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Title: **Bad science and good intentions prevent effective climate action**

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Abstract

Although the 2015 Paris Agreement climate targets seem certain to be missed, only a few experts are questioning the adequacy of the current approach to limiting climate change and suggesting that additional approaches are needed to avoid unacceptable catastrophes. This article posits that selective science communication and unrealistically optimistic assumptions are obscuring the reality that greenhouse gas emissions reduction and carbon dioxide removal will not prevent climate change in the 21st Century. It also explains how overly pessimistic and speculative criticisms are behind opposition to considering potential climate cooling interventions[1] as a complementary approach for mitigating[2] dangerous warming.

There is little evidence supporting assertions that: 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.

These largely unsupported assumptions distort risk assessments and discount the urgent need to develop a viable mitigation strategy. Owing to political pressures, many critical scientific concerns are ignored or preemptively dismissed in international negotiations. As a result, the present and growing crisis and the level of effort and time that will be required to control and rebalance the climate are severely underestimated.

[1] "Climate intervention" and "climate cooling" are used interchangeably throughout this paper and are intended to encompass all methods and measures of technological and nature-based solar radiation management (SRM), albedo modification, sunlight reflection, and solar geoengineering.

[2] As used in this paper "mitigation" encompasses all measures and actions designed to make climate change "less severe, dangerous, painful, harsh, or damaging" as defined in the Merriam-Webster Dictionary.

The paper concludes by outlining the key elements of a realistic policy approach that would augment current efforts to constrain dangerous warming by supplementing current mitigation approaches with climate cooling interventions.

Summary

Although the 2015 Paris Agreement's climate targets will almost certainly be missed, surprisingly few experts are challenging the current mitigation strategy as being fundamentally flawed, and calling for new approaches to avoid an escalating climate change crisis. This article argues that overly optimistic assumptions and failure to recognize the reality of ever more disastrous climate events underlie both the lack of public debate over the need for a new climate strategy and the opposition of many well-meaning scientists and environmentalists to even researching climate cooling measures.

Fossil fuel interests are the primary sources of climate denialism and misinformation, but their efforts to downplay the climate emergency and delay effective actions are unwittingly supported by flawed risk assessments from leading scientific and environmental organizations. Our paper describes these flaws, which are due in part to the failure to consider the full range of risks associated with relying solely on greenhouse gas (GHG) emissions reduction and carbon dioxide removal (CDR) to abate the climate crisis. We do not promote any particular research finding or mitigation measure, but rather we confront the failing international climate strategy and urge immediate consideration of viable complementary approaches that offer a credible path to abating catastrophic climate change.

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 recent climate assessments. It belies the reality that rising temperatures and associated changes in other climate parameters are exceeding projections and already causing serious and often irreversible impacts including melting icefields, degraded ecosystems and increasingly extreme weather. If climate change is already environmentally and socially disruptive at +1.2°C, how could it be safely stabilized at a higher temperature? More global warming will inevitably make climate change impacts more damaging and disruptive.

Largely driven by the need to ensure political acceptability, the 2015 Paris Agreement climate temperature targets were set far too high. In particular, they were not based on the original 1992 United Nations Framework Convention on Climate Change (UNFCCC) requirement to 'stabilize greenhouse gas emission concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. We need to reestablish the 1992 objective to avoid increasingly disruptive climate change. Instead of the Paris Agreement's unrealistically high temperature targets, the goal must be to reduce the increase in global average temperatures to safe levels, i.e., well below the current average.

The consensus that present international climate targets will be overshot is acknowledged in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Synthesis Report (AR6). However, the UNFCC Conference of the Parties (COP) and many other leading organizations continue to argue that emissions reduction and carbon dioxide removal can be ramped up in time to avoid dangerous climate change. In reality, destructive and very disruptive climate change is already occurring around the world; emissions continue to rise; existing national promises to cut back on emissions are not being fulfilled; it will take many decades for slowly developing new technologies to

replace existing infrastructure; and meeting mid-century targets relies on the rapid, massive deployment of presently undeveloped and unproven technologies, such as carbon capture and storage.

The Paris Agreement plan to achieve its targets is for the world to reach net zero emissions (NZE) by mid-century. This is a highly unlikely event given the continuing upward trend in anthropogenic emissions, and the failure of many countries to follow through with their voluntary Nationally Determined Contributions (NDC) to reduce emissions. Moreover, reaching NZE is unlikely to stop further warming because nature's capabilities to remove carbon dioxide (CO2) are decreasing (e.g., due to Amazon deforestation, Arctic melting, and slowing ocean overturning circulation). At the same time, natural system greenhouse gas emissions are rising (e.g., from thawing permafrost). Even with NZE, temperatures will still rise above 2°C. Reductions in anthropogenic cooling aerosols, the long life of atmospheric CO2, increasing natural emissions due to human-induced climate change, and the enormous thermal inertia of the oceans make long-term warming inevitable.

IPCC models now indicate that CDR must be coupled with NZE to reduce total atmospheric GHG concentrations. Present estimated costs of this removal are $100 to $200 per tonne of CO2. With estimates of how much CO2 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.

The Paris Agreement has created confusion through a political focus on maximum acceptable temperatures and reducing GHG emissions, rather than on the need to stabilize the climate through eliminating the Earth Energy Imbalance (EEI)—the difference between the amount of solar energy arriving at the Earth and the amount returning to space. GHG concentrations in the atmosphere are limiting the amount of the sun's energy that returns to space.

Unreturned heat is being absorbed in the ocean, land, the atmosphere, and ice. Dissipating accumulated heat, referred to by James Hansen as "warming in the pipeline," and increasing capacity to return heat to space are necessary to stabilize the climate. Atmospheric CO2 concentrations are now higher than they have been for over 3 million years—when sea levels were 15m higher and trees were growing in polar regions. NZE alone or coupled with CDR will not restore EEI or prevent temperatures and sea levels from rising to ever more dangerous levels.

IPCC models also incorrectly assume that rising temperatures will have incremental impacts, and that overshoot can be managed with adaptive measures and reversed within decades. Their assessments greatly underestimate the devastating non-linear environmental, economic, and social risks of overshooting safe global temperatures. The frequency and intensity of extreme weather events is increasing at rates much greater than the rate of global average temperature rise, making it increasingly difficult and costly to develop resilience to climate impacts. Moreover, it is impossible to adapt to irreversible, catastrophic impacts such as species extinction, the loss of glaciers, the inundation of island states by rising seas, and the release of gigatonnes of methane (CH4) from warming permafrost and oceans. Any suggestion otherwise is a political, not a scientific, statement.

A major problem with IPCC cost-benefit models is that they estimate future climate damage based on analyses of the smaller weather impacts of the past. The IPCC Sixth Assessment Report warns that rising temperatures will trigger the interaction of climatic and non-climatic risks, resulting in compounding and cascading risks across sectors and regions. Yet the Summary for Policymakers omits information on the nonlinear increase of risk with warming. Analyses also tend to minimize the likelihood and risks of high-temperature scenarios, although these are already occurring and are the most impactful.

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.

The biggest dangers are associated with passing climate tipping points. These are non-linear, irrevocable changes in the climate, such as the melting of permafrost, the dieback of rainforests, or the disruption of ocean currents. There is overwhelming evidence that the present amount of warming is nearing or has already crossed critical tipping points. The only surprise is how unprepared we appear to be in view of the accelerating frequency of increasingly dire reports of disastrous floods and forest fires, desertification, bleaching coral reefs, and shrinking sea ice.

A transition to NZE will take decades. During this time major climate tipping points will be passed. Because these shifts will create amplifying feedback loops (e.g., melting permafrost releases GHGes that further warm the planet), passing even some of these tipping points risks triggering runaway climate change.

Alarms should be ringing in the scientific community because observations are taking us close to the IPCC's highest GHG concentration pathway scenario, RCP 8.5. This concentration pathway may become the most likely if positive feedback loops are activated sooner than expected, e.g., by melting icefields reflecting less sunlight, accelerating degradation of the Amazon rainforest, or the release of permafrost CH4. Also, the IPCC low emission scenarios assume not only phasing out fossil fuels, but also the sustained large-scale deployment of CDR that may not be technologically, economically or politically feasible.

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's Summaries for Policymakers do not convey the seriousness and level of risk this failure entails in ways that interface with the traditional risk-management approach to building resilience to worst plausible outcomes. Safety standards for critical infrastructure like planes, buildings, and medical equipment assume that acceptable failure rates are fractions of one percent. Yet IPCC scenarios regularly include carbon budgets that have only a 50% or 66% likelihood of meeting climate targets: that is, the analyses are accepting risks to the Earth system and to human civilisation that we would not permit in our own lives, and that would not pass the safety standards of any competent regulatory body.

The world does not have decades to prevent dangerous climate change: the climate crisis is here with us now. The grim truth is that dangerous climate overshoot is already occurring, the world is still many decades away from significantly reducing emission of GHGs, the international mitigation strategy is inadequate and failing, and the risks of catastrophic climate change are real and increasing.

Catastrophe is not inevitable; it will only occur if we fail to develop and deploy safe, realistic mitigation strategies. These will require the application of rapid climate cooling measures to reduce risks during the long time it will take to decarbonize the global economy and restore a safe, stable climate.

The main obstacle to considering climate interventions beyond emissions reduction and CDR is the opposition of many well-meaning scientists and environmentalists to further investigating and potentially deploying climate cooling measures and technologies. Their case rests on the false supposition that the risks of climate interventions are greater than the risks of not intervening. Their main concern is “moral hazard” – fear that cooling global temperatures will give fossil fuel producers more excuses to continue polluting. Other concerns include potential for dangerous side effects such as interfering with the planet’s monsoons and the risk that climate cooling could be suddenly terminated causing severe shock to the global climate and ecosystems.

These are valid concerns that should receive serious consideration in climate cooling research and public policy development, but they fail to reflect the gravity of the climate crisis and the dangers posed by the narrow, inadequate, and failing strategy now in place. Climate interventions will have risks, but the risks and moral hazards of not intervening are not only much greater, but existential.

Choosing not to deploy climate cooling means to accept global temperatures rising by more than 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 (e.g., James Hansen) believe that an increase of 4°C would threaten the survival of human civilization.

We are not facing a choice between continuing with a safe, proven strategy of gradual emissions reductions versus deploying dangerous geoengineering technologies with known risks. The choice is between pursuing an inadequate strategy that will almost certainly fail with disastrous consequences or researching the still unknown benefits and risks of a variety of climate cooling measures, ranging from small and local to large scale, that could be a critical part of a safe, viable strategy.

Given the catastrophic costs and risks of accelerating climate change, it is essential to give priority to researching all overshoot and mitigation risks and options including all potentially viable climate cooling methods. This will allow the comparative evaluation of the risks of overshooting safe temperatures versus the risks of various climate interventions. In turn, this will enable the development of a credible, integrated strategy for cooling global temperatures to within safe, stable limits. Cooling interventions will be needed while GHG emissions are lowered, atmospheric concentrations reduced, and adaptive and nature-based restorative measures take hold to secure a sustainable and healthy planet.

Some opponents of climate interventions believe that even researching new technologies is dangerous, as it will legitimize their use. To reduce the risks of negative side effects, they are calling for an international moratorium on all geoengineering research. This position is mistaken for two reasons:

- First, the genie is already out of the bottle. China, the US, and other countries are already researching geoengineering. As temperatures rise, it is inevitable that climate interventions will be made to prevent the increasing occurrence of crop failures and other disasters. There is an urgent need to develop an international program to research safe climate cooling methods to forestall the possible unilateral deployment of untested technologies by individual countries.

- Second, without scientific research and testing, the international community will not be able to evaluate the relative benefits and risks of using various geoengineering measures. Dozens of potentially useful methods have been proposed for cooling the climate and removing GHGs; to increase effectiveness and reduce risks, it is likely that a viable mitigation strategy will deploy a wide range of intervention technologies at different scales in different regions.

