Title: **Human 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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Human Civilization will Collapse (High Confidence[1]):

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

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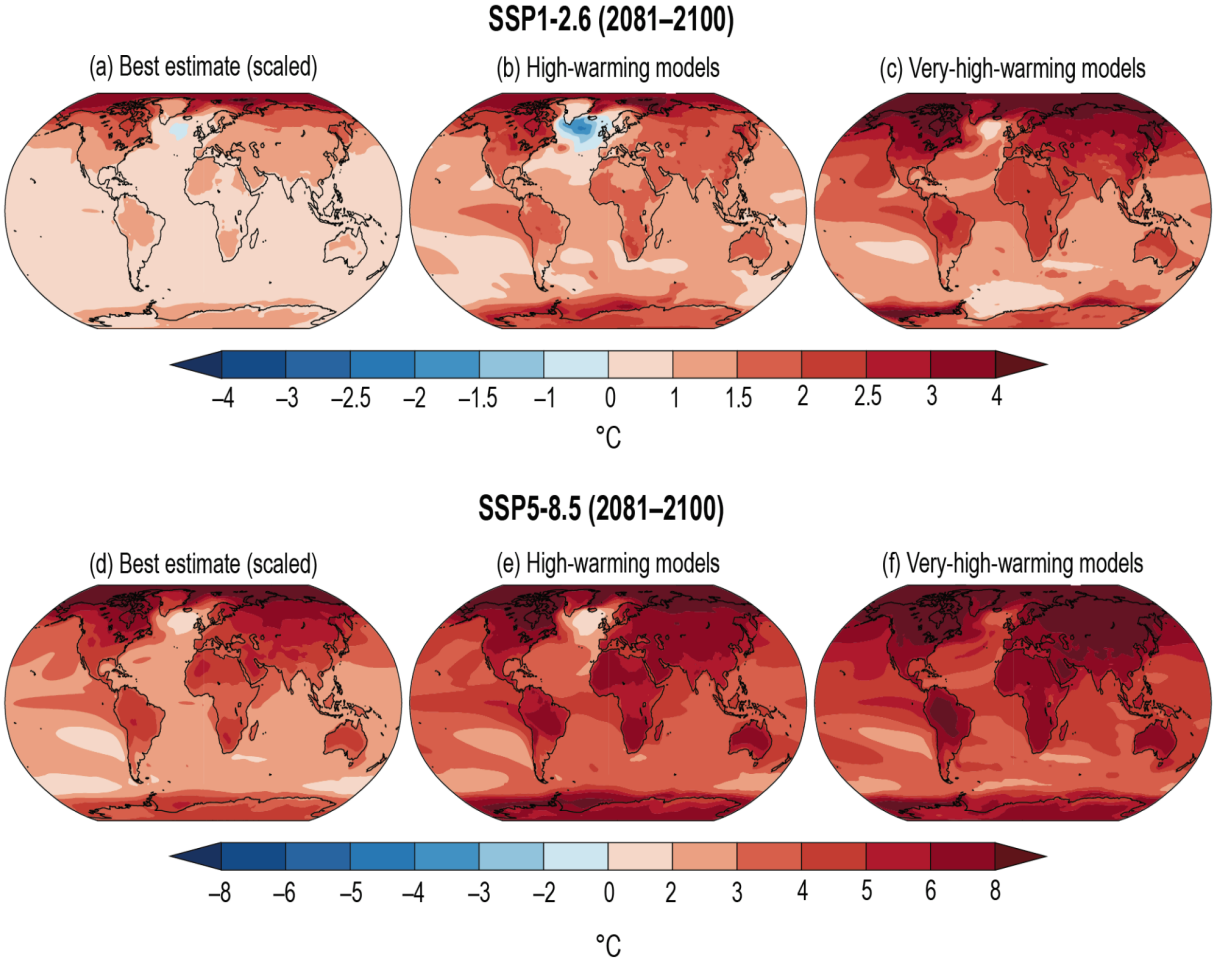

[1] "High Confidence" is one of the "calibrated uncertainty" terms of the Intergovernmental Panel on Climate Change (IPCC). The thesis of this paper is that there should now be high confidence that human civilization will collapse. However, quantifying this prediction with a high degree of certainty 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 is 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.

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 footprint.

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 much 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, and the required rapid decarbonization is unlikely to occur. Staying below the 1.5°C limit of the 2015 Paris Agreement is impossible at this point, and it is also 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.

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, technological, geopolitical, and societal factors that will increase the probability of societal collapse.

Although a global mobilization is required to deal with climate change, 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 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 direct effects of climate change will result in millions of deaths from floods, droughts, heat waves, 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. The extreme consequences of climate change will start first in “fragile” states, as they have less resilience and adaptive capacity. 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. 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. At this point, 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 you as an individual in a rich country do so long as other countries continue to build coal-fired power plants, cut down forests, and degrade the 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. Recent proclamations that

after we reach net zero warming will quickly stop are disingenuous. Reaching net zero will take decades, and there are so many positive feedback loops and tipping points we may soon cross that it is likely that a variety of biophysical processes will continue to warm the earth even after we stop emitting greenhouse gases.

When it is clear that it is impossible to adapt to our changing climate, geoengineering via solar radiation management or other means will become inevitable. In fact, some scientists now already argue that any realistic approach to the climate crisis must include “climate cooling” via geoengineering.

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.

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.

Given the unlikelihood of immediate and drastic actions, there is really no chance of remaining below either 1.5° or 2°C. And despite what we are constantly told, we may now be at a point where every tenth of a degree no longer matters. 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[3] 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).

[3] IPCC: Intergovernmental Panel on Climate Change

- 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).
- "Earth is now well outside of the safe operating space for humanity" (Richardson et al., 2023).
- "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.

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.

A Message to Students and Young Adults

Despair is not the answer or a solution. Work for change, but enjoy your life. 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. If the crisis does continue, geoengineering may save us. Don't give up. Join one of the many climate organizations or start your own. 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. My recommendation is to read the Executive Summary, the section on Solutions, and then explore the sections that interest you.

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

The situation is already very bad. There are record-breaking heat waves, droughts, fires, floods, and hurricanes. Glaciers 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 than usual.[4] "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).[5]

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 their 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). Even after greenhouse gases are reduced, the

[4] See Ripple et al.'s (2023a) Table 1 for a list of climate-related disasters since the end of 2022.
[5] 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. 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.

accumulated heat in the ocean will continue to melt sea ice and ice shelves and to heat the atmosphere. Adaptation is no longer a solution.

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.[6] 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.[7] But emissions still increased by 410 million tonnes in 2023, leading to a new record; although emissions are increasing less dramatically than in the past, they are still increasing.[8]

Despite all the positive aspects of the recent Inflation Reduction Act for creating clean energy jobs and reducing emissions, the United States, under President Biden, pumped more oil than under President Trump, and more than either Saudi Arabia or Russia. The U.S. recently pumped more oil than any other country in history. According to the IPCC, modelled 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."

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[6] https://globalcarbonbudget.org/fossil-co2-emissions-at-record-high-in-2023/

[7] https://www.iea.org/news/major-growth-of-clean-energy-limited-the-rise-in-global-emissions-in-2023

[8] 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.

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 NY 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."

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 recent communication (Hansen, Sato, & Ruedy, 2023), "That is pure, unadulterated, hogwash." In a recent paper, Hansen and over a dozen coauthors argue that, "Thus, 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).[9] 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."[10]

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 water resources.

Only recently are some scientists and economists predicting realistic deaths this century: "If warming reaches or exceeds 2°C this century, mainly richer humans

[9] 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.
[10] https://www.columbia.edu/~jeh1/mailings/2024/Groundhog.04January2024.pdf

will be responsible for killing roughly 1 billion mainly poorer humans through anthropogenic global warming" (Pearce & Parncutt, 2023).[11]

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 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.[12]

As Taylor et al. (2023b) argue cogently, there is no convincing evidence supporting the following assertions, despite their being widely promoted by many scientists and the media.

- "Current greenhouse gas emissions reduction and removal methods can and will be ramped up in time to prevent dangerous climate change;
- overshoot of Paris Agreement targets will be temporary;
- net zero emissions will produce a safe, stable climate;
- the impacts of overshoot can be managed and reversed;
- Intergovernmental Panel on Climate Change models and assessments capture the full scope of prospective disastrous impacts;
- and the risks of climate interventions are greater than the risks of inaction."

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."

[11] 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.
[12] For an excellent primer on climate change, see Emanuel (2016). See also MIT's Climate Portal at https://climate.mit.edu/

Richardson et al. (2023), writing within a planetary boundaries 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.[13] (Ripple et al., 2022)

Note that 3 degrees by 2100 is almost certainly an underestimate. 2023 was a year of 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 said, "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."[14] As Pope Francis writes in a recent Apostolic Exhortation (Pope Francis, 2023), "...the world in which we live is collapsing and may be nearing the breaking point."

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).

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.").

The three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[15]

> The latest analysis of observations from the WMO [World Meteorological Organization] Global Atmosphere Watch (GAW) in

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

[14] 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

[15] There are four other greenhouse gases covered by the Kyoto Protocol: Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6), and Nitrogen trifluoride (NF_3). 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.

> 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)

See Appendix 2 for a plot of US and Global Changes in Average Surface Temperature, and Appendix 3, which includes a figure titled, “Human Activities are Responsible for Global Warming.”

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, and 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 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."[16]

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.
>
> 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."

[16] 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."

Planetary Boundaries

Richardson et al. (2023)[17] 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.[18]

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.

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.

[17] There were 29 scientists from eight different countries involved in this research.

[18] 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."

Warming is 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." Global warming is steadily increasing, but is the rate actually accelerating? 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.[19]

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

[19] https://www.nytimes.com/2023/10/13/opinion/climate-change-excessive-heat-2023.html?smid=em-share

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 there is an increase in global warming.

Radiative forcing is an important concept:

> 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.[20]

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

[20] https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-forcing

> apportion the albedo change between aerosol forcing and cloud feedbacks because of limited global measurements.[21]

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 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

[21] Global Warming Acceleration: Causes and Consequences, Jan. 12, 2024 Communication, https://www.columbia.edu/~jeh1/

GHG emissions) (CarbonBrief has a similar analysis), even if we might differ on whether it is yet detectable.[22]

COP28

The United Nations Framework Convention on Climate Change (UNFCCC) has a yearly Conference of the Parties (COP). COP28, the 28th meeting, ended on December 12, 2023. Those who don't follow the COP meetings will not believe the big breakthrough that just happened. For the 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 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. 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.

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.

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

[22] https://www.realclimate.org/index.php/archives/2024/04/much-ado-about-acceleration/

of climate change, readers are directed to a short list of the most comprehensive reports in the Suggested Reading section at the end of this document. The most serious direct consequences of climate change on human civilization are presented in Appendix 1, and they can be summarized succinctly by listing some of the sections within that appendix: extreme shortages of fresh water, extreme rainfall and floods, extreme heat waves, extreme droughts, 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, 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 1 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."[23] This is from a climate newsletter, and I have seen this exact statement, or one almost identical, dozens of times. It is partly true, as every tenth of a degree does matter – with respect to warming – but it is not necessarily the case that

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

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[24]: "'A Miracle Will Occur' is Not Sensible Climate Policy."

