people who hear the message will change their attitudes and take the recommended actions.

1. “Make it do-able and show change is possible
2. Focus on the big things and how we can change them
3. Normalise action and change, not inaction
4. Connect the planet’s health with our own health
5. Emphasise our responsibility to young people and future generations
6. Keep it down to earth”[174]

For each of these techniques the article provides examples of how to improve messaging. For example, for the first suggestion, “Make it do-able and show change is possible”:

Before: “Climate change is the biggest challenge we face. Life on earth is in crisis. Our house is on fire and our leaders are not listening or acting. In fact, many of them are fanning the flames.”

After: “We face major threats to the future of our planet and human life on it. But we have it within our power to repair and restore our world. Our leaders can and must act now.”[175]

Framing and storytelling help, but it is still very difficult to change an individual’s views on the climate crisis, and there is now evidence that you need to tailor interventions to target specific outcomes (Vlasceanu et al., 2024).

> In a global megastudy conducted on a sample of 59,440 people from 63 countries, we empirically assessed the relative effectiveness of 11 expert-crowdsourced, theoretically-derived behavioral interventions at stimulating climate mitigation beliefs and behaviors (i.e., climate change beliefs, policy support, willingness to share information, and tree planting contributions). We found that different interventions tended to have small global effects, which varied across outcomes and largely impacted non-skeptics, emphasizing the importance of examining the impact of climate interventions on a range of outcomes before drawing conclusions regarding their overarching relative efficacy. These findings suggest that the impact of behavioral climate interventions varies across audiences’ characteristics and target behaviors. (Vlasceanu et al., 2024)

[174] Ibid.
[175] Ibid.

If the approach in this paper is considered to be in the “doom and gloom” category, and thus unhelpful, Vlasceanu et al. (2024) provide evidence that with respect to some behaviors this approach can be effective. “Willingness to share climate change information on social media was increased most by inducing negative emotions through ‘doom and gloom’ styled messaging about the consequences of climate change.”

Later is Too Late

What is the best way to communicate and educate people in order to accelerate climate action? The marketing firm Potential Energy, in partnership with the Yale Program on Climate Change Communication[176] and the Meliore Foundation, conducted a large study testing the efficacy of different types of messaging (“Later is Too Late: A comprehensive analysis of the messaging that accelerates climate action in the G20 and beyond”).

In their study, they “tested multiple framings of 18 different policies with nearly 60,000 people across 23 countries…to answer these questions: Does the world want action on climate? How can we motivate the public to accelerate progress?”[177]

Here are their main findings (verbatim):

- **There is significant support for immediate government action on climate change in every country we surveyed.** On average across the 23 countries in the study, 77% of people agree with the statement, “It is essential that our government does whatever it takes to limit the effects of climate change,” and just over 10% disagree.
- Although comprising 25% of historical carbon emissions and 25% of the world’s GDP, **US citizens’ support for 18 climate policies is the lowest** among all countries measured.
- **The data clearly shows that framing is a key difference maker** and can turn policy winners into losers.[178]

Here is an example of how the way a message is framed can dramatically influence how many people agree with a statement:

[176] https://climatecommunication.yale.edu/
[177] https://potentialenergycoalition.org/guides-and-reports/global-report/; the full report is available here: https://potentialenergycoalition.org/wp-content/uploads/2024/01/Later_is_Too_Late_Global_Report.pdf, November 2023.
[178] Ibid.

> Research shows that homes using gas have high indoor air pollution. We should ban the use of gas-powered appliances and heating/cooling systems in buildings.
> **54% agree**
>
> As better technologies come onto the market, we should require their use in all new buildings and construction. These smart upgrades ultimately save us in energy and money.
> **74% agree**

Note, however, that these messages differ not just in their framing, but in their content as well, as the first suggests we should ban existing gas-powered appliances, while the second talks about the future.

Continuing with the results:

- Frames that included the words mandate, ban or phaseout on average had **9 points lower support** (and in some cases, up to 20 points lower support) than those that did not. Framings that included ideas like upgrading, setting standards, making solutions accessible, and reducing dependency performed significantly better.
- While policy and political leaders often focus on messages like green jobs, economic prosperity, ending injustice and even fighting the costs of extreme weather, the data gives a clear signal that there is a better message to grow the overall size of support. **Across every country, love for the next generation was the dominant reason for action on climate change.** This reason was 12 times more popular than creating jobs.[179]

“Love for the next generation was the dominant reason for action on climate change.” Note how this ties in nicely with the FrameWork Institute’s advice quoted above: “To motivate, reasoning must be linked to emotion, identity, and values - the things that we hold dear.”

> **Social Contagion, Social-Norm and Social-Tipping Interventions**

Information can also spread through “social contagion,” which is a powerful way to change attitudes and behavior in a population.

> Social contagion is a powerful force in human affairs: People tend to copy the thoughts, feelings, and actions of those to whom they are socially connected. Advances in the understanding of human social network structure and function have made it possible to exploit such social contagion to intervene in the world to

[179] Ibid.

> foster objectives, such as improving health, wealth, sustainability, learning, and more. (Airoldi & Christakis, 2024)

Airoldi & Christakis (2024) delivered a face-to-face public health intervention over 22 months in isolated villages in Honduras, examining the percentage of households that needed to be targeted to change their outcome measures. They found that, "... intervening in a smaller fraction of a population, especially if it is chosen shrewdly, could have the same effect as targeting 100% of the population." The implications with respect to changing climate change attitudes and behaviors are clear: targeting selected individuals in a population (e.g., by a federal agency or a nonprofit organization) and convincing them of what needs to be done can help to spread this information throughout the population. Social contagion is part of what Constantino et al. (2022) call "simple contagion," where ideas or processes can be transmitted by a single contact. Complex contagion requires reinforcement or contact with multiple sources.

Psychological Science in the Public Interest

Psychological Science in the Public Interest is an unusual but important journal. There is just one article in each issue, typically about 50 pages, involving "comprehensive and compelling reviews of issues that are of direct relevance to the general public."[180] The article in the October, 2022 issue is critically important because it reviews the research on how to change attitudes and behaviors via social-norm interventions and social-tipping interventions ("Scaling up change: A critical review and practical guide to harnessing social norms for climate action," Constantino et al., 2022). Politicians will act only when social norms change, so it is worthwhile to summarize their review of the current state-of-the-science in detail.

Constantino and her coauthors review the extensive research in the social sciences on the use of social-norm and social-tipping interventions to promote behavioral change, including changes related to the climate crisis. Social norms are "Patterns of behaviors or beliefs that depend on expectations about what others do and/or think should be done" (Constantino et al., 2022). There is research showing that social norms can influence smoking, alcohol consumption, bullying, and beliefs about same-sex marriage. With respect to climate change, social norms can influence water and energy conservation, residential recycling, demand for sustainable goods, carbon offsetting, and many other areas (Constantino et al., 2022). Changing social norms around climate change is critical – one could argue that the consequences are life threatening if we don't – but exceedingly difficult given the opposition of special interests and the fact that many politicians claim that taking action on climate change is a threat to our personal

[180] https://journals.sagepub.com/overview-metric/PSI

freedom and national energy security.[181] It is imperative that we change our social norms.

> Collective action on climate change would benefit from a society predicated on and organized around different social norms, including the beliefs that:
>
> - business as usual is unacceptable because it prioritizes the short-term economic profits of a few over the well-being of future life on this planet;
> - global public goods, such as a livable climate, ultimately affect all people and are worth protecting, even if this entails immediate costs;
> - existing consumption patterns and disparities are unfair and unsustainable, and that people need more equitable and inclusive metrics of progress and well-being than GDP and economic growth;
> - people should prioritize both social and environmental outcomes because they are inextricably linked; and
> - addressing climate change is not a zero-sum game—nations, despite their geopolitical borders, should work together to address this global challenge.
>
> When existing norms are unsustainable, social-tipping interventions can be used to "seed" new norms. The logic underlying social tipping is that localized interventions can incentivize change in a subset of a population, creating minorities committed to a nonnormative belief or behavior. Coordination or conformity incentives, in turn, lead others to adopt the nonnormative behavior, creating endogenous social change. Once a critical mass has adopted the nonnormative behavior, social dynamics can trigger abrupt, widespread, and nonlinear change, eventually tipping societies toward a new social norm. (Constantino et al., 2022)

Constantino et al. (2022) explain how old norms can be replaced by new ones, how social norms can spread through populations, and how to "seed" social norms or social-tipping interventions. They also provide many examples, such as what happened in Europe in the late 1980s. At that time, there was a push to increase the number of households with solar panels. The technology was there, there were incentive programs to motivate consumers, but people were not adopting them. "Research suggests that

[181] Our political problems are discussed elsewhere in the paper. Here's an example of opposition by special interest groups. I heard an ad on the radio today (June 21, 2024) sponsored by https://oilfacts.com/. It was filled with misleading or false information, similar to what's on their website, which included the following: "Did you know humans actually face less climate threats today than at any time in history? That's right… we are actually safer today from storms, floods, extreme temperatures, wildfires, drought, and other climate dangers than ever before. In fact, the rate of climate-related disaster deaths has plummeted by an astonishing 98% over the last 100 years, even as CO2 levels have risen."

this may have been due to the absence of social norms around solar panels and the challenge of reaching a ‘tipping point.’”

> Although most early efforts to increase solar-panel installations were not terribly successful, researchers noticed something unexpected. In neighborhoods in which a small group of early adopters were collocated (i.e., on the same street or within a few blocks of each other), the adopters’ neighbors also started to adopt. One or two early adopters were insufficient to generate these local cascades, but a small cluster of three or four houses in close proximity to each other created a local “critical mass” within that block or on that street. As an increasing number of neighbors installed solar power on their homes, people began to see the behavior as more socially legitimate. The result was a growing concentration of households within a community with solar panels. In social-network terms, this is referred to as a “social cluster”—a group of tightly interconnected individuals (or households) who influence each other to adopt a new behavioral norm. Once a “critical mass” is established within a neighborhood, people come to believe that they are expected to adopt as well—even without any explicit social sanctions. Eventually, the norms change and the “odd household out” becomes the household that has not adopted the new norm. (Constantino et al., 2022)

The intervention process for both social-norm and social-tipping involves the same series of steps (verbatim):

1. Identification of broad aims and sociocultural processes;
2. Identification of a target community and behavior or value that, if changed, would go some way toward achieving the broader aims;
3. Identification of local stakeholders and consideration of the ethics and efficacy of an intervention;
4. Measurement to diagnose the problem, the social context, and the psychological context;
5. Assessment of the desirability of the intervention (inputs from 1–4, above);
6. Design, implementation, and evaluation of the intervention in an iterative process of piloting and adapting; and
7. Scaling-up of the intervention with continued monitoring. (Constantino et al., 2022)

Creating successful social interventions is not easy, and requires pilot programs to fine tune the process and make sure there are no unintended consequences. It is not a panacea, but is an approach that should receive more attention, more funding, and more discussion.

What Should We Call It?

"Climate change" and "global warming" are used most frequently to describe what is currently happening to our climate. Google's Ngram Viewer (https://books.google.com/ngrams/) confirms this (looking at frequency in books), with "climate change" occurring many times more often than "global warming. "Climate crisis" is also frequently used, and a few writers now use "global overheating". Over 15 years ago Hunter Lovins coined the term "global weirding," which was then promoted by the columnist Thomas Friedman, but it never really caught on, despite its accurate depiction of what really happens when global temperatures rise. More recently, Chen (2024) writes that, "'climate upheaval' frames and communicates the global climate situation more informatively," because "'climate change' does not differentiate itself from natural climate variations" and "'climate upheaval' seeks to emphasize the anthropogenically accelerated change in climate." This is important, he argues, because "Terminology frames reality and influences people's perceptions of climate." The terms we use are indeed very important for framing the debate, and although global weirding, climate upheaval, and global overheating have advantages, my current favorite is climate crisis, which emphasizes that there is now a crisis resulting from the changes in our climate.

Support for this choice comes from Haueis, who writes that "'climate crisis' is most suitable to formulate and pursue climate mitigation and adaptation goals" (Haueis, 2023). Haueis reviews the literature on climate concepts, provides a detailed history on the use of each term, reviews survey data, and provides a framework for evaluating the concepts, focusing on the goals of the scientific community and the need to promote democratic participation.

> "Climate crisis" promotes investigating a wide variety of causes and effects of human activity on the climate, builds a communicative bridge among scientists, policymakers and activists to talk about climate politics, and allows for democratic participation in articulating mitigation and adaptation policies. "Climate crisis" also avoids various deficits of the other concepts, such as being too narrow ("global warming"), too neutral ("climate change") or too urgent ("climate emergency"). (Haueis, 2023)

Global warming has a "one-sided focus on temperature," climate change has "ambiguity between human and nonhuman causes," and in a climate emergency there is "no time for democratic debate" and a "focus on techno-fixes." Haueis provides a graphical abstract of his conclusions in Figure 21:

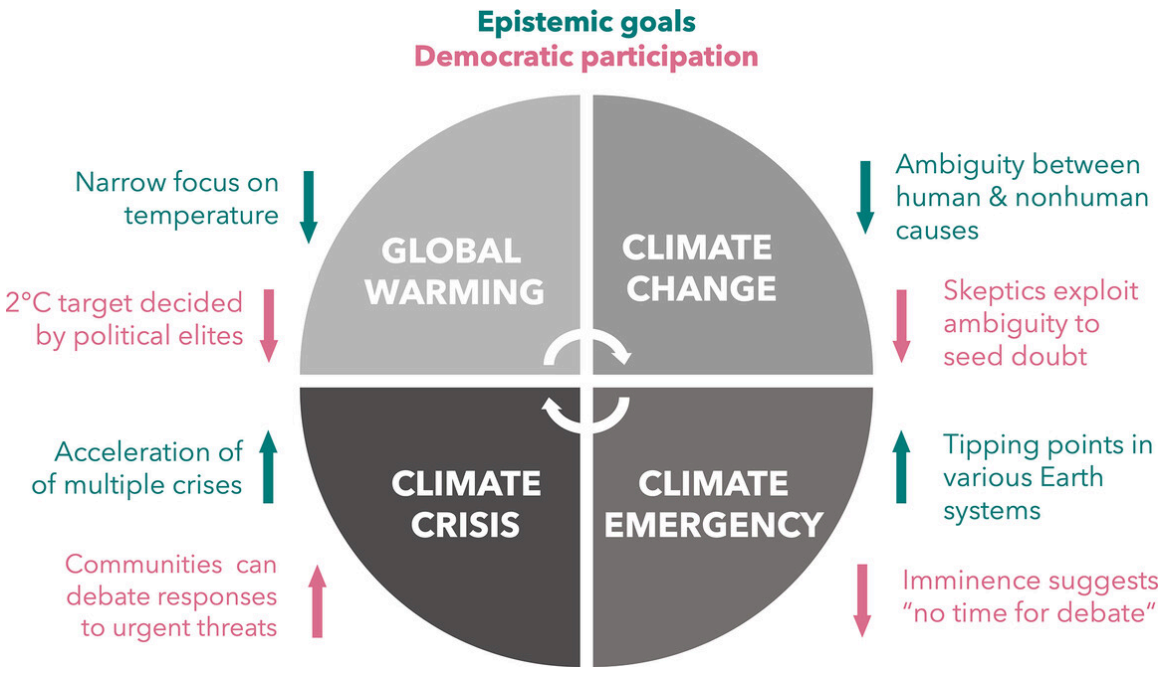

Figure 21. Benefits and Deficits of Different Climate Concepts

"Figure illustrating the benefits (upwards arrows) or deficits (downwards arrows) for using different climate concepts (grey sectors) to formulate and pursue mitigation and adaptation goals" (Haueis, 2023).

More recent research offers no good reasons to change the recommendation to use climate crisis. Bruine de Bruin et al. (2024) conducted a survey in which they asked respondents about their familiarity, concern, urgency, willingness to support policies, and willingness to eat less red meat for five terms: "climate change," "global warming," "climate crisis," "climate emergency," or "climate justice" (each respondent rated their familiarity and response to just one of the five terms).

> Overall, "climate change" and "global warming" were rated as most familiar and most concerning, and "climate justice" the least, with ratings for "climate crisis" and "climate emergency" falling in between. Moreover, we find no evidence for "climate crisis" or "climate emergency" eliciting more perceived urgency than "climate change" or "global warming." (Bruine de Bruin et al., 2024)

There are two interesting aspects to this study. First, how the results were distorted by both the authors and those reporting on the study in the media. The bottom line was supposedly that Americans are more familiar and concerned when rating "climate change" and "global warming" than the other terms – and so these are the terms that are best to use – but this is not really true, as the differences were tiny, if you actually look at the data. Considering just the overall percentage of participants reporting urgency for each term, here are the percentages:

- Climate change 68%
- Global warming 74%
- Climate crisis 69%
- Climate emergency 71%
- Climate justice 57%

Climate justice was the outlier for most of the ratings, but the other terms were very closely clustered in most of the results. The second interesting aspect of the study was the enormous differences in ratings between participants who identified as Democratic versus Republican. The percentage who associated urgency with the climate crisis, for example, was 69% overall, but this was broken down into 95% for Democrats and 36% for Republicans! The other obvious problem with the results is that they focus on current attitudes and beliefs, whereas we also need to consider the changes over time that each term may produce.

Why Is It So Hard?

Daniel Kahneman, the Nobel prize-winning psychologist, explained in an interview why it's so difficult for people to take the necessary action on climate change. The interviewer, Jean-Baptiste Bouzige asked, with respect to climate change, "We ask ourselves why is it so hard to change when the need for change is so obvious?"

> It's obvious without being urgent, and urgency is mainly what we lack when we think about climate change….it's the kind of problem that people are really very ill-equipped to deal with. It's abstract, it's long term, it's invisible, it's contested, so there is no complete agreement. So there is uncertainty about every aspect of it. And so something that is remote and uncertain has no urgency. And it's extremely difficult to mobilize people when there is no urgency.[182]

In another interview, Kahneman said that if you were to define a problem that we are not equipped to deal with, it would be climate change. Kahneman went on to say that he is pessimistic of democracy's ability to deal with climate change. Others write that "Climate change is a 'wicked problem'—a multidimensional challenge characterized by incomplete information, complex interactions with other issues, and competing social interests" (Constantino et al. 2022).

Paleoclimatology

There is evidence in the paleoclimatic data that the Earth has warmed very rapidly in the past, where "rapid" is on a human scale of decades rather than a geological scale of

[182] https://www.youtube.com/watch?v=NM_dvVyoJwI

thousands or millions of years. For example, during Meltwater Pulse 1A (MWP-1A) about 14,650 years ago, sea level rose at a rate of slightly more than two inches per year. That's almost two feet a decade! Meltwater Pulse 1A is referred to as a catastrophic rise event. Blanchon et al. (2009) studied fossil reefs during the last interglacial period and found that reef death was caused by a two to three meter jump in sea level, and that during this time sea level rose over a foot a decade, primarily from ice sheet instability and melting. Scientists are not currently predicting a near-term sea level rise of a foot or more a decade, but it is quite possible that such a catastrophic rise event could occur during the next century. If warming exceeds 2°C, the International Cryosphere Climate Initiative (2023) warns that there is a chance that sea level rise could be more rapid than at any time during the last 130,000 years, which covers the period of Meltwater Pulse 1A.

There are cyclical changes in the Earth's orbit that occur over tens of thousands of years and lead to changes in the climate (e.g., Milanković forcing), including the triggering of ice ages. But considering only Milanković cycles, the Earth should now be cooling. In fact, since 1980 there has actually been a slight decrease in solar energy reaching the Earth, based on precise satellite measurements.