Opponents also argue that if geoengineering tools were deployed to mask a high level of global warming and then suddenly terminated, there would be a rapid and damaging rise in temperatures. On the contrary, "termination shock" is more likely to occur from not intervening than intervening. For example, not giving a diabetic insulin to avoid the risk that they might suddenly stop taking it, would change a potential problem into an inevitable crisis. Similarly, unless climate cooling is used to keep temperatures at safe levels, the inevitable outcome of rising temperatures will be dangerous and potentially catastrophic climate change.

Climate cooling is not an alternative to emissions reduction or carbon removal. The EEI must be rectified. Beyond ever more frequent heat waves, extreme weather events, and sea level rise, increasing concentrations of CO2 and CH4 in the atmosphere are making the oceans more acidic and unliveable for aquatic species. To prevent rising acidity from destroying critical marine ecosystems, further emissions must be stopped and GHG levels rapidly reduced.

The Paris Agreement's NZE goal is an essential part of any realistic climate mitigation strategy. The problem is that this goal will not be achieved in time to prevent dangerous climate change and will not be sufficient to keep global temperatures at safe, stable levels. For this reason, the Paris Agreement needs to be supplemented with a strategy that uses climate interventions to rapidly lower average global temperatures to safe levels while GHG emissions and atmospheric concentrations are reduced as fast as possible to concentrations that correct EEI.

A realistic and credible overshoot risk management plan must combine three approaches: (1) rapidly reducing GHG emissions; (2) deploying large-scale CDR 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.

We currently find ourselves adrift in the story of "The Emperor Has No Clothes". Although most experts are painfully aware that international climate targets will be missed, many fear that criticisms will weaken mitigation efforts. As a result, they continue to support a flawed, failing strategy. But this is a road to disaster. For the sake of the planet, our children, and future generations, we must find the clarity and courage to speak truth to power, change course and develop strategies and solutions for success, not failure.

Summary of Fallacies and Facts

Section 1: Why climate targets will be missed (p. 10)

Fallacy 1: International climate targets can still be met using current mitigation strategies.

Fact 1.1: The AR6 Synthesis Report and most experts recognize that the climate target of 1.5°C will be missed, and the 2°C target will very likely be missed.

Fact 1.2: Heating from warming oceans, existing GHGes, and the removal of aerosols will raise temperatures above 2°C.

Fact 1.3: GHG emissions are still rising and national pledges are not being met due to opposition from vested interests and the magnitude of the needed transformation: it will take decades for renewable technologies to replace existing infrastructure.

Fact 1.4: Strategies for climate stabilization rely on deploying unproven and as yet undeveloped technologies to remove large amounts of atmospheric CO2 and counter the increasing natural emissions caused by climate change.

Section 2: NZE will not stabilize the climate (p. 14)

Fallacy 2: Overshoot will be temporary with NZE enabling the global average temperature increase to be stabilized at +1.5°C - 2°C.

Fact 2.1: The global climate is neither safe nor stable now at 1.2°C. Even stabilizing temperatures at 1.5°C - 2°C would involve greater extremes with much more disruptive and irreversible impacts.

Fact 2.2: Because of the ongoing EEI, NZE will not stop temperatures and sea levels from rising.

Fact 2.3: With emissions continuing to rise, the transition to NZE will clearly take decades. During this time major climate tipping points will be passed, making it virtually impossible to prevent increasing warming.

Fact 2.4: Although achieving NZE will require large scale CDR, no feasible plans exist for developing and deploying the necessary new technologies.

Fact 2.5: Because of the massive scale and long-term nature of global heating, mitigation will still be required for centuries after NZE is reached.

Section 3: The danger of overshooting safe temperatures (p. 18)

Fallacy 3: Overshoot risks and costs are manageable.

Fact 3.1: Most reports greatly underestimate the devastating non-linear environmental, economic, and social risks and costs of overshooting safe global temperatures.

Fact 3.2: The deadly impacts and costs of increasingly acidifying oceans are also greatly underestimated.

Fact 3.3: Virtually irreversible tipping points are already being passed. Acceleration of the rate of climate change is a real and existential risk.

Fact 3.4: 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.

Fact 3.5: Incomplete accounting is resulting in fundamentally flawed assessments of risks and costs.

Section 4: IPCC assessments are wrong (p. 24)

Fallacy 4: Climate models represent all possible future risks from climate change, and IPCC assessments and international agreements are objective and accurate.

Fact 4.1: The Paris Agreement has created confusion by focusing on maximum acceptable temperatures, rather than on the need to reduce the EEI.

Fact 4.2: 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 4.3: Models incorrectly assume that rising temperatures will have incremental impacts, and that overshoot can be managed with adaptive measures and reversed within decades.

Fact 4.4: Analyses tend to minimize the likelihood and risks of high-temperature scenarios, although these are already occurring and are the most dangerous.

Fact 4.5: Because IPCC reports are developed through a political process requiring consensus, many key issues are downplayed or ignored.

Fact 4.6: Risk assessments need to be informed by reality as evidenced by current and past data.

Section 5: We need climate cooling (p. 35)

Fallacy 5: Climate interventions are so dangerous, even research should be banned

Fact 5.1: Because current mitigation methods are failing to prevent dangerous temperature increases, there is an urgent need to develop a supplemental strategy.

Fact 5.2: While climate interventions will have risks, the risks and moral hazards of not intervening are not only much greater, but also existential.

Fact 5.3: The risks and benefits of climate interventions can only be assessed in comparison to the risks and costs of all possible policy options, including continuing with the current strategy.

Fact 5.4: Many potentially safe, viable geoengineering approaches merit attention. All options should be explored for their capacity to safely offset dangerous warming.

Fact 5.5: Termination shock is inevitable if climate cooling is not used to keep temperatures at safe levels.

Conclusion

Direct climate cooling: the crucial missing element of a viable mitigation strategy

The real moral hazard

References (listed by subsection) (p. 49)

Introduction

Even though the Paris Agreement's climate targets will almost certainly be missed, only a few experts are questioning current mitigation strategies. Even fewer are researching effective alternatives. Policy analysts David Spratt and Ian Dunlop offer an explanation:

> *It is unsurprising that there is a lack of understanding amongst the public and elites of the full measure of the climate challenge…. A fast, emergency-scale transition to a post-fossil fuel world is absolutely necessary to address climate change. But this is excluded from consideration by policymakers because it is considered to be too disruptive. The orthodoxy is that there is time for an orderly economic transition within the current short-termist political paradigm. Discussion of what would be safe — less warming than we presently experience — is non-existent. And so we have a policy failure of epic proportions.* (Spratt and Dunlop, 2018)

Although the Intergovernmental Panel on Climate Change (IPCC) is responsible for coordinating the global response to climate change, "it has become apparent that there exists a gap between the realities of our world and the assessment reports provided by the IPCC." (Kyle Kimball, 2022) Incomplete modelling and erroneous premises distort risk assessments, discounting the urgent need to develop a realistic mitigation strategy. False assumptions underlie the lack of public debate over the failure of current climate mitigation approaches, and underpin the opposition by many well-meaning scientists and environmentalists to testing climate cooling technologies.

Almost everyone is familiar with the story of the *Titanic*. Although Captain Smith had been warned of drifting ice, following standard practice, he steamed ahead at full speed. By the time a lookout saw the iceberg and the First Officer gave orders to reverse engines and change course, it was too late to overcome the enormous forward inertia of the ship and avoid a fatal collision.

We can draw parallels between the fate of the Titanic and the climate crisis—in both cases systemic inertia makes it impossible to change course in time to avoid disaster. However, we are not on a steamship, but on Spaceship Earth, and instead of the threat coming from frozen ice, it comes from rising heat threatening the stability and survival of critical biophysical life support systems. Moreover, while the *Titanic's* captain had absolute authority over everyone aboard his ship, our leaders, including the UN Secretary General and the Chair of the IPCC, can only try to exert moral pressure on fractious governments and corporations, some of whom are actively subverting mitigation efforts.

So, even though this article focuses critical attention on the IPCC, it is important to note that climate change is a wicked systemic problem, the product of complex interactions between multiple physical, biological and social systems. For this reason, no single actor is solely to blame, and no single lever can be pressed to solve the crisis. Because atmospheric pollution is a byproduct of a dysfunctional global political economy, ultimately the climate crisis can only be resolved through a long process of structural change.

Humanity—especially youth—is now thoroughly alarmed by the dangers of climate change. The World Economic Forum's 2023 survey of global risks found that public and private sector leaders believe that the three biggest risks in the coming decade are all climate-related. In contrast, "geo-economic confrontation" (read China) comes in ninth (WEF, 2023).

Most politicians, business leaders, scientists and environmentalists are doing their best to improve the world. But because the international climate strategy is wrong, much of the hard work and good intentions are wasted. Now we must challenge and change this doomed strategy or risk destroying life on Earth as we know it and the future of our children and generations to come.

Although this paper cites many articles, its purpose is not to promote any particular research finding, technology, or mitigation measure, but rather to make three crucial points:

1) The current approach is failing to prevent ever more dangerous climate change.

2) Contributing to this failure is a reductionist scientific philosophy that ignores research on the non-linear dynamics of interactive systems, while creating a false "scientific consensus" through a process that builds agreement at the lowest common denominator.

3) To develop a credible strategy for keeping global temperatures within safe limits, urgent research and debate is needed at a global scale on all overshoot and mitigation risks and options.

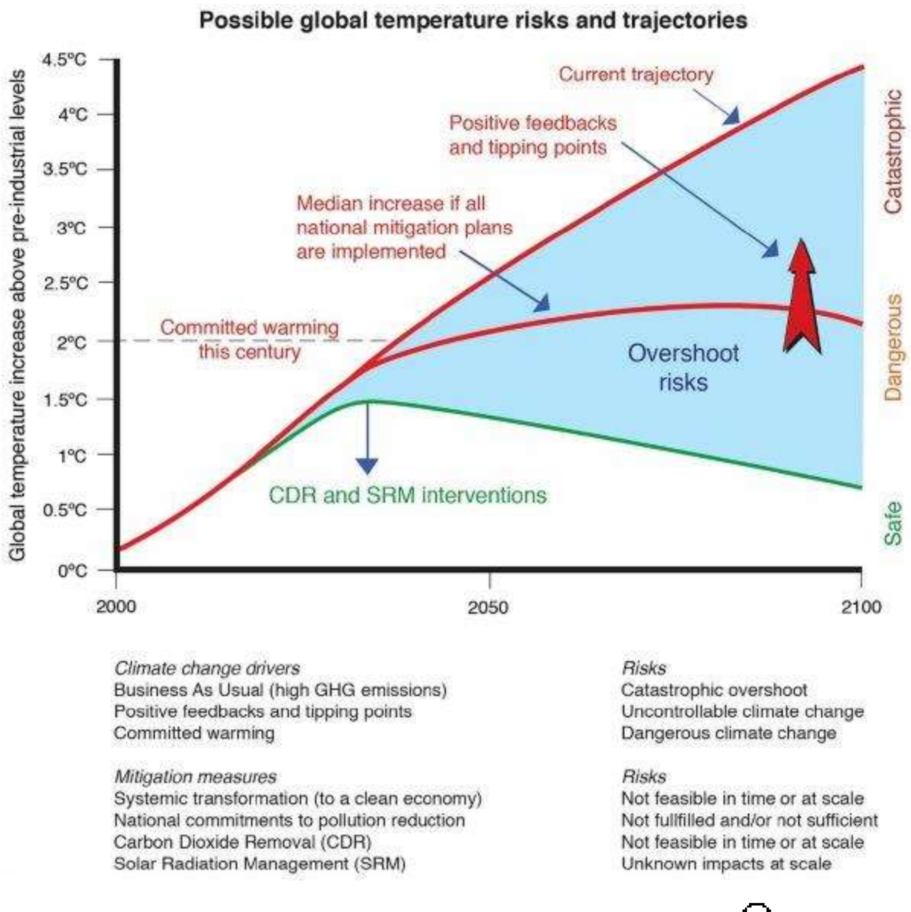

Figure 1. Possible global temperature risks and trajectories. 🅭 Taylor and Vink, 2021.