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

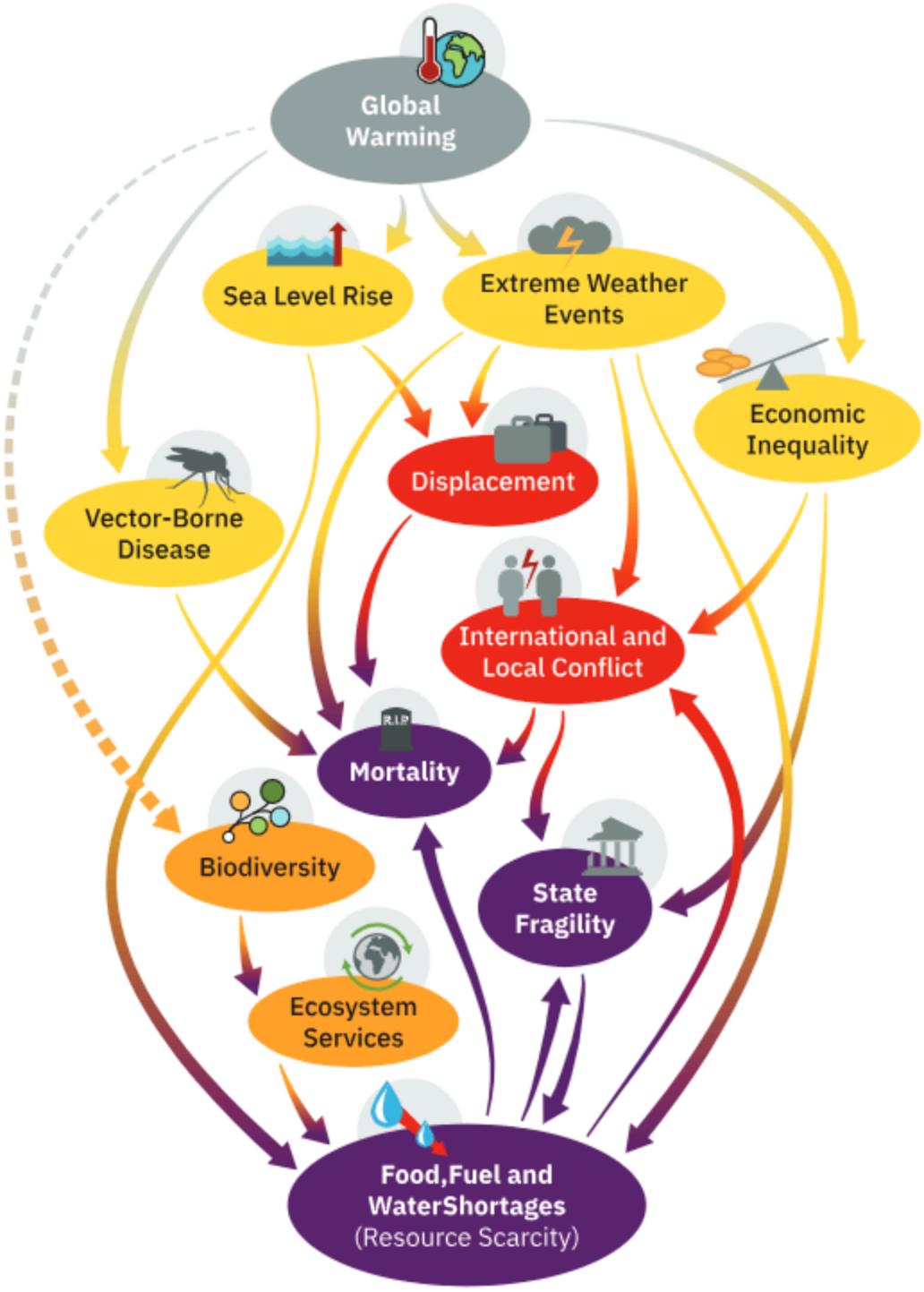

Figure 1. (This is Fig. 3 from Kemp et al., 2022.) *"Cascading global climate failure. This is a causal loop diagram, in which a complete line represents a positive polarity (e.g., amplifying feed-back; not necessarily positive in a normative sense) and a dotted line denotes a negative polarity (meaning a dampening feedback."*

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,[25] 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?"[26] 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 good part of Texas, instead of being just barely livable as they are now, would become real deserts.[27]

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.[28]

The Future

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 a thousand years for heat to mix completely throughout the ocean. This creates an extreme 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

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[25] 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)

[26] 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.

[27] 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

[28] https://climatebrad.medium.com/climate-hearings-af27a3886a43

release the heat they have been accumulating, and glaciers and ice sheets will continue to melt. Land and atmospheric temperature will drop only slightly during that 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 (International Cryosphere Climate Initiative, ICCI, 2023):

> 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.

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 that is likely to lead to the collapse of human civilization. In the following passages, Steffen et al. (2018) describe our future in terms of this new trajectory (which is illustrated in Figures 2 and 3 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. (References within the quotation have been omitted.) (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 2 and 3 on the next two pages: 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.

Possible Future Pathways

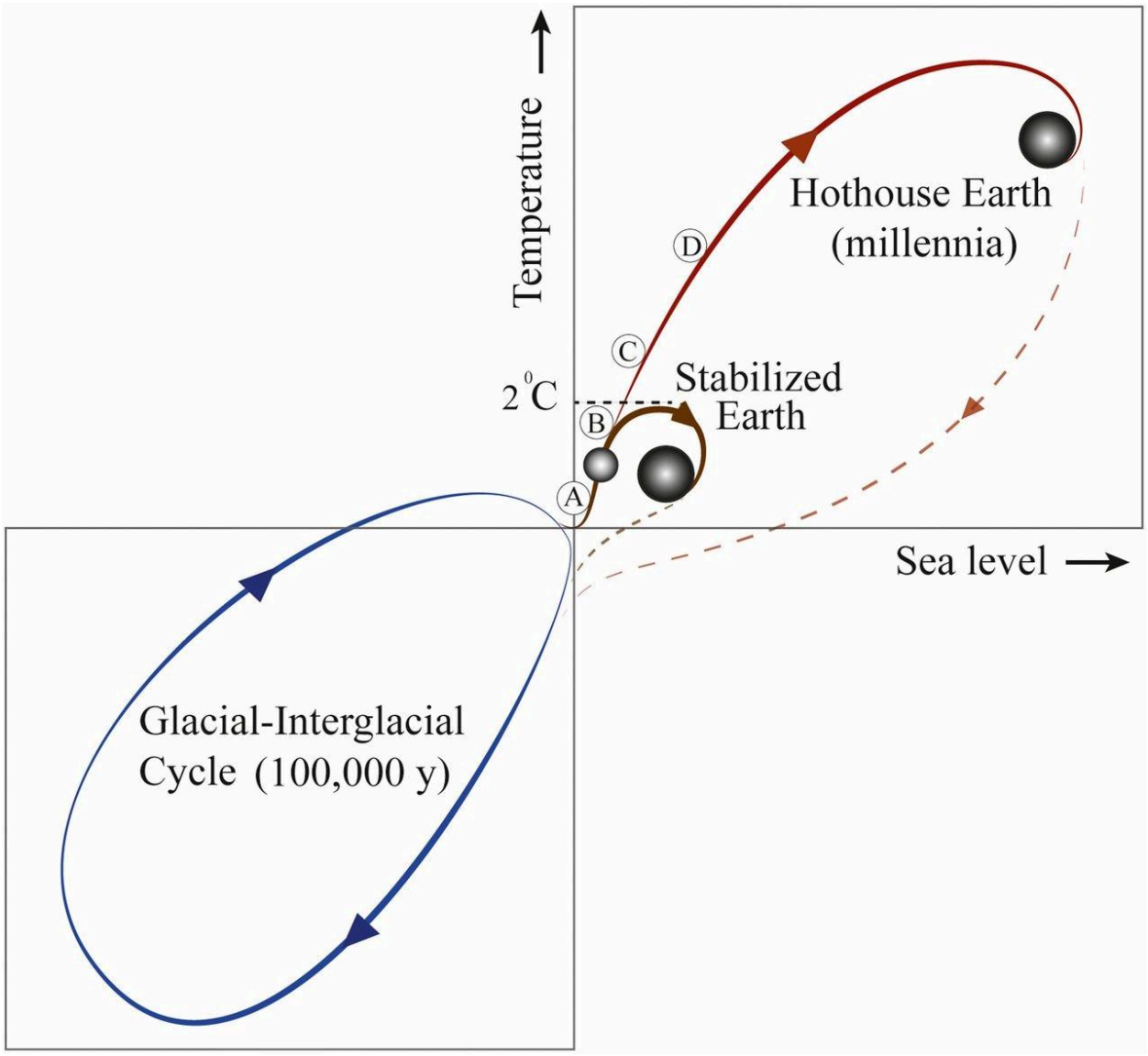


Figure 2. (Figure 1 from Steffen et al., 2018.) *"A schematic illustration of possible future pathways of the climate against the background of the typical glacial–interglacial cycles (Lower Left). The interglacial state of the Earth System is at the top of the glacial–interglacial cycle, while the glacial 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 [an Appendix]."*

Pathways of the Earth System out of the Holocene

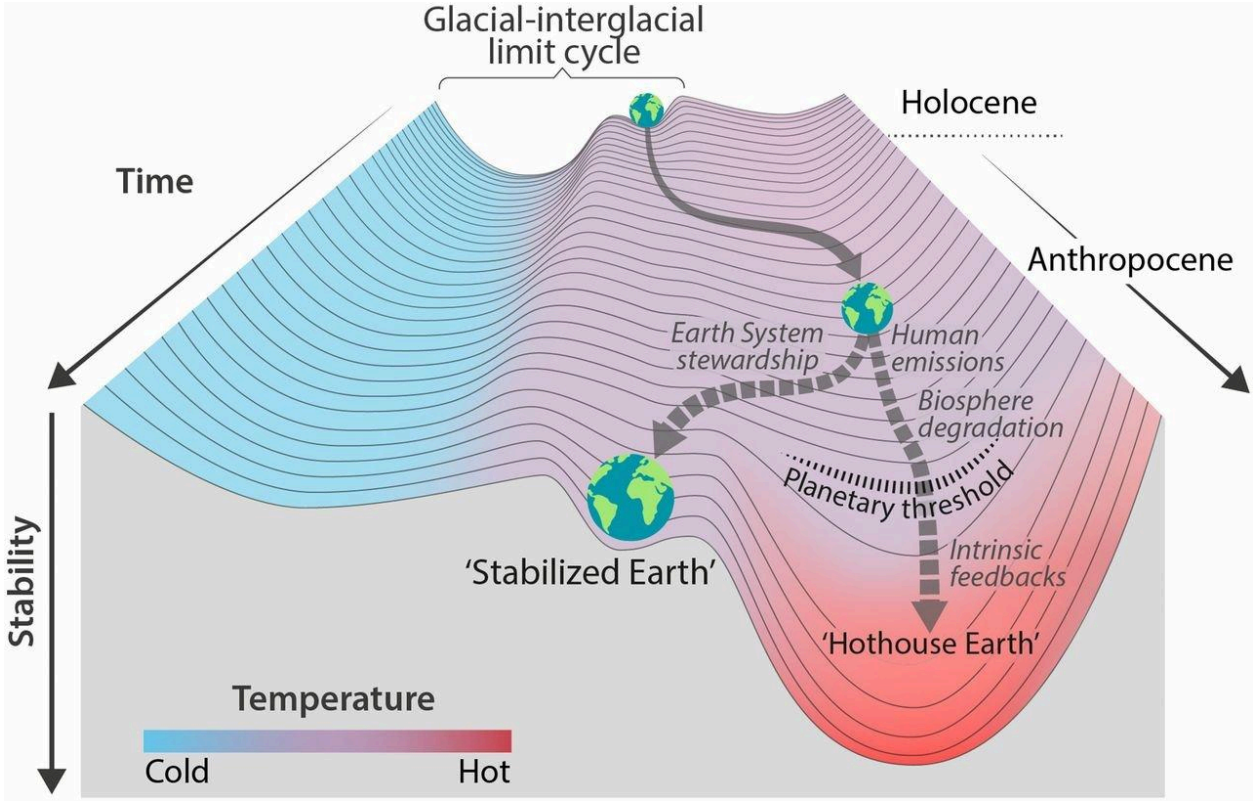


Figure 3. (Figure 2 from Steffen et al., 2018.) *"Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 [Figure 2 above in this paper] is 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."*

Another informative way to describe future temperature risks and trajectories is in Figure 4.