Note that CO_2 can act as either a forcing agent or a response:

> A very close and careful analysis of the records of temperature and CO_2 in ice cores shows that during Milanković cycles, CO_2 mostly lags temperature, suggesting that the CO_2 variations were caused by the warming and cooling, not the other way around. In this case, the CO_2 was acting as a positive feedback, amplifying the Milanković oscillations. But in the last 100 years, the huge increase in CO_2 drove the temperature change. (Emanuel, 2016)

The Atlantic Meridional Overturning Circulation (AMOC) transports heat to the north Atlantic, warming the air by up to 10°C. As Rahmstorf (2023) writes, "We know from paleoclimatic data that there have been a number of drastic, rapid climate changes with focal point in the North Atlantic due to abrupt AMOC changes, apparently after the AMOC passed a tipping point. They are known as Heinrich events and Dansgaard-Oeschger events...". Dansgaard-Oeschger (D/O) events involve abrupt warming followed by gradual cooling. They can occur in less than 30 years. The point here is not that these events will be involved in climate change this century, but that very rapid changes in the climate have occurred in the past – and it is thus not unreasonable to assume they could also occur in the future, especially given how quickly we are altering the climate.

The paleoclimatic record has critical information about how the climate system operates, and one of the serious flaws in climate models is that they have not incorporated this information.

> Because there is little pre-industrial data, and due to the focus on shorter timescales, most models ignore the paleoclimatic record. However, historical evidence indicates that high GHG concentrations are likely to cause much higher temperatures than are indicated by current modelling. In fact, given that the present anthropogenic carbon release rate has no precedent since the Palaeocene–Eocene Thermal Maximum 66 million years ago, some scientists argue that climate conditions are increasingly entering 'no-analogue' state that cannot be readily modelled (Taylor et al., 2023b).

According to Dr. James Hansen, "There are well-educated people who do not recognize how much is known from Earth's climate history. Paleoclimate data show how sensitive climate is to forcings and the magnitude of the consequences, if the forcings are left in force long enough to bring "slow" feedbacks strongly into play."[183]

Societal Collapse and Paleoclimatic Data

Using anthropological, archaeological, and paleontological data, along with data from paleoclimatology, many researchers have claimed that natural climate change has been a major factor in past societal collapse. Both solar and volcanic forcing have resulted in changes to the climate, often resulting in collapse via extended droughts. Richards et al. (2021) reviews some of the literature on the collapse of over a dozen societies going back over 4,000 years and occurring in multiple locations around the world.

There are more recent examples of extreme societal stresses caused by changes to the climate. For example, in *The Price of Collapse: The Little Ice Age and the Fall of Ming China*, Brook (2023) described how environmental disasters were one important factor leading to the end of the Ming dynasty. As the climate changed during the Little Ice Age, there were heavy rains for months on end in 1640, with flood waters rising and the landscape becoming a swamp.[184] Then in 1641 there was a drought so severe that the river beds ran dry. Relying on the first person account of a school teacher at the time, Brook follows the effects of these disasters by tracking the price of rice, which multiplied several times, until eventually there was no rice at all in the markets. Starvation, disease, migration, and social unrest followed.

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[183] https://www.columbia.edu/~jeh1/mailings/2024/May30Email.2024.05.30.pdf

[184] It's interesting to note that although it was colder in both Europe and China during the Little Ice Age, there was excessive rainfall in Europe and drought in China.

For a readable account of how environmental disasters can lead to societal collapse, see Jared Diamond's *Collapse: How Societies Choose to Fail or Succeed* (2005). Diamond was a professor of geography, however, and received withering criticism in the essays by historians, archaeologists, and anthropologists in *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire* (McAnany & Yoffee, 2010).[185]

A Society's Ability to Withstand Downturns

Riris et al. (2024) performed a meta-analysis on a global sample of regions around the world over a period of 30,000 years. Using a method that involved radiocarbon dating, they studied population downturns during 154 different time periods. They had two key questions: "(1) how quickly do past populations recover after downturns; and (2) what factors mediate past resistance and resilience to downturns?....Results demonstrate that a single factor—the frequency of downturns— increases both the ability to withstand disturbances and to recover from them." Environmental crises, especially from aridity (long term droughts) were the most common driver leading to population downturns.

The authors write that their results

> …indicate that populations experience an enhanced ability to withstand disturbances as frequency increases, as well as to recover in the aftermath….
>
> Our contribution indicates that downturns play an important role in human population history by enhancing the resilience of survivor populations. We speculate that the creation of biased cultural transmission may be responsible; downturns provide critical opportunities for landscape learning and the strengthening of local-to-regional knowledge networks to propagate through a cultural system. Population downturns have been identified as potential triggers of labour investment in infrastructure, social cohesion and technological advancement. (Riris et al. 2024)

If humanity survives the current environmental crisis, there is no question we will learn from the experience and, as with prehistoric societies, invest in "infrastructure, social cohesion and technological advancement." However, it's not clear that Riris et al.'s (2024) claim that understanding how past societies responded to disturbances "will support the development of solutions to future crises" in our particular case. The prehistoric societies studied had long downturns that often lasted centuries (the median was 98 years), but these societies were not dependent on technologies that required

[185] The American Society for Environmental History (https://aseh.org/) focuses on trying to "understand the complex entanglements of humans and the rest of nature over time."

global supply chains. They also did not have populations in the billions. In addition, although climatic changes often led to decline in the past, those changes were primarily regional in focus. If the current climate crisis continues, our geophysical environment will be radically changed everywhere on Earth, and the previously hospitable environments will no longer be conducive to human civilization. The changes will last for many hundreds, and probably thousands, of years.

Climate Models

There are several dozen different climate models used by various scientific organizations around the world. These models continue to improve but don't adequately capture the complexity of clouds, ocean currents, and other physical phenomena. Clouds, for example, depending on their type and altitude, can either reflect sunlight, producing a cooling effect, or absorb and reradiate infrared radiation producing a warming effect. Because exactly how climate change will affect clouds is unknown, cloud formation is not represented well in climate models. Some significant feedbacks and tipping points that could lead to high greenhouse gas concentrations are also missing from climate models. Note that these are models based on physics and not statistical models. They "describe how energy flows through the atmosphere and ocean, as well as how the forces from different air masses push against each other."[186]

One problem with climate models is that the spatial resolution is relatively low, with a three-dimensional grid of boxes that are often 100 km square and 1 km thick, although some models can use boxes as small as 50 km square. As computing power increases so does the resolution of climate models, and state-of-the-art models today have a resolution as "fine" as 25 kilometers square. In general, model accuracy improves as resolution improves.

For models to work, you need to feed in the amount of future greenhouse gas emissions, and this requires a lot of guesswork – how fast will population and economies expand, how much energy will be produced by nuclear or renewable sources, and so on.

> To deal with all this, the Intergovernmental Panel on Climate Change (IPCC) came up with a set of just four "representative concentration pathways" (RCPs),[187] expressing plausible evolutions of greenhouse gases and other

[186]Rasmus Benestad (Nov. 11 2023), A Distraction Due to Errors, misunderstanding and misguided Norwegian Statistics, *RealClimate*, https://www.realclimate.org/index.php/archives/2023/11/a-distraction-due-to-errors-misunderstanding-and-misguided-norwegian-statistics/

[187] RCP2.6 (very low future greenhouse gas concentrations), RCP4.5, RCP6.0, and RCP8.5 (very high concentrations)

> anthropogenic influences on climate, such as aerosols. These are labeled with the associated net radiative forcing in the year 2100; so, for example, RCP 6.0 has a radiative forcing of 6 watts per square meter by the year 2100. (For comparison, doubling CO_2 produces a radiative forcing of about 4 watts per meter squared.) (Emanuel, 2016)

There are many new approaches to creating Earth system models, some using various AI techniques such as machine learning, and incorporating more observational data; see for example, the Climate Modeling Alliance, a collaboration between scientists, engineers, and applied mathematicians from Caltech, MIT, and NASA's Jet Propulsion Laboratory (https://clima.caltech.edu/).

With respect to climate models, Hansen and his colleagues argue that the IPCC places too much emphasis on global climate models (GCMs). Hansen advocates a three-pronged approach that "gives comparable weight to paleoclimate, GCM modeling, and observations of ongoing climate physics" (Hansen et al., 2024).

The World Climate Research Programme (WCRP) and the Coupled Model Intercomparison Project (CMIP)

The WCRP coordinates research on climate around the world. One of their most important initiatives is CMIP, which tries to compare and assess climate models from multiple research groups. CMIP6 models are now being used, and CMIP7 models will be available within a few years. The output from CMIP models are used extensively in the IPCC reports.

> The primary objective of the Coupled Model Intercomparison Project (CMIP) is to better understand past, present, and future climate changes arising from natural, unforced variability or in response to changes in forcing in a multi-model context. Successive generations of CMIP have seen the project grow in scope, with increasing process-specific Model Intercomparison Projects (MIPs) to better address specific scientific questions, while continuing to play a critical role in the IPCC Assessment Reports.[188]

CMIP models have been fairly reliable when compared against both future or historical climate changes. For more information, see these websites:

- World Climate Research Programme, https://www.wcrp-climate.org/wgcm-cmip
- CarbonBrief's article, CMIP6: The next generation of climate models explained, https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained/

[188] https://www.wcrp-climate.org/wgcm-overview

The current IPCC scenarios are presented in Figure 22.

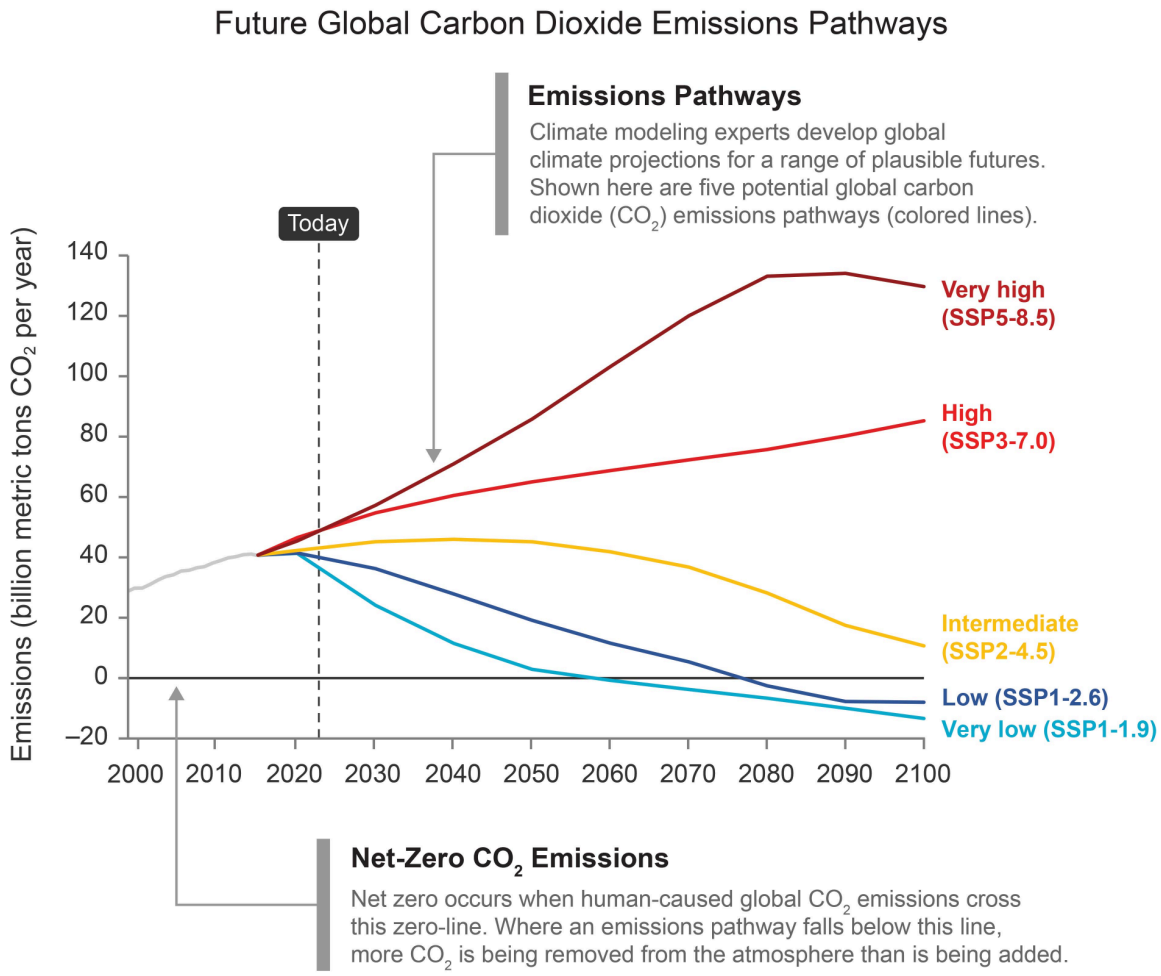

Figure 22. Future Global Carbon Dioxide Emission Pathways

(Figure 1.4 from Crimmins et al., 2023, the Fifth National Climate Assessment). "*The five scenarios shown (colored lines) demonstrate potential global carbon dioxide (CO_2) emissions pathways modeled from 2015 through 2100, with the solid light gray line showing observed global CO_2 emissions from 2000 to 2015. See Table 3 in the Guide to the Report for scenario definitions. Many projected impacts described in this report are based on a potential climate future defined by one or more of these scenarios for future CO_2 emissions from human activities, the largest long-term driver of climate change. The vertical dashed line, labeled "Today," marks the year 2023; the solid horizontal black line marks net-zero CO_2 emissions. Adapted with permission from Figure TS.4 in Arias et al. 2021.*"

"SSP" in the pathway names stands for "Shared Socioeconomic Pathways."

Geoengineering is Inevitable

We have been engaged in a global geoengineering experiment for the last 100 years and have now succeeded in warming the planet. From a physics perspective, there are

effective techniques for cooling the planet, such as solar radiation management (SRM), also called solar geoengineering, stratospheric aerosol injection (SAI), and climate cooling. This involves the injection of aerosols (typically sulfur dioxide) into the stratosphere to reflect sunlight. There are also techniques for thinning cirrus clouds in the troposphere, and marine cloud brightening at low altitudes near the ocean. Not all techniques involve clouds or the atmosphere, and there are now literally dozens of various geoengineering techniques. Examples of solar climate intervention methods are depicted in Figure 23 below.

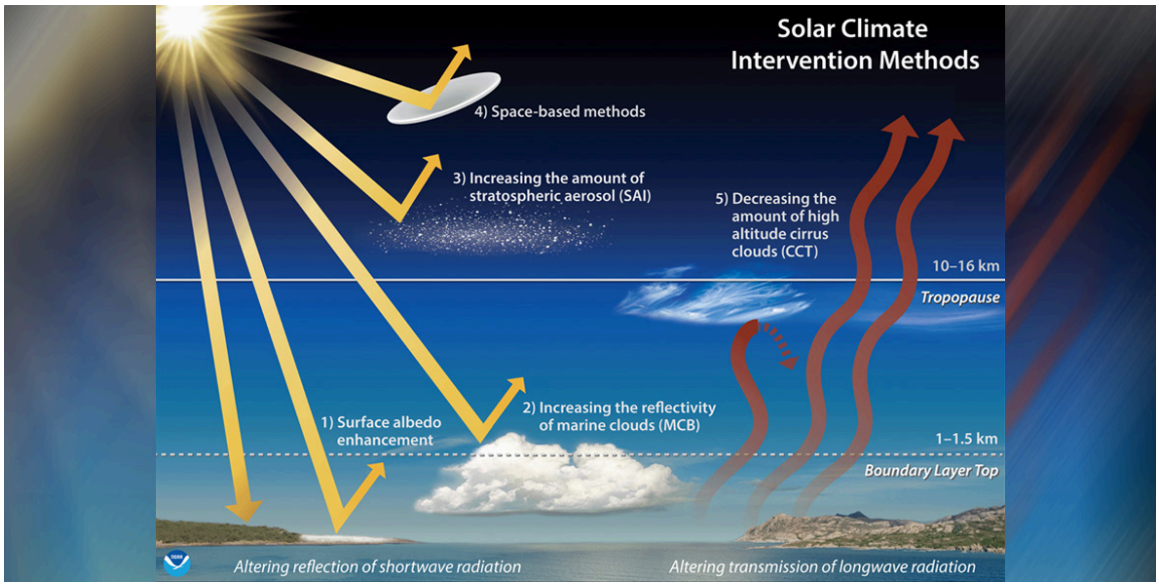

Figure 23. Techniques for Solar Radiation Management

"Proposed methods for climate intervention that would affect climate by modifying either incoming or outgoing solar radiation. Credit: Dr. Chelsea Thompson"[189]

The problem is that scientists currently don't know enough to be able to predict what will happen on a regional level, and there is consensus that changes in global weather patterns could be significant. If the Earth cools, but the summer monsoon rains over Asia and Africa are disrupted and millions die from starvation, this can hardly be called a success. Recent model-based research confirms that regional side effects can be dangerous, and are not well understood. Wunderlin et al. (2024), for example, show that although there may be an overall cooling effect, some regions will continue to get hotter. When sulfate aerosols are injected over low latitudes in the tropics, these aerosols will remain longer in the atmosphere, and thus provide a greater cooling effect for each kilogram released. This is why most research assumes tropical SAI. Side effects, however, may include the heating of the tropical tropopause and the lower stratosphere.

[189]From https://cpo.noaa.gov/atmospheric-aerosols-and-their-potential-roles-in-solar-climate-intervention-methods/

Wunderlin et al. (2024) "...conclude that, while sulfate-based SAI with tropical injections can alleviate many of the global effects of climate change, they may induce regional effects that are comparable to those from unabated GHG emissions on some key metrics." Should we therefore engage in SAI at higher latitudes, even though it will be more expensive? Perhaps, but scientists just don't know for sure.

Injecting aerosols into the atmosphere would require fleets of aircraft flying at high altitudes (or balloons), and would cost billions. However, this is inexpensive enough for any one of the dozen richest countries to embark upon alone. Should one country decide to begin geoengineering unilaterally and there are negative consequences for other countries, this is a clear recipe for conflict. Another problem is "termination shock," or the warming rebound that will occur if geoengineering ever stops.

Solar Radiation Management is by far the most studied and discussed type of geoengineering, in part because there seems to be agreement that it would not only be effective, but it would also be technically and economically feasible in the immediate future. Several organizations within the United Nations have been studying solar geoengineering, as well as many other international organizations, nations, NGOs, professional societies, and the private sector. To create an overview of the field, The Alliance for Just Deliberation on Solar Geoengineering and the Forum on Climate Engineering Assessment collaborated to produce a comprehensive report (Burns & Talati, 2023, "The Solar Geoengineering Ecosystem: Key Actors Across the Landscape of the Field"). Although the report focuses on all the agreements, pronouncements, and warnings about solar geoengineering, and not the technical and scientific aspects, I highly recommend it.

SRM Will Not Save Ocean Ecosystems

SRM may succeed in cooling the earth, but it won't stop ocean acidification, which will devastate ocean ecosystems.

> There is currently no practical way for humans to reverse ocean acidification. The only way to slow and eventually halt the acidification process is through rapid CO_2 emissions reductions and future carbon dioxide removal (CDR). If emissions continue to rise, these more acidic conditions will persist for tens of thousands of years. This is because processes that buffer (decrease) the acidity in the ocean occur very slowly, over nearly geologic time scales. Although CO_2 "only" lasts for 800–1000 years in the atmosphere, ocean processes are much slower. It will take some 30–70,000 years to bring acidification and its impacts back to pre-industrial levels, following the weathering of rocks on land into the ocean. This very long lifetime of acidification in the oceans is a crucial reason why

> mitigation efforts focused on "solar-radiation management," as opposed to decreasing atmospheric CO_2 represent a special threat to the health of the world's oceans, especially those at the poles. (ICCI, 2023)

Other Types of Geoengineering

Another type of geoengineering now receiving attention, which may be even cheaper than SRM, involves adding iron to the oceans. The iron would fertilize algae and plankton, they would convert carbon dioxide in the air to organic carbon, and this carbon would then sink and be sequestered at the bottom of the ocean. This approach would augment natural processes that occur when iron-rich dust blows from the land to the seas. Toxic algae blooms are possible, however, and more research is needed. Some scientists predict that after ten years of experiments that involve spreading iron over several thousand square miles of ocean we may know enough to proceed on a global or regional scale.

It's also possible to remove CO_2 directly from seawater, as Captura is doing.