Section 1: Climate targets will be missed

Fallacy 1: International climate targets can still be met using current mitigation strategies

Fact 1.1: The AR6 Synthesis Report and most experts recognize that the climate target of 1.5°C will be missed, and the 2°C target will very likely be missed.

In 1992, recognizing that human-made GHGes are causing global warming, governments signed an international treaty to reduce emissions—the United Nations Framework Convention on Climate Change. In the 2015 Paris Agreement, states further pledged to limit average global temperature increases to no more than 1.5°C−2°C above pre-industrial levels (UNFCCC, 2015).

Alarmingly, rather than falling, emissions have steadily increased over the last three decades. Atmospheric levels of carbon dioxide, methane and nitrous oxide have constantly risen (e.g., in 2022 CO2 increased by 2 ppm to 417 ppm, with CO2 equivalent (CO2e) concentrations reaching 523 ppm) and are expected to continue their high rates of growth (NOAA, 2022; NOAA, 2023; BOM, 2022). In July, 2023, the world's average temperature topped 17°C for the first time in 120,000 years (Gayle, 2023; Rannard, Rivault, Tauschinski, 2023); spikes in the global average temperature are now exceeding the 1.5°C lower Paris Agreement threshold (Turton, 2023).

In 2023 the extent of Antarctic sea ice also reached a historic low, with an area the size of Mexico failing to freeze. Will Hobbs, a sea ice scientist at the University of Tasmania, said, "Unprecedented is a word that gets bandied around a lot, but it doesn't really get to just how shocking this is. It is very much outside our understanding of this system." (Readfearn, 2023)

The extreme temperatures sweeping the globe prompted World Meteorological Organisation (WMO) Secretary-General Petteri Taalasspikes to warn that "Heatwaves are going to be normal. We will see stronger extremes. We have pumped so much carbon dioxide in the atmosphere that the negative trend will continue for decades." (WMO, 2023a) In 2023, 6,500 wildfires raged across Canada, burning an area twice the size of Portugal and released 1.7bn tons of planet-heating gases – three times the total emissions that Canada, a major fossil fuel-producing nation, produces each year (MIlman and Witherspoon, 2023).

Although global emissions are still rising, the International Energy Agency (IEA) projects that fossil fuel consumption will peak before 2030 and fall into permanent decline as climate policies take effect (Ambrose, 2023). However, to stay below 1.5°C, the UN states that global GHG emissions need to be reduced from 2019 levels by 43 per cent by 2030 and by 60 per cent by 2035 (UNFCCC, 2023). This cannot happen: the UNEP Emissions Gap Report 2022 finds that there is no longer a credible pathway to 1.5°C (UNEP, 2022). In fact, the carbon dioxide budget for staying below the 1.5°C target may have already been exceeded (Breyer et al., 2023).

The feasibility of current efforts is also problematic: though many countries have pledged to reduce their emissions to net zero by 2050 or 2060, not only are national goals insufficient to keep global warming below 2°C (Harvey, 2021; IPCC, 2021), but also existing pledges are unlikely to be met (Liu and Raftery, 2021), and analysis concludes that deep decarbonization by 2050 is not likely (Stammer et al., 2021). For example, a few days before signing the 2021 Glasgow Climate Pact, the Xinhua news agency proudly announced that China had produced more coal than ever before in a single day—12 million tonnes. When burnt for energy, this one day of coal will emit as much CO2 as Ireland's output for an entire year (McGrath, 2021).

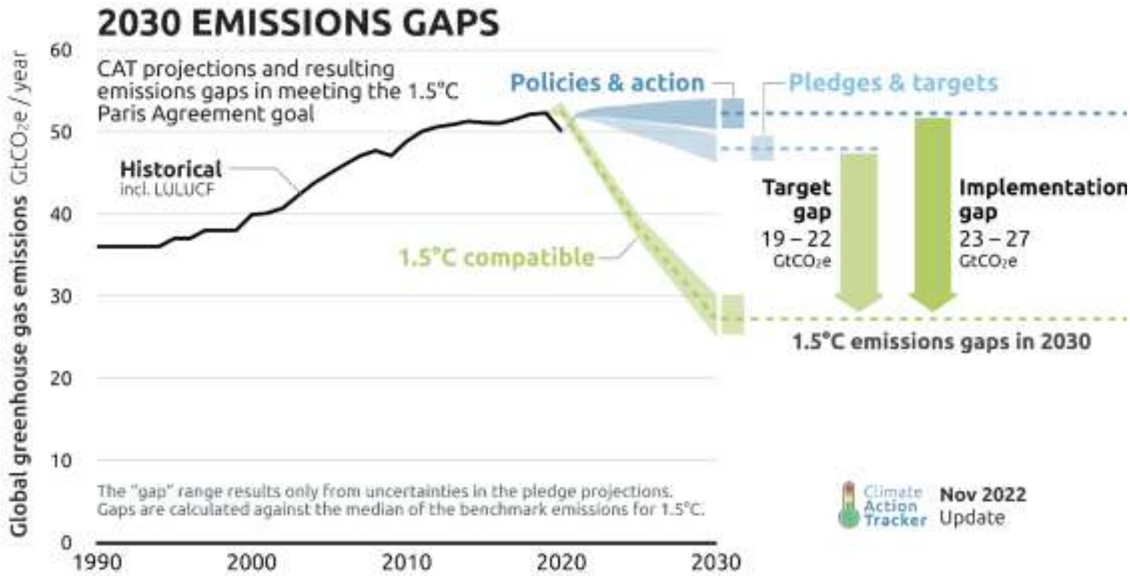

Figure 2. 2030 Emissions Gaps. Reducing emissions this quickly is an impossible fantasy.
Climate Action Tracker, 2022. © Climate Analytics and NewClimate Institute.

At the opening of COP27, António Guterres, the UN Secretary-General, summed up the crisis: "We are in the fight of our lives. And we are losing. GHG emissions keep growing. Global temperatures keep rising. And our planet is fast approaching tipping points that will make climate chaos irreversible. We are on a highway to climate hell with our foot still on the accelerator." (UN, 2022)

While laudable, the UN has been issuing these warnings for many years. In 2007 then IPPC chair Rajendra Pachauri said, "If there's no action before 2012, that's too late…. What we do now will determine our future. This is the defining moment." (Rosenthal, 2007) Many climate activists are unimpressed by the rhetoric. Greta Thunberg commented, "COP26 even watered down the blah, blah, blah." (BBC, 2021)

Unfortunately, the clock has now run out. It is high time for politicians and scientists to recognize that current strategies have not and cannot prevent dangerous climate change. Now we need to face the grim facts and develop a new, realistic mitigation strategy.

Fact 1.2: Heating from warming oceans, existing GHGes, and the removal of aerosols will raise temperatures above 2°C.

Between 1971 and 2020, GHGes trapped roughly 380 zettajoules of extra heat (von Schuckmann et al., 2020), which is 25 billion times the energy emitted by the Hiroshima nuclear bomb. Ocean heat uptake nearly doubled during 2010–2020 relative to 1990–2000 (Li, England & Groeskamp, 2023). The global net radiative flux imbalance means that oceans are now warming at the equivalent of five atomic bombs *every second* (Cheng et al., 2020; Lubben, 2020). The long life of CO2 (Rae et al., 2021; Ying, Schubert and Jahren, 2020; Snyder, 2016) and the large thermal inertia of the oceans make long-term future warming inevitable (IPCC, 2021).

Global heating is also masked by anthropogenic air pollution, which creates aerosols that reflect sunlight and lower global mean surface temperatures by 0.5°C– 1.5°C (Lelieveld et al., 2019; Rogelj et al., 2020; Nair et al., 2023; Hansen et al., 2023). Temperatures will rise as pollution from burning fossil fuels is reduced, although increases could be partially moderated by the simultaneous reduction of tropospheric ozone and CH4.

Because warmer atmospheres retain more water, the concentration of water vapour—a GHG — increases with rising temperatures. A one degree C rise in temperature causes a 7% increase in atmospheric humidity. While doubling CO2 from pre-industrial levels (280 ppm) to around 550 ppm without feedbacks would produce a global warming of about 1°C, because of water vapour and other 'fast' feedbacks, a CO2 doubling will amplify the long-term average warming to around 3°C. This 'fast climate sensitivity' is estimated by various climate models between 2°C and 4.5°C (Raupach and Fraser, 2011).

Even if all emissions stopped tomorrow, current committed warming will raise global temperatures by 2°C – 5°C above pre-industrial levels by 2100 (Cheng et al., 2022; Huntingford et al., 2020; von Schuckmann et al., 2020; Zhou et al., 2021; Hansen et al., 2023). These are massive, long-term problems: the energy imbalance caused by elevated GHG concentrations will continue to drive warming and sea level rise for centuries to millennia (Wadhams, 2016).

Fact 1.3: GHG emissions are still rising and national pledges are not being met due to opposition from vested interests and the magnitude of the needed transformation: it will take decades for renewable technologies to replace existing infrastructure.

Even under the most optimistic scenarios, decarbonization is not likely to occur quickly enough to mitigate the effects of system inertia and lags caused by factors including committed warming from previous emissions, the delayed impacts of existing warming (e.g., Samset et al., 2020; Brown et al., 2019), cultural and political inertia, and the resistance of fossil fuel producers and other vested interests (Michaelowa et al., 2018; Westervelt, 2022; Varadhan and Verma, 2023). For example, although there is no carbon budget left for building any more CO2 emitting power stations, vehicles and industrial facilities (Vaughan, 2018), fossil fuel subsidies are expected to rise from $5.9 trillion in 2020 to $6.4 trillion in 2025 (Parry et al., 2021). Fossil fuel investment in 2023 is more than double the levels required to achieve NZE by 2050 (IEA, 2023a).

Another obstacle is the greed of the rich world. Although developed countries committed in 2019 to mobilising USD 100 billion per year by 2020 to support climate action in poor countries, little real aid has materialised as most assistance has been given in the form of loans or repurposed from other foreign aid (Oxfam, 2023).

Moreover, developing new low-carbon technologies and replacing existing infrastructure is a complex, time-consuming process (e.g., Åhman, 2020). Although significant progress is being made (IEA, 2023a), only 2 out of 55 clean energy technologies and sectors are on track to help hit international emissions reduction targets (IEA, 2023b). The inertia of existing systems and the long lifespan of infrastructure assets further contribute to the challenge of rapid decarbonization (Sawal, 2020).

Other sectors are even more resistant to change: e.g., forestry and land clearing (WRI, 2023), and agrifood systems (FAO, 2022), which are responsible for almost 30% of all emissions. Even if all other emissions are halted, GHG emissions from global food production will push Earth beyond 1.5°C. (Sawal, 2020), with the majority of this coming from animal husbandry rather than arable farming. (Xu et al., 2021).

Fact 1.4: Strategies for climate stabilization rely on deploying unproven and as yet undeveloped technologies to remove large amounts of atmospheric CO2 and counter the increasing natural emissions caused by climate change.

Although it will not be possible to achieve net zero without large-scale CDR (IPCC, 2022), many methods may not be politically and/or technologically feasible (Anderson 2015, Vaughan and Gough 2016; IPCC, 2018), and no plans have been made to deploy the required technologies (Schenuit et al., 2021; Larkin et al., 2018; Friedmann, 2019).

For example, although scenarios rely on the widespread use of Carbon Capture and Storage (CCS) technologies, high costs and limited storage capacity have restricted deployment (IEA, 2020). Global CCS capacity is only 0.1% of annual global emissions from fossil fuels (BloombergNEF, 2022), and even if this technology becomes economically and technically viable, optimistic forecasts do not anticipate significant CCS capacity until the 2030s (Freites and Jones, 2021). Bioenergy with Carbon Capture and Storage (BECCS), also faces challenges, including the availability of feedstocks and permanent storage (Creutzig, 2016; Fuss et al., 2018). Currently, only around 2 Mt of biogenic CO2 are captured per year, far short of the circa 250 Mt/yr that needs to be removed through BECCS by 2030 in the NZE by 2050 Scenario (IEA, 2022).