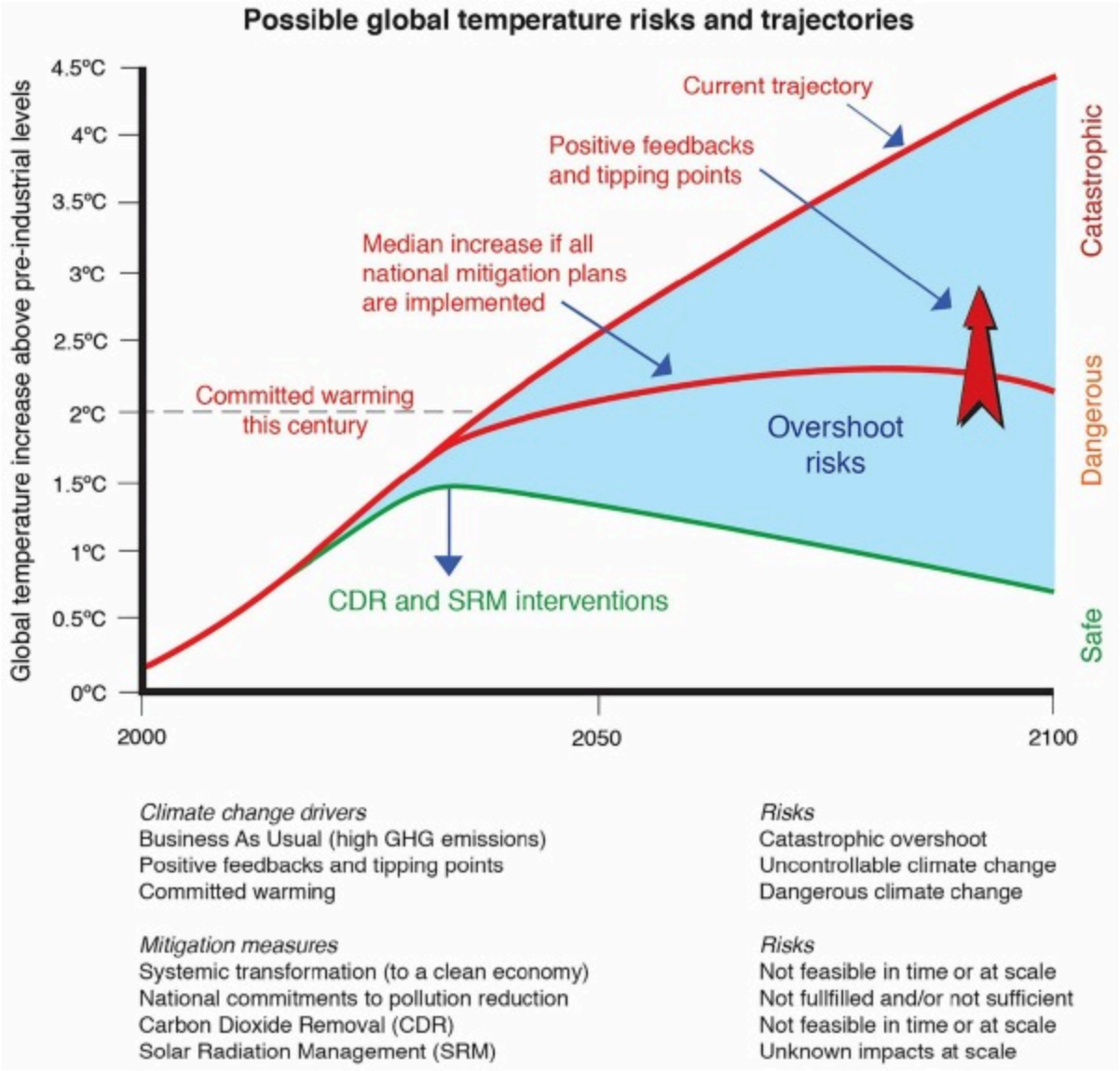


Figure 4. (Figure 1 from Taylor et al. (2023b.) *"Possible global temperature risks and trajectories. Taylor and Vink, 2021.")*

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).

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 et al. (2021) 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 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)

Tipping Points

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.[29]

The Amazon region is amazing.

> 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 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)

[29] https://wapo.st/47V4Fd0

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.

Randers & Goluke (2020)

> ...report that in the ESCIMO[30] climate model 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.

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

[30] ESCIMO: Earth System Climate Interpretable Model

changes to the climate within the very near future.[31] However, “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.”

See Appendix 1 for evidence that 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). Also in Appendix 1 are details from a new paper on the Atlantic Meridional Overturning Circulation, or AMOC, which 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.[32]

Feedback Loops

Amplifying climatic feedback loops are one of the main reasons why pessimism is warranted.[33] “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 below, a rapid drawdown is theoretically possible

[31] 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.

[32] 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 is a complete mess. News articles always repeat the report’s assertion that over 200 authors were involved, but this seems like marketing hyperbole, as I think they must have counted everyone who reviewed any of the chapters, and only 15 authors are actually listed as editors.

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

but extremely unlikely to happen in the near future. Ripple et al. (2023b) discuss 27 positive (reinforcing) feedback loops. The most 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 continue to lead to increased warming. 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, which will contribute to warming for up to 10 years.[34]

Compound Hazard Analyses and Cascading Effects

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

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

> 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 1 above on a cascading global climate failure. What makes compound hazards involving interactions with human infrastructure and populations more likely is the interaction among tipping elements themselves. As Klose et al. (2021) write, there are several ways in which multiple tipping elements may interact (some causal and some not),[35] 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.”[36] “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

[35] Klose et al. (2021) identify three types of tipping dynamics: two phase cascades, domino cascades, and joint cascades.
[36] 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.

> concurrent heatwaves and droughts, compound flooding and 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 1 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 described in 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 5, on the next page, presents global risks in five categories: economic, environmental, geopolitical, societal, and technological.