> Our Direct Ocean Capture system runs with just two ingredients: seawater and renewable electricity. Using Captura's proprietary membrane and electrodialysis technology, it extracts CO_2 directly from seawater to be permanently stored or reused. Once the carbon is removed, the ocean naturally draws down CO_2 from the atmosphere to rebalance.[190]

In recent years, there have also been several papers on space-based solar shields. These shields could be placed at a static position near the Sun-Earth L1 Lagrange point and block a small percentage of the sunlight reaching the Earth – but enough to lower global temperatures. The Planetary Sunshade Foundation now promotes this idea (https://www.planetarysunshade.org/); however, this type of geoengineering would be extraordinarily expensive and its technical feasibility is still unclear.

It is time to start studying geoengineering seriously and discard the "moral hazard" excuses that it would undermine mitigation efforts. Buck and Nicholson (2023) present a promising proposal on the advantage of a "global network of climate action research centers that would provide appropriate conditions to produce reliable and legitimate solar geoengineering research."

When the effects of climate change lead to a sufficiently high level of disruption and death, and it becomes clear that it is too late to reduce greenhouse gases in a meaningful way, then the only recourse is geoengineering. When the choice is societal

[190] https://capturacorp.com/technology/

collapse or geoengineering, then geoengineering will surely win. Some argue that we have already lost the fight against climate change using mitigation, adaptation, and the new techniques for directly removing carbon dioxide from the atmosphere. We thus need to start geoengineering now. Taylor et al. (2023b) call this “climate cooling” and summarize the risks of not proceeding.

> Choosing not to deploy climate cooling means to accept global temperatures rising by at least 2°C above pre-industrial levels within a few decades. This increase will destroy coral reefs and other vital ecosystems, doom thousands of species to extinction, contribute to massive crop failures, and induce heat waves that will make many tropical regions uninhabitable and trigger mass population migrations. (Taylor et al., 2023b)

Many climate scientists mention human extinction at 4° or 5°C, but they do not take into account all the disruptive effects of climate change and the second and third-order effects that can lead to intra and interstate conflict (see Appendix 5). Given these effects, 2°C is likely to lead to global societal collapse, but it is unclear when extinction will occur.

Note that we are inadvertently continuing with our world-wide geoengineering experiment in a new way. Thousands of rockets are now launched annually, and this number is rising quickly. Pollutants from these rockets are left in the stratosphere, and scientists currently have little detailed understanding of their effects. Neither the Montreal Protocol, the Environmental Protection Agency, the Federal Communications Commission (which licenses satellite launches), or the Federal Aviation Administration currently examines or regulates the environmental impact of rockets in the stratosphere.

Geopolitical Strategic Complexities

Given geopolitical realities and rivalries, there are complex implications of one country unilaterally employing geoengineering. Morrissey (2024) argues that, “solar geoengineering deployment creates a risk of interstate tensions through other states’ interpretation of and reaction to a deploying state’s presumed prioritization of their domestic climate interests.” He goes on to write that

> …the situation of geoengineering governance within individual state governments combined with the technology’s substantial, unforeseeable consequences present a potential security dilemma that heightens tensions between states and risks conflict, including potential environmental catastrophe….[There are] four elements of the technology that potentially generate interstate tension: the

> potential for independent action, low costs, ambiguity surrounding deployment, and the possibility of counter-geoengineering. (Morrissey, 2024)

Morrissey explores security implications of large-scale stratospheric aerosol injection (SAI) geoengineering using four speculative scenarios, some of which involve counter geoengineering. For example, in what Morrissey calls *The Extortionist*,

> …a single actor unilaterally pursues solar geoengineering technology but then attempts to use the technology to force global obeisance….The deploying state could modify the solar geoengineering regime as a means of ratcheting up pressure to secure its demands. Given a prolonged deployment that suppresses substantial global heating, the geoengineer could even directly threaten termination shock as a retaliatory threat. (Morrissey, 2024)

Another scenario, *Cloud Wars*,

> …represents the clearest parallel with nuclear escalation fears, highlighting the potential for states to engage in competing global SAI deployments resulting in a global environmental catastrophe….Under this scenario, an individual state anticipates a global SAI deployment by another state but views the potential deployment as misaligned with its strategic climate considerations. This judgment prompts the second state to begin developing counter-geoengineering technology while diplomatic outreach and international messaging fail to generate cooperation. (Morrissey, 2024)

There is now extensive discussion on the moral hazards and potential for unexpected regional consequences of geoengineering, but there is very little discussion on the geopolitical strategic complexities that Morrissey raises.

Climate Anxiety is Inevitable

All countries will suffer from the effects of climate change, but in some fragile countries there will be societal collapse in the near future. Watching the extreme suffering in these countries and worrying about whether you will be next, as well as personally experiencing the effects of multiple extreme weather events, will lead to what some call “eco-anxiety.” Consider what is happening already. During the summer of 2023, parts of Italy, Greece, and several other countries experienced multiple extreme weather events related to heat, fires, and flooding. Some news reports, perhaps slightly exaggerating, wrote that “Europe is a continent on the verge of a nervous breakdown.” One news report described the situation in Italy:

> Italy was in the grip of extreme heat waves, hellish wildfires and biblical downpours, and a nerve-wracked young Italian woman wept as she stood in a theater to tell the country's environment minister about her fears of a climatically apocalyptic future.
>
> "I personally suffer from eco-anxiety," Giorgia Vasaperna, 27, said, her eyes welling and her hands fidgeting, at a children's film festival in July. "I have no future because my land burns." She doubted the sanity of bringing children into an infernal world and asked, "Aren't you scared for your children, for your grandchildren?"
>
> Then the minister, Gilberto Pichetto Fratin, started crying.
>
> "I have a responsibility toward all of you," he said, visibly choked up. "I have a responsibility toward my grandchildren."[191]

In the United States, many therapists are seeing various forms of climate anxiety in their clinical practice, and in the Pacific Northwest extreme smoke from wildfires has been shown to exacerbate anxiety. The beautiful summers in the northwest became something to dread rather than exalt in.

> … those beloved blue skies began to disappear. First, the smoke came in occasional bursts, from wildfires in Canada or California or Siberia, and blew away when the wind changed direction. Within a few summers, though, it was coming in thicker, from more directions at once, and lasting longer. The sun turned blood-red or was all but blotted out, disappearing along with the city skyline; the sky turned gray, or sepia, or eerily tangerine, and ash floated down like snow. Sometimes there were weeks when you were advised not to open your windows or exercise outside. Sometimes there were long stretches where you weren't supposed to breathe the outside air at all.
>
> In one of climate psychology's founding papers, published in 2011, Susan Clayton and Thomas J. Doherty posited that climate change would have "significant negative effects on mental health and well-being." They described three broad types of possible impacts: the acute trauma of living through climate disasters; the corroding fear of a collapsing future; and the psychosocial decay that could damage the fabric of communities dealing with disruptive changes. All

[191] Jason Horowitz (Sep. 16 2023), How Do We Feel About Global Warming? It's Called Eco-Anxiety., *The New York Times*, https://www.nytimes.com/2023/09/16/world/europe/italy-greece-eco-anxiety.html

> of these, they wrote, would make the climate crisis "as much a psychological and social phenomenon as a matter of biodiversity and geophysics."
>
> Many of these predictions have since been borne out. Studies have found rates of PTSD spiking in the wake of disasters, and in 2017 the American Psychological Association defined "ecoanxiety" as "a chronic fear of environmental doom."[192]

There is now academic research on all the various aspects of climate anxiety. As Cianconi et al. (2023) write:

> The threat to humankind [from climate change] is not only physical (ie, heat waves, floods, droughts) but also psychological, especially for some groups. Insecurity, danger, chaos, and an unstable system due to climate change have both short- and long-term psychological effects. In this scenario, the need for new psychological categories is emerging, namely, eco-emotions and psychoterratic syndromes which include eco-anxiety, ecological grief, climate worry, and climate trauma.

Psychoterratic syndromes are, "Earth-related mental syndromes where people's mental wellbeing (psyche) is threatened by the severing of healthy links between themselves and their home/territory." Cianconi et al. define almost twenty overlapping mental states related to climate change, including climate change distress (eco-distress), eco-guilt and eco-shame, eco-fear, eco-phobia, eco-PTSD, and eco-paralysis, among others. This is, perhaps, bordering on the ridiculous, but eco-anxiety is certainly real. Here is the definition of eco-anxiety by Cianconi et al. (2023):

> It refers to anxiety related to the ecological crisis, and frequently used to refer to anxiety related to climate change in general, that is a reaction to the changing state of the planetary ecosystem, a "chronic fear of environmental doom", as the differences become blurred because climate change has an effect on many ecological problems. It emerges directly from an experienced environmental problem (sometimes traumatic), but often indirectly from the simple awareness of the problem (eg, through the media), because it is principally a "forward looking" emotion concerned with upcoming threats about which there is uncertainty, unpredictability, uncontrollability, and that is taking away the future. It is characterized by frustration, powerlessness, feeling overwhelmed, hopelessness,

[192]Brooke Jarvis (Oct. 21 2023), Climate Change is Keeping Therapists Up at Night: How anxiety about the planet's future is transforming the practice of psychotherapy, *The New York Times*, https://www.nytimes.com/2023/10/21/magazine/climate-anxiety-therapy.html

> helplessness, and it may show a combination of clinically relevant symptoms, such as worry, rumination, irritability, sleep disturbance, loss of appetite, panic attacks, physical symptoms of anxiety. (Cianconi et al., 2023)

There are now even psychometric tests available for validating eco-emotions and psychoterratic syndromes, including The Inventory of Climate Emotions, the Climate Change Worry Scale, the Eco-anxiety Scale, and the Ecological Grief Questionnaire.

Eco-Anxiety and the Decision to have Children

Can there be any doubt that eco-anxiety and other climate-related mental states will become more common and more severe? When they do, how will they affect people's decisions to have children? There is actually little research on this topic, but it is obviously of great impact, as fewer people mean less GHG emissions. Dillarstone et al. (2023) identified 13 relevant studies in the last decade, and summarized them as follows:

> Climate change concerns were typically associated with less positive attitudes towards reproduction and a desire and/or intent for fewer children or none at all. Four themes explaining this relationship were identified: uncertainty about the future of an unborn child, environmentalist views centred on overpopulation and overconsumption, meeting family subsistence needs, and environmental and political sentiments. The current evidence reveals a complex relationship between climate change concerns and reproductive decision-making, grounded in ethical, environmental, livelihood, and political considerations. (Dillarstone et al., 2023)

Since some of these studies were published several years ago (as far back as 2012 and 2013), the relationship between climate change concerns and decisions on having children is probably now much stronger.

"Eco-terrorism" is Inevitable

Nonviolent mass movements, such as the Sunrise Movement and Extinction Rebellion, will grow rapidly, but as the climate crisis continues, despair and rage will drive offshoots of these organizations that will engage in acts of violence and sabotage. Radical environmentalists and other groups have engaged in a variety of tactics over the years, including tree spiking, arson, "monkeywrenching," and sometimes bombing. The impact of these acts have been minimal, but my expectation is that they will increase dramatically in the future. The best predictions of what might happen come from fiction, including books such as *The Deluge*, by Markley (2023), and *The Ministry for the Future*, by Robinson (2020). See also Andreas Malm's *How to Blow up a Pipeline*, and

his new book (with William Catton), *Overshoot: How the World Surrendered to Climate Breakdown* (coming out in October, 2024). And, of course, Edward Abbey's *The Monkey Wrench Gang* (1975) is now a classic, and was revered by the radical environmental movements of the late twentieth century.

New Technologies

Apart from geoengineering, there are a variety of new technologies that will help in the future. While there are literally hundreds of ongoing research and development projects related to sustainability, it is unlikely these technologies will arise soon enough to help resolve the climate crisis, given the feedback loops and tipping points discussed above. I present just a small sample of these new technologies here, as well as briefly discussing well-known technologies such as CRISPR and fusion.

Liquid-Infused Windows for Universal Climate Control

Here is an example of one recent project on sustainability from Harvard's new Salata Institute:

> Over 25% of the energy and 50% of electricity consumed globally are spent conditioning the indoors to keep humans comfortable. Nearly all that energy is dedicated to regulating temperatures within buildings using air conditioners, furnaces, and electric lights. Biology inspires a different approach. In many animals, sunlight and temperature are filtered at their first point of contact – the skin. Skin, or other animal coverings often dynamically reflect, absorb, or transmit heat, helping to regulate the animal's internal temperature. Scaling these capabilities to buildings is a promising path to urban sustainability. The Aizenberg lab has pioneered an approach to managing indoor climate using a bio-inspired building "skin" that leverages the properties of liquids, carried through vein-like channels to control interior climates. With seed grant funding, researchers will work towards the first proof-of-concept for applying this promising approach to windows.[193]

Earthships

Passive solar building practices can radically reduce the need to use electricity or fossil fuels for heating or cooling. Taking this to the extreme, Earthships have been built that are almost totally self-sufficient and can exist off the grid. They are passive solar structures that use primarily recycled and natural materials. They rely in part on having a large thermal mass, often by using over 1,000 old tires in the exterior walls, with each tire filled with several hundred pounds of sand, silt, or clay. For a variety of reasons,

[193] https://salatainstitute.harvard.edu/salata-institute-to-fund-five-new-climate-and-sustainability-projects-across-harvard/

they are not a generalizable solution to reducing housing energy costs. Consider just the number of tires required: there are not enough used tires in the U.S. to build a large number of Earthships. In addition, it is not feasible to build them in most urban areas.

CRISPR

Using CRISPR scientists can precisely edit the DNA in living organisms. CRISPR has already been used to create rice plants resistant to both disease and drought, and more genetic engineering is certainly inevitable, despite opposition from some groups. The collection of microbes living within our bodies and the bodies of other animals is called the microbiome (plants also have a microbiome). CRISPR, along with metagenomics (used to understand the species in a complex microbiome), can be used for precision microbiome editing, and there are plans and efforts to reduce methane emissions from farm animals, landfills, wastewater, rice paddies, and other sources. In the future, this could have a major impact on the emission of methane, a powerful greenhouse gas. In my opinion, genetically engineered food crops will be essential for human survival in a world that is hotter and often drier and wetter than many current crops can tolerate.

Fusion

Fusion holds great promise, but most scientists dismiss it as irrelevant in the near future. In fact, some dismiss fusion with some variation of this pessimistic summary: In 1970, fusion was 30 years away. In 2000 fusion was 30 years away. Today fusion is still 30 years away.

Artificial Intelligence (AI) and the “Singularity”

When artificial intelligence programs can learn and improve upon themselves, or create other more intelligent programs, then there may be an exponential increase in intelligence and capabilities that could result in a superhuman “singularity.” Some researchers believe this will happen within the next few decades, others think it will never happen. If it does happen, and the resulting superhuman intelligence is benevolent, then surely it will be able to help us solve the climate crisis. This is possible, but it’s impossible to assign a probability to it happening, and is obviously not something we should be counting on. The large language models (LLM) such as Chat GPT and Google Bard and Gemini are unlikely to be a step in the direction of a singularity, but they demonstrate dramatically how useful LLMs can be. LLMs and machine learning are advancing quickly, and even without reaching a singularity it is clear that they will help speed scientific research, helping with everything from planning experiments to analyzing data.

Many now believe that Artificial General Intelligence (AGI) may be achieved within a few years, and that OpenAI’s new model called o1, which is “designed to spend more time

thinking" before responding, is a step in this direction (https://openai.com/o1/). There is no question that these new models will be extraordinarily useful in many fields, but it's hard to imagine how they will result in rapid and deep decarbonization. They may help in developing detailed plans for how to transform multiple sectors of the economy, and help in designing new technologies, but developing these technologies and putting those plans into operation will require agreement by both governments and industry, and in many cases new legislation. It is thus not clear how these models can lead to significant reductions in greenhouse gases within the next decade.

Carbon Taxes (or Fee and Dividend)

Most economists think that some type of carbon tax or fee is the best way to reduce emissions rapidly, and in fact over 30 countries have introduced some type of carbon pricing (although often at a very low rate). "There exists a general consensus among economists that an efficiently designed carbon pricing policy is preferable to nonmarket and regulatory instruments to reduce GHG emissions" (Timilsina, 2022). Here is a simplified description from Citizens Climate Lobby (CCL):

> CCL supports an economy-wide carbon tax, where the money is given to people, typically referred to as a carbon fee and dividend or carbon tax and dividend. With a carbon tax, a fee is applied wherever fossil fuels enter the economy. This price flows through the economy, incentivizing businesses and people to switch to clean energy. Fossil fuels such as oil, natural gas, and coal all contain carbon. When burned, they release potent greenhouse gases (GHG) and carbon dioxide (CO_2) into the atmosphere. Putting a price on carbon involves placing a fee on these fossil fuels and carbon pollution. This fee is based on the metric tons of carbon dioxide (CO_2) the fuel would generate, and it would be assessed at the earliest point of sale into the economy—as close as possible to the well, mine, or port.

To ensure that imported goods don't have an unfair advantage, the European Union (EU) implemented a "carbon border adjustment" that adds a fee to imported goods based on the carbon cost in the EU (often abbreviated as CBAM, with M for "mechanism"; this happened in October of 2023). MIT's Climate Portal page on Carbon Border Adjustments presents CBAM clearly, and explains how carbon pricing can spread when exporters want to escape from the CBAM:

> …if the exporting country has its own carbon price, then the CBAM is lowered to only cover the difference between the two prices. This prevents "double taxing" of carbon emissions. It also has the happy effect of nudging other countries to enact their own carbon prices. Since their exporters will pay a fee for their carbon

emissions anyway, policymakers might well decide it would be better to collect that fee themselves than let it go to a foreign government.[194]

There are certainly complexities involved in implementing a tax on carbon, such as being able to measure the carbon output of foreign industries, but this is still probably the best way to rapidly reduce emissions. For a review of the literature since 1970, see Timilsina (2022). For a summary of emissions trading systems around the world, see the World Bank Report on the State and Trends of Carbon Pricing 2023 (World Bank, 2023).

Senator Sheldon Whitehouse (Democrat from Rhode Island) is the Co-Chair of the U.S. Senate Climate Task Force. During a discussion as part of Harvard Climate Action Week, he said: “If we want a path to climate safety, it’s going to require us to do what is economically and morally right, which is to price carbon pollution.” He also said that, “there are now no remaining known scenarios for a pathway to climate safety that don’t include carbon pricing…There can be no more quarrel on that.”[195] There was also discussion during the climate action week in a meeting on a new working paper on “Climate Policy Reform Options in 2025” by Bistline and others. The paper used an integrated model of energy supply and demand. One of the model results was that, “the emissions reductions of the Inflation Reduction Act are significantly augmented under scenarios that add a modest carbon fee or, to a lesser extent, that implement a clean electricity standard in the power sector.”[196]

Quantifying Collapse

There’s no accurate way to quantify the probability of collapse, or even the extent of climate change several decades from now. There are just too many unknown variables: will there be a world-wide mobilization to mitigate climate change? Will new technologies emerge? Will feedback loops and tipping points lead to dramatic accelerations? Will authoritarian nationalist regimes come to power and ignore or rollback climate change mitigation strategies? Will individual countries take it upon themselves to engage in solar geoengineering? Will climate change lead to wars and regional conflicts over resources and mass migration that derail any existing mitigation efforts? Will eco-anxiety lead to a population decline? Will mass movements quickly alter the political landscape?

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[194] https://climate.mit.edu/explainers/carbon-border-adjustments

[195] June 10, 2024, https://salatainstitute.harvard.edu/senator-sheldon-whitehouse-on-carbon-pricing-theres-no-other-path-to-climate-safety/

[196] John Bistline, Kimberly A. Clausing, Neil Mehrotra, James H. Stock, Catherine Wolfram (Feb. 2024), Climate Policy Reform Options in 2025, *National Bureau of Economic Research* , https://www.nber.org/system/files/working_papers/w32168/w32168.pdf

Although we can't assign probabilities, we know the situation will get much worse because global warming is not only continuing but accelerating. As Kemp et al. (2022) write, "We don't know the probabilities attached to different outcomes, the exact chain of cause and effect that will lead to outcomes, or even the range, timing, or desirability of outcomes. Uncertainty, deep or not, should motivate precaution and vigilance, not complacency."