At the same time, methane production is still increasing (McKinsey, 2021), with producers promoting “natural gas” as a transitional fuel on the basis that it is a cleaner alternative to coal. Critics question this, since CH4 production (e.g., in Russia and the United States) is a major contributor to climate change (Kemfert et al., 2022). If atmospheric CH4 continues to increase at >5 ppb/year in the coming decades, by itself it will be sufficient to challenge the Paris Agreement (Nisbet et al., 2019).

Counting ‘biofuel’ as a clean, renewable source of energy also doesn’t make sense (Haberl et al., 2012). Wood-burning is not a credible alternative energy source: the UK Drax biomass plant, for example, is the 3rd biggest single emitter of CO2 in Europe (Proactive, 2021).

As well, many carbon offsets and credits have dubious value. For example, research into Verra, the world’s biggest certifier for the rapidly growing $2bn voluntary offsets market, discovered that more than 90% of their rainforest carbon offsets do not produce genuine carbon reductions (Greenfield, 2023; Lakhani, 2023).

Despite decades of missed goals and rising emissions, most governments, experts and environmental organizations still believe that the Paris Agreement targets can be met through a strategy of emission reductions, and that overshoot can be mitigated through the use of still unproven and undeveloped CDR technologies.

Section 2: NZE will not stabilize the climate

Fallacy 2: Overshoot will be temporary with NZE enabling the global average temperature increase to be stabilized at +1.5°C - 2°C

Fact 2.1: The global climate is neither safe nor stable now. Even stabilizing temperatures at 1.5°C - 2°C would involve greater extremes with much more disruptive and irreversible impacts.

Average global temperatures have risen 1.2°C above 1850-1900 levels—the IPCC “pre-industrial” reference period (IPCC, 2018). This increase is causing changes to the climate system in every region of the world that are unparalleled over centuries to millennia. Already, rising temperatures are having serious impacts including disappearing mountain glaciers retreating sea ice, degrading terrestrial and marine ecosystems, rising sea levels, regional desertification, intensifying fire weather in some regions, increasingly extreme precipitation events in some others, increasing soil erosion, decreasing crop yields, and more frequent and dangerous heat waves (IPCC, 2023).

Logical inferences from this are: If the global climate is neither safe nor stable now, how could it be safely stabilized at a higher temperature?

Overshoot doesn't begin after we pass the Paris targets: overshoot began decades ago when rising concentrations of GHGes created the radiative imbalance driving global warming. In order to have a safe, stable climate, temperature increases will have to be kept below 1.0°C, which in turn means that atmospheric CO_2 concentrations will have to be reduced and kept below 350 ppm (Breyer et al. 2023). Disturbingly, the total concentration of GHGs and other forcing agents, including cooling aerosols, passed 523 parts per million carbon dioxide equivalent (CO_2e) in 2022 (NOAA, 2022).

Because of the warming that is already in the system, and because cumulative emissions are steadily increasing, 2023's record temperatures will soon be broken. UN chief António Guterres warns that the planet is entering an "era of global boiling" (McGrath and Poynting, 2023).

A plan to temporarily overshoot "safe" temperatures may make climate model simulations and political negotiations easier, but it doesn't solve the problem of irreversible impacts. As the International Cryosphere Climate Initiative says, "We cannot negotiate with the melting point of ice" (ICCI, 2021). 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 succeeds in stopping further temperature increases, this will not produce a safe, stable climate.

Fact 2.2: Because of the ongoing EEI, NZE will not stop temperatures and sea levels from rising.

There are differing opinions on the subject of decadal changes in temperatures after a complete emission stop: sometimes these are driven by differing meanings for "net-zero emissions" (i.e. if it includes only CO_2, other GHGs, or aerosols as well), but sometimes by differing definitions of "warming would immediately stop". Nevertheless, even if all emissions stopped tomorrow, it is very likely that temperatures would still reach 1.5°C. The removal of aerosols (even if counter-balanced by reduction in CH_4 and other short-term forcers), the long life of atmospheric CO_2 and the large thermal inertia of the oceans make some long-term future warming inevitable (Koven et al., 2023).

Von Schuckmann et al. (2020) argue that climate stabilization is impossible without reducing the EEI to approximately zero. They calculate that to prevent further warming and bring the Earth back into an energy balance, atmospheric CO_2 cannot be above 353 ppm.

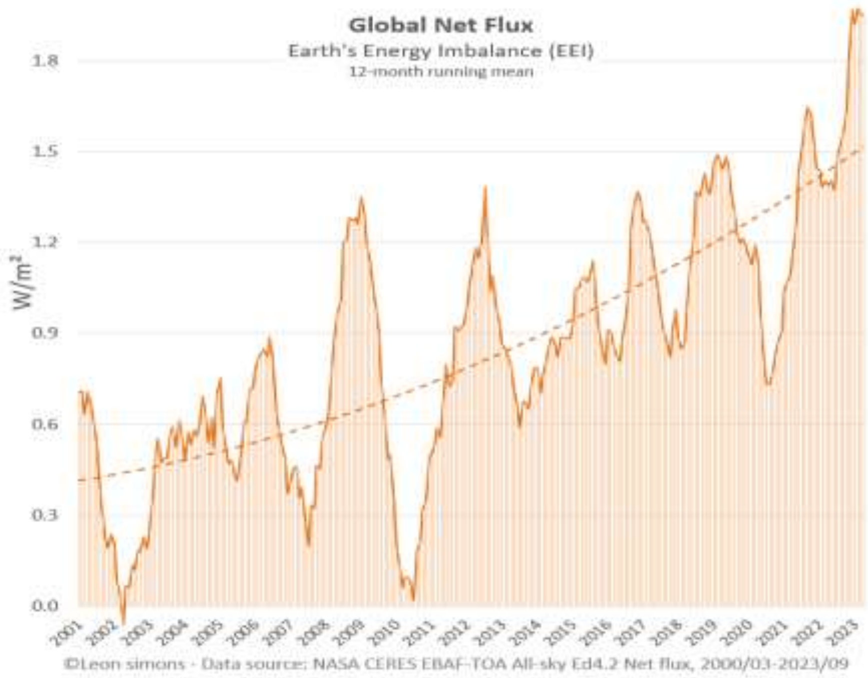

Figure 3. Global Net Flux. © Leon Simons.

Other scientists dispute this, suggesting that once NZE is reached, additional warming will eventually end due to radiative forcing being cancelled out by the progressive absorption of CO2 in the ocean and land-biosphere (e.g., Dessler and Hausfather, 2023). However, this assumes that all further anthropogenic emissions will be effectively countered through a combination of (declining) natural sinks and large-scale CDR, and that climate tipping points will not be passed and trigger positive feedback loops.

Given present trends, it is doubtful whether any of these counteracting conditions will be achieved using current mitigation methods. For example, Randers and Goluke (2020) warn that the ESCIMO climate model shows that the world is already past a point-of-no-return for global warming. ESCIMO indicates that self-sustained thawing of the permafrost has begun and will continue for hundreds of years, even if all emissions of human-made GHGs end immediately. This positive feedback loop is the combined effect of three processes: (1) declining surface albedo (driven by melting of glacial ice and the Arctic ice cover), (2) increasing amounts of water vapour in the atmosphere (driven by rising temperatures), and (3) increasing concentrations of atmospheric GHG (driven by declining natural carbon sinks and emission of CH_4 and CO_2 from thawing permafrost).

NZE studies also show very large uncertainties over how long the additional warming should last. Different models yield very different results (MacDougall et al., 2020), and the difference between 5 or 50 years would be incredibly important for risk management. Considering such uncertainty, we simply can't afford to bet on the lower end of the estimate.

The paleoclimatic record indicates that the planet can only reach thermal equilibrium after all the internal response feedback time lags have played out. Earth history shows many examples where climate responses to hyperthermal events lasted tens or hundreds of thousands of years, and the biological responses to them took millions of years.

Even if CO_2 concentrations are limited to less than 450 parts per million, the long-term consequences are likely to be devastating: they haven't been above 400 ppm for 3 million years. Then sea levels were 15 m higher than now and trees were growing in Antarctica (Carrington, 2019; Galey and Hood, 2019).

A proxy reconstruction of global temperature over the past 2 million years by Carolyn Snyder suggests that stabilization at today's GHG levels may already commit Earth to an eventual total warming of 5 degrees Celsius (range 3 to 7 degrees Celsius, 95 percent credible interval). This would take place over the next few millennia as ice sheets, vegetation and atmospheric dust continue to respond to global warming (Snyder, 2016).

Fact 2.3: With emissions continuing to rise, the transition to NZE will clearly take decades. During this time major climate tipping points will be passed, making it virtually impossible to prevent increasing warming.

Achieving NZE is an extremely difficult and complex challenge (Fankhauser et al., 2022). 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) (e.g., Edwards, 2015), and because the technologies do not yet exist to allow the rapid decarbonization of the global economy in many sectors, e.g., agriculture (Costa et al., 2022) and aviation (Bergero and Davis, 2023).

The transition to net zero will (very optimistically) take 30 to 40 years. Due to the relationship between warming and cumulative emissions, during this time global temperatures will keep rising before they stabilize. Without large scale SRM and CDR, major climate tipping points will be passed in the coming decades, making it even more difficult to prevent increasing warming (see section 3.3).

Fact 2.4: Although achieving NZE will require large scale CDR, no feasible plans exist for developing and deploying the necessary new technologies at the scale needed.

Although all Illustrative Mitigation Pathways (IMPs) that limit warming to 2°C or lower require removing 450 to 1,100 $GtCO_2$ between 2020 and 2100 (IPCC, 2022; Smith et al., 2023), no feasible plans exist for deploying them at scale, in part because of the high costs and difficult trade-offs required (e.g., converting croplands to forests).

To remove sufficient CO_2 from the atmosphere to meet the Paris targets it will be necessary to create a new carbon sink on the scale of the ocean sink (Rockström et al., 2016). Additional problems are that the potential capacity of many CDR measures is constrained by available land, water and nutrients and by environmental concerns (e.g., Kramer, 2020; Anderson and Peters, 2016; Heck et al., 2018; Dooley et al., 2021; Clark et al., 2023). Another major obstacle is cost (IPCC, 2018; Carrington, 2021).

For example, projected GHG emissions pathways call for bioenergy with carbon capture and storage (BECCS) to be deployed at levels as high as 400 exajoules (EJ) per year of primary energy production, and 22.5Gt of CO_2 per year of carbon removal. However, this would require between 0.4 and 1.2 billion hectares of land: i.e., switching 25% to 80% of current global cropland from growing food to producing energy and capturing carbon (Fajardy et al., 2019).

Although natural carbon sinks — mainly forests — currently mitigate ~30% of anthropogenic carbon emissions (~2 billion tonnes per year), these are shrinking, largely due to deforestation. Only a tiny fraction of CO2 removal (0.1% or 0.002 $GtCO_2$ per year) comes from current CDR methods such as bioenergy with carbon capture and storage (BECCS), biochar, and direct air capture with carbon capture and storage (DACCS). The issue is also confused by false accounting—e.g., the false assumption that harvesting and then replanting trees results in low or even negative GHG emissions (Peng et al., 2023).

At least 1,300 times more CDR from new technologies, and twice as much from trees and soils are needed to limit temperatures below 2°C by 2050 (Smith et al., 2023). However, because photosynthesis sharply declines with rising temperatures, the land sink strength may be almost halved as early as 2040 if emissions continue at current rates (Duffy et al., 2021).