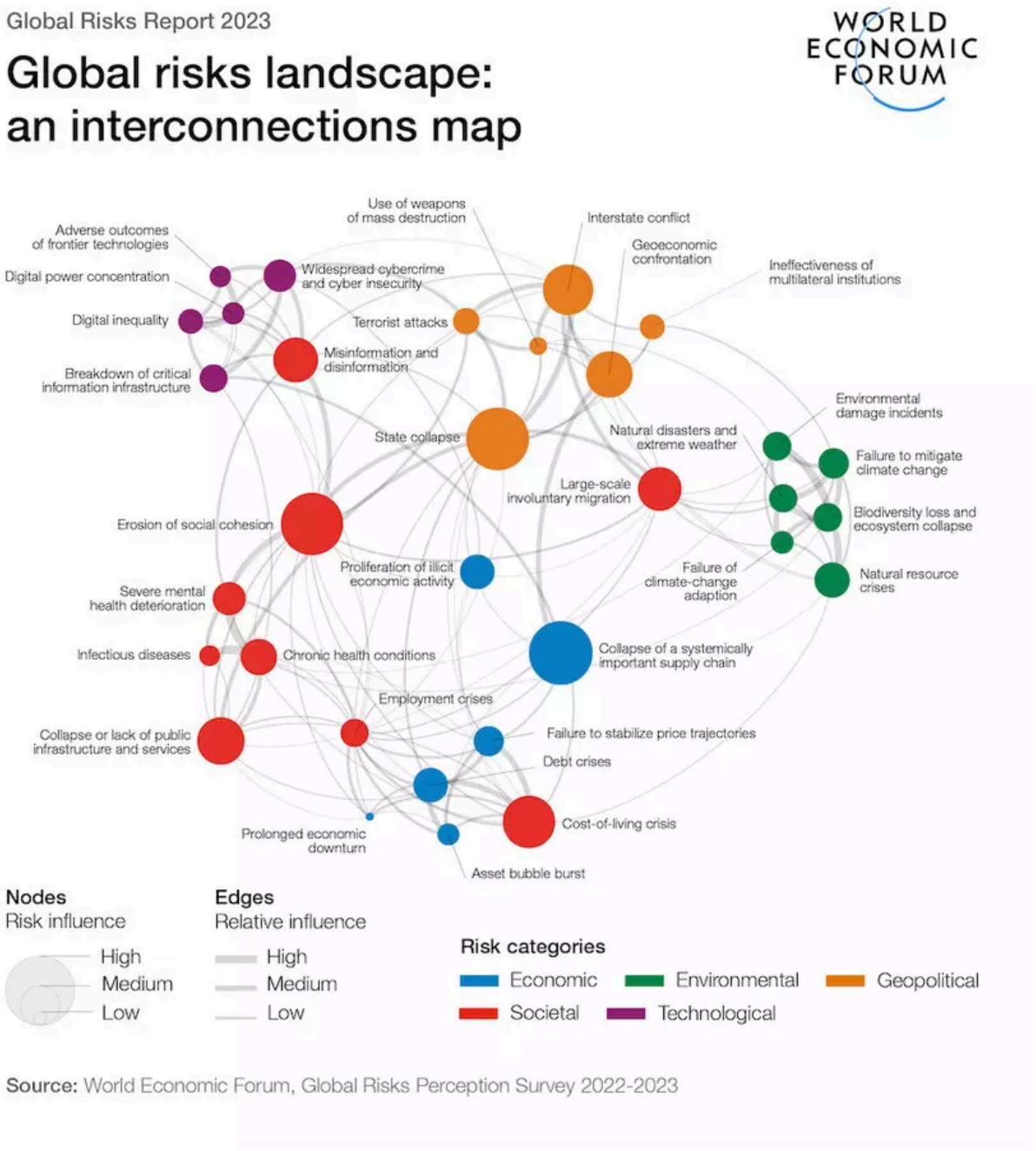


Figure 5. Global risks landscape: An interconnections map

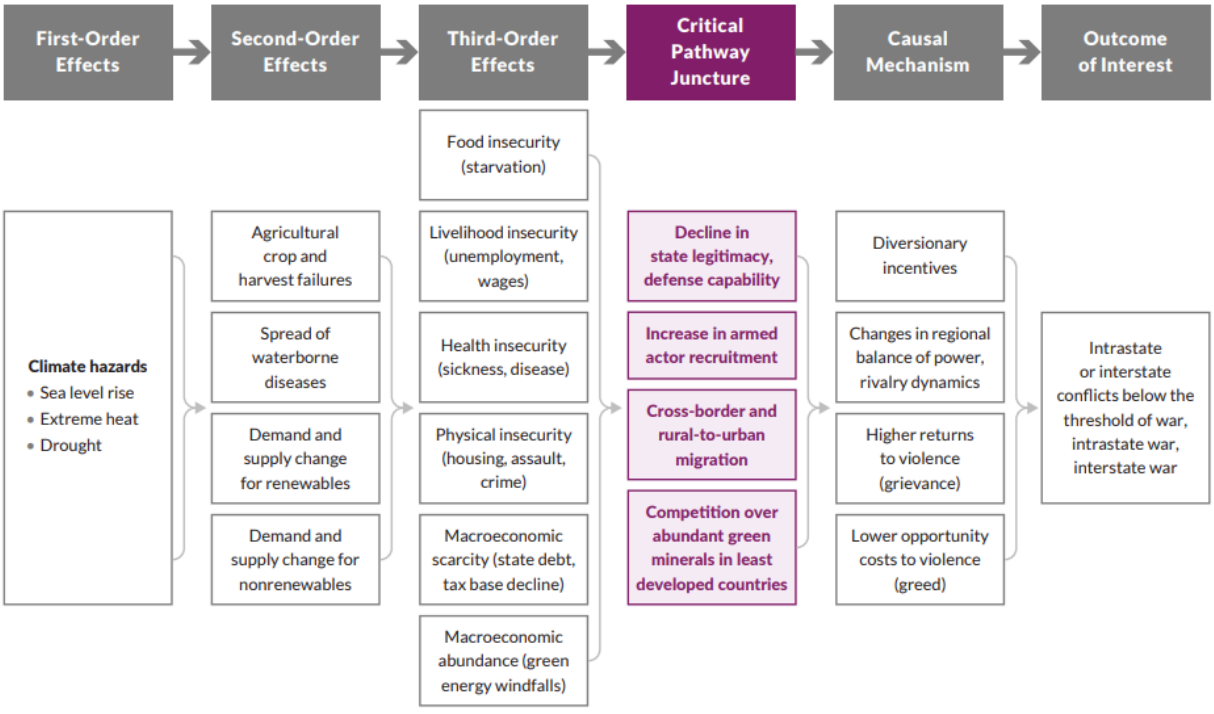
Armed Conflict and Standing Armies

The U.S. military has been 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."[37]

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 6 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.

[37] https://councilonstrategicrisks.org/wp-content/uploads/2023/01/38-CCThreatMultiplier.pdf

Figure 6. 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 gas emissions, 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."[38] Cement, used in large quantities to rebuild after military conflict, is responsible for a large percentage of global greenhouse gas emissions. And there are 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."[39]

[38] See "The 'carbon boot-print'", https://www.ipb.org/wp-content/uploads/2019/11/IPB-Information-Paper-the-carbon-boot-print-1.pdf

[39] https://www.theguardian.com/environment/2021/nov/11/worlds-militaries-avoiding-scrutiny-over-emissions

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 a particular 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….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 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)

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, 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 storms or 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 in the next paragraph.

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.

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 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.[40]

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).

[40] 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/).

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 inevitably 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 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, destroying 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. The 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. Then, 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.[41] 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.

[41] 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."

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 forest fires destroy entire cities. The 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 then 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, and 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.

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 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 are two barrier islands immediately adjacent to Miami, and they are now totally under water, as are low lying areas for over 150 miles up and down the 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.

The situation is even worse in central and South America, also stemming from drought, heat, and floods. In addition, large parts of the Amazon rainforest have now collapsed and are turning into savannah. Millions of people head to the U.S., streaming across the border, but they are met with armed vigilantes who turn them back or shoot them.

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 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).[42] 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. Although very conservative (see below), these organizations survey the literature and provide excellent technical summaries, although their summaries for policy makers and the public are problematic because they neglect to present the risks of extreme outcomes accurately.

For several decades there have been a series of international meetings sponsored by the IPCC and United Nations, during which member countries have made pledges on how much they will reduce their use of fossil fuels. 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. Yes, 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

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

> so-called leaders. Words that sound great but so far have not led to action. Our hopes and ambitions drown in their empty promises.[43]

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 over 100 governments required to approve the results, the IPCC is inherently conservative in nature.[44] 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.[45] 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)

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[43] Greta Thunberg's speech at the Youth4Climate summit in Milan Italy on September 28, 2021.
[44] "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#:~:text=The%20Panel%20and%20the%20Plenary%20Sessions&text=Currently%2C%20the%20IPCC%20has%20195,countries%20and%20from%20observer%20organizations.
[45] For details on the underestimation of sea level rise, see Garner et al. (2018), Oppenheimer & Alley (2016), in addition to Brysse et al. (2012)

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

> 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, and they are doing the same thing now.[46] Indeed, 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

[46] Despite these criticisms of the IPCC, it has done amazing work over the last 35 years.

> from overshoot …, are projected to become increasingly severe with every increment of global warming (very high confidence). (IPCC, 2023)

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 are starting 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 the figure below. As meetings continue, and warnings become more dire, atmospheric CO_2 and global temperatures continue to climb.

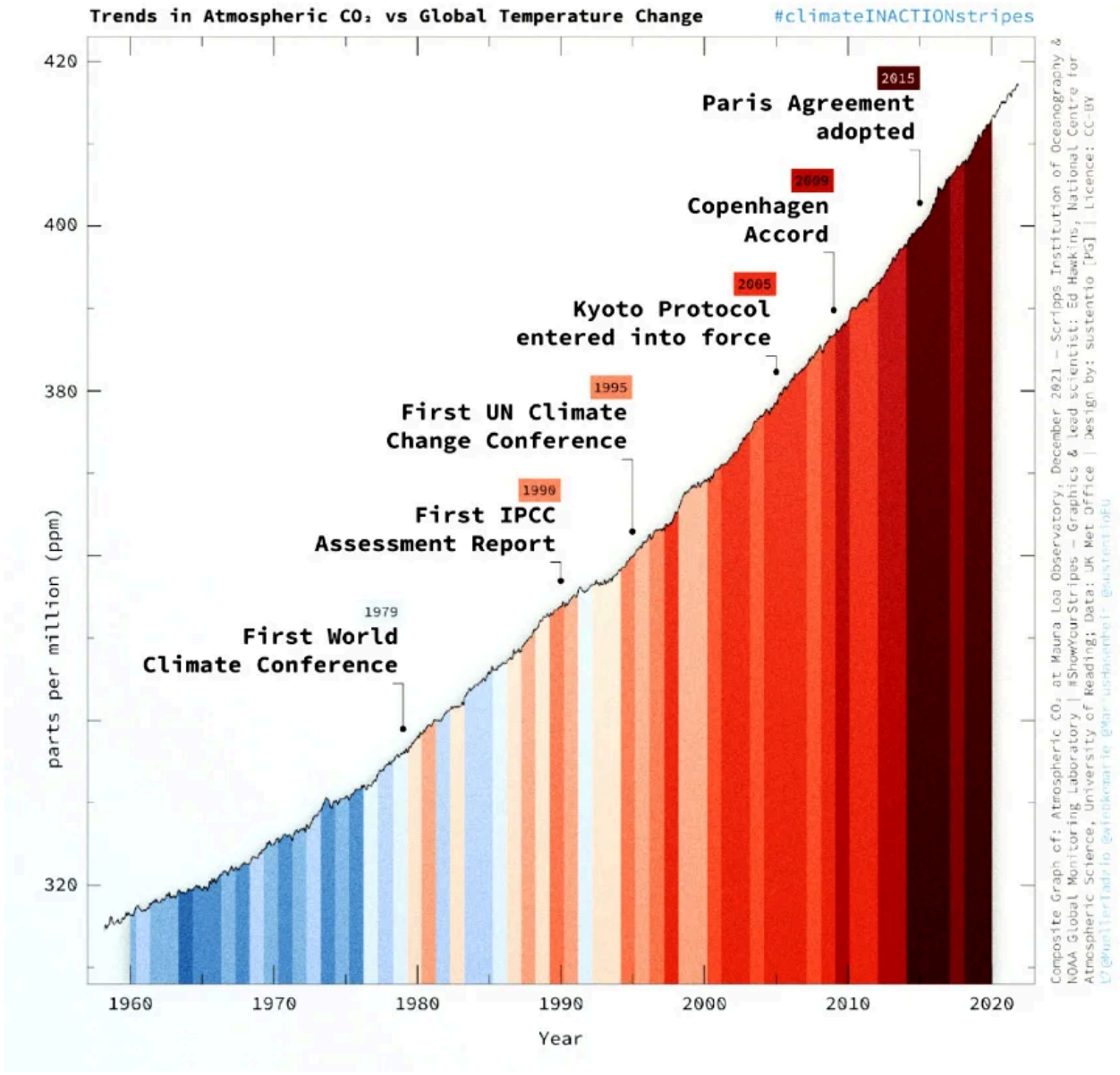

Figure 7. Trends in Atmospheric CO_2 vs Global Temperature Change, from Scientist Rebellion, https://scientistrebellion.org/

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.
>
> 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:[47]

> 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.

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

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).

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., 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.

Magical Thinking

Greenhouse gases have been accumulating in the atmosphere for decades, climate scientists have been warning that the situation is serious for decades, and they 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 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 modeling different future outcomes, and 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. In fact, the Paris Agreements 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)[48] 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)."

[48] 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).

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.

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:

> 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)

Rapid Decarbonization is Unlikely

A World-Wide Mobilization is Required

The earth will continue to warm, but how much it warms will depend primarily 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. In fact, fossil-fuel subsidies are actually increasing worldwide![49] "Fossil fuel subsidies from G20 countries in 2022 amounted to at least USD 1

[49] "Fossil-fuel subsidies surged to a record $7 trillion last year…. 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)."
https://www.imf.org/en/Blogs/Articles/2023/08/24/fossil-fuel-subsidies-surged-to-record-7-trillion

trillion, more than four times the annual average in the previous decade, driven by vast consumption subsidies in response to the energy crisis."[50]

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 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 basically 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 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.[51]

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. 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

[50] https://www.energypolicytracker.org/G20-fossil-fuel-support
[51] https://en.wikipedia.org/wiki/War_Production_Board

despite efforts by several organizations, this is very unlikely to happen in the near future.

Natural Carbon Sinks

In the future, we will also get less assistance from natural carbon sinks. Forests and oceans help tremendously with mitigation by capturing more than half of annual CO_2 emissions. However, 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 is reducing the ability of oceans to remove CO_2 from the atmosphere.

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.[52]

In summary,

[52] https://earthobservatory.nasa.gov/features/OceanCarbon#:~:text=For%20eons%2C%20the%20world's%20oceans,carbon%20dioxide%20dissolves%20in%20water

> 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 from the oceans 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.”[53]

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)

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).

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

[53] Ibid.

use of fossil fuels and deal with the climate emergency? 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 rapidly phased out. Deforestation and the destruction of natural carbon sinks would cease. 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.

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).[54]

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:

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

> 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.

Many have pointed out that utilities have incentives to build capital intensive fossil fuel plants because most public utilities pay utilities 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:

> 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.[55]

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

There is no question that more "heavier-handed intervention will be necessary," because we need to move quickly. Public utility commissions, or the federal government, needs 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 (yes, 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 nuclear power is also much safer. It 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".[56] There is still a problem in dealing with nuclear waste, but it is minor when compared to the possibility of global societal collapse.