Although we can't quantify the probability of global societal collapse, we can marshall all the arguments that lead to the conclusion that it is not only possible, but probable. The twelve points below describe the main points made in this paper: the current state of affairs, the most likely future situation, and what needs to be done. All these points were supported throughout this paper with multiple references and extensive discussion.

1. **The situation is now serious.** There are extreme heat waves, droughts, floods, fires, and storms. Coral reefs are bleaching and dying, sea levels are rising, natural habitats are being destroyed, and millions of species are declining or in the process of going extinct.
2. **There is universal agreement that drastic actions to reduce greenhouse gases are required immediately.** All major national and international organizations that have studied the climate crisis conclude that drastic actions need to be taken immediately. Climate scientists and international organizations have been saying this for a long time.
3. **Drastic actions to reduce greenhouse gases require policies and commitments at the national and international level.** It is now clear that a worldwide mobilization is required to reduce greenhouse gases. The only effective ways to do this are via actions taken at the national and international level. The actions of individuals are clearly not sufficient; individuals can't block the construction of power plants fueled by coal or speed improvements to our electrical grid. A good example of how quickly governments can refocus their economies comes from the U.S. during WWII, when industry retooled incredibly quickly to support the war effort.
4. **Given the political situation, it is very unlikely that the required drastic actions will be taken in the near future at either national or international levels.** Although drastic action is required immediately, the political situation in both the U.S. and the rest of the world indicates it is unlikely to take place any time soon. One of the two major political parties in the United States includes in its party platform the phrase, "We will DRILL, BABY, DRILL," and President Trump, in his first day in office (January 20, 2025), signed dozens of executive orders that will increase the use of fossil fuels and aggravate the climate crisis. Authoritarian leaders in multiple countries downplay the risks of climate change,

want to extract as much fossil fuel as possible, and speak out against international organizations that try to restrict their freedom. A worldwide mobilization is unlikely to occur in this political climate.

5. **Because drastic actions are not being taken, greenhouse gases will continue to increase.** The required drastic actions are not being taken and greenhouse gases are still increasing in the atmosphere. Climate change mitigation has failed.
6. **Because greenhouse gases will continue to increase, it is inevitable that the situation will get much worse.** In addition, we continue to degrade the biosphere, including Earth's peat bogs, forests, and other natural carbon sinks. Positive feedback loops are also becoming a significant contributor to greenhouse gases, and we will also soon pass several tipping points, which will further destabilize the Earth's climate.
7. **As the situation gets worse, many millions will die.** Millions will die from heat waves, floods, droughts, tropical storms, wildfires, and rising sea levels, but many more will die from starvation, infectious diseases, and from civil unrest and regional and international conflicts.
8. **Nation states will start to collapse.** Climate change is a "threat multiplier" that will lead first to the collapse of "fragile" states by interacting with economic, biophysical, and geopolitical problems to make the situation worse. When crop failures, extreme weather events, and mass migration continue for years, social unrest will increase and intra- and interstate conflict is likely. A multitude of related problems will lead to the collapse of "fragile" states.
9. **Economic losses, compound hazards, and cascading effects will eventually threaten the collapse of even the most resilient nation states.** Economic losses will increase dramatically, and compound hazards and cascading effects will start occurring more frequently. When governments are unable to meet the basic needs of their populations, public dissatisfaction will grow and political instability will follow. This, along with continued heat and extreme weather events will eventually lead to an overwhelming strain on the adaptive capacity of even the wealthiest and most resilient nations.
10. **Geoengineering is inevitable.** There are serious problems and many unknowns with geoengineering, but the situation is already serious; as the situation deteriorates further, it will become inevitable that we will need to employ some type of geoengineering to cool the Earth. Effective geoengineering may delay or prevent societal collapse.
11. **After we stop emitting greenhouse gases, it will still be necessary to remove carbon dioxide from the atmosphere.** In the future, even if we are able to come close to net zero, the Earth will not only remain hot, but natural processes will continue to release greenhouse gases into the atmosphere (e.g.,

via melting permafrost and burning forests), and other processes, such as changing albedo, will lead to an increase in the earth's energy imbalance. For these reasons, we will need to remove carbon dioxide from the atmosphere.

12. **Individuals should join mass movements and work on changing the political environment and social norms as well as protecting the biosphere and supporting research.** The solution on a national level is clear: reduce greenhouse gases and protect our biosphere. Individuals should work toward changing the political landscape and transforming social norms about the climate so this can happen. Only when the vast majority of a population supports the required drastic actions will politicians find the will to act decisively. There is already an increase in mass movements demanding change, and these movements will expand dramatically. The most effective actions that individuals can take are to join these mass movements and work toward the required policies and research, from putting a tax on carbon to advocating for more research and development on renewable energy, geoengineering to cool the Earth, nuclear power, and various technologies for removing carbon dioxide from the atmosphere.

"Drastic actions" are those with extreme, immediate, and far-reaching effects. For example, Citizens Climate Lobby suggests an initial carbon fee of $15/metric ton for emissions of CO_2 equivalent fossil fuels, but the fee should be closer to $50 or more, and the yearly increase should be far greater than the $10 they recommend. There should be additional taxes on non-essential fossil fuel use, such as for cruise ships and most air travel, as well as the use of motor boats and other recreational equipment. There should be extensive subsidies for renewable energy and the transition to electric vehicles and equipment of all types. We need to shut coal-based power plants and expand nuclear power, including small modular reactors. We should also rapidly expand mass transportation and institute congestion pricing in cities. Private planes should be banned, as well as private yachts above a certain size. Alternative cement[197] and climate friendly building practices should be mandatory, and there should be no fossil-fuel based heating in new construction. How all of these transitions can occur quickly without completely destroying the economy is a difficult problem, and there will be major disruptions to all segments of the economy. Major disruptions, however, are preferable to societal collapse.

An Optimistic Note: After a long buildup, change can come quickly

Grassroots movements helped end slavery, and grassroots movements can help end the use of fossil fuels and prevent societal collapse. Elizabeth Heyrick, an English abolitionist, died despondent in 1831. After working to abolish slavery for many years,

[197] See https://drawdown.org/solutions/alternative-cement

little progress was made, and she wrote to a friend, “Nothing human can dispel that despairing torpor into which I have been plunging deeper and deeper for many months.”[198] We are moving too slowly to reduce the emission of greenhouse gases, just as in the early 1800s the abolition movement was progressing too slowly. In 1824, Heyrick wrote an essay called “Immediate, Not Gradual Abolition.”

> She blasted the male-dominated abolitionist establishment for its timid pursuit of a slow-motion eradication of slavery – “the spirit of accommodation and conciliation has been a spirit of delusion” – while making an impassioned case for complete emancipation.
>
> Just two years later [after Heyrick’s death], the once remote and seemingly hopeless cause of British abolitionism succeeded. In 1833, Parliament passed the Slavery Abolition Act, which eventually emancipated more than 800,000 enslaved Black men, women, and children throughout the empire. An act of law – driven largely by grassroots action – had eradicated a great evil.
>
> Today those of us in the movement for climate justice find ourselves in a position similar to that of the abolitionists in the early 19th century. We too are engaged in a great moral struggle, with the fate of generations hanging in the balance. We too confront impossible odds, with all the power and wealth of mighty corporations piled against us. History, though, is our ally. It can help us to see our present plight more clearly and sharpen our imaginings of the future.[199]

The Emancipation Proclamation was issued in the United States on January 1, 1863, 30 years after Great Britain. That delay resulted in enormous suffering and many deaths, but when emancipation arrived it still set slaves free. The situation is very different with respect to the elimination of fossil fuels, because if we wait too long, natural processes may increase the release of carbon dioxide (e.g., by melting permafrost) and replace the fossil fuel emissions that we reduce. Eliminating our use of fossil fuels very quickly is not the same as eliminating them at our current more leisurely pace. We no longer have 30 years.

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[198] Jason Mark (Fall 2024). Abolish Fossil Fuels: A moral case for ending the age of coal, oil, and gas, *Sierra Magazine*, https://digital.sierramagazine.org/publication/?m=43145&i=829286&view=articleBrowser&article_id=4839157&ver=html5

[199] Ibid.

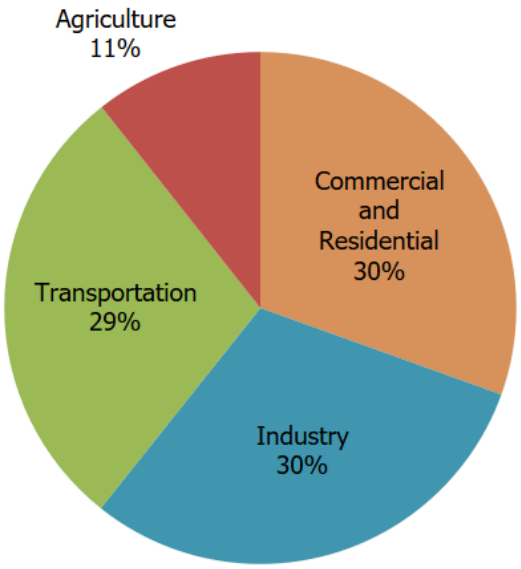
Solutions

What Should You As an Individual Do?

1. **Reduce Your Carbon Footprint?**

There are two classes of action that you, as an individual, can take. The first involves reducing your carbon footprint (and ecological footprint, more generally) and is certainly worthwhile, but this will make no difference whatsoever in preventing catastrophic global warming. The near-term effects (e.g., by 2035) will just be too small and insignificant on a global scale. You can reduce your carbon footprint by insulating your home, putting up solar panels, switching from heating with fossil fuel to heat pumps, buying more energy-efficient appliances, biking or taking public transportation, driving an electric car, and reducing air travel (see https://www.un.org/actnow and https://drawdown.org/insights/whats-the-best-climate-action-you-can-take-you-tell-me for lots of good ideas that individuals can take). Not everyone, however, can take these steps. First, because most people don't have the extra disposable income,[200] and second, because for all those living in cities and apartment buildings (especially those who are renting) installing solar panels is typically not possible (although it may be possible to participate in a community solar farm project). These city dwellers and renters also may not have permission or the ability to increase insulation or install heat pumps. Consequently, if those who were able took these steps, the reduction in fossil fuel usage would be minimal, given where greenhouse gas emissions come from in the United States. What follows are just some back-of-the-envelope calculations to demonstrate that individual actions will just not be sufficient to make a meaningful difference in global GHG emissions.

[200] In a 2021 survey conducted by the Federal Reserve Board, about 37% of people in the U.S. said they did not have the cash to deal with a $400 emergency. https://www.federalreserve.gov/publications/2020-economic-well-being-of-us-households-in-2019-dealing-with-unexpected-expenses.htm



U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021

Figure 24. Total U.S. Greenhouse Gas Emissions by Economic Sector and Electricity End-Use[201]

According to the Environmental Protection Agency (Figure 24 above), 30% of U.S. GHG emissions come from industry and 11% from agriculture. This means 41% of greenhouse gas emissions are outside of an individual's direct control from these two sectors. Almost half of GHG from transportation comes from passenger cars, so we could remove a maximum of half, or about 15% from the 29% for transportation. We are now at 56% (41 + 15) of GHG emissions out of an individual's control. About 40% of GHG from commercial and residential buildings come from the commercial part, so that removes another 12%, bringing us to 68% (56 + 12) out of an individual's control. Some individuals can make improvements to the 32% of GHGs from their residences and cars, but the improvements are unlikely to be large, given that many people can't make these improvements, and those who can will not be able to reduce their output to zero.

Some private homes will be able to add insulation and switch to heat pumps, but many will not, due to financial and other constraints. Switching to heat pumps can save significant amounts of GHGs, but the amount depends on carbon emissions from the electrical grid (see Pistochini et al., 2022, for a detailed analysis). Given financial and

[201] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

practical considerations, only a small percentage of residential homes can be converted to heat pumps per year.

Electric cars currently make up only about 1% of cars in the U.S. Even if 50% of new cars sold in the United States are electric by 2030, the percentage of electric cars on the road will still probably be between 10 and 30%, because cars stay on the road for over ten years in the U.S.. Also, note that electric vehicles only save around two-thirds of GHG emissions when compared to gas vehicles on a per-mile basis.[202]

Taking all of this into account, the 32% of GHGs under an individual's control might be reduced to 25% (of the current mix) in the near future, but it would be difficult to reduce it much further. The situation in Europe is similar, although there will be even less of a reduction in GHGs given that there are fewer cars per population level and they are driven less than in the U.S. Therefore, even if everyone in the United States and the Global North who had the means made a serious effort to do all of these things, but the rest of the world continued on its current path, the effect would be negligible, and certainly not enough to prevent us from crossing multiple tipping points.

Some organizations, however, claim that individual actions can lead to dramatic reductions of GHGs. For example, an analysis by Project Drawdown, "reveals that individual and household actions have the potential to produce roughly 25–30 percent of the total emissions reductions needed to avoid dangerous climate change (>1.5°C rise)."[203] However, not only is this looking at a 30-year time frame, but their figure of a 25-30% reduction is a worldwide theoretical maximum and not, in my opinion, a reasonable estimate (as they write, it has "the potential to…").

In fact, according to Project Drawdown's own figures, the situation is worse than the calculations above from the EPA data. There are many ways to measure and allocate greenhouse gases, and the allocation in Figure 25 below from Project Drawdown is very different from the EPA chart. The percentage under an individual's control is less than 20% here, primarily from a subset of the Transportation, Buildings, and Other sectors.

[202] This is an estimate from using the Beyond Tailpipe Emissions Calculator on several different car models. See https://www.fueleconomy.gov/feg/Find.do?action=bt2.
[203] https://drawdown.org/solutions

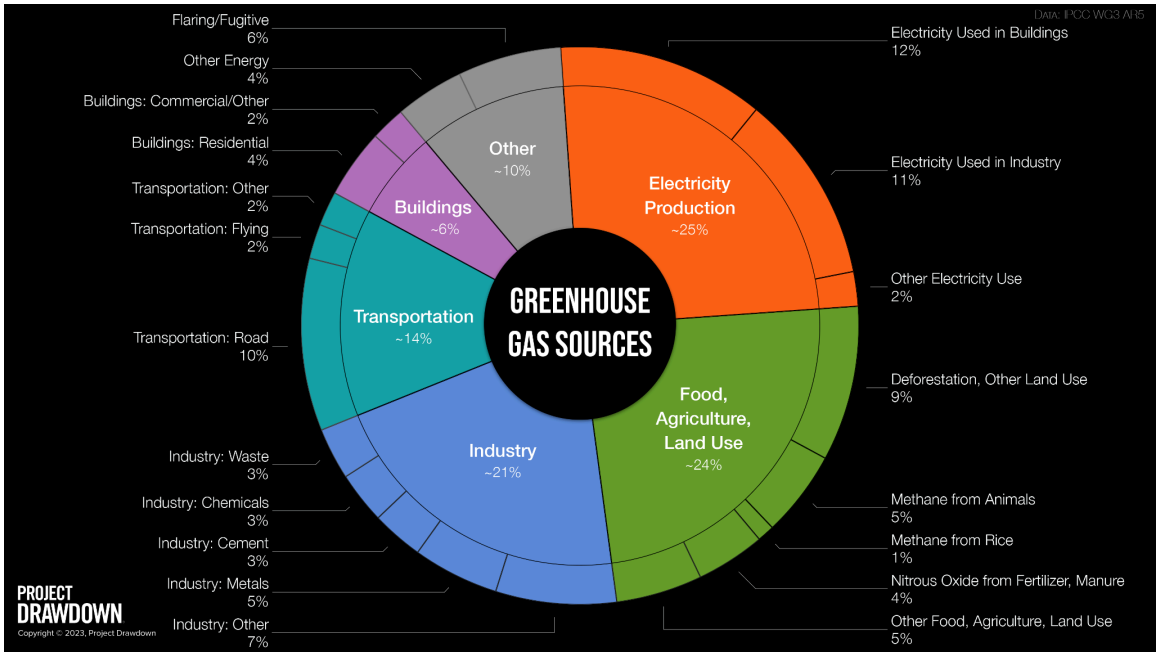


Figure 25. Greenhouse Gas Sources by Sector
(From https://drawdown.org/drawdown-roadmap)

If you live in Phoenix, Arizona, which had a month of temperatures above 110°F in 2023, and 100 days above 100°F in 2024, will you give up your air conditioning? To do so would be to risk death. How then can you deny air conditioning and refrigerators to those coming out of poverty in India, China, and Africa? Power usage is increasing, so despite the increase in renewable energy, hundreds of new coal-fired plants are still being built. Fossil fuel-powered cars, trucks, farm and construction equipment, planes, and ships will be operating for at least several more decades,[204] and houses and office buildings are still being built heated by oil, gas, and wood. Cement production, a major source of emissions, will also continue.[205] There are also no serious efforts to eliminate or replace plastics, which are made from fossil fuels.[206] Given this state of affairs, what

[204] The following is quite amazing to me, and indicates how long the transition will take: "... the average age of cars and light trucks in the US has risen again this year to a new record of 12.5 years, up by more than three months over 2022," and the average for passenger cars is 13.6 years. From https://www.spglobal.com/mobility/en/research-analysis/average-age-of-light-vehicles-in-the-us-hits-record-high.html#:~:text=With%20more%20than%20284%20million,analysis%20from%20S%26P%20Global%20Mobility.

[205] Mark Fischetti, Nick Bockelman, and Wil V. Srubar (Feb. 1 2023), Solving Cement's Massive Carbon Problem, *Scientific American*, https://www.scientificamerican.com/article/solving-cements-massive-carbon-problem/

[206] Plastics account for 3.3% of global emissions according to some estimates (Hannah Ritchie (2023) - "How much of global greenhouse gas emissions come from plastics?" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/ghg-emissions-plastics'

you as an individual choose to do in your personal life is effectively meaningless on a global scale in the short term, although there are other reasons to do these things. In the long term, however, the situation is very different, and as Pope Francis (2023) points out, “a broad change in the irresponsible lifestyle connected with the Western model would have a significant long-term impact.”

Individual Actions

If we survive the immediate climate crisis, individual actions will become incredibly important. Eating less meat and promoting a primarily vegetarian diet can lead to significant improvement to land and water usage and a reduction in the use of fossil fuels.[207] Not only do cattle produce methane during digestion, but the land currently used to raise cattle can typically produce much more nutrition by growing grains and vegetables. Most grazing land, however, is not suitable for raising crops, and in this case, returning grazing land to forests (as in the Amazon), can also have dramatic effects. And, as Richardson et al. (2023) write, “...one of the most powerful means that humanity has at its disposal to combat climate change is respecting the land system change boundary. Bringing total global forest cover back to the levels of the late 20th century would provide a substantial cumulative sink for atmospheric CO_2 in 2100.” For some farmland, however, rewilding is better than afforestation.[208]

> Low-productivity croplands and pasturelands are being widely abandoned at a global scale, especially in mountainous and remote areas….Afforestation on these abandoned farmlands is highly popular, but it only addresses the climate crisis, not the biodiversity emergency. An alternative to afforestation is rewilding, which would contribute to combating both the biodiversity and climate crises while also facilitating socio-ecological sustainability by increasing ecosystem resilience. (Wang, Pedersen, & Svenning, 2023).

For those living in the U.S., you should also contact your Senators and congressional representative and advocate for nuclear power, additional funding for climate research and monitoring, and research into both negative emissions technologies and geoengineering. More satellites and autonomous underwater vehicles (such as are used in the Argo program) are needed to collect data, and more planes are needed to

[207] There are exciting new ways to create high-protein food in vats using precision fermentation processes.