Moreover, there are currently few plans by countries to scale CDR above current levels. Two extensive reviews (Lawrence et al., 2018; Nemet et al., 2018) conclude that it is implausible that CDR technologies can be implemented at the scale needed by 2050. Reliance on "nature-based" CDR might also be made more difficult by increasing temperatures, if weather systems are disrupted (i.e. due to an increase in droughts and fire weather).

Additionally, since CO2 would only be removed slowly, CDR methods will not have an appreciable effect on the global climate for decades. Nevertheless, both decarbonization and CO2 removal measures will have to be ambitiously deployed to limit the duration of climate temperature overshoot to less than two centuries (Ricke, Millar and MacMartin, 2017).

Although CDR costs are likely to fall as technologies are developed and scaled up (e.g., Plumer and Flavelle 2021), Dooley and Kartha (2018, p. 94) point out that it is dangerous to assume that CDR measures can and will be deployed on time and at scale: "If the promise of future negative emissions leads policy makers to grossly underestimate the effort needed in the near term to meet these targets, the results would be disastrous."

Fact 2.5: Because of the massive scale and long-term nature of global heating, mitigation will still be required for centuries after NZE is reached.

Solomon et al. (2009) estimate that climate change resulting from increases in carbon dioxide concentrations will be largely irreversible for 1000 years after emissions stop. Deep ocean warming, acidification and sea level rise will continue for millennia after global surface temperatures initially stabilize (IPCC, 2021).

Based on the climatological record, Hansen et al. (2023) estimate that committed warming from existing concentrations of GHGs will continue to increase global average temperatures for the next 400 years, until equilibrium is reached at approximately 10°C above pre-industrial levels. Note that 10°C of warming is certainly adequate to wipe out the human race.

Temperature increases of this magnitude pose an existential threat to human civilizations. Also, since these forecasts are based on current GHG concentrations, temperatures will rise even higher with further emissions. On the other hand, climate interventions have the potential to both constrain temperatures at safe levels and remove GHGes, but only if applied at globally serious levels and maintained for as long as required to safely stabilize the climate.

Section 3: The dangers of overshoot

Fallacy 3. *Overshoot risks and costs are manageable.*

Fact 3.1: Most assessment reports greatly underestimate the devastating non-linear environmental, economic, and social risks and costs of overshooting safe global temperatures.

The scientific consensus is that climate change is likely to push most natural and human systems into increasingly dangerous and irreversible states (IPCC, 2018). For example, global warming above 1.5°C will make much of the tropics unliveable (Zhang, Held and Fueglistaler, 2021); 20% to 30% of the world's land surface will experience aridification at less than a 2°C temperature rise (Park et al., 2018); and conflicts over increasing shortages of food and water are forecast to increase (e.g., Farinosi et al., 2018).

Quiggin et al. (2021) point out that in the absence of dramatic emissions reductions before 2030, many climate change impacts are likely to be locked in by 2040, and become so severe they go beyond the limits of what nations can adapt to. For example, by 2040 some 3.9 billion people are likely to experience major heat waves, 12 times more than the historic average, and while agriculture will need to produce almost 50 per cent more food by 2050, yields could decline by 30 per cent.

Rising temperatures also increase oceanic heatwaves and damage marine ecosystems, which are another key food source for humans. Heat stress causes dramatic die-offs: e.g., after a series of marine heatwaves, between 2018 and 2021, the population of snow crab in the Bering Sea declined by 10 billion (Szuwalksi et al., 2023), and massive mortality of coral reefs has already happened around the world following extreme heat events (Goreau & Hayes, 2021).

Burke, Davis and Diffenbaugh (2018) estimate that the 2.5°C–3°C of global warming implied by current national commitments may reduce per capita output by 15%–25% by 2100, with output reduced by more than 30% if warming reaches 4°C.

Additionally, the probable triggering of uncontrollable feedback loops poses substantial risks. Global warming is already producing feedback effects from warming oceans and drying land sectors, including releasing CH4 from permafrost (Anthony et al., 2018) and releasing CO2 from forest fires. These feedback loops have not yet been modelled in NZE scenarios (Climate Council, 2021).

Earth is now losing at least 1.2 trillion tons of ice each year (Mooney and Freedman, 2021). An International Cryosphere Climate Initiative report warns that the Paris commitments will not prevent crossing irreversible thresholds: e.g., melting glaciers that will result in the loss of reliable water resources for millions of people; melting polar ice sheets that will eventually flood coastal cities; the release of additional GHGes from melting permafrost; and the loss of fisheries from ocean acidification. Cryosphere climate change is slow to manifest but once triggered "inevitably forces the Earth's climate system into a new state, one that most scientists believe has not existed for 35–50 million years." (Pearson et al., 2015, p. v)

Every degree of warming up to 2°C will add at least 1.3 meters to sea levels from accelerated ice flow into the ocean and melting from the Antarctic Ice Sheet, while warming between 2°C and 6°C is predicted to add 2.4 meters per degree (Garbe, Albrecht, Levermann, Donges and Winkelmann, 2020).

While the IPCC Working Group III reports frequently refer to 'cost-effectiveness', the cost against which the effectiveness is being assessed never includes the cost that would arise from exceeding a climate tipping point.

It should also be noted that there are no credible technological solutions for many climate change impacts: for example, the Arctic and boreal permafrost contain 1460 to 1600 Gt of organic carbon, almost twice the carbon in the atmosphere (WMO, 2020), and if gigatonnes of methane are released from melting permafrost and warming oceans, the process cannot be reversed.

Fact 3.2: The deadly impacts and costs of increasingly acidifying oceans are also greatly underestimated.

When carbon dioxide combines with seawater it forms carbonic acid, which makes the ocean more acidic. Since around 1850, the oceans have absorbed between a third and a half of the CO2 emitted to the atmosphere. As a result, the average pH of ocean surface waters has fallen from 8.2 to 8.1 units. This corresponds to a 30% increase in ocean acidity, a rate of change roughly 10 times faster than any time in the last 55 million years (CoastAdapt, 2017; Jiang et al., 2023).

If GHG emissions continue at the current rate (the RCP8.5 trajectory), by the end of the century average pH is projected to decrease by 0.3–0.4 units (~100%–150% increase in acidity) (Kwiatkowski et al., 2020). Increasing acidity will make it difficult for marine organisms such as corals, clams, mussels, crabs, and some plankton, to form calcium carbonate, the material used to build shells and skeletal material. The survival of many microscopic marine species will also be threatened (Bird, 2023). In addition, ocean acidification will disrupt pelagic food webs via the proliferation of toxic algal blooms (Doney et al., 2020). The increasing degradation of marine food chains will seriously damage fishing industries and tourism.

Ocean systems are not able to adapt to these rapid changes in acidity—a process that naturally occurs over millennia. Declining ocean pH levels will persist as long as concentrations of atmospheric CO2 continue to rise. The stress on marine organisms will be exacerbated by rising temperatures and exposure to multiple biogeochemical changes. To avoid significant harm to critical marine ecosystems and the food security of billions of people, atmospheric concentrations of atmospheric CO2 must be rapidly reduced to at least 320-350 ppm or less (IUCN, 2017).

Fact 3.3: Virtually irreversible tipping points are already being passed. Acceleration of the rate of climate change is a real and existential risk.

Climate tipping points (CTPs) are irrevocable changes in the climate, such as the melting of ice sheets, or the dieback of rainforests. These are points of no return: once glaciers and ecosystems like coral reefs have disappeared, they cannot be restored. For example, warming oceans make the collapse of the West Antarctic Ice Sheet unavoidable (Naughten, Holland and De Rydt, 2023). Evidence is all around us that we are nearing or have already crossed CTPs associated with critical parts of the Earth system—we see catastrophic fires in rainforests, spreading deserts, degrading ecosystems, and shrinking sea ice (e.g., Walsh, 2016; Bochow and Boers, 2023; Kim et al., 2023).

Another example is rainfall in Greenland, which has increased by 33% since 1991, with flooding rain darkening and melting the ice sheet and baring rocks (Box et al., 2023). However, the accelerating rate of melt and the positive feedbacks of increasing rainfall and reducing albedo are not represented in IPCC models.

Armstrong McKay and colleagues (2022) identify six tipping points that are likely to be crossed within the Paris Agreement targets of 1.5°C - 2°C of warming. These are:

- Greenland Ice Sheet collapse
- West Antarctic Ice Sheet collapse
- Coral reef die off at low latitudes
- Sudden thawing of permafrost in northern regions
- Abrupt sea ice loss in the Barents Sea
- Collapse of ocean circulation in the high-latitude North Atlantic

They point out that crossing these climate tipping points can generate positive feedbacks that will increase the likelihood of crossing other CTPs. For example, Arctic permafrost may permanently thaw even if warming stays between 1.1 °C and 1.5°C. Above 1.5°C of warming, losing the permafrost becomes "likely," and we are currently on track for 2.7°C of warming in this century. If all the permafrost thawed, emissions would be equivalent to 51 times all GHG emissions in 2019.

Alarmingly, the ESCIMO climate model indicates that a self-sustaining process of permafrost thaw has already begun, which suggests that the world is already past a point-of-no-return for global warming. This cycle consists of decreasing surface albedo, increasing water vapour feedback and increasing thawing of the permafrost, which releases both methane and carbon dioxide, resulting in even further temperature rises, and so on. Even after no more man-made GHG are emitted, this cycle will continue on its own until all carbon is released from permafrost and all ice is melted (Randers and Goluke, 2020).

The likelihood of passing additional CTPs becomes non-negligible at ~2°C and increases greatly at ~3°C. Above 2°C the Arctic would very likely become summer ice-free, and land carbon sink-to-source transitions would become widespread.

Scientists are detecting warning signs for many CTPs. For example, researchers have found an almost complete loss of stability of the Atlantic meridional overturning circulation (AMOC). These currents are already at their slowest point in at least 1,600 years, and new analysis indicates that the AMOC could collapse between 2025 and 2095, with a central estimate of 2050, if global carbon emissions are not reduced (Ditlevsen and Ditlevsen, 2023). This would have catastrophic consequences, severely disrupting the rains that billions of people depend on for food in India, South America and West Africa; increasing storms and lowering temperatures in Europe; and raising sea levels in the eastern North America (Boers, 2021)

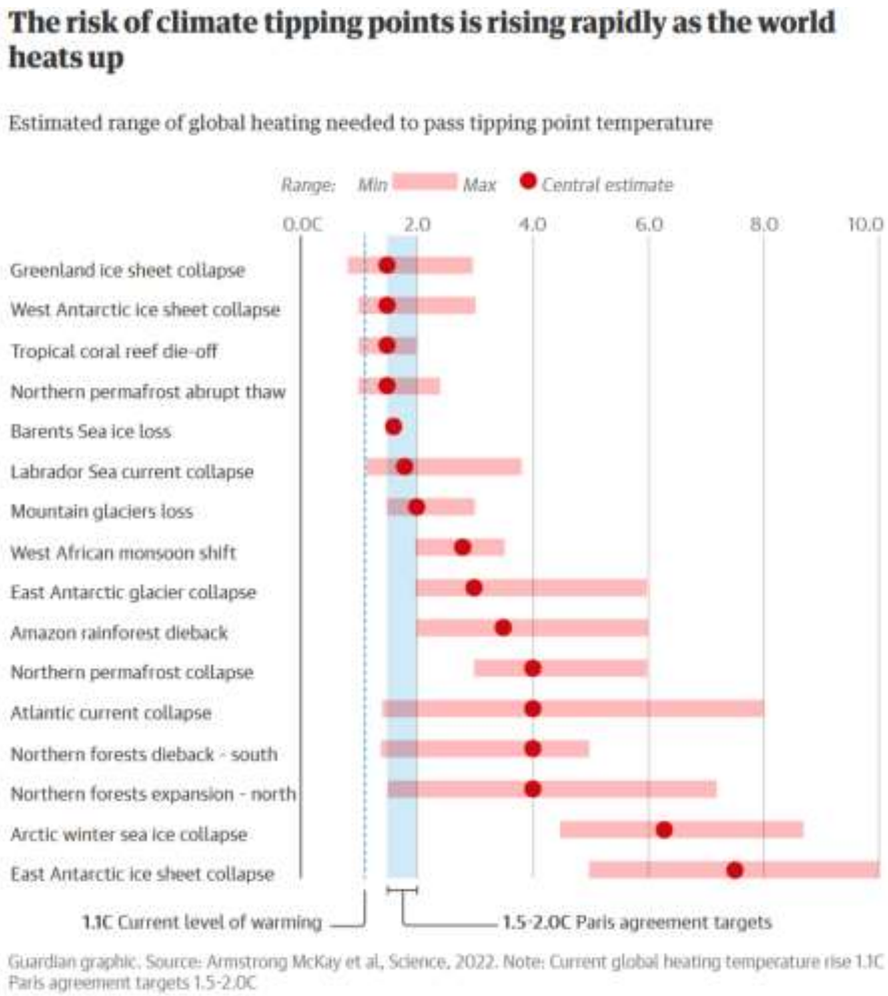

Figure 4. The risk of climate tipping points is rising rapidly as the world heats up. © AAAS.