Research on nuclear technology is 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)

[56] https://ourworldindata.org/nuclear-energy

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. 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.

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."[57]

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.

[57] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2023.pdf

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.[58]

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![59] (See Appendix 6 for information about Global Warming Potential, or GWP.) 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."[60]

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[58] https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

[59] 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

[60] https://repeatproject.org/docs/Clean_Investment_in_2023_02-21-24.pdf

The Zero Lab at Princeton University[61] 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 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.[62]

Unfortunately, nothing is currently happening that will accelerate transmission expansion. 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. 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.

[61] “Zero” stands for the Zero carbon Energy systems Research and Optimization Laboratory.
[62] https://repeatproject.org/docs/REPEAT_IRA_Transmission_2022-09-22.pdf

Planting Trees Will Not Save Us

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.”[63] In the original study, Brastin et al. (2019; Crowther was 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”[64]) 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:

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[63] https://www.wired.com/story/stop-planting-trees-thomas-crowther/; see also https://www.nytimes.com/2023/11/13/climate/trillion-trees-research.html?unlocked_article_code=1.HE0.3dfV.boz-4csZou7m&hpgrp=k-abar&smid=url-share

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

> 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 planting 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 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.[65]

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.

Mass Delusion: Reducing Methane will not Save Us

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.”[66] 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

[65] https://research.wri.org/gfr/latest-analysis-deforestation-trends?apcid=0065aea1ba4a6d4198f26f00&utm_campaign=treecoverloss2023&utm_medium=bitly&utm_source=WRIDigest
[66] http://tinyurl.com/2h5bhxh5

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.

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.[67]

Direct Air Capture Will Not Save Us

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 is

[67] Jessica McKenzie, December 18, 2023, Bulletin of the Atomic Scientists, http://tinyurl.com/3vpjmwkc

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 carbon capture and storage]—has to be stored somewhere permanently. The scale of this challenge 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 carbon capture and 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)

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.[68]

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.

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.[69]

> 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.[70]

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:

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

[69] *The Superyachts of Billionaires Are Starting to Look a Lot Like Theft,* By Joe Fassler, The New York Times, April 10, 2023. https://tinyurl.com/29sth47e.

[70] Ibid.

> 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.[71]

There are also 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. And just last week — after sustained pressure from activists — Schiphol Airport in Amsterdam announced it would ban private jets as a climate-saving measure.)[72]

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

[71] Ibid.
[72] Ibid.

> 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.[73]

According to most of the models in the new research, warming will stop within a few decades, not three to five years, and some models suggest it may take even longer. 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).

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. In reality, reaching net zero will take decades, and we will have already reached a catastrophic degree of warming before the temperature stops increasing. 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

[73] https://www.newyorker.com/news/q-and-a/al-gore-doesnt-say-i-told-you-so

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 achieve 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.

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."[74] 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 et al. (2023) conducted in-depth interviews with people who do not think there is a climate crisis that 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 contrast, most do not believe what they hear from the national news

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

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.[75]

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."

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

[75] https://www.congress.gov/bill/118th-congress/house-bill/1435/text?utm_source=newsletter&utm_medium=email&utm_campaign=wp_climate202&wpisrc=nl_climate202&s=1&r=1&q=%7B%22search%22%3A%5B%22preserving+choice%22%5D%7D

> global warming does not cause climate change." (Tranter et al., 2023)

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,[76] 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.[77]

[76] 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/

[77] 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”[78]

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.”[79]

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

[78] Ibid.
[79] Ibid.

> audiences' characteristics and target behaviors. (Vlasceanu et al., 2024)

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".

What Should We Call It?

"Climate change" and "global warming" are used most frequently to describe what is currently happening to our climate. "Climate crisis" is also frequently used. 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 both global weirding and climate upheaval have advantages, my current favorite is climate crisis, which emphasizes that there is now a crisis resulting from the changes in our climate.

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.[80]

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 democracies ability to deal with climate change.

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.
> …

[80] https://www.youtube.com/watch?v=NM_dvVyoJwI

> 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.[81]

COP28 is no different, with many news outlets reporting that the fossil fuel industry is 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 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.[82] "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.[83]

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[81] 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.

[82] "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

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

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."

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.

Climate Change and "Fragile" Countries

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,[84] which examines economic, political, and social indicators as well as 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.[85]

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

[84] "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 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/).

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

> 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.[86] The background: "Libya's infrastructure has suffered repeated blows during a civil war that broke out after the fall of Moammar Gaddafi in 2011. The country now remains divided between rival governments in the east and the west."[87]

> 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.[88]

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.

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

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

[88] Ibid.

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. Several thousand 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.[89]

The Rise of Nationalism and Right-wing Populist Leaders

It is likely, as several political scientists have pointed out, that mass migration and resource scarcity will lead to nationalistic and authoritarian political regimes. This is 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."[90]

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 treating the Mediterranean as a Trumpian wall, and basically paying other countries to stop migrants from getting to Europe.

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

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[89] http://tinyurl.com/2j5hann8 from https://transportgeography.org/

[90] https://www.washingtonpost.com/politics/2023/11/21/heres-how-many-fossil-fuel-lobbyists-have-attended-un-climate-talks/

environmentalism," however, is already here, and may expand in the future. Mittiga (2021) defines authoritarian environmentalism as follows[91]:

> 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.

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 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 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)

[91] 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."

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.[92] 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.

Economic Impacts

Economic impacts will manifest in multiple areas, but 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.

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

> 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)

$26,000,000,000,000

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 they 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.

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, and working during the day under extreme heat significantly reduces productivity.

Disruptions to Transportation

Disruptions to transportation can have a major impact on commerce and industry. Consider what happens 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, 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 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.[93]

In South America, severe drought in parts of the Amazon region this year has led to extremely low water levels in some rivers and disrupted shipping (especially around Manaus), with boats running aground.[94] 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. As one example, increased wildfire smoke, such as that from Canadian fires experienced throughout large parts of the United States during 2023, can lead to coughing, asthma attacks, headaches, chest pain, and there are long-term effects of COVID-19 complications, increases in deaths from heart disease, and multiple other effects.

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

[94] https://www.reuters.com/world/americas/amazon-drought-stalls-shipping-boats-run-aground-low-rivers-2023-10-11/

Global Food Production

Rising temperatures, droughts, floods, and 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 marched to Ouagadougou, the capital, to force the government to subsidise the cost of some cereals.[95]

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 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[96] 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.

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[95] C40: Food Security, https://www.c40.org/what-we-do/scaling-up-climate-action/adaptation-water/the-future-we-dont-want/food-security/#:~:text=Food%20scarcity%20can%20also%20lead,sparked%20unrest%20in%20many%20countries.

[96] 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."

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. From their 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.

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.

In addition, there is already extreme hunger and famine in the world today, and "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 make the situation much worse. "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."[97] See also the World Food Programme review.[98]

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 complex, and there are political, economic, social, and demographic factors in addition to climate. Consider the impact of devastating hurricanes on Honduras, a fragile state, as reported by Miriam Jordan in the NYTimes[99]:

> 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 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.

[97] Alex de Waal, NYTimes, March 9, 2024, "I Said the Era of Famines Might Be Ending. I Was Wrong."https://www.nytimes.com/2024/03/09/opinion/famine-war-gaza.html?unlocked_article_code=1.hk0.3vOm.NK13tebovh3d&smid=url-share
[98] https://www.wfp.org/global-hunger-crisis
[99] November 28, 2023, https://www.nytimes.com/2023/11/28/us/climate-migrants-asylum.html

> 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.
> …
> While they await the outcome of their cases, asylum seekers are allowed to remain in the United States, and they become eligible for employment authorization after six months.

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)[100]

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

[100] 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."

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. 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.[101]

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 move 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 respect 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 extremes are also clearly important in addition to temperature. Lenton et al. "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 8 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 8 will need to migrate as the temperature increases.

[101] Polgreen, L. (Aug. 24, 2023). "In a Report From a Distant Border, I Glimpsed Our Brutal Future." NYTimes Opinion. https://www.nytimes.com/2023/08/24/opinion/saudi-arabia-ethiopians-border-politics.html

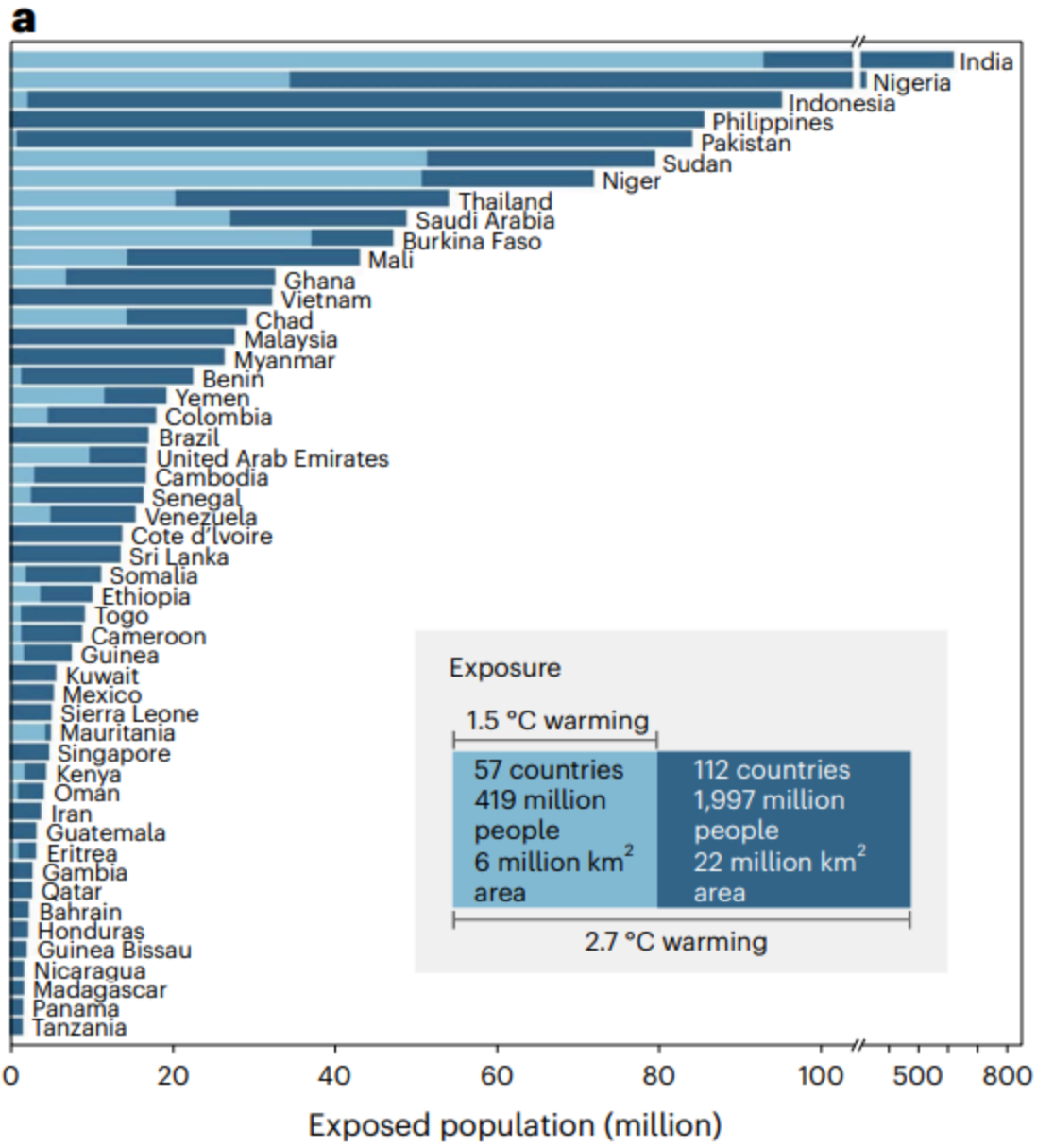

Figure 8 (Fig. 5a from Lenton et al., 2023b). "Country-level exposure to unprecedented heat (MAT ≥29 °C) at 2.7 °C and 1.5 °C global warming in a world of 9.5 billion people (around 2070 under SSP2). a, Population exposed for the top 50 countries ranked under 2.7 °C global warming (dark blue) with exposure at 1.5 °C global warming overlaid (pale blue). Note the break in the x axis for the top two countries."