[208] Reforestation is not the same as afforestation: “**Forestation**, including forest restoration, reforestation, and afforestation, is the process of restoring damaged forests or growing forests on currently unforested land. **Forest restoration** involves helping degraded forest land recover its forest structure, ecological processes, and biodiversity. **Reforestation** includes planting trees or allowing trees to regrow on land that had recently been covered with forest. **Afforestation** involves planting trees on land that has not recently been covered with forest” (https://www.american.edu/sis/centers/carbon-removal/fact-sheet-forestation.cfm)

track hurricanes and other extreme weather events (e.g., there were not enough specially equipped planes to track Hurricane Idalia before it hit Florida on August 30th, 2023). More monitoring on land is also required, such as that proposed by the World Meteorological Congress in its new program of the Global Greenhouse Gas Watch (GGGW).[209]

Given the current political realities, and the dangers from crossing tipping points and feedback loops, it is unlikely that we will be able to prevent a global societal collapse. Rather than giving up, however, we should assume that we have more time than I argue here. We need to use this time to bring about radical and fundamental transformations in our economy and society. To start this process, I recommend that we should each work to do the following:

- Elect politicians who will take action on climate change
- Work to pass a tax on carbon (a "fee and dividend" if "tax" scares you)
- Support research on negative emissions technology, nuclear power, geoengineering, and climate research in general
- Protect our biosphere, especially carbon sinks such as peat bogs, the Amazon and boreal forests
- Convince your family, friends, community, and as many other people as possible that there is a climate emergency that requires immediate action
- Organize and participate in a mass movement to combat climate change; participate in non-violent civil disobedience and civil resistance

With respect to the last bullet item, Chenoweth & Stephan (2012) argue convincingly, based on data and case studies from over 100 years, that civil resistance involving protests, boycotts, and a variety of forms of nonviolent noncooperation are more than twice as effective as violence in achieving goals. Also see Chenoweth's (2021) more recent book, *Civil Resistance: What Everyone Needs to Know*, a more practical exposition with answers to common questions, as well as a discussion on the increase in nonviolent resistance since 2010 and the new challenges these movements face.

2. "Control Political Power" and Protect the Biosphere

The second class of actions can make a difference in the short term, and this is where you should focus your efforts. You should support and vote for politicians who will act decisively on climate change. You should support organizations promoting a carbon tax, such as Citizens Climate Lobby.[210] You should help organize and participate in

[209] https://wmo.int/activities/global-greenhouse-gas-watch/global-greenhouse-gas-watch-programme

[210] https://citizensclimatelobby.org/

non-violent mass movements to combat climate change involving civil resistance and civil disobedience. As Pope Francis (2023) writes, quoting a 2015 Encyclical Letter:

> The demands that rise up from below throughout the world, where activists from very different countries help and support one another, can end up pressuring the sources of power. It is to be hoped that this will happen with respect to the climate crisis. For this reason, I reiterate that "unless citizens control political power – national, regional and municipal – it will not be possible to control damage to the environment". (Pope Francis, 2023)

Presenting more evidence is not sufficient to change people's attitudes, but most people pay attention to top musicians, athletes, religious leaders, and all the people now called social influencers. It is thus imperative to get these people to speak out about climate change. There is a large body of research on social contagion and social-norm and social-tipping interventions, as described earlier in this paper, and we need to apply effective interventions to change social norms. Political leaders need to speak out, and the National Science Foundation and the National Institutes of Health should fund both research and intervention projects.

3. Participate in Mass Movements

Politicians and governments will act when forced to by their constituents, and mass movements will be required to change the conversation about the climate crisis. As Constantino et al., (2022) write, "social activism and social movements are one mechanism by which new social norms emerge, spread and effect political change." The Climate Majority Project in the United Kingdom (https://climatemajorityproject.com/) has an excellent approach, which I endorse. The following is verbatim from their paper on the Theory of Change.[211]

> We aim to catalyse an inclusive, creative mass movement for climate action. Rather than a neat, linear blueprint for change, we here sketch four mutually reinforcing strands that combine to support a necessarily-messy, distributed, collective response:
>
> #### 1. Narrative Shift toward truthfulness
>
> A widespread public narrative that has persistently insisted (across decades) that there is just enough time to 'fix' the climate crisis ("Five to Midnight") delays climate action. It props up belief that deteriorating business-as-usual can continue, and masks increasing understanding that institutions have already

[211] https://usercontent.one/wp/climatemajorityproject.com/wp-content/uploads/2023/05/ToC-Pre-Launch-Disseminate.pdf?media=1714307355

failed to prevent a climate crisis…. The CMP [Climate Majority Project] aims to challenge scientists and institutional insiders to be fully honest with the public.

2. **Creating Cultures of Awareness and Resilience**

Transformative social movements need deep inner resources. To hear, understand and accept the painful truth, negotiate grief and anxiety, and find the will to respond appropriately, factors such as community support, self-care, belonging and resilience are essential. The escalating public health crisis of climate anxiety must be taken seriously and may present an important opportunity to advance the conversation around inner resources.

3. **Tangible Pragmatic Action**

Mass activation of citizens in diverse, distributed, mostly self-organising action towards climate mitigation, adaptation, and protection of nature. Adequate climate response from Government is a massive undertaking requiring resolute planning, coordination and purpose. It hasn't happened, and won't until citizens force governments to act ... .We do not offer a neat roadmap for this action - people need in the first instance a means of finding mutual support, and together finding the work that is their own to do.

4. **Building Shared Understanding**

The developing CMP [Climate Majority Project] will be underpinned by an ongoing conversation aimed at making sense of the changing world and of collective action in the long term, listening to our network and evolving the strategic picture. We will include the public in a credible, principled, honest process of shared understanding, rather than presenting a fete accompli mission, inappropriate to the hyper-complex task of achieving zero carbon and biodiversity loss.

The Climate Majority we see forming will involve mass mobilisation of citizens via diverse, distributed, mostly self-organising action for climate mitigation, adaptation, and protection of nature; combining to drive change at all different institutional levels.

Mass Movements and the Criminalization of Climate Protests

Groups advocating civil resistance are increasing. It is clear that they are starting to have an effect, because some governments and companies are taking actions to stop

their disruptive actions, and multi-year prison sentences are now being handed down for non-violent protests and civil disobedience (the “criminalization of climate protests”).[212]

Just Stop Oil

Just Stop Oil is one such group. It is “a nonviolent civil resistance group in the UK. In 2022 we started taking action to demand the UK Government stop licensing all new oil, gas and coal projects.”[213] Roger Hallam, one of the group’s founders, was also one of the founders of Extinction Rebellion, and he was recently sentenced to a five-year prison term for organizing a protest on the M25 (a major highway around London) that disrupted traffic

Just Stop Oil’s plan involves facing “up to the scale of the crisis that we are facing,” coming together as a community, training in nonviolence, and then taking action.

> **Action**
> This is how civil resistance works: applying nonviolent pressure until we force change to happen. It’s how the Freedom Riders forced an end to segregated buses in 1961. It’s how disabled people won accessible transport in the nineties. It's how we'll win and force this criminal government to act on the unfolding climate disaster by stopping new oil and gas. No-one’s going to save us, we need to come together to do that for ourselves.[214]

Just Stop Oil is part of an international network of similar organizations, and lists sister organizations in 13 other countries on their website. Just Stop Oil has provoked the government by disrupting traffic in the UK, while in Germany, the climate activist group Letzte Generation (The Last Generation) blocked runways at Frankfort’s International Airport on July 25, 2024, which led to the cancellation of 140 flights.[215]

Stand.earth

Stand.earth (https://stand.earth/) is another organization fighting to reduce our use of fossil fuels, increase funding for renewable energy, and “respect human rights and

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[212] Oscar Berglund (July 23, 2024), In the UK, a dangerous escalation in the criminalization of climate protests, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2024/07/in-the-uk-a-dangerous-escalation-in-the-criminalization-of-climate-protests/

[213] https://juststopoil.org/

[214] Ibid.

[215] July 25, 2024, Climate activists block runways at Germany’s Frankfurt airport, *Al Jazeera,* https://www.aljazeera.com/news/2024/7/25/climate-activists-block-runways-at-germanys-frankfurt-airport

indigenous sovereignty as part of a just transition."[216] Stand.earth is organizing a sustained civil disobedience campaign in New York City during the summer of 2024 (aptly called The Summer of Heat, https://www.summerofheat.org/).

> Since June 10, the Summer of Heat on Wall Street campaign has repeatedly engaged in nonviolent civil disobedience at Citibank's global headquarters to demand the dirty bank stop funding fossil fuels. Citi has poured $396.33 billion into coal, oil and gas companies and is the world's #1 funder of fossil fuel expansion since 2016. The need to highlight this bad behavior cannot be overstated.
>
> Activists have blockaded Citi's doors 15 times, at least 3,500 total people have participated, and 462 people have been arrested to date. We stand in solidarity with all participants exercising their constitutional right to peacefully demand and advocate for climate justice. Unfortunately, instead of being accountable, Citi has answered by targeting campaign leaders and organizers to try and stop our momentum. (This is verbatim from an email I received, but all of this information is available on the Summer of Heat website, https://www.summerofheat.org/.)

Scientist Rebellion

Scientist Rebellion now has local groups in over 30 countries and advocates for non-violent civil disobedience.

> We are scientists and academics who believe we should expose the reality and severity of the climate and ecological emergency by engaging in non-violent civil disobedience. Unless those best placed to understand behave as if this is an emergency, we cannot expect the public to do so. Some believe that appearing "alarmist" is detrimental - but we are terrified by what we see, and believe it is both vital and right to express our fears openly. (https://scientistrebellion.org/)

Collapse is Likely, But Not Inevitable: What Should We As a Society Do?

Radical and transformative change is possible, but it is not happening, and time is running out.

[216] "From Arizona to the Congo, the energy transition risks driving a new wave of human rights abuses and violations of Indigenous sovereignty. Wall Street must ensure that human rights, Indigenous sovereignty and the rights of workers are respected by every company they finance, including renewable energy and rare earth mining companies" (from https://www.summerofheat.org/).

> Incremental linear changes to the present socioeconomic system are not enough to stabilize the Earth System. Widespread, rapid, and fundamental transformations will likely be required to reduce the risk of crossing the threshold and locking in the Hothouse Earth pathway; these include changes in behavior, technology and innovation, governance, and values. (Steffen et al., 2018)

We are now, unfortunately, on a "hothouse Earth" trajectory that will end human civilization as we know it. Humans are capable, however, of creating a new pathway to what Steffen et al. (2018) call "Stabilized Earth" by taking actions that result in negative feedbacks that will keep the global temperature at 2°C or less.

> The negative feedback actions fall into three broad categories: (*i*) reducing greenhouse gas emissions, (*ii*) enhancing or creating carbon sinks (e.g., protecting and enhancing biosphere carbon sinks and creating new types of sinks), and (*iii*) modifying Earth's energy balance (for example, via solar radiation management, although that particular feedback entails very large risks of destabilization or degradation of several key processes in the Earth System). (Steffen et al., 2018)

Although there are efforts in the first two categories, overall they are failing. We are not reducing greenhouse gas emissions, and we are not protecting carbon sinks such as the Amazon, boreal forests, and peat bogs. In fact, deforestation continues in the Amazon and it may be reaching a tipping point that turns part of it into a dry savanna. Forest fires are now destroying millions of acres of boreal forests in Canada and Russia, and these fires are likely to get even worse.

The United States and other governments should stop subsidizing fossil fuels. This may result in higher prices and more price fluctuations, but will reduce the use of fossil fuels. Higher prices via fees or taxes and the elimination of subsidies is one of the easiest and simplest things we can do to advance mitigation efforts.

The third category above involves geoengineering, which Taylor et al. (2023b) call climate cooling, arguing that it is now essential. They agree with Steffen et al.'s (2018) recommendations, although they don't focus as much on enhancing natural carbon sinks. Taylor et al. (2023b) write that three approaches must be combined: "(1) rapidly reducing GHG emissions; (2) deploying large-scale CDR [carbon dioxide removal] to reduce atmospheric carbon concentrations; and (3) using climate cooling measures across a range of scales to maintain temperatures within safe limits until GHG concentrations have been reduced to a sustainable level that stabilizes the climate." Taylor et al. (2023) are certainly wrong on their second point about carbon dioxide removal. Yes, we will eventually need to focus on CDR, but the economics and science

are clear that it will be much better, in the immediate future, to use the renewable energy required for CDR to reduce GHGs.

A Massive Information Campaign is Needed
Can Change Happen Quickly Enough?

It is theoretically possible for change to happen quickly, and for a countries' economy to change rapidly; whether this will be enough to prevent societal collapse depends primarily on the extent of feedback loops and tipping points. It will not matter how much we reduce GHGs if they are replaced by GHGs emitted by melting permafrost and burning forests, and if the earth's energy balance continues to increase due to changes in worldwide albedo (e.g., via melting sea ice and land use changes). Consider again the analogy to WWII. In the late 1930s, war was raging in Europe but isolationism reigned in the United States. Then Japan attacked Pearl Harbor and the U.S. entered the war. In 1942, and 1943, and 1944, and 1945 you could not buy a new car, or refrigerator, or washing machine. Factories in the U. S. were retrofitted to build ships, planes, tanks, and all types of military hardware and armaments. And millions of Americans left to fight for their country, risking their lives. Over 400,000 died with many more wounded.

To unite the country behind the war effort, the government engaged in a massive propaganda effort. "During World War II, the US government waged a constant battle for the hearts and minds of the public. Persuading Americans to support the war effort became a wartime industry, just as important as producing bullets and planes."[217]

> In 1942 the Office of War Information (OWI) was created to both craft and disseminate the government's message. This propaganda campaign included specific goals and strategies. Artists, filmmakers, and intellectuals were recruited to take the government's agenda (objectives) and turn it into a propaganda campaign. This included posters found across America – from railway stations to post offices, from schools to apartment buildings.
>
> During WWII the objectives of the U.S. government for the propaganda campaign were recruitment, financing the war effort, unifying the public behind the war effort and eliminating dissent of all kinds, resource conservation, and factory production of war materials.
>
> To meet the government's objectives the OWI (Office of War Information) used common propaganda tools (posters, radio, movies, etc.) and specific types of

[217] https://www.nationalww2museum.org/war/articles/wwii-propaganda

propaganda. The most common types used were fear, the bandwagon, name-calling, euphemism, glittering generalities, transfer, and the testimonial.

"The principal battleground of the war is not the South Pacific. It is not the Middle East. It is not England, or Norway, or the Russian Steppes. It is American opinion." --Archibald MacLeish, Director of the Office of Facts and Figures, forerunner of the Office of War Administration.[218]

Posters were mass produced and hung around the country in train stations, post offices, schools, churches, factories, grocery stores and other locations. Messages on some of these posters entered the public consciousness and are still remembered today, including "Loose Lips Might Sink Ships" and "Rosie the Riveter." Another poster encouraged Americans to carpool to save gasoline for the war effort: "When you ride alone, you ride with Hitler." Now this poster could be rewritten to reduce the use of fossil fuels and combat the climate crisis rather than supporting the war effort.

In just a few years there was a transition to a war economy in order to defeat the common enemy. Climate change is a common enemy more serious than a foreign power, for rather than "just" conquering us it has the potential to kill us all. It's possible to recover from a foreign invasion, while it's not possible to recover from an escalating climate crisis.

Given what happened during World War II, it's clear that it's theoretically possible for change to happen extremely rapidly if the population believes we are in serious trouble. At a national level, we need a new government Office of Environmental Information to spread information about the climate crisis. On an individual level, we need a "mass mobilisation of citizens via diverse, distributed, mostly self-organising action for climate mitigation, adaptation, and protection of nature; combining to drive change at all different institutional levels" (The Climate Majority Project Theory of Change[219]).

Imagine the impact if President Biden, during his four years in office, had given a lecture on climate change once a month, each time inviting a prominent climate scientist to join him and explain the crisis we are now in. Imagine a new Office of Environmental Information recruiting artists, athletes, movie stars and online influencers. By some estimates, Taylor Swift alone has over 500 million followers across social media. What if she were to write songs about the climate crisis and post to her followers about what we should all do? And what if she were to lead by example, giving up her private plane and

[218] http://enroll.nationalww2museum.org/learn/education/for-students/ww2-history/at-a-glance/propaganda-posters-of-ww2.pdf
[219] https://usercontent.one/wp/climatemajorityproject.com/wp-content/uploads/2023/05/ToC-Pre-Launch-Disseminate.pdf?media=1714307355

becoming a vegetarian, while posting about the environmental problems that result from the meat and airline industries?

Limiting Free Speech and Nationalizing Oil and Gas Companies

During the first and second world wars, there were limits on free speech and dissent was crushed. Given all the disinformation about the climate, there may once again need to be reductions in free speech. The Espionage Act was passed in 1917, and the Sedition Act of 1918 was passed a year later.

> Congress passed the Espionage Act shortly after the U.S. entered the war. The Act made it a crime to convey information intended to interfere with the war effort. Later, the Sedition Act imposed harsh penalties for a wide range of dissenting speech, including speech abusing the U.S. government, the flag, the Constitution, and the military. These laws were directed at socialists, pacifists, and other anti-war activists. The Wilson Administration argued that these Acts were essential to the war effort and prosecuted thousands of anti-war activists under their various provisions. While modern scholars view these Acts as violating core free speech protections, the Supreme Court at the time upheld these convictions.[220]

We don't need to be as harsh as during the first two world wars; all we really need to do is to outlaw the spreading of false information and conspiracy theories about the environment; granted, this may not be as easy and clear cut as implied here, but there is now a well-established body of scientific literature on the climate, and there is universal consensus that the warming and other changes we are now experiencing are not caused by normal variations in the climate. To say otherwise is to spread false information. In Germany it is now against the law to write that the Holocaust never happened (under Section 130 of their Penal Code). It is even more important to outlaw the denial of anthropogenic climate change.[221]

Almost 15 years ago, Naomi Oreskes and Erik Conway wrote *Merchants of Doubt* (Oreskes & Conway, 2010). The subtitle explains the thesis: *How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*." The authors explain how for both the tobacco and oil industry, "Doubt is our product." The oil industry has been incredibly successful in raising doubt about well-established scientific findings and offering inaccurate alternative explanations.

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[220] https://constitutioncenter.org/the-constitution/historic-document-library/detail/espionage-act-of-1917-and-sedition-act-of-1918-1917-1918

[221] See the European Commission on Climate Disinformation, https://climate.ec.europa.eu/eu-action/climate-disinformation_en

The government may need to nationalize the oil and gas industries and then phase out their extractive work, while putting their expertise to work on renewable energy and other projects For example, the skills and equipment required for hydraulic fracking include most of what is needed for the production of geothermal energy.

With the survival of the human species at risk, there may now need to be limitations on free speech, just as there was during wars in our past. The disinformation activities of major industries need to be curtailed, the platforms of climate change deniers need to be shut down, and some may need to be jailed.

The Use of Presidential Emergency Powers

A theme throughout this paper is that in many cases we are not taking the necessary actions because there is no political consensus, or because the process is inherently slow (e.g., in the case of expanding the electrical grid, or building new nuclear plants). We are now in a crisis and emergency actions are required. This is the appeal of authoritarian environmentalism, because one leader can take decisive action alone. However, even within the democratic system in the United State, a president is allowed to take decisive and unilateral action during an emergency. A president could declare a national climate emergency and then use the associated emergency executive powers. A report by the The Center for Biological Diversity provides details ("The Climate President's Emergency Powers: A Legal Guide to Bold Climate Action from President Biden.)"[222]

The report details what a president could do after declaring a national climate emergency, and provides details on the legal authority for each action.

- Under the *National Emergencies Act*, the president could halt crude oil exports, stop oil and gas drilling in the outer continental shelf by suspending all offshore leases, and restrict international trade and private investment in fossil fuels.
- Under the *Defense Production Act*, the president could increase manufacturing for clean energy and transportation.
- Under the *Robert T. Stafford Disaster Relief and Emergency Assistance Act,* and in the aftermath of a major disaster, the president could "direct the Federal Emergency Management Agency to construct renewable energy systems, optimizing distributed energy resources in partnership with environmental justice communities vulnerable to climate disasters, as well as limit construction of fossil fuel infrastructure."[223]

[222] https://www.biologicaldiversity.org/programs/energy-justice/pdfs/Climate-Emergency-Powers-Report.pdf
[223] Ibid.

If President Biden had taken these actions there would have been a political and legal firestorm, and perhaps obstruction and even the refusal to obey orders by some states. This is why it's so important to convince our family, friends, and community about the climate crisis and to organize and participate in mass movements. Only when there is support from a majority of the populace will a president be able to use emergency powers effectively.