The IPCC's highest-end GHG concentration pathway, RCP 8.5, remains close to observations in many regions and may eventuate if negative feedback loops are activated, such as emissions from melting permafrost and forest die-backs (Schwalm, Glendon and Duffy, 2020). Both of the high-emission pathways considered in the IPCC's most recent Working Group I report contain 4°C increases in the "very likely" range for 2081 through 2100, temperatures that many scientists believe would pose a significant threat to civilization (Steel, DesRoches, Mintz-Woo, 2022).

Tipping elements have been identified in all earth systems including cryosphere, ocean circulation systems and the biosphere, and a growing risk is that even if the Paris Agreement targets are met, a cascade of positive feedbacks could push the Earth System irreversibly onto a "Hothouse Earth" pathway (Steffen et al. 2018; Klose, Karle, Winkelmann and Donges, 2020). During the last glacial period abrupt climate changes sometimes occurred within decades, with temperatures over the Greenland ice-sheet warming by 8°C to 16°C at each event (Corrick et al., 2020).

The IPCC has been cautious in its evaluation of climate tipping points. For example, its latest report stated that there was a chance of a tipping point in the Amazon by the year 2100. However, while most studies only focus on one driver of destruction, such as climate change or deforestation, in reality ecosystems are simultaneously impacted by multiple interacting threats, e.g., water stress, degradation and pollution. Because tipping points can amplify and accelerate one another, more than a fifth of ecosystems worldwide, including the Amazon rainforest, are at risk of a catastrophic breakdown within a single human lifetime (Willcock et al., 2023). Record drought in Amazonia in 2023 suggests we are much closer to these thresholds than models predict.

Fact 3.4: 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.

IPCC scenarios assume that if overshoot occurs, temperatures can be returned to safe levels by 2100 through large-scale CDR (Anderson, 2015). The caveat is that many of the proposed CDR measures may not be politically and/or technologically feasible (IPCC, 2018). Most policy makers also assume that most human and environmental systems will be able to adapt to a few degrees of higher temperatures without serious consequences. Unfortunately, both assumptions are questionable and don't match available evidence (IPCC, 2018).

Many changes will be irreversible. For example, the International Cryosphere Climate Initiative points out that while it will only take a global mean temperature increase of around 1.6°C to melt most of the Greenland Ice Sheet, it will take another ice age to replace the lost ice (ICCI, 2015; Bochow et al., 2023).

Climate change has already driven some species to extinction and is expected to drive many more species and ecosystems towards tipping points that are beyond their adaptive capacity (Román-Palacios and Wiens, 2020). The IPCC notes that: "Extinction of species is an irreversible impact of climate change, with increasing risk as global temperatures rise (very high confidence). The median values for percentage of species at very high risk of extinction…are 9% at 1.5°C rise in GSAT, 10% at 2°C, 12% at 3.0°C, 13% at 4°C and 15% at 5°C (high confidence), with the likely range of estimates having a maximum of 14% at 1.5°C and rising to a maximum of 48% at 5°C." (IPCC, 2022, p. 202)

For a foretaste of the future, we can look at how climate change has already increased wildfire season length, wildfire frequency, and burned area (MacCarthy, Tyukavina, Weisse and Harris, 2022). For example, the megafires that engulfed south-eastern Australia in 2019–2020 were so intense that they burned habitats rarely exposed to fire, killing or displacing nearly three billion mammals, reptiles, birds, and frogs (WWF, 2020). Counting tiny invertebrates, 120 trillion creatures died in the fires (Gibb and Porch, 2023). These fires do irreversible damage: complex forest ecosystems cannot adapt to fires of this scale and intensity, and their thousands of interconnected species cannot be repopulated by human interventions.

Extinction is forever, and losing many keystone species and critical ecosystems will do catastrophic damage not only to the environment, but also to our human societies, which utterly depend on the biosphere for health and sustenance. Tragically, since it is impossible to adapt to these catastrophes, most politicians find it easier to pretend that each crisis is an aberration, rather than early warnings of an ever more deadly trend.

Fact 3.5: Incomplete accounting is resulting in fundamentally flawed assessments of risks and costs.

The current approach to managing climate change risks is fundamentally flawed because the risks and costs of failing are likely catastrophic and therefore unacceptable (Kemp, Xu, Depledge, Lenton 2022; Kimball, 2022).

As David Spratt points out, “The fact that the IPCC incorporates in its core business risks of failure to the Earth system and to human civilisation that we would not accept in our own lives raises fundamental questions about the efficacy of the whole IPCC project…. IPCC carbon budgets regularly include risks of failure (overshooting the target) of 33% or 50%, that is, a one-in-two or one-in-three risk of failure. Thus a 2-degree carbon budget with a 50% chance actually has a 10% risk of ending up with 4 degrees of warming, which is incompatible with the maintenance of human civilization.

“These are risks of failure that no government or person would agree to in any other aspect of life — whether it be buildings and bridges, safety fences or car seats — where acceptable failure rates are tiny fractions of one per cent. The fact that the IPCC incorporates in its core business risks of failure to the Earth system and to human civilisation that we would not accept in our own lives raises fundamental questions about the efficacy of the whole IPCC project.” (Spratt, 2023)

Robert Pindyck argues that the integrated assessment models (IAMs) used to estimate the social cost of carbon (SCC) and evaluate alternative abatement policies have crucial flaws: some inputs (such as the discount rate) are arbitrary, but have huge effects on the models’ final estimates; the models' descriptions of the impact of climate change are ad hoc, without theoretical or empirical foundation; and the models ignore the most important driver of the SCC, the possibility of a catastrophic climate outcome. “IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading.” (Pindyck, 2013)

A major problem with these cost-benefit models is that they estimate future climate damage based on the analyses of past weather impacts (Pezzey, 2019). The evaluation of climate risks needs to take into account not only linear developments and their impacts, but also likely non-linear developments since climatic tipping elements, climatically sensitive social tipping elements, and climate-economic shocks may be the largest contributors to the costs of climate change (Kopp, Shwom, Wagner and Yuan, 2016). The economist Nicholas Stern (2016) argues that while these hard-to-predict estimates are difficult to estimate, future IPCC reports need to take them into account as they have the most troubling potential consequences. Another area that deserves more attention is the higher-risk scenarios, which are less predictable but also hold more devastating implications.

A study conducted by William Nordhaus noted, ‘Natural scientists’ estimates [of the damages from climate change] were 20–30 times higher than mainstream economists’’ (Nordhaus, 1994, p. 49). Nevertheless, the IPCC 2014 report reflects the economists’ conservative outlook: “For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers (medium evidence, high agreement). Changes in population, age, income, technology, relative prices, lifestyle, regulation, governance, and many other aspects of socioeconomic development will have an impact on the supply and demand of economic goods and services that is large relative to the impact of climate change.” (Arent et al., 2014, p. 662)

After summarizing the peer-reviewed economic literature, the 2022 IPCC Report concluded that: “warming of ~4°C may cause a 10–23% decline in annual global GDP by 2100 relative to global GDP without warming.” (IPCC 2022, p. 2459) In contrast, Pearce and Parncutt (2023) argue that global warming of even 2 °C will kill approximately 1 billion (mainly poorer) humans, and many climate scientists argue that the impact of even a 3°C increase could be “catastrophic” (e.g., Kemp et al. 2022).

DeFries et al. (2019) suggest that IPCC economic assessments of the potential future risks of climate change grossly underestimate many of the most serious consequences because these risks are difficult to quantify precisely and lie outside of human experience.

Steve Keen suggests that it would have been prudent for the IPCC to have climate scientists peer-review the climate change assumptions made in economic papers, as most economists have little expertise in the area. Instead, referees with expertise only in economics approved the publication of economic impact assessments that climate scientists would almost certainly have disputed. As a result, the empirical components of the vast majority of climate change economic papers are based on scientifically false assumptions that drastically underestimate the likely economic damages of climate change (Keen, 2023).

Keen believes that the reasons why economists' estimates of future climate change damage have been much more optimistic than the forecasts of scientists is because economists used three spurious methods to estimate damage: assuming that about 90% of GDP will be unaffected by climate change, because it happens indoors; using the relationship between temperature and GDP today as a proxy for the future impacts of global warming; and using surveys that dilute extreme warnings from scientists with optimistic expectations from economists. "Correcting for these errors makes it feasible that the economic damages from climate change are at least an order of magnitude worse than forecast by economists, and may be so great as to threaten the survival of human civilization." (Keen, 2020)

Section 4: IPCC assessments are wrong

Fallacy 4: Climate models represent all possible future risks from climate change, and IPCC assessments and international agreements are objective and accurate

Fact 4.1: The Paris Agreement has created confusion by focusing on maximum acceptable temperatures, rather than on the need to reduce the EEI.

The ultimate objective of the 1992 United Nations Framework Convention on Climate Change, the 1997 Kyoto Protocol is "to stabilize GHG concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development." (UNFCCC, 2023). However, the IPCC moved from an atmospheric stabilization target to an average surface temperature target, in order to keep having achievable targets, mostly with an "inspirational" objective. The result is that rather than focusing attention on reducing the EEI, the Paris Agreement negotiated temperature goals that are dangerously high, unsafe, unstable and probably unachievable with the proposed policies.

Temperature targets became acceptable with a scientific and political convergence on defining 2°C as a boundary beyond which there would be risks to many unique threatened ecosystems, a large increase in the number of extreme weather events, sea level rise and the risk of triggering dangerous instabilities in the climate system. The 2°C target has become a critical part of the EU, UN Conference of Parties, and other organizations policies, both because it provides a clear goal for (gradual) decarbonization efforts, and because it suggests that temperature rises below this target can be safely managed.

The IPCC's fourth assessment report from 2007 (AR4) stated that in order to keep global average surface temperature increases at 2°C to 2.4 °C above pre-industrial values by the end of this century, atmospheric emissions need to be stabilized at 445 to 490 ppm of CO2e (IPCC, 2007). AR4 also stated that in order to stabilize atmospheric concentrations of CO2e at 450 ppm, anthropogenic CO2 emissions needed to peak in 2015, and Annex I countries would have to make emission reductions of 25–40% by 2020, and 80–95% by 2050. Even though the 450 ppm CO2e threshold was exceeded by 2014, this analysis provided the basis for subsequent UNFCCC negotiations (Lucas, 2021).

Not only is the 2°C target now almost certainly unachievable, but even the research justifying the 450 ppm CO2e/2°C target is questionable, as it ignored paleoclimate research on the relationship between GHG concentrations and temperatures (Hansen et al. 2020; Lucas, 2021a). (See section 4.2)

Research by Katrina von Schuckmann et al. (2020) concluded that to ensure a safe, stable climate, maximum concentrations of GHGes will have to be reduced to approximately 350 ppm CO2e. Above these levels, rising temperatures increasingly destabilize the climate system through the introduction of positive feedbacks.