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.[102]

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

[102] From an NPR interview, https://www.npr.org/2024/03/26/1239904742/how-climate-driven-migration-could-change-the-face-of-the-u-s

> 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 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

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 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 was also 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 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.

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.

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).

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 two thousand years BCE 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.[103] 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.

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 comes in for withering criticism in the essays by historians, archaeologists, and anthropologists in *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire* (2010).[104]

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."[105]

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[103] 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.

[104] 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."

[105] https://www.realclimate.org/index.php/archives/2023/11/a-distraction-due-to-errors-misunderstanding-and-misguided-norwegian-statistics/

The spatial resolution of climate models 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.

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),[106] expressing plausible evolutions of greenhouse gases and other 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)

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.[107]

[106] RCP2.6 (very low future greenhouse gas concentrations), RCP4.5, RCP6.0, and RCP8.5 (very high concentrations)

[107] https://www.wcrp-climate.org/wgcm-cmip/call-members-cmip7

CMIP models have been fairly reliable when compared against both future or historical climate changes. For more information, just search for “CMIP climate models” or something similar.

The current IPCC scenarios are presented in Figure 9.

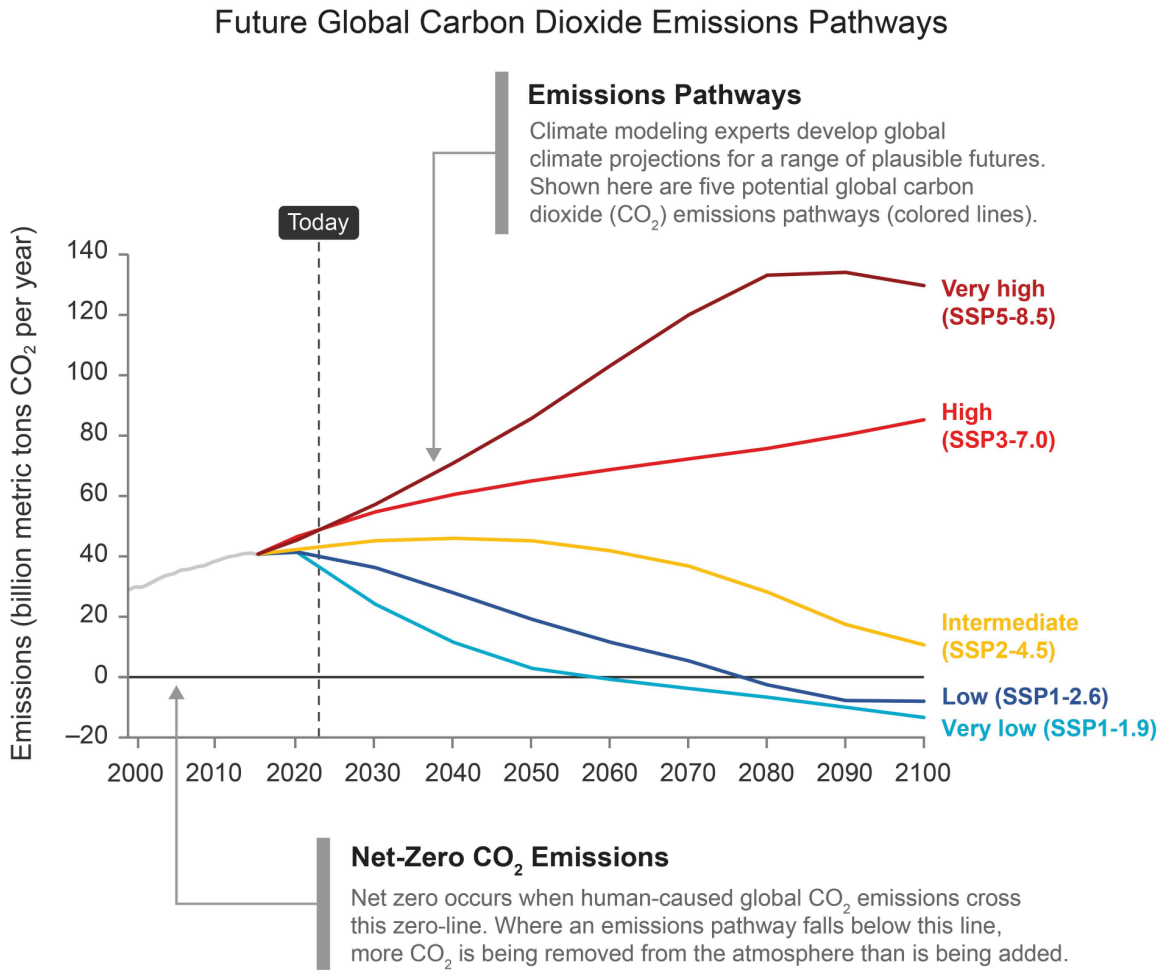

Figure 9 (FIGURE 1.4 from Crimmins et al., 2023, the Fifth National Climate Assessment). “*The five scenarios shown (colored lines) demonstrate potential global carbon dioxide (CO_2) emissions pathways modeled from 2015 through 2100, with the solid light gray line showing observed global CO_2 emissions 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.*”

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.

The problem is that scientists currently don't know enough to be able to predict what will happen on a regional basis, 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. 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.

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 CO2 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.[108]

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

[108] https://capturacorp.com/technology/

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 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. Several climate tipping points have already been passed and it is probable that a 2°C increase will cause half a dozen more significant climate tipping points to be exceeded, setting off cascades of feedbacks that will further raise temperatures and amplify associated impacts. Without climate intervention within the next two to three decades, it is projected that global average temperatures will rise by 3°C or more by the end of this century. Many scientists believe that an increase of 4°C would threaten the survival of human civilization. (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 now starting on another geoengineering experiment, this time inadvertently. 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)

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."[109]

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 can 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 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."[110]

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[109] Jason Horowitz, "How Do We Feel About Global Warming? It's Called Eco-Anxiety." The New York Times, Sept. 16, 2023.
https://www.nytimes.com/2023/09/16/world/europe/italy-greece-eco-anxiety.html

[110] "Climate Change is Keeping Therapists Up at Night: How anxiety about the planet's future is transforming the practice of psychotherapy," Brooke Jarvis, NYTimes, Oct. 21, 2023

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 ecoanxiety is certainly real. Here is the definition of eco-anxiety by Cianconi et al.:

> 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, 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)

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https://www.nytimes.com/2023/10/21/magazine/climate-anxiety-therapy.html?unlocked_article_code=1.4kw.usFv.0IJkUa89HlTk&smid=url-share

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.

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.

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).

New Technologies

Apart from geoengineering, there are a variety of new technologies that will help in the future, assuming there is not a global societal collapse. It is unlikely, however, that these technologies will arise soon enough to solve our problems, given the feedback loops and tipping points discussed above.

Liquid-Infused Windows for Universal Climate Control

There are literally hundreds of ongoing research and development projects related to sustainability. Consider, as an example, this project 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.[111]

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 cows and other mammals, is called the 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

[111] https://salatainstitute.harvard.edu/salata-institute-to-fund-five-new-climate-and-sustainability-projects-across-harvard/

reduce methane emissions from farm animals, landfills, wastwater, rice paddies, and other sources. In the future, this could have a major impact on the emission of methane, a powerful greenhouse gas.

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 will be an exponential increase in intelligence and capabilities that may 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 demonstrate dramatically how useful these LLMs can be. AI is advancing quickly, and even without reaching a singularity it is clear that it will help speed scientific research, helping with everything from planning experiments to analyzing data.

Carbon Taxes (or Fee and Dividend)

Most economists think that some type of carbon tax or fee is the best way to rapidly reduce emissions, 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.

What happens when goods enter a country? 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.[112]

Other countries are indeed already considering their own carbon pricing. There are various complexities involved, 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).

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 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

[112] http://tinyurl.com/yckzkvcb

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?

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."

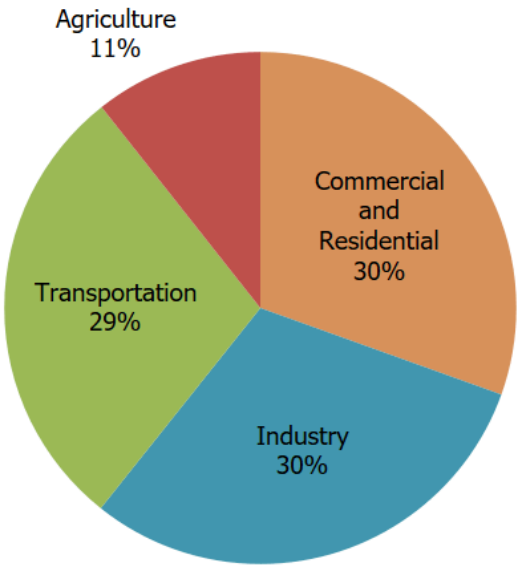
Solutions

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 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, driving an electric car, and reducing air travel (see https://www.un.org/actnow for lots of good ideas). Not everyone, however, can take these steps. First, because most people don't have the extra disposable income,[113] 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.

[113] 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 10. Total U.S. Greenhouse Gas Emissions by Economic Sector and Electricity End-Use[114]

According to the Environmental Protection Agency (Figure 10 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 can remove 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

[114] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

analysis). Given financial and practical considerations, only a small percentage of residential homes can be converted to heat pumps per year.

Electrical 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.[115]

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.

If you live in Phoenix, Arizona, which had a month of temperatures above 110°F in 2023, 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,[116] 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. There are also no serious efforts to eliminate or replace plastics, which are made from fossil fuels.[117] Given this state of affairs, what you as an individual choose to do in your

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[115] 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.

[116] 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.

[117] 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'

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.”

2. “Control Political Power” and Protect the Biosphere

The second class of actions you can take 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.[118]

You should help organize and participate in non-violent civil disobedience and mass movements to combat climate change. 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”.

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. When enough people demand action, politicians will listen.

Eating less meat and promoting a primarily vegetarian diet can also lead to significant improvement to land and water usage and a reduction in the use of fossil fuels.[119] 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

[118] https://citizensclimatelobby.org/

[119] There are exciting new ways to create high-protein food in vats using precision fermentation processes.

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.[120]

> 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).

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 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).

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)

[120] 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)

- 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.

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.

> 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.

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 Burke and Fishel, 2020, for details on a Coal Elimination Treaty.)