Facing Reality and Managing the Inevitable

If the thesis of this paper is correct, and global societal collapse will be starting in the near future, then a new question arises: how can we "manage" this collapse? Even if it is too late to prevent this catastrophe, surely there must be things we can do to reduce suffering.

Adaptation

The best way to manage collapse, at least in the early stages, is via adaptation, and Working Group II of the IPCC has an entire report as part of their sixth assessment on Impacts, Adaptation and Vulnerability.[224] Chris Field, a scientist from Stanford, includes adaptation as a core component in his recommendations. He uses the acronym CARE: cutting emissions, adapting, removing greenhouse gases, and exploring sunlight reflection.[225] Even if there is a global societal collapse, as I predict, effective adaptation may make our final days as a species slightly less horrible. But this will only be effective in the early stages, for as Taylor et al. (2023b) write, "It is impossible to adapt to irreversible, catastrophic impacts like species extinction, the loss of glaciers, rising sea levels, and the release of methane from permafrost and oceans."

Information Sharing

Given the increasing frequency of extreme weather events, one imperative is to increase information sharing among multiple governmental institutions and local authorities. There are now organizations trying to disseminate climate information to regional authorities. For example, there is an initiative called Regional Information for Society (RIfS) organized by the World Climate Research Program, which "coordinates new research required to provide actionable climate information at the regional scale….The focus of RifS is to grow the foundations for effective links between climate research and the information needs of society."[226] There have been five International Conferences on Regional Climate, also organized by the World Climate Research Program, where these issues are discussed.

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[224] https://www.ipcc.ch/report/ar6/wg2/
[225] Lecture at Harvard University, October 19, 2023.
[226] https://www.wcrp-climate.org/rifs-overview

Norway provides a good example of how this can work. "...the Norwegian Meteorological Institute collaborates with various institutions and authorities, such as the Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Institute of Public Health (NIPH), the Norwegian Directorate for Civil Protection, power production (StatKraft) and grid (Statnett), road authorities, aviation, rail, and defense. Our experience is that relevant information flows quite well within such a professional network."[227]

The Common Alerting Protocol (CAP)

In many situations, early warnings can substantially reduce death and the destruction of property (e.g., cars can be moved to higher ground before a flood). The CAP system has multiple advantages; according to the United Nations Office of Disaster Risk Reduction (UNDRR):

> The Common Alerting Protocol (CAP) is the international standard format for emergency alerting and public warning. It has been developed by the Organization for the Advancement of Structures Information Standards and adopted by the International Telecommunication Union (ITU).
>
> It is designed for all hazards – weather events, earthquakes, tsunamis, volcanoes, public health crises, power outages and other types of emergencies.[228]

The main current "problem" with CAP is that many developing countries – where it is needed the most – don't have the money, infrastructure, and IT personnel to implement it fully.

Conclusion

There are literally hundreds of ongoing efforts on mitigation, adaptation, and sustainability. Renewable energy, especially solar, is expanding faster than expected and the price has fallen rapidly. Many of these efforts have been dramatic, innovative, and wildly successful, but none of this matters in the short term. Greenhouse gas concentrations in the atmosphere are increasing, forests and peat bogs are being

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[227] Rasmus Benestad (Oct. 4 2023), The 5th International Conference on Regional Climate, *RealClimate*, https://www.realclimate.org/index.php/archives/2023/10/the-5th-international-conference-on-regional-climate/

[228] https://www.undrr.org/early-warnings-for-all/common-alerting-protocol; see also FEMA's description at https://www.fema.gov/emergency-managers/practitioners/integrated-public-alert-warning-system/technology-developers/common-alerting-protocol

destroyed, permafrost is melting, the ocean and soil are being degraded, and biodiversity is declining. As NOAA Administrator Dr. Rick Spinrad said recently,

> Over the past year, we've experienced the hottest year on record, the hottest ocean temperatures on record and a seemingly endless string of heat waves, droughts, floods, wildfires and storms. Now we are finding that atmospheric CO_2 levels are increasing faster than ever. We must recognize that these are clear signals of the damage carbon dioxide pollution is doing to the climate system, and take rapid action to cut fossil fuel use as quickly as we can.[229]

In the 2024 state of the climate report, the conclusions are dire:

> Despite six IPCC reports, 28 COP meetings, hundreds of other reports, and tens of thousands of scientific papers, the world has made only very minor headway on climate change, in part because of stiff resistance from those benefiting financially from the current fossil-fuel based system. We are currently going in the wrong direction, and our increasing fossil fuel consumption and rising greenhouse gas emissions are driving us toward a climate catastrophe. We fear the danger of climate breakdown. (Ripple et al., 2024)

The biophysical situation is bad, but it will get much worse because our activities continue to release huge amounts of greenhouse gases into the atmosphere and we continue to degrade and destroy our natural carbon sinks. In addition, we are already crossing tipping points, and feedback loops are making the situation worse. We have the technology to rapidly decarbonize our economy, but we are not taking the necessary steps because of political opposition and lobbying by special interest groups.

Given our current situation, only binding international agreements and aggressive governmental actions can remedy the situation, including putting a price on carbon. Not only are some politicians and special interest groups unwilling to give up their control over the economy and energy production, but many politicians and industries are actively working against rapid decarbonization. This is why it is imperative to speak the truth about the severity of our situation and change the social norms about the climate crisis and the actions we must take. We must do this to "pressure the sources of power," as Pope Francis writes. To convince politicians to act, individuals should focus their energy on political campaigns, on participating in mass movements, and on civil

[229] https://www.noaa.gov/news-release/during-year-of-extremes-carbon-dioxide-levels-surge-faster-than-ever

resistance and civil disobedience,[230] rather than focusing on their own lifestyle and carbon footprint.

Reducing – and then eliminating – greenhouse gases will be incredibly difficult. We must do this, but it will not solve our problems, as the Earth will take hundreds of years to cool by itself. We will also need to actively remove carbon dioxide from the atmosphere and to cool the Earth. This is why we need to support research on both negative emissions technology and geoengineering.

And we cannot give up, even though our way forward may now seem almost impossible. The climate scientist Michael Mann refers to Tolkien's *Lord of the Rings*, and how Frodo is about to become despondent given the "seemingly hopeless task he has been given: to save Middle Earth by destroying the evil ring of power in the fires of Mount Doom." Sam helps Frodo gain the strength to proceed, and Mann writes that we must also find the strength to continue:

> We too must choose to do battle against the forces of darkness, fighting back against a malevolent movement that represents fascism, authoritarianism, racism, misogyny, and bigotry, a movement that uses antiscientific disinformation as its preferred weapon. We do this not because our success is guaranteed. Given the forces mobilized against us, we are clearly the underdog. No white wizard will come to our rescue. But we have truth and justice on our side. And the stakes simply couldn't be greater. We continue to fight for a livable planet, for us, our children, and future generations. Because it's worth fighting for.[231]

Hundreds of thousands of people now die every year from heat waves, flooding, and extreme weather made worse by climate change. The situation will get worse over the next few years, and mass migration, crop failures, and damage to critical infrastructure may lead to civil unrest and societal collapse in "fragile" nations. Unless we act decisively, the political and geophysical situation will deteriorate quickly and global societal collapse is possible. This is why we must elect politicians who will take immediate action on climate change. We must force the fossil fuel industry and carbon intensive manufacturing to change their practices, and we must protect our biosphere. We have no other options.

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[230] Both civil resistance and civil disobedience are nonviolent, but civil disobedience involves breaking the law.

[231] Michael E. Mann (November 7, 2024), Welcome to the American petrostate, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2024/11/welcome-to-the-american-petrostate/

Suggested Reading

I suggest reading the following papers in the order in which they are listed below. There are also a few quick quizzes you can take, but they tend to be good primarily for kids, as they're very short and simple, although they do provide some of the basic facts:

- Nasa: https://climate.nasa.gov/quizzes/global-temp-quiz/
- Britannica's climate quiz: https://www.britannica.com/quiz/climate-change
- Environmental Protection Agency: https://www.epa.gov/climate-change/climate-change-quiz

Emanuel (2016): Read this first. Even if you follow the news about climate change, start by reading this 16-page primer on "Climate Science and Climate Risk" by Kerry Emanuel (2016), a distinguished professor of atmospheric science at MIT (now retired). He provides a brief history of 200 years of climate science research, explains the greenhouse effect, and reviews the sources of information that climate scientists rely on. See the excellent update for 2024, https://climateprimer.mit.edu/, which has an audio version and interactive graphics. I also suggest MIT's Climate Portal at https://climate.mit.edu/. See also

- NASA's climate change website: https://science.nasa.gov/climate-change/
- The NYTimes FAQ page: https://www.nytimes.com/interactive/2023/climate/climate-change-faq.html
- The United Nations Climate Action page: https://www.un.org/en/climatechange
- The Global Climate Dashboard, on https://www.climate.gov/. There are charts showing changes over time for greenhouse gases, arctic sea ice, carbon dioxide, mountain glaciers, ocean heat, sea level, and so on.

Climate Change: Lines of Evidence: An excellent 25-minute video produced by the National Academy of Sciences. https://www.youtube.com/watch?v=gIUN5ziSfNc

Climate Solutions 101: Watch this sequence of six videos from Project Drawdown (they range from 13 to 23 minutes). They clearly explain why there is climate change and how to reduce sources of greenhouse gases and improve carbon sinks. https://drawdown.org/climate-solutions-101

Pope Francis (2023). Read this Apostolic Exhortation next. I don't know how much of it Pope Francis actually wrote, but it is a masterful summary of the scientific literature, along with his explanation of how the "ethical decadence of real power" of the "technocratic paradigm" (the term "capitalism" is never used) has led to the current crisis. He also talks about justice and the suffering of people not responsible for the crisis, and how we must not see ourselves as separate from nature.

ICCI, 2023: This detailed report from the International Cryosphere Climate Initiative is excellent, and lays out clearly the consensus among scientists studying the cryosphere that “Two degrees is too high,” because “We cannot negotiate with the melting point of ice.” The Arctic is warming 2-4 times faster than the rest of the world, and when the average global temperature increases by 2°C the Arctic will warm 4-8°C.

IPCC, 2023: Read the 30-page Summary for Policymakers within this larger 186-page report. Despite my criticisms about the IPCC’s conservatism and underestimation of climate change, the IPCC is the gold standard for climate information. The IPCC has produced dozens of different reports, totalling over a thousand pages.

Fifth National Climate Assessment (Crimmins et al., 2023): This assessment focuses on how climate change will impact the United States. Like the IPCC, it is a comprehensive work by hundreds of scientists.

Steffen et al. (2018): I quote heavily from this paper, on the “*Trajectories of the Earth System in the Anthropocene*.” It focuses on climate science, but is readable by non-scientists.

Ripple et al. (2022): I quote from this “*World Scientists’ Warning of a Climate Emergency”* at the beginning of this paper.

Taylor et al. (2023b). Taylor et al. refer to much of the climate science I cover, and extensively discuss the problems with the IPCC. This is an unreviewed preprint, and apart from repeating all of the main points several times (which I assume will be corrected in the final version) it is an excellent paper.

Lynas, M. (2021). *Our Final Warning:Six Degrees of Climate Emergency.*
This book is for a general audience. I read the first edition of this book, published in 2008, which was great. There is a chapter for what happens for each degree of warming. From the description on Amazon:

> At one degree – the world we are already living in – vast wildfires scorch California and Australia, while monster hurricanes devastate coastal cities. At two degrees the Arctic ice cap melts away, and coral reefs disappear from the tropics. At three, the world begins to run out of food, threatening millions with starvation. At four, large areas of the globe are too hot for human habitation, erasing entire nations and turning billions into climate refugees. At five, the planet is warmer than for 55 million years, while at six degrees a mass extinction of unparalleled proportions sweeps the planet, even raising the threat of the end of all life on Earth.

Fiction

What will happen as climate change intensifies even more? The best accounts probably come from science fiction. Consider the description of a heat wave that kills millions in *The Ministry for the Future*, or the eco-terrorism and mass movements in *The Deluge*.

- Stephen Markley (2023), ***The Deluge*.**
- Kim Stanley Robinson (2020), ***The Ministry for the Future*.**
- Neal Stephenson (2021), ***Termination Shock*.**

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Many people gave me feedback on earlier versions of this paper, and the paper improved dramatically as a result. They do not, of course, agree with all of my arguments and the views presented here are mine alone. I would especially like to thank Russ Klein and Al Race, who provided insightful comments throughout the paper. Many others also provided excellent feedback and suggestions, including Earle Williams, Tony Jagodnik, Sharon Rider, Deborah Johnson, Joel Angiolillo, Greg Cermak, Steve Goldfinger, Aleck Karis, Michael Northrop, and Rich Fakelman. Two college interns, Grant Himes and Ethan Moreland, working as part of a “micro internship,” provided detailed feedback and suggestions throughout the report.

Author Bio

Demetrios Karis received a B.A. in Psychology from Swarthmore College, a Ph.D. in experimental psychology from Cornell University, and an NIMH postdoctoral fellowship at the University of Illinois. For most of his career he worked as a user experience practitioner and researcher, designing, and evaluating consumer products and services for Verizon, GTE, Grumman Aircraft Systems, and the University of Illinois. Demetrios holds multiple patents and has published widely in diverse areas, including usability evaluation methodologies, CSCW (Computer Supported Cooperative Work), automation using speech recognition, autobiographical memory, and cognitive psychophysiology. He is now an independent consultant and has worked as a contractor at Google, Fidelity, as well as several small consulting firms. He is also an adjunct faculty member at Bentley University, where he has taught courses in the User Experience Certificate program as well as the graduate program in Human Factors in Information Design. He currently works as a volunteer user experience researcher for the Trial Court of Massachusetts. Demetrios has no formal training in climate science, but has read widely and taken online courses. Over 20 years ago he started ranting to his friends about how climate change would lead to the end of human civilization. Some of them thought he was a crazy lunatic; now they are not so sure.

Why I Wrote This Paper

Imagine this scene: You're having a picnic on a beautiful sunny summer day, sitting on a blanket on the grass with a number of good friends on top of a hill with amazing views. You are sitting across from your friends, who are facing the mountains to the west. You are facing the town, which lies across the train tracks to the east. Something catches your attention and you look down the hill. You see a yellow school bus stopped on the train tracks, unmoving. It is filled with 50 young children, and you hear faint yelling in the distance. It's 1:00 pm and you know that a freight train usually travels through town at 1:30. What should you do? Do you continue your lunch, laughing with friends and eating the delicious food that everyone has brought? Or do you try to get your friends to turn around and see what is happening down below? Perhaps if you all work together you can get the bus off the tracks. The crisis here is immediate, whereas the climate crisis seems as if it is not immediate (although it is!). As I quoted Kahneman in the paper, explaining why it's so difficult to take action on the climate, "It's abstract, it's long term, it's invisible, it's contested, so there is no complete agreement. So there is uncertainty about every aspect of it. And so something that is remote and uncertain has no urgency. And it's extremely difficult to mobilize people when there is no urgency." I am hoping that this paper will change your view of the climate crisis and help you to realize that it is not abstract, but concrete, and it is immediate, clearly visible and certain, and thus urgent.

If you want details, and not a story, here are four interconnected reasons why I wrote this paper.

1. ***To educate non-scientists on climate change***, providing the latest research up through mid 2024, with some of it in a tutorial format (e.g., explaining what the IPCC is, or CMIP models, or AMOC, the Atlantic Meridional Overturning Circulation). People who do not believe in anthropogenic climate change are unlikely to read this paper, but many people who read the secondary sources about climate change and believe we are in a climate emergency still don't understand how critical the situation is. My hope is that this paper will help to convince these readers that the situation is indeed "code red," and unless we take immediate action a "ghastly future" awaits us.
2. ***To fill a gap in the literature on climate change***. There are many excellent research papers and popular articles on climate change, but few focus on all the related topics – not just the physical basis of climate change, but the conservative nature of the Intergovernmental Panel on Climate Change (IPCC), the underestimation of future problems, the political environment making it impossible to take the necessary actions, the economic impacts, the psychological effects of witnessing extreme weather events, and geoengineering and new technologies. All this information leads to descriptions of how societal

collapse will unfold – not so much from the direct effects of a warming planet, but from the indirect effects of starvation, infectious diseases, mass migration, civil unrest, regional conflict, and political instability – and how collapse will start in "fragile" states.

3. ***To make clear, given the current situation, which individual and national actions are meaningful in the near term and which are not.***
4. ***To encourage people to take action***; after education there must be action. I lay out the most important steps we need to take, but they will only happen if we overcome political and special interest opposition via mass mobilization, mass protests, and the election of leaders who will act decisively on climate change.

List of Acronyms

AMOC: Atlantic Meridional Overturning Circulation
ASR: Absorbed Solar Radiation
BECCS: Bioenergy with Carbon Capture and Storage
CCS: Carbon Capture and Storage
CDR: Carbon Dioxide Removal
CFCs: Chlorofluorocarbons
CLD: Causal Loop Diagram
CMIP: Coupled Model Intercomparison Project
COP: UN Conference of the Parties
CTP: Climate Tipping Points
DACCS: Direct Air Capture with Carbon Storage
DALY: Disability Adjusted Life Years
D/O: Dansgaard-Oeschger events
ENSO: El Niño-Southern Oscillation
EPA: U.S. Environmental Protection Agency
ESCIMO: Earth System Climate Interpretable Model
ESS: Earth-system Sensitivity
EU: European Union
FEMA: Federal Emergency Management Agency
FERC: Federal Regulatory Energy Commission
GAW: Global Atmosphere Watch
GCMs: Global Climate Models
GDP: Gross Domestic Product
GGGW: Global Greenhouse Gas Watch
GHG: Greenhouse Gases
GLOF: Glacial Lake Outburst Floods
GWP: Global Warming Potential
HCFCs: Hydrochlorofluorocarbons
IEA: International Energy Agency
IPC: Integrated Food Security Phase Classification (IPC)
IPCC: Intergovernmental Panel on Climate Change
IRA: Inflation Reduction Act (U.S.)

MAT: Mean Annual Temperature
MENA: Middle East and North African
MIPs: Model Intercomparison Projects
MWP-1A: Meltwater Pulse 1A
NDC: Nationally Determined Contributions
NERC: North American Energy Reliability Corporation
NHC: National Hurricane Center
NOAA: National Oceanic and Atmospheric Administration
NZE: Net Zero Emissions
PFCs: Perfluorocarbons
PV: Photovoltaics
RCPs: Representative Concentration Pathways
SAI: Stratospheric Aerosol Injection
SGR: Scientists for Global Responsibility
SLR: Sea-Level Rise
SRM: Solar Radiation Management
SSP: Shared Socioeconomic Pathways
TC: Tropical Cyclone
UN: United Nations
UNFCCC: United Nations Framework Convention on Climate Change
USGCRP: U.S. Global Change Research Program
WAIS: West Antarctic Ice Sheet
WCRP: World Climate Research Programme
WGI, II, III: IPCC Working Group 1, 2, 3
WMO: World Meteorological Organization
WPB: War Production Board
WWF: World Wildlife Fund

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Appendix 1: The Current Situation is Dire

Conflict Over Water

Consider the following example of potential conflict over fresh water.[232]

Egypt, Ethiopia, and Sudan

Ethiopia started construction on the Grand Ethiopian Renaissance Dam in 2011 and started filling the reservoir in 2020 by diverting water from the Blue Nile (the reservoir is still filling). From the beginning there were complaints from Egypt, which gets over 90% of its water for both irrigation and drinking from the Nile, and Egypt has demanded restrictions on how Ethiopia operates the dam. Egypt has threatened to go to war over the dam, and the United Nations Security Council has encouraged negotiation. The Ethiopian government has gone so far as to purchase several air defense systems to prevent possible air strikes on the dam (presumably by Egypt).