Proponents of the planetary boundary framework argue that climate change thresholds should be framed in terms of atmospheric CO2 concentrations rather than temperature (Mathias et al., 2017). Below 350 ppm is safe, 350–550 ppm is dangerous, and above 550 ppm is catastrophic.

Fact 4.2: 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.

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 (Zeebe, Ridgwell and Zachos 2016; Lear et al. 2020).

Most of the early data used in IPCC models is from the 19th century, a time-frame that may be too short to enable accurate forecasts. Based on assessments of climate dynamics over the last 66-million-years, James Hansen and his colleagues argue that more than 80% of the warming from past GHG emissions has yet to emerge, once slow feedbacks from ice sheet cover, vegetation and long-lived GHGs other than CO2 (not all of these feedbacks are included in IPCC models) are taken into account (Hansen et al., 2023). These findings would have two major implications: first, that committed warming from existing concentrations of GHGs will continue to accelerate especially as the cooling effect from man-made aerosol pollution declines, potentially reaching 5°C above pre-industrial levels by 2100 even when considering emission pathways lower than RCP8.5; and second, that that global average temperatures will continue to rise over the next 400 years.

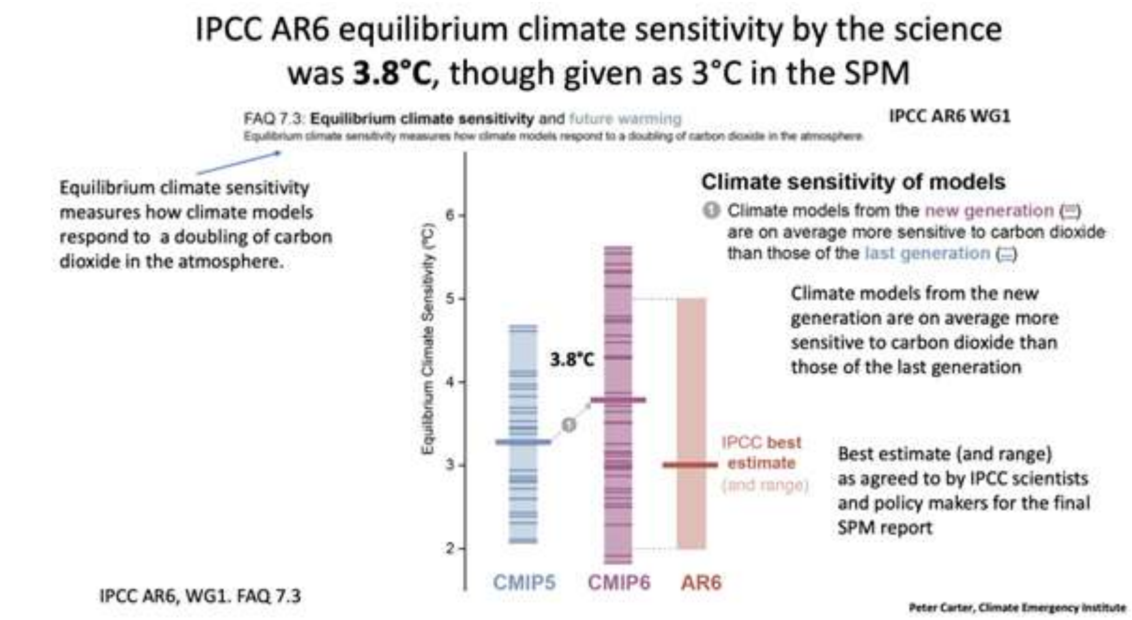

Fig. 5 The AR6 final report may have underestimated equilibrium climate sensitivity, especially by focusing on the best estimate rather than the potential for higher sensitivities. Hansen et al. (2023) argue that doubling CO_2 will result in a global warming of 4.8°C. © Peter Carter.

The next 400 years may not matter to currently living beings, but the period up to 2100 does. Continued global heating would intensify all the disastrous impacts that are already occurring. The question of elevated GHG levels has to be seriously addressed: many experts believe that tipping cascades caused by rising temperatures could be an existential threat to civilization (Lenton et al, 2019).

Assessments of future risks also need to be better informed by paleoclimatic precedents. For example, modeling, paleoclimate evidence, and on-going observations together imply that 2 ◦C global warming above the preindustrial level could be dangerous (Hansen et al., 2016). Levels of carbon dioxide in the atmosphere are 1.5 times higher now than they were 400,000 years ago, when a large part of Greenland was ice-free: if Greenland's ice sheet melts completely, sea levels will rise by 7 meters, devastating coastal cities (Paddison, 2023).

125,000 years ago, a brief episode of meltwater-induced weakening of the Atlantic meridional overturning circulation (AMOC) resulted in a massive CH4 release (Weldeab et al., 2022): new research warns that there is a risk that the AMOC may severely slow down during this century, up to the point of a functional shut down (Ditlevsen and Ditlevsen, 2023). Rapid global warming and accompanying ocean oxygen loss led to the Permian-Triassic mass extinctions (Penn, Deutsch, Payne and Sperling 2018), and Rothman (2017) estimates that carbon emissions are likely to reach the tipping point for the next catastrophic mass extinction event by 2100.

Fact 4.3: Models incorrectly assume that rising temperatures will have incremental impacts, and that overshoot can be managed with adaptive measures and reversed within decades.

Due to imperfect representations, especially in the biosphere, of the dynamics of the climate system, most models project that rising temperatures will have incremental impacts, and that overshoot can be managed and reversed. In reality many changes will be irreversible and catastrophic (e.g., the loss of species and glaciers), and many changes will be non-linear due to positive feedbacks and exceeding tipping points. These feedback loops have not yet been modelled in NZE scenarios (Climate Council, 2021).

IPCC analyses tend to presume that steady decadal average increases in global average temperatures rises will have incrementally rising global impacts. Many types of impacts are a result of short-term fluctuations above the mean, such as very intense storms and extended periods of very high-heat index. These concentrate their impacts over relatively small regions, overwhelm plausible adaptive measures, and set back regional development by decades. It is aperiodic extreme events that lead to the most damage. The assessments tend to significantly underestimate the devastating non-linear and long-lasting environmental, economic, and social disruption that occurs, and this will become especially the case as the Paris targets are overshot.

The IPCC Sixth Assessment Report concludes that erratic climate events will continue throughout this century, with multiple climate hazards occurring simultaneously, and that multiple climatic and non-climatic risks will interact, compounding overall risk and causing risks to cascade across sectors and regions (IPCC, 2021). Nevertheless, although the IPCC has discussed nonlinear responses in successive assessments and special reports, the word 'nonlinear' is not mentioned in the AR6 Summary for Policymakers.

Critics within the scientific community also argue that IPCC assessment reports have failed to capture the speed at which climatic changes have actually taken place (Pearson et al., 2015), to acknowledge that the global average temperature is already at a dangerous level, or to accurately assess the risks and costs associated with overshooting safe limits. For example, although the IPCC assessed in 2018 that there is now a high probability that the 1.5°C target will be passed, it neglected to highlight the probability of catastrophic climate damages if these temperatures are maintained (Xu and Ramanathan, 2017).

As a result, there is a growing disconnect between how climate risk is characterized and interpreted by many climate scientists, and the way the IPCC selects and represents relevant research. Some believe that critical findings are often been de-emphasised or ignored in the highly technical reports of Working Group I, or not given due consideration in the summaries for policymakers compiled by Working Groups II and III (Lucas, 2021a).

An increasing number of climate scientists argue that a new climate policy regime is required which takes into account the nonlinearity of the climate system and which places greater focus on preventing more tipping points from being crossed over the coming decades (e.g., Lenton et al., 2019). As Kopp et al. (2017) point out, there have been many times during the earth's history when the earth's climate has been pushed past a critical threshold. Frequently this has thrown it into a period of chaotic fluctuations, after which it has settled into a new and very different dynamic regime.

It is important to recognize that climate change is only one of multiple interacting non-linear threats to the global environment: in the planetary boundary framework (Richardson et al., 2023), many of them have been declared as transgressed, potentially placing Earth outside of the safe operating space for humanity (Richardson et al., 2023). The 2023 State of the Climate Report (Ripple et al., 2023) points out that 20 of Earth's 35 vital signs are now showing record extremes. "Life on planet Earth is under siege. We are now in an uncharted territory…. We are entering an unfamiliar domain regarding our climate crisis, a situation no one has ever witnessed firsthand in the history of humanity."

Fact 4.4: Analyses tend to minimize the likelihood and risks of high-temperature scenarios, although these are already occurring and are the most dangerous.

Although the IPCC has published fourteen special reports, none have covered extreme or catastrophic climate change. Considering temperature increases alone rather than heat index tends to minimize the seriousness and risks of high-temperature scenarios, even though it is combined temperature and humidity increases that most threaten workers and the public.

In the latest assessment report (AR6), only 14 % of the temperature mentions are above 2°C, although on the current trajectory global average temperatures will rise more than 2°C (Jehn et al., 2022). These omissions are especially egregious given that temperatures are already dangerous with extreme weather events becoming more frequent and damaging (Di Capua and Rahmstorf, 2023; Davariashtiyani et al., 2023), and because a number of climate tipping points will almost certainly be passed in the coming decades. As explained in Section 3, passing tipping points will have irreversible, catastrophic consequences.

It is far too soon to count on the success of current mitigation efforts. Both of the high-emission pathways considered in the most recent IPCC report contain 4°C increases in the "very likely" range for 2081 through 2100. Many scientists believe that these temperatures would pose a significant threat to civilization.

Alarms should be ringing as the IPCC's highest GHG concentration pathway, RCP 8.5, is for now close to observations. While its future carbon emissions might be on the high end compared to current proposed policies, it may still become a likely scenario due to missing carbon cycle climate feedbacks such as emissions from melting permafrost, changes in soil carbon dynamics, and changes to forest fire frequency and severity (Schwalm, Glendon and Duffy, 2020). Furthermore, many of the IPCC low emission scenarios assume not only phasing out fossil fuels, but the sustained large-scale deployment of CDR technologies that may not be technologically or economically feasible (Steel, DesRoches, and Mintz-Woo, 2022).

Luke Kemp and colleagues point out that the IPCC focus on lower-end warming is mismatched to the risks and potential damages posed by climate change. "We know that temperature rise has "fat tails": low-probability, high-impact extreme outcomes. Climate damages are likely to be nonlinear and result in an even larger tail…. Prudent risk management demands that we thoroughly assess worst-case scenarios." (Kemp et al., 2022) They suggest that the IPCC reports focus on lower-end warming and simple risk analyses out of a desire to support the Paris Agreement goals of limiting warming to well below 2 °C.

Other reasons are the culture of climate science to "err on the side of least drama" and avoid alarmism (Brysse et al., 2013). This is compounded by the consensus processes of the IPCC (Oppenheimer et al., 2019), which many scientists argue leads to reaching agreement around the "lowest common denominator". Even lead authors in the fourth Assessment Report have criticised that "in the effort to reach consensus, some key details and high-risk scenarios were not fully explored" (Hoppe and Rödder, 2019). While complex risk assessments are more realistic, they are also more difficult to conduct. Nevertheless, as the IPCC notes, climate risks are becoming more complex and difficult to manage, and are cascading across regions and sectors (IPCC, 2021).

British economist Nicholas Stern says: “Scientists describe the scale of the risks from unmanaged climate change as potentially immense. However, the scientific models, because they omit key factors that are hard to capture precisely, appear to substantially underestimate these risks. Many economic models add further gross underassessment of risk because the assumptions built into the economic modeling on growth, damages and risks, come…close to excluding the possibility of catastrophic outcomes. A new generation of models is needed in all three of climate science, impact and economics...” (Stern, 2013).