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. Even within our democratic system, however, a president is allowed to take decisive and unilateral action during an emergency. President Biden 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.)"[121]

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."[122]

If President Biden took these actions today there would be a political and legal firestorm, and perhaps obstruction and even the refusal to obey orders by some

[121] https://www.biologicaldiversity.org/programs/energy-justice/pdfs/Climate-Emergency-Powers-Report.pdf

[122] Ibid.

states. This is why it's so important to convince your 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.[123] 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.[124] 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 between 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."[125] 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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[123] https://www.ipcc.ch/report/ar6/wg2/
[124] Lecture at Harvard University, October 19, 2023.
[125] 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.”[126]

[126]https://www.realclimate.org/index.php/archives/2023/10/the-5th-international-conference-on-regional-climate/

Suggested Reading

I suggest reading the following papers in this order. 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. I also suggest MIT's Climate Portal at https://climate.mit.edu/.

Pope Francis (2023). Read this Apostolic Exhortation second. I don't know how much Pope Francis actually wrote, but it is a masterful summary of the scientific literature, along with his explanation of how the "ethical decadence" of the 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."

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 in the Reference list below): This is the Fifth National Climate Assessment, which 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-climate 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 most 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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arguments and the views presented here are mine alone. I would like to thank Al Race, Tony Jagodnik, Sharon Rider, Deborah Johnson, Joel Angiolillo, Greg Cermak, Steve Goldfinger, Michael Northrop, and Rich Fakelman for all of their comments and feedback. 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 has worked as a user experience practitioner, researching, 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

There 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 thermohaline 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, what 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.

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Appendix 1: The Current Situation is Dire

The IPCC goes through the current situation in great detail (IPCC, 2023), over hundreds of pages, but here I want to provide a summary of some of the disturbing aspects of each of the major parts of the climate crisis, along with some newspaper-style human interest stories.

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 it 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.[127]

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

[127] Search for "Aral sea ecological disaster" or something similar to find a variety of articles.

> 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).

Conflict over water

Consider the following example of potential conflict over fresh water.[128]

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 from Egypt).

Iran and Afghanistan

> 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)

[128] Here's a headline from the NYTimes on September 15, 2023: "Dominican Republic Will Close Border With Haiti Amid Water Dispute."

Extreme Rainfall and Floods

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 moisture. There are also dynamical aspects that can lead to extreme rainfall due to changes in winds and cloud structures.[129]

In 2023, Beijing experienced the heaviest rainfall in recorded history and had to evacuate over a million people. On the other extreme, Iran, also in 2023, was unable to provide sufficient water and electricity during its heat wave in August.

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, and 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.”

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

[129] Explained briefly by Rasmus Benestad, RealClimate, https://www.realclimate.org/index.php/archives/2023/09/old-habits/

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.”

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.”

Ocean Heating

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, however, 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'.[130]

Extreme Droughts

"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).

Extreme Fire

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."[131]

David Wallace-Wells, in an opinion piece in the NY Times titled, "Forests Are No Longer Our Climate Friends,"[132] starts his column like this:

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

[131] 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/

[132] September 6, 2023, https://tinyurl.com/4sbmf4fj

> Canadian wildfires have this year 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.

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.[133] In the future, we will have more major hurricanes, defined as category 3, 4, or 5, than in the historical record.

> Tropical cyclones (TCs) are the most damaging natural hazard to regularly impact 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, 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)

[133] "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.

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.

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).

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.

> "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."[134]

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."[135]

In addition to this effect of the loss of sea ice, ice shelves in the Antarctic are incredibly important. 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 et al. (2023) "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." What is especially concerning is that not only did almost 44% of the ice shelves lose mass, but two thirds of the

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[134] Kasha Patel, "Antarctica just hit a record low in sea ice — by a lot." *Washington Post*, September 25, 2023.
[135] Rasmus Benestad, RealClimate, https://www.realclimate.org/index.php/archives/2023/09/old-habits/

ice shelves that lost mass lost more than 30% of their initial mass. This 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.

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 9 above on the different RCP pathways.)

> 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)

Warming and melting trends in each scenario are presented below in Figure 11. Here is some background from the Introduction:

> 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.

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.”

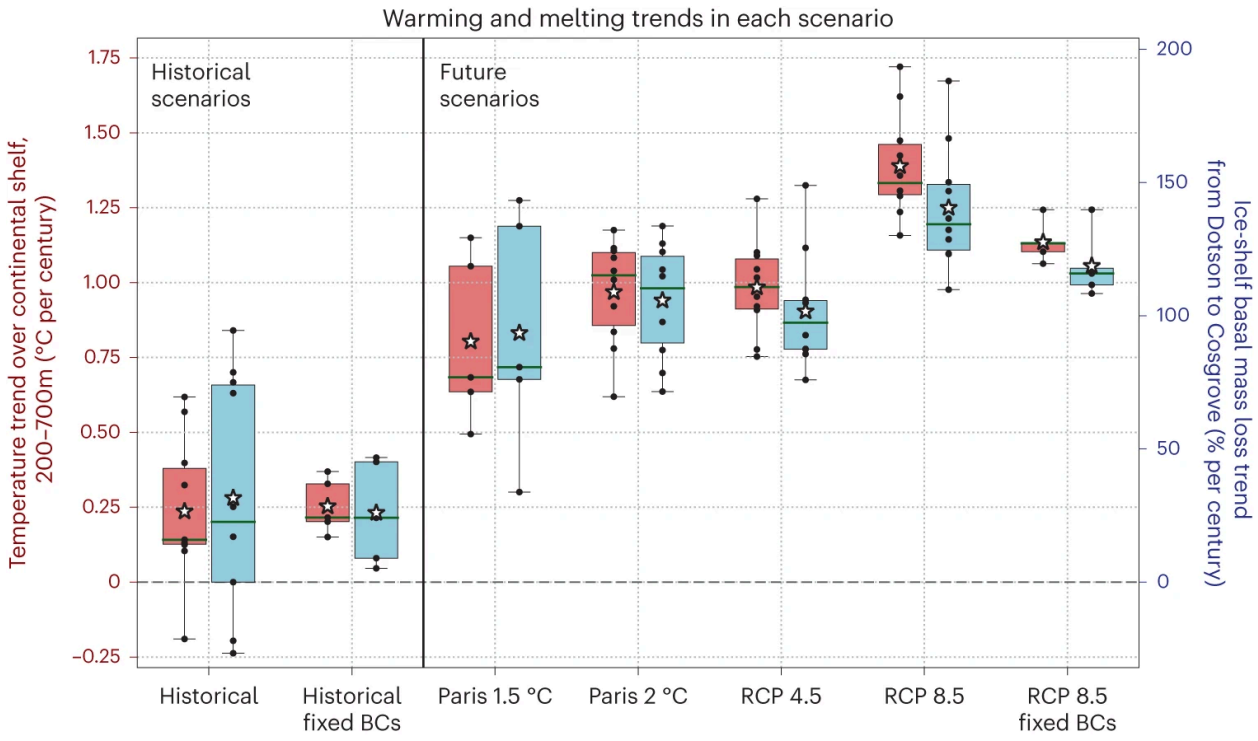


Figure 11. *"Ocean temperature trends are plotted in red (left axis); ice-shelf basal mass loss trends in blue (right axis). The scenarios are described in Extended Data Table 1; note different time spans and ensemble sizes (n = 5 for Paris 1.5 °C and the Fixed BCs scenarios, and n = 10 for all others). Temperature is averaged over the continental shelf and the depth range 200–700 m. Basal mass loss is integrated over the ice shelves between Dotson and Cosgrove inclusive and expressed as a percentage of the 1920–1949 historical ensemble mean. Both variables are smoothed with a 2-yr running mean before computing trends. Each scenario shows the ensemble mean (white stars), median (green lines), 25–75% range (boxes), full ensemble range (whiskers) and individual trends (black dots)."*

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)

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, which 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.[136]

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)

Scientific predictions get better 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:

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

> 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) also 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).

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)

Mass Migration

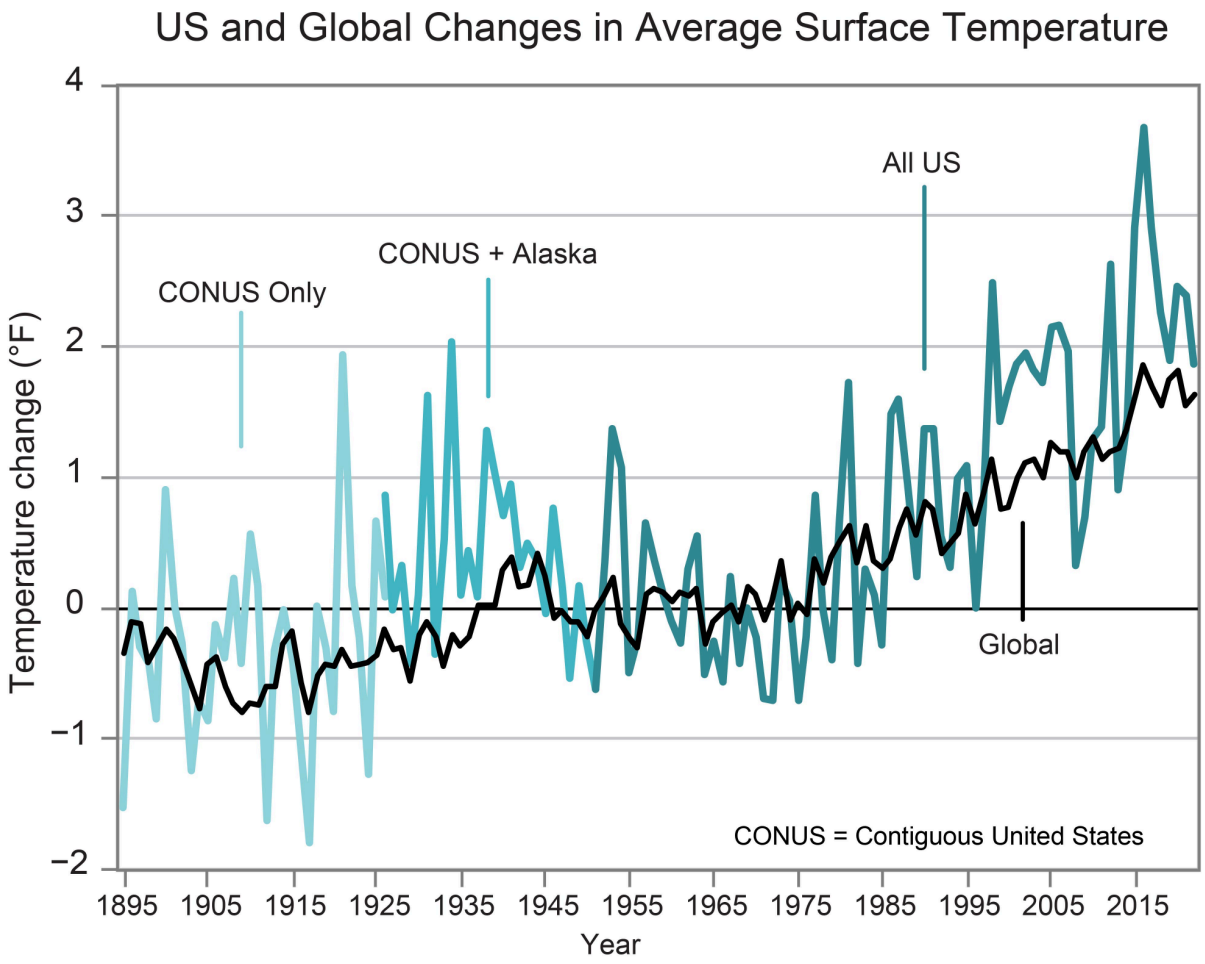
As described in the main body of this report, it is inevitable that mass migration will increase, and most countries will not welcome these migrants. For example, consider what happened recently in Saudi Arabia. Human Rights Watch interviewed 42 Ethiopian migrants and asylum seekers and their friends, 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[137]:

> 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.