Iran and Afghanistan

From Kumar (2023), in *Science*:

> Fueled in part by a prolonged drought, tensions over water between Iran and Afghanistan have escalated this year, with Iran accusing Taliban leaders of violating a long-standing agreement to share water from the Helmand River, which flows from Afghanistan into Iran. In late May, clashes near the river reportedly killed at least two Iranian border guards and one Taliban fighter.
>
> Researchers estimate the amount of Helmand River water reaching Iran has dropped by more than half over the past 2 decades, in part because of the construction of new dams and the expansion of irrigation in Afghanistan. (Kumar, 2023)

Extreme Droughts

As the IPCC concludes, “Human-caused climate change has contributed to increases in agricultural and ecological droughts in some regions due to increased land evapotranspiration (medium confidence)” (IPCC, 2023). Droughts, along with extreme heat, are one of the most dangerous aspects of climate change, as they can have devastating impacts on both crops and livestock.

[232] Here’s a headline from the NYTimes on September 15, 2023: “Dominican Republic Will Close Border With Haiti Amid Water Dispute.”

Mass Migration

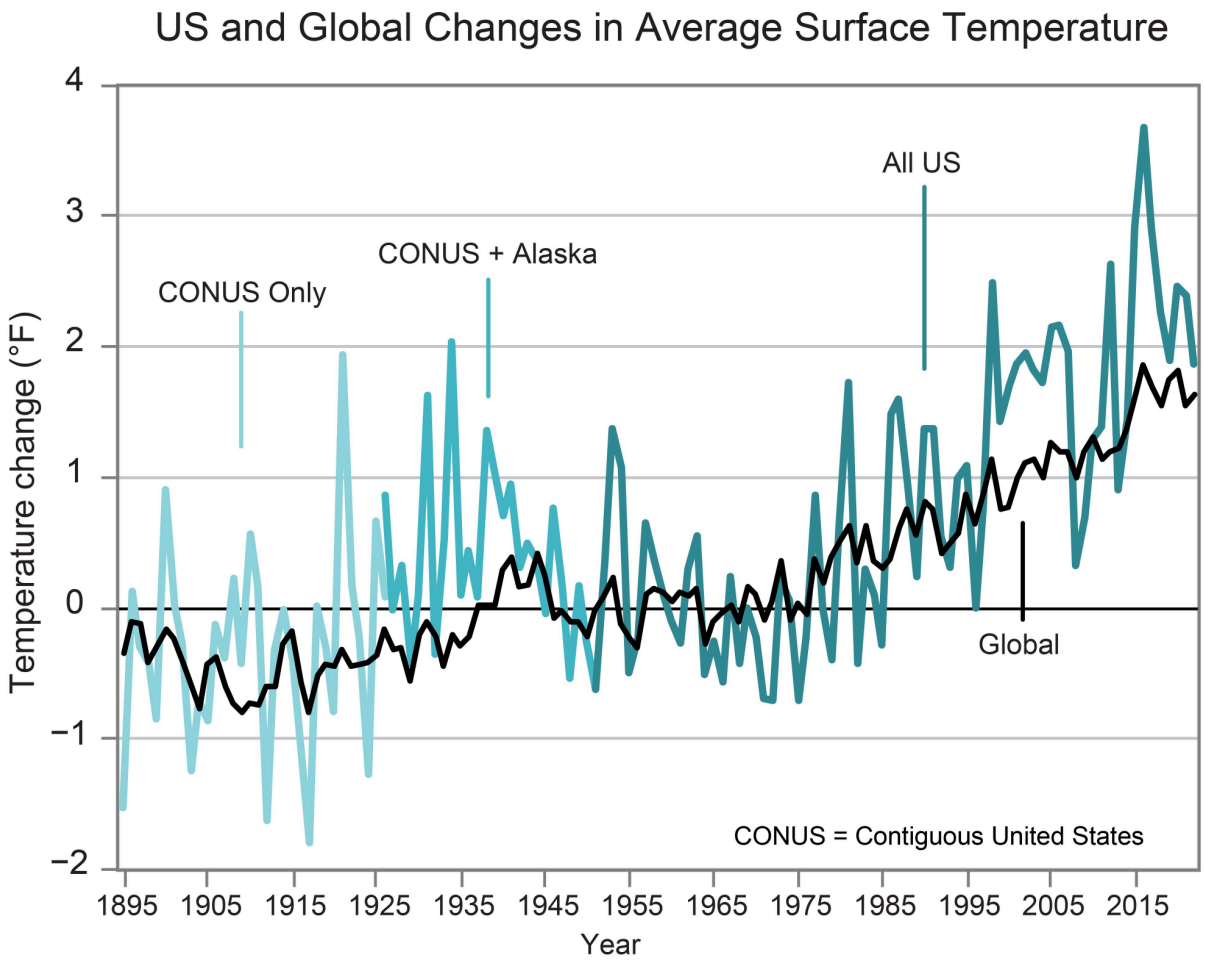
As described in the main body of this report, it is inevitable that mass migration will increase, and most countries will not welcome these migrants. For example, consider what happened recently in Saudi Arabia. Human Rights Watch interviewed 42 Ethiopian migrants and asylum seekers and their friends, analyzed over 350 videos and photographs posted to social media, and examined several hundreds square kilometers of satellite imagery. Here is a summary from their report[233]:

> Saudi border guards have killed at least hundreds of Ethiopian migrants and asylum seekers who tried to cross the Yemen-Saudi border between March 2022 and June 2023. Human Rights Watch research indicates that, at time of writing, the killings are continuing. Saudi border guards have used explosive weapons and shot people at close range, including women and children, in a pattern that is widespread and systematic. If committed as part of a Saudi government policy to murder migrants, these killings would be a crime against humanity. In some instances, Saudi border guards first asked survivors in which limb of their body they preferred to be shot, before shooting them at close range. Saudi border guards also fired explosive weapons at migrants who had just been released from temporary Saudi detention and were attempting to flee back to Yemen.

[233] The Human Rights Watch report on Saudi Arabia's murder of refugees is available at https://www.hrw.org/report/2023/08/21/they-fired-us-rain/saudi-arabian-mass-killings-ethiopian-migrants-yemen-saudi

Appendix 2: Selected Figures from the Fifth National Climate Assessment

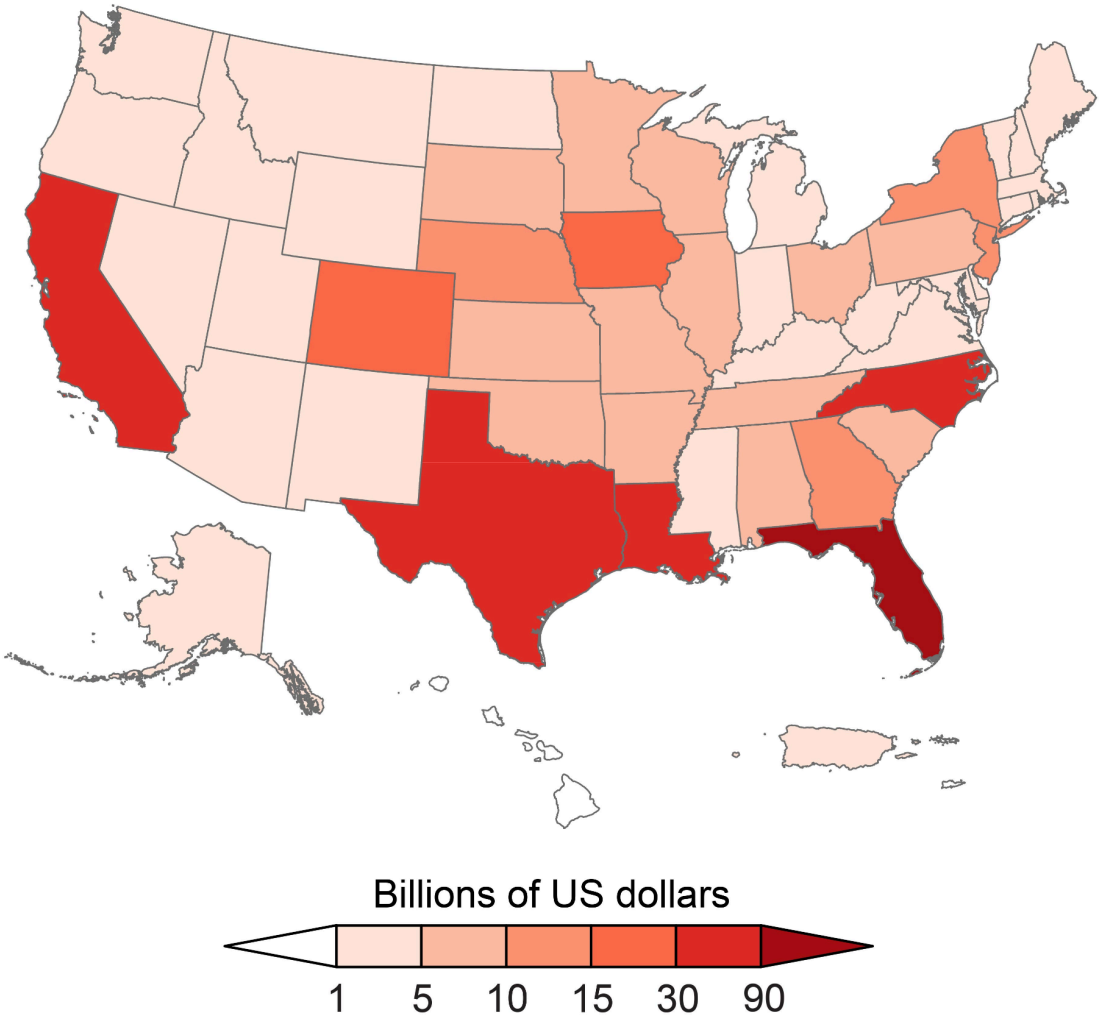
(Crimmins et al., 2023)



The US has warmed rapidly since the 1970s. From Crimmins et al. (2023):

"FIGURE 1.5. The graph shows the change in US annual average surface temperature during 1895–2022 compared to the 1951–1980 average. The temperature trend changes color as data become available for more regions of the US, with Alaska data added to the average temperature for the contiguous US (CONUS) beginning in 1926 (medium blue line) and Hawai'i, Puerto Rico, and US-Affiliated Pacific Islands data added beginning in 1951 (dark blue line). Global average surface temperature is shown by the black line. Figure credit: NOAA NCEI and CISESS NC."

Damages by State from Billion-Dollar Disasters (2018–2022)



The US now experiences, on average, a billion-dollar weather or climate disaster every three weeks. From Crimmins et al. (2023):

"FIGURE 1.7. Billion-dollar weather and climate disasters are events where damages/costs reach or exceed $1 billion, including adjustments for inflation. Between 2018 and 2022, 89 such events affected the US, including 4 droughts, 6 floods, 52 severe storms, 18 tropical cyclones, 5 wildfires, and 4 winter storm events (see Figure A4.5 for the number of billion-dollar disasters per year). During this period, Texas had the highest total damages ($375 billion); Florida experienced the highest damages from a single event—Hurricane Ian ($113 billion). While similar data are not available for the US-Affiliated Pacific Islands, Super Typhoon Yutu caused $500 million in property damage alone in Saipan and the northern Marianas in 2018 (NCEI 2019). Increasing costs over time are driven by changes in the assets at risk and the increase in frequency or intensity of extreme events caused by climate change. Adapted from NCEI 2023."

Appendix 3: Selected Figures from IPCC, 2023

Human activities are responsible for global warming

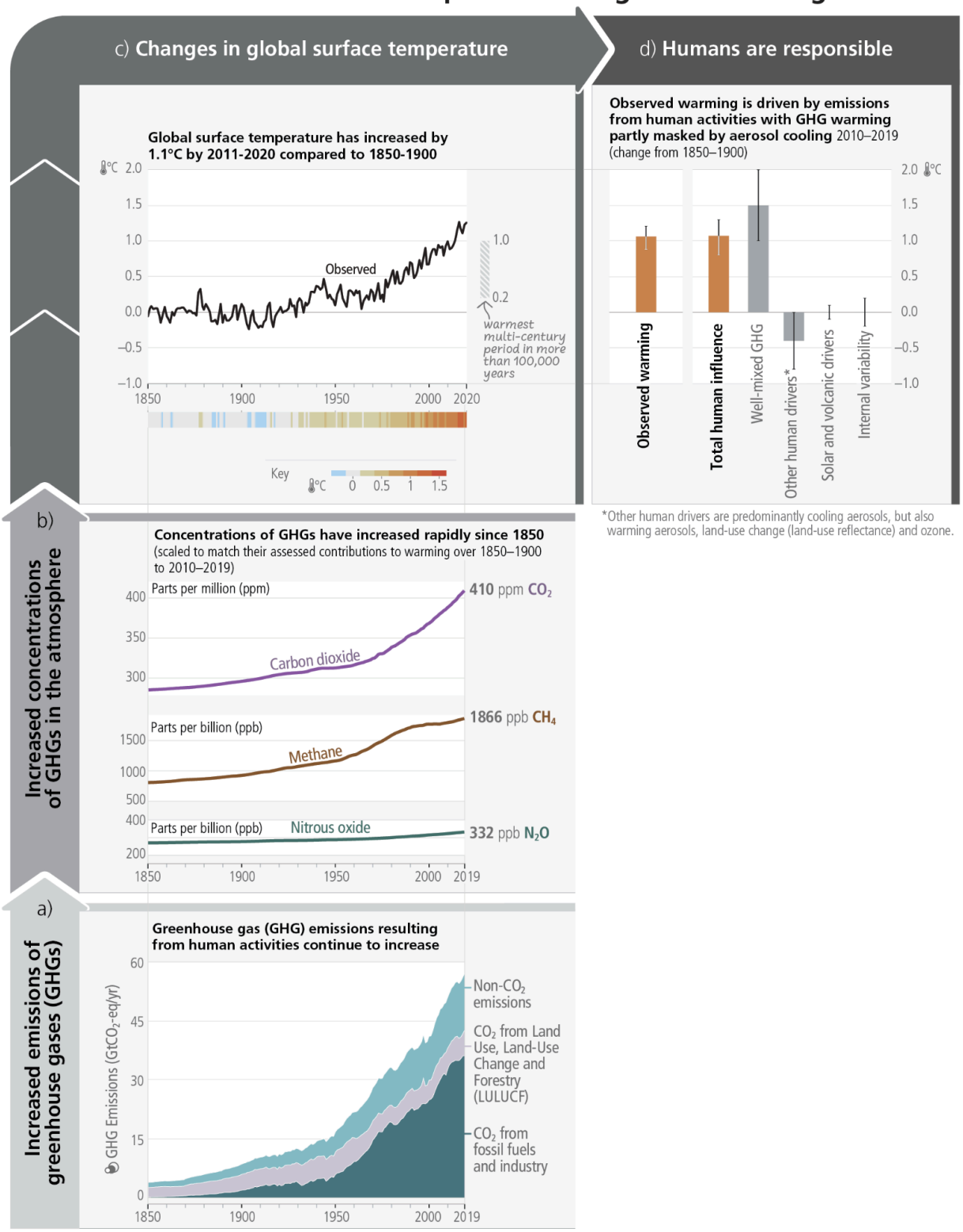
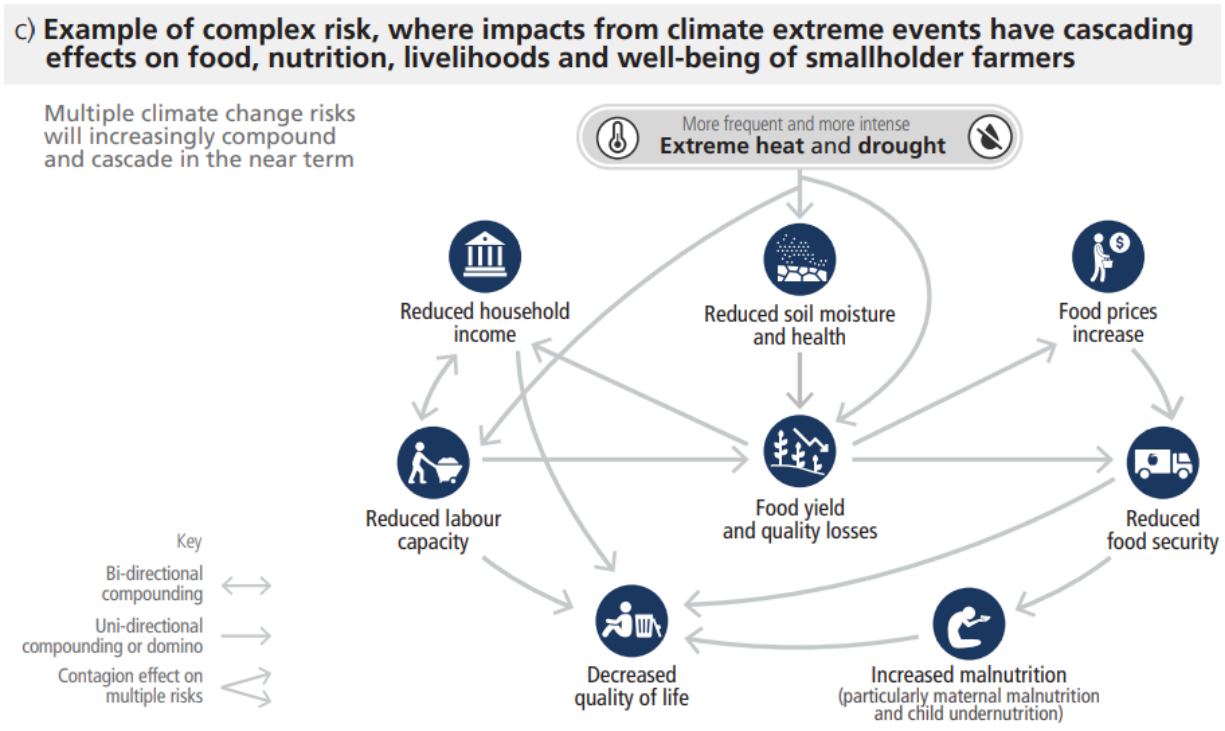


Figure 2.1 from IPCC (2023): *"The causal chain from emissions to resulting warming of the climate system. Emissions of GHG have increased rapidly over recent decades (panel (a)). Global net anthropogenic GHG emissions include CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI) (dark green); net CO_2 from land use, land-use change and forestry (CO_2- LULUCF) (green); CH_4; N_2O; and fluorinated gases (HFCs, PFCs, SF_6, NF_3) (light blue). These emissions have led to increases in the atmospheric concentrations of several GHGs including the three major well-mixed GHGs CO_2, CH_4 and N_2O (panel (b), annual values). To indicate their relative importance each subpanel's vertical extent for CO_2, CH_4 and N_2O is scaled to match the assessed individual direct effect (and, in the case of CH_4 indirect effect via atmospheric chemistry impacts on tropospheric ozone) of historical emissions on temperature change from 1850–1900 to 2010–2019. This estimate arises from an assessment of effective radiative forcing and climate sensitivity. The global surface temperature (shown as annual anomalies from a 1850–1900 baseline) has increased by around 1.1°C since 1850–1900 (panel (c)). The vertical bar on the right shows the estimated temperature (very likely range) during the warmest multicentury period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). Prior to that, the next most recent warm period was about 125,000 years ago, when the assessed multicentury temperature range [0.5°C–1.5℃] overlaps the observations of the most recent decade. These past warm periods were caused by slow (multi-millennial) orbital variations. Formal detection and attribution studies synthesise information from climate models and observations and show that the best estimate is that all the warming observed between 1850– 1900 and 2010–2019 is caused by humans (panel (d)). The panel shows temperature change attributed to: total human influence; its decomposition into changes in GHG concentrations and other human drivers (aerosols, ozone and land-use change (land-use reflectance)); solar and volcanic drivers; and internal climate variability. Whiskers show likely ranges. {WGI SPM A.2.2, WGI Figure SPM.1, WGI Figure SPM.2, WGI TS2.2, WGI 2.1; WGIII Figure SPM.1, WGIII A.III.II.2.5.1}"*



IPCC, 2023: *"Figure 4.3: Every region faces more severe or frequent compound and/or cascading climate risks in the near term. Changes in risk result from changes in the degree of the hazard, the population exposed, and the degree of vulnerability of people, assets, or ecosystems….Panel (c) Climate hazards can initiate risk cascades that affect multiple sectors and propagate across regions following complex natural and societal connections. This example of a compound heat wave and a drought event striking an agricultural region shows how multiple risks are interconnected and lead to cascading biophysical, economic, and societal impacts even in distant regions, with vulnerable groups such as smallholder farmers, children and pregnant women particularly impacted. {WGI Figure 9.32; WGII SPM B4.3, WGII SPM B1.3, WGII SPM B.5.1, WGII TS Figure TS.9, WGII TS Figure TS.10 (c), WGII Fig 5.2, WGII TS.B.2.3, WGII TS.B.2.3, WGII TS.B.3.3, WGII 9.11.1.2}"*

Appendix 4: A Warning from 1983, IPCC Conferences and Uncertainty Language

A Warning from 1983

Here is the abstract to Seidel's 1983 EPA report titled, "Can we delay a greenhouse warming?" (Seidel, 1983). Seidel, it turns out, was more accurate in his predictions of temperature rise than the IPCC reports 30 years later.