[137] 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

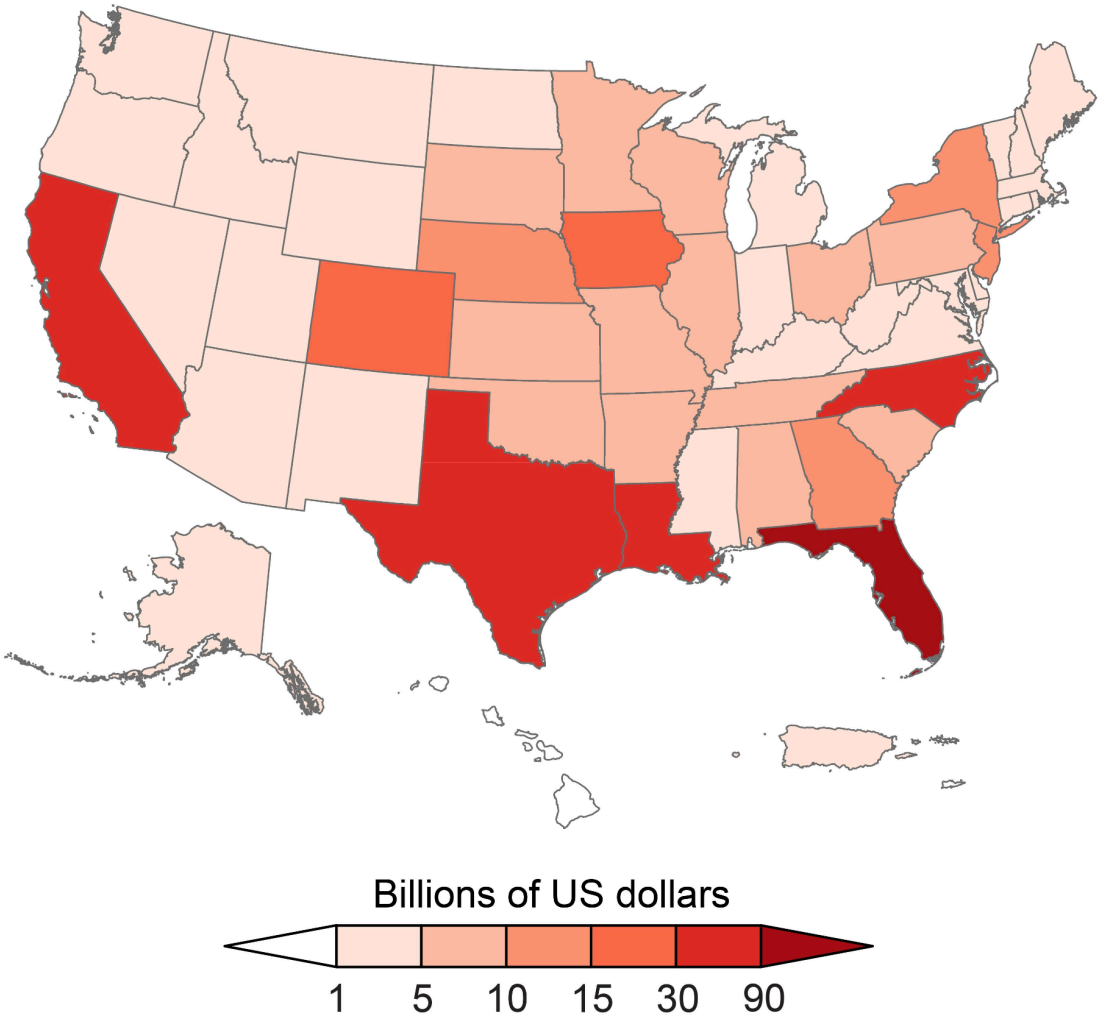
(Crimmins et al., 2023)



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

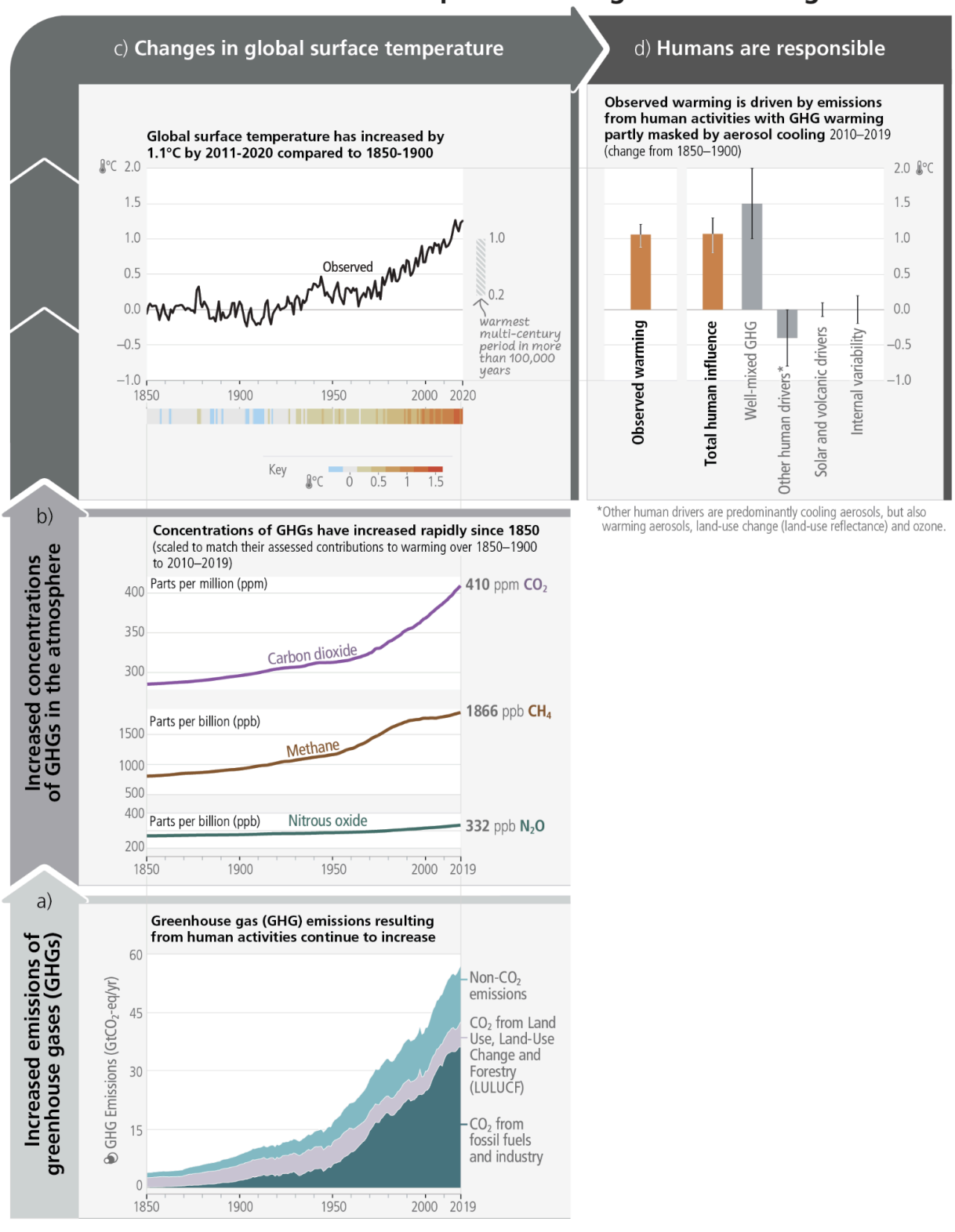
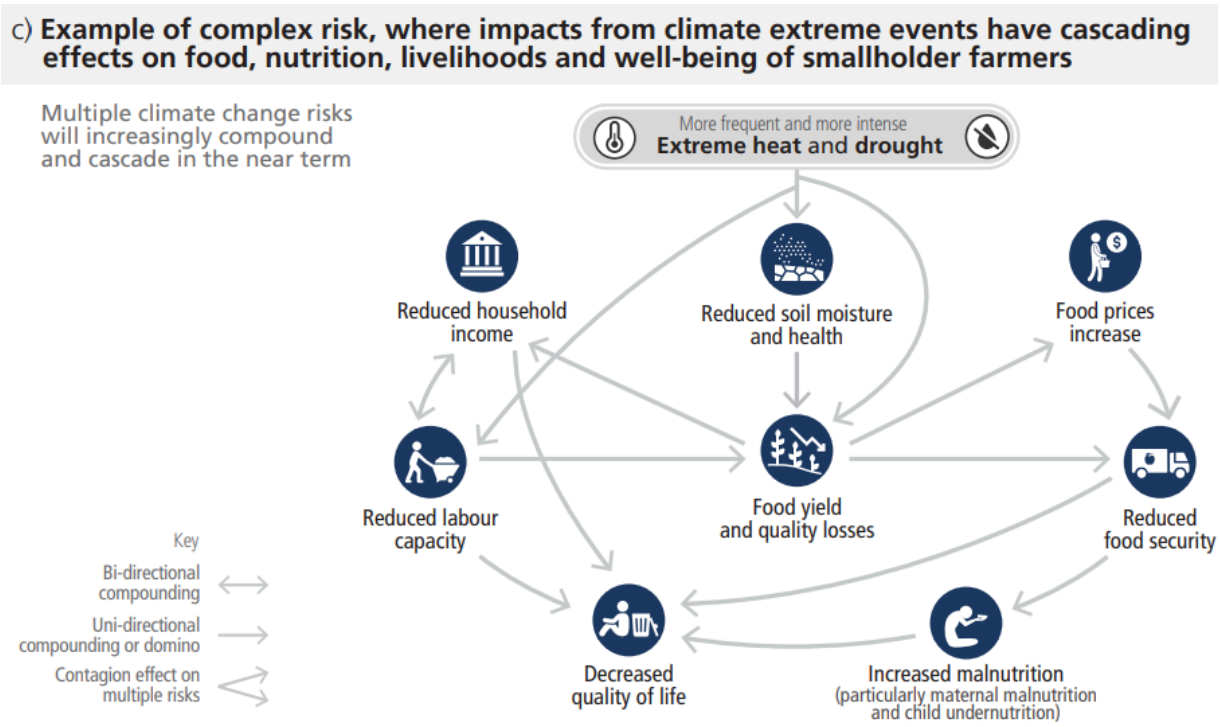


Figure 2.1 from IPCC (2023): *"The causal chain from emissions to resulting warming of the climate system. Emissions of GHG have increased rapidly over recent decades (panel (a)). Global net anthropogenic GHG emissions include CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI) (dark 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°C] 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.” (p. 3, footnote 4).

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

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.)[138]

[138] 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

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).[139]

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

[139] https://thewalrus.ca/seven-truths-climate-crisis/

> 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.

Backpage: A cartoon by Ilex Opaca.