> Evidence continues to accumulate that increases in atmospheric carbon dioxide (CO_2) and other greenhouse gases will substantially raise global temperature. While considerable uncertainty exists concerning the rate and ultimate magnitude of such a temperature rise, current estimates suggest that a 2°C (3.6°F) increase could occur by the middle of the next century, and a 5°C (9°F) increase by 2100. Such increases in the span of only a few decades represent an unprecedented rate of atmospheric warming.
>
> Temperature increases are likely to be accompanied by dramatic changes in precipitation and storm patterns and a rise in global average sea level. As a result, agricultural conditions will be significantly altered, environmental and economic systems potentially disrupted, and political institutions stressed.
>
> Responses to the threat of a greenhouse warming are polarized. This study aims to shed light on the debate by evaluating the usefulness of various strategies for slowing or limiting a global warming. This study takes a first look at whether specific policies aimed at limiting the use of fossil fuels would prove effective in delaying temperature increases over the next 120 years. These policies are also evaluated for their economic and political feasibility. To put our findings in perspective, alternative, nonenergy approaches to limiting a greenhouse warming are also reviewed. [I corrected minor typos.]

Climate Conferences: Progress and Failures

The title of this section is from Pope Francis (2023), who writes in paragraph 44 of his recent Apostolic Exhortation:

> For several decades now, representatives of more than 190 countries have met periodically to address the issue of climate change. The 1992 Rio de Janeiro Conference led to the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), a treaty that took effect when the necessary ratification on the part of the signatories concluded in 1994. These States meet annually in the Conference of the Parties (COP), the highest decision-making

> body. Some of these Conferences were failures, like that of Copenhagen (2009), while others made it possible to take important steps forward, like COP3 in Kyoto (1997). Its significant Protocol set the goal of reducing overall greenhouse gas emissions by 5% with respect to 1990. The deadline was the year 2012, but this, clearly, was not achieved.

Pope Francis goes on to write about how COP21 in Paris in 2015 was a "significant moment" but that there were "scarce results" at the following conferences, and ends this section by noting that the accords have not had much impact.

> Today we can continue to state that, "the accords have been poorly implemented, due to lack of suitable mechanisms for oversight, periodic review and penalties in cases of noncompliance. The principles which they proclaimed still await an efficient and flexible means of practical implementation". Also, that "international negotiations cannot make significant progress due to positions taken by countries which place their national interests above the global common good. Those who will have to suffer the consequences of what we are trying to hide will not forget this failure of conscience and responsibility".

COP28, which was held in Dubai, was no different from previous COPs. Pope Francis described what should have happened for it to make a difference.

> If there is sincere interest in making COP28 a historic event that honours and ennobles us as human beings, then one can only hope for binding forms of energy transition that meet three conditions: that they be efficient, obligatory and readily monitored. This, in order to achieve the beginning of a new process marked by three requirements: that it be drastic, intense and count on the commitment of all. That is not what has happened so far, and only a process of this sort can enable international politics to recover its credibility, since only in this concrete manner will it be possible to reduce significantly carbon dioxide levels and to prevent even greater evils over time.

Unfortunately, COP28 was not an historic event, and it failed "to achieve the beginning of a new process."

IPCC "Calibrated Uncertainty Language"

Calibrated uncertainty language has been used by the IPCC since 1998. From the Intergovernmental Panel on Climate Change (IPCC, 2023):

> The IPCC calibrated language uses five qualifiers to express a level of confidence: very low, low, medium, high and very high…. The following terms are

> used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; and extremely unlikely 0–5%) are also used when appropriate." (IPCC, 2023, p. 3, footnote 4).

Herrando-Pérez et al. (2019) describe how the IPCC's use of these calibrated qualifiers (confidence and likelihood) have led to problems in conveying results to non-scientists, and that the "tone" is "remarkably conservative."

Appendix 5: Military Reports on the Climate and Conflict

The U.S. Central Command (CENTCOM) commissioned the Rand Corporation to analyze the literature and produce a series of reports on the causal pathways from climate change to conflict, plus related areas. The reports were completed in May of 2023 but were not publicly released until late in the year given the time required for prepublication and security reviews.

OAI: operations, activities, and investments
AOR: area of responsibility

Five Reports
The titles of the five reports, with brief descriptions (verbatim from the report introductions), are below.

1. *Hotter and Drier Future Ahead: An Assessment of Climate Change in U.S. Central Command* presents an analysis of projected climate impacts in the CENTCOM AOR in 2035, 2050, and 2070. (Miro et al., 2023)
2. *Pathways from Climate Change to Conflict in U.S. Central Command* details causal pathways from climate change to conflict, including cases in which those pathways have played out in the CENTCOM AOR. (Chandler et al., 2023)
3. *Conflict Projections in U.S. Central Command: Incorporating Climate Change* generates ranged forecasts of future conflict in the region with climate change incorporated as one driver of that conflict. (Toukan et al., 2023)
4. *Mischief, Malevolence, or Indifference? How Competitors and Adversaries Could Exploit Climate-Related Conflict in the U.S. Central Command Area of Responsibility* presents an analysis of how U.S. competitors—China, Russia, and Iran—may attempt to exploit climate-induced conflict in the CENTCOM AOR. (Shatz et al., 2023)
5. *Defense Planning Implications of Climate Change for U.S. Central Command* analyzes “off-ramps” to climate-influenced conflict and the operations, activities, and investments CENTCOM needs to be prepared to execute, given climate impacts on the security environment. (Sudkamp et al., 2023)

Causal Pathways from Climate Change to Conflict
The second report is the most relevant to this paper. Here are the key findings (verbatim):

- Although climate hazards may have direct impacts on violence, the pathways from climate events to war involve multistep processes in which the initial hazard typically triggers several intervening steps before manifesting as high-intensity conflict.

- The causal pathways from climate hazard to conflict vary but often begin with a hazard that results from a form of insecurity (such as food, livelihood, physical, or health insecurity) that then combines with climate impacts on state capacity, population flows, and other factors. When filtered through individuals' and armed groups' incentives to mobilize around greed or grievance, the impacts of these hazards culminate in conflict.
- The causal pathways from climate hazards to conflict below the threshold of interstate and intrastate war are the same; what varies is the intensity of the ensuing conflict, not the path to get there.
- In total, the research identified seven broad families of causal pathways — and many more individual hypotheses — from which climate impacts could evolve into conflict.
- Climate-related conflict has already occurred in the CENTCOM AOR, contributing to conflict below the threshold of interstate and intrastate war.
- The research did not find a compelling case of past climate-related interstate war in the region; however, there are plausible future contingencies for this outcome, based on analysis of the defense acquisitions of potential disputants. (Chandler et al., 2023)

Appendix 6: Miscellaneous Information

Radiative forcing

Here is an explanation from climate.gov.

> In accordance with the basic laws of thermodynamics, as Earth absorbs energy from the sun, it must eventually emit an equal amount of energy to space. The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF). In the same way as applying a pushing force to a physical object will cause it to become unbalanced and move, a climate forcing factor will change the climate system. When forcings result in incoming energy being greater than outgoing energy, the planet will warm (positive RF). Conversely, if outgoing energy is greater than incoming energy, the planet will cool. Another way to refer to climate forcings is to call them climate drivers. Natural climate drivers include changes in the sun's energy output, regular changes in Earth's orbital cycle, and large volcanic eruptions that put light-reflecting particles into the upper atmosphere. Human-caused, or anthropogenic climate drivers include emissions of heat-trapping gases (also known as greenhouse gases) and changes in land use that make land reflect more or less sunlight energy. Since 1750, human-caused climate drivers have been increasing, and their effect dominates all natural climate drivers.[234]

When the Sun Doesn't Shine…

There are times when the sun doesn't shine and there is little or no wind, and when this happens more frequently energy planning and grid-stabilization become much more complex. The German word Dunkelflaute refers to a time when there is little wind and solar power. A "cold Dunkelflaute" occurs when power demand is also high. In Europe, cold Dunkelflautes have occurred for up to two weeks. This means that there has to be dispatchable backup power (i.e., a system that can be turned on or off, or vary its output).

Zheng et al. (2024) studied extreme power shortage events of wind-solar hybrid systems in 178 countries since 1980. Unfortunately, it seems that Dunkelflaute may occur more frequently as the climate warms and changes.

> Extreme long duration events are defined as periods during which electricity demand is unmet for more than 100 consecutive hours according to the upper operation limit of long-duration energy storage; extreme low-reliability events refer to load deficits that last for at least 12 h but have an over 30% power supply

[234] https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-forcing

> gap. We further design three metrics to characterize extreme power shortage events, including frequency (the number of extreme power shortage events in each year), duration (hours of each extreme power shortage event), and intensity (the total power gap in each extreme power shortage event).
>
> In particular, we find that extreme long-duration events over the last two decades always outnumbered those over the first two decades. For example, the annual average duration of extreme long-duration events rose evidently from 146.9 ± 4.6 h during 1980–2000 to 155.1 ± 4.7 h during 2001–2022 ($P < 0.001$).
>
> Our results suggest that the past several decades may have witnessed increasingly frequent, prolonged, and intensified extreme shortage events across the globe, particularly in low- and middle-latitude developing countries. Such ascending trends in extreme power shortage events are attributable to growth in extremely low wind speed and solar radiation, affected partly by increased cloud cover, reduced aerosol emissions, enhanced surface roughness, and weakened pressure gradient associated with global warming. More importantly, if the detected growing extreme power shortage events persist in a warmer future, wind-solar systems may face weakened energy security and enhanced system costs. (Zheng et al., 2024)

Given the relatively short time frames involved, and the variability in their data, Zheng et al. (2024) have not convincingly established the relationship between climate change and extreme power shortage events. One way to improve their thesis would be to run climate models and examine the combination of variables (such as cloud cover and wind speed) that can lead to power shortages in wind-solar hybrid systems.

Global Warming Potential (GWP)

From the EPA (verbatim):

> The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.

- CO_2, by definition, has a GWP of 1 regardless of the time period used, because it is the gas being used as the reference.
- Methane (CH_4) is estimated to have a GWP of 27-30 over 100 years.
- Nitrous Oxide (N_2O) has a GWP 273 times that of CO2 for a 100-year timescale.
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. (The GWPs for these gases can be in the thousands or tens of thousands.)[235]

Average Temperatures over the Sea Versus the Land

The following is from an article by Gwynne Dyer, "Seven Hard Truths about the Climate Crisis: The consensus is in: cooling the planet will be impossible without direct human intervention. How can we safely save the world?"

> The average global temperature is an indispensable concept when discussing the broad topic of global warming, but it is very unreliable as a guide to what the temperature will be in any specific location. Moreover, there is a big difference between temperatures at sea and on land. Temperatures are generally more extreme on land, because it heats up more quickly in sunshine and loses heat more quickly at night and in winter. The further away from the sea, the truer this is, which is why it's deep in the interiors of the continents that most of the record temperatures, both high and low, have been observed.
>
> But since two-thirds of the planet's surface is covered by oceans, the average global temperature is always closer to the average temperature over the oceans than it is to the average land temperature. These values are not usually calculated, but a rise in average global temperature of 2.0°C really means a rise of roughly 1.0°C in average maritime temperature and a rise in average land temperature of between 3.0°C and 4.0°C (depending mainly on how far inland).[236]

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[235] From the EPA, see https://www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=The%20Global%20Warming%20Potential%20; also see the IPCC report, "The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity Supplementary Material," https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf

[236] Gwynne Dyer (Apr. 1 2024), Seven Hard Truths about the Climate Crisis, https://thewalrus.ca/seven-truths-climate-crisis/

A Hypothetical Amplifying Feedback Loop Involving Soil and Drought

A recent paper by Vahedifard et al. (2024) points out a potential amplifying feedback loop involving CO_2 released from soil during droughts that is not fully appreciated, and not accounted for in models.

> While the primary anthropogenic source of increased atmospheric CO_2 concentration is the combustion of fossil fuels, the largest terrestrial source of CO_2 emissions is soil where 80% of the total terrestrial carbon is stored. Approximately 62% of soil carbon is in organic form and readily released as CO_2, while the remaining is made up of inorganic carbon (soil inorganic carbon (SIC)). Here, we postulate that there is an amplifying feedback loop between drought, soil desiccation cracking, and CO_2 emission in a warming climate — a critical aspect that has been overlooked in the existing literature…. The problems associated with desiccation cracks are becoming more prevalent as anthropogenic climate change exacerbates the severity and frequency of droughts, heatwaves, and drought-heavy precipitation cycles. As the warming trends continue, more (and possibly older) CO_2 is released from the soil, which can further contribute to global warming. Thus, a chain of events happens in a cascading manner. Failure to consider the hypothesized feedback loop can result in significant inaccuracies when modeling and predicting GHG emissions from soil. It may also lead to underestimating the overall impact of climate change on critical aspects such as soil health, crop production, and the structural integrity of earthen infrastructure. (Vahedifard et al., 2024)

More on Causal Loop Diagrams

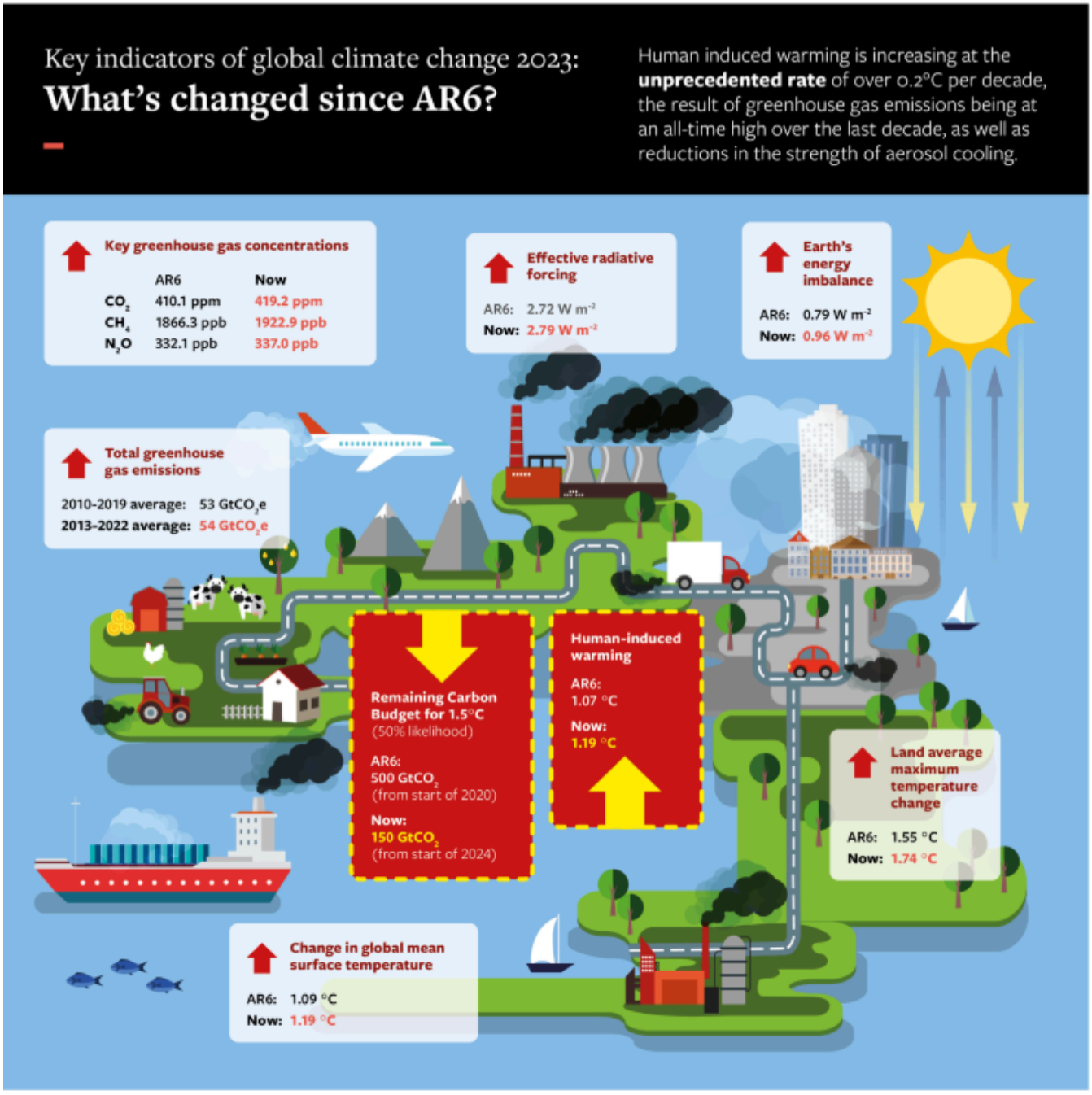
Richards et al. (2021) review an extensive body of literature in order to create more complex causal loop diagrams (CLDs) that present the relationships among climate change, food insecurity, and societal collapse. He describes the benefits of CLDs:

> A key benefit of CLDs is that they simply present a myriad of information in a single diagram; in doing so, CLDs enable comprehension of the structure and behaviour of complex systems, including feedbacks, intervention points and far-reaching interdependencies. Our CLD visually depicts a system of 39 variables, 105 links and 32,000 feedback loops, integrating information from different fields including climate science, food security, conflict, migration and health research. (Richards et al., 2021)

Although these CLDs present the relationships among multiple variables, they do not offer predictions about the future. They may, however, be useful in guiding data-driven projects to define thresholds and to develop quantitative modeling.

What has Changed Since AR6?

The IPCC releases reports only every 5 to 10 years. To provide annual updates for policymakers, Forster et al. (2024) "...follow methods as close as possible to those used in the IPCC Sixth Assessment Report (AR6) Working Group One (WGI) report." The infographic below summarizes their findings: the Earth is now in even greater energy imbalance, greenhouse gas emissions are increasing, along with concentrations in the atmosphere, temperatures are higher, and the carbon budget to remain below 1.5C is much lower. In summary, "Human induced warming is increasing at an **unprecedented rate** [emphasis in original] of over 0.2°C per decade…"


Key indicators of global climate change 2023:
What's changed since AR6?
Human induced warming is increasing at the unprecedented rate of over 0.2°C per decade, the result of greenhouse gas emissions being at an all-time high over the last decade, as well as reductions in the strength of aerosol cooling.
Key greenhouse gas concentrations
AR6 Now
CO2 410.1 ppm 419.2 ppm
CH4 1866.3 ppb 1922.9 ppb
N2O 332.1 ppb 337.0 ppb
Effective radiative forcing
AR6: 2.72 W m-2
Now: 2.79 W m-2
Earth's energy imbalance
AR6: 0.79 W m-2
Now: 0.96 W m-2
Total greenhouse gas emissions
2010-2019 average: 53 GtCO2e
2013-2022 average: 54 GtCO2e
Remaining Carbon Budget for 1.5°C
(50% likelihood)
AR6:
500 GtCO2
(from start of 2020)
Now:
150 GtCO2
(from start of 2024)
Human-induced warming
AR6:
1.07 °C
Now:
1.19 °C
Land average maximum temperature change
AR6: 1.55 °C
Now: 1.74 °C
Change in global mean surface temperature
AR6: 1.09 °C
Now: 1.19 °C

Backpage: A cartoon by Ilex Opaca.