The approach of the IPCC and most governments has been to treat climate change as an economic problem that can be primarily managed through market forces (e.g., cf. UNFCCC, 2023), rather than as an existential threat to our collective survival that will require urgent government interventions (e.g., limiting emissions). In emergencies, effectiveness is prioritised over cost effectiveness: the reason why governments usually operate militaries, police, fire departments, and other emergency services. This is a vital distinction as markets do not have the capacity to respond to climate change at the speed and scale needed to prevent dangerous impacts.

Non-linear dynamics greatly increase risk (e.g., Gunderson and Holling, 2002; Barnosky et al., 2012). For example, Liu et al. (2023) have found strong correlations between tipping elements in regions as diverse as the Amazon Rainforest Area, the Tibetan Plateau and West Antarctic ice sheet. Their study shows the potential predictability of cascading tipping dynamics.

“A major concern for the world’s ecosystems is the possibility of collapse, where landscapes and the societies they support change abruptly. Accelerating stress levels, increasing frequencies of extreme events and strengthening intersystem connections suggest that conventional modelling approaches based on incremental changes in a single stress may provide poor estimates of the impact of climate and human activities on ecosystems…. Prudent risk management clearly requires consideration of the factors that may lead to these bad-to-worst-case scenarios.” (Willcock et al., 2023).

In particular, there is a need to shift from conventional risk assessment, which is focused on the likelihood and potential harm of individual events, to systemic risk assessment, which focuses on the risk or probability of breakdowns in an entire system (Lawrence et al., 2023; Monbiot, 2023). [See Fact 4.3]

Fact 4.5: Because IPCC reports are developed through a political process requiring consensus, many key issues are downplayed or ignored.

The Intergovernmental Panel on Climate Change has done indispensable work in collating peer-reviewed studies, and identifying key issues and trends for the consideration of policymakers. Their periodic assessment reports summarize the efforts of thousands of the world’s best scientists. Nevertheless, the IPCC’s summary reports are fundamentally flawed.

Although the IPCC’s scientific inputs are not directly manipulated or biased by politicians, the summary reports are arrived at by consensus of governments, not scientists—a process that allows governments to change or veto the content at the very last step of communication with policymakers and the public (e.g., Westervelt, 2022)—many key issues are either entirely 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.

For example, fossil fuels are mentioned in only seven, and livestock in only three of the first 27 climate summits. In regards to fossil fuels, the only actions the summaries propose are increasing efficiency and "management", and other than phasing down "unabated" coal burning, nowhere is there a word about reducing oil or gas production and consumption. "It's as though nuclear non-proliferation negotiators had decided not to talk about bombs. You cannot address an issue if you will not discuss it." (Monbiot,2022a)

The Paris Agreement is another example. David Spratt points out that while it avoids discussing the causes of climate change and contains no reference to "coal", "oil", "fracking", "shale oil" or "fossil fuel", nor to "ban", "prohibit" or "stop", it refers more than eighty times to "adaptation". "Emphasis is given to speculative, but potentially highly-profitable, market-based solutions…. [such as] carbon capture and storage, a technological imaginary that would pay oil and gas producers to pump gigantic volumes of carbon dioxide into wells they have emptied of fossil fuels. The focus is on the "efficiency" of the market; in the IPCC's most recent Working Group 3 report, the expression "cost-effectiveness" is mentioned 173 times." (Spratt, 2022, p. 124)

Another egregious omission is food production, which produces a third of all GHGs (Crippa et al., 2021). Over half of this pollution comes from raising livestock (Xu et al., 2021; Blaustein-Rejto and Gambino, 2023), which is more than the direct emissions from ships, planes, trucks, cars and all other transport put together (Bailey, Froggatt and Wellesley, 2014). Emissions from livestock production are projected to grow by ~70% by 2050 as the global population nears 10 billion and diets shift to incorporate more meat (Ivanovich, Sun, Gordon & Ocko, 2023).

Fossil fuel, food industry and other lobbies are effectively ensuring that discussion of many critical climate change causes and solutions are censored from the final IPCC summaries. Because emerging technologies are an enormous threat to vested agricultural interests, policy makers are not told of the existence of non-polluting alternatives to industrial agriculture, such as creating food products with precision fermentation processes. For example, proteins produced by feeding microbes hydrogen or methanol in vats require 1,700 times less land than soy, and 138,000 and 157,000 times less land than beef and lamb (Monbiot, 2022b).

Replacing livestock production with meat alternatives would not only cut GHG emissions and reduce animal suffering, but prevent the further destruction of rainforests and permit the rewilding and ecological restoration of the vast tracts now used to raise and feed livestock. Restoring forests, wetlands, savannahs, natural grasslands, mangroves, reefs and sea floors would enable us to simultaneously stop the sixth great extinction, and draw down much of the atmospheric carbon heating the planet.

However, COP27 was not focused on changing human diets but rather on cows' diets (to lower their CH4 emissions), and not on replacing polluting synthetic fertilizers with sustainable agricultural practices (e.g., regenerative agriculture), but instead on increasing fertilizer efficiency and use (Lakhani, 2022). Given that corporate lobbyists outnumbered delegates from developing countries and civil society organizations (Michaelson, 2022), and that fossil fuel producing countries have systematically vetoed any agreement on reducing fossil fuels through 27 successive UNFCCC COPs, it is not surprising that no mention was made of the need to reduce oil and gas production, or the need to cut the massive farm subsidies found to harm human and environmental health (Carrington, 2021). The lobbyists' efforts were supported by large delegations from fossil fuel and meat producing countries.

International climate policies are primarily the result of compromises made by governments under pressure from powerful polluting industries and their political and business allies (Lucas, 2021b). In particular, the governments of fossil fuel producing countries have acted as spoilers in international climate negotiations. This opposition was demonstrated at the 2019 UN Environment Assembly, when the United States and Saudi Arabia blocked a Swiss proposal to assess potential geoengineering methods and governance frameworks (Reynolds, 2019).

This process is demonstrated by the United Arab Emirates selection of Sultan Al Jaber as president of the COP28 climate talks, which the oil-rich state hosted. Al Jaber, a UAE minister and climate envoy, headed both the renewable energy company Masdar and the state-owned Abu Dhabi National Oil Company (ADNOC), which is one of the biggest oil companies in the world. The Sultan's multiple roles illustrate the strategy of many fossil fuel producers, which is to maximise oil and gas production and sales for as long as possible, while simultaneously positioning their companies for the inevitable transition to clean energies. Unsurprisingly, Al Jaber's appointment outraged climate activists (Hart, 2023).

Political compromises have produced systematic biases in the kinds of expertise and evidence that national governments are prepared to accept via the IPCC and UNFCCC frameworks. Because the IPCC primarily focuses on summarizing and evaluating research from the earth sciences and economics, critical and contextual perspectives and approaches are excluded, producing outcomes that favour the interests of economically dominant industries and businesses. The reductionist and technocratic disciplinary composition of the IPCC, biases it towards endorsing incremental and voluntary change and supposedly low cost but universally applicable economic 'solutions' (Lucas, 2021b).

Governments have also tasked IPCC with examining only the short-term impacts of climate change, not the long-term impacts (scenarios rarely look past 2100). This political decision is fundamentally flawed from a scientific point of view, as it effectively produces underestimations of impacts and risks.

Another reason that there has been little action on climate change is because higher-income countries want to maintain their economic dominance. For example, the late Saleemul Huq pointed out that the IPCC is only allowed to discuss "loss and damage" instead of talking about the real issue of "liability and compensation" for poor countries suffering the climate impacts caused by emissions from industrialized countries (Thunberg, 2022). The US recently stated that it will not "under any circumstances" pay reparations to developing countries hit by climate change-fuelled disasters (Slow, 2023).

Figure 6. We are destroying the Earth. © Union of Concerned Scientists/Justin Bilicki

Fact 4.6: Risk assessments need to be informed by reality as evidenced by current and past data.

Following the release of the final instalment of the IPCC's Sixth Assessment Report (AR6) on April 4 2022, United Nations Secretary-General António Guterres commented that it was "a litany of broken climate promises … a file of shame." He then called for a redoubling of efforts, saying that "Choices made by countries now will make or break the commitment to 1.5 degrees." IPCC Chair Hoesung Lee echoed his words: "We are at a crossroads…. There are policies, regulations and market instruments that are proving effective. If these are scaled up and applied more widely and equitably, they can support deep emissions reductions and stimulate innovation." Jim Skea, co-chair of Working Group III (and the new IPCC chair) added: "It's now or never, if we want to limit global warming to 1.5°C. Without immediate and deep emissions reductions across all sectors, it will be impossible." (WEO, 2022)

Unfortunately, not only is the 1.5°C target no longer achievable, but it could not create a safe or stable climate. The grim reality is that the world is already experiencing dangerous, irreversible climate impacts, and rising temperatures can only make the climate increasingly unstable and dangerous.

Good science is based on empirical observations and testable explanations. If a hypothesis fails to reflect real developments, it has to be discarded and replaced with a better hypothesis. So, a good question is why and how has the IPCC has managed to turn its scientific assessments into arguments for continuing with an obviously failing mitigation strategy in pursuit of clearly unworkable targets?

The IPCC's methodology conceals the fact that the basics of climate change science are straightforward and have been settled for decades. In a statement to the US Congress in 1988, James Hansen explained the impacts CO2 emissions have on global temperatures, and predicted the current situation. At the time his analysis was widely accepted, including by ExxonMobil's own scientists.

Hansen's forecasts have proven to be more accurate than the IPCC's, and as Jackson Damian says, "Thirty-five years on, it is now blindingly obvious you can't radically alter the chemistry of the atmosphere, melt 75% of Arctic sea ice plus epic quantities of ice/permafrost elsewhere, increase ocean temperatures, alter jet streams…without causing the climate to catastrophically change faster than ever before." (Damian, 2023)

Now James Hansen says of the record 2023 heatwaves, "There's a lot more in the pipeline, unless we reduce the GHG amounts. These superstorms are a taste of the storms of my grandchildren. We are headed wittingly into the new reality – we knew it was coming. It means we are damned fools-- we have to taste it to believe it." (Milman, 2023) Nevertheless, despite a constant stream of scientific studies warning that the global climate is rapidly destabilising, IPCC summaries keep arguing that current policies, if fully implemented, can avert dangerous climate change.

Instead of focusing on hypothetical scenarios, we need to look at reality as evidenced by present and past data. The paleoclimate data proves that the climate sensitivity of temperature and sea level to CO2 is much higher than the models indicate. This is because of the failure of the models to adequately describe complex climate dynamics (Lucas, 2021a).

Hans Joachim Schellnhuber criticises the IPCC for having a "probability obsession", which makes little sense because "we are in a unique situation with no precise historic analogue." (Spratt and Dunlop, 2017, p. 3) While calculating probabilities can be useful, it is impossible in the most critical instances, such as the CH4-release dynamics in thawing permafrost areas or the potential failing of entire natural and social systems in the climate crisis.

The scientific data that the IPCC uses is also often out of date, due to the slowness of the process and the mode of work – through no fault of the scientists. For example, 'Working Group One' (WG1) is responsible for advising humanity on the 'present state' of the climate and future trajectories, based on scientifically-verified data. The WG1 report date was February 2021, two years in advance of the end of their 7-year reporting cycle. This means that the AR6 assessments ignored all scientific reports published after 2020, and because studies take at least a year to complete, the latest data they referenced was from before 2019. (The next global stocktake—AR7—will not take place until 2028.)

As a result, important science is missing, including:

- Increasing sea surface temperatures are reducing low level cloud cover. Decreasing albedo between 1998–2017 is equivalent to a radiative increase of 0.5 W/m2 (Goode et al., 2021).

- The Arctic is warming nearly four times faster than average global temperatures—faster than predicted by the latest models (Rantanen et al., 2022).

- Numerous, devastating, unpredicted climate-change extreme events including; 5 failed rainy seasons across the Horn of Africa; 2019 Australian 'Black Summer' wildfires; 2022 Cyclones Freddy and Gabriel (unprecedented in their size/trajectories); 2022 Pakistan floods that inundated an area the size of the UK.

- Unprecedented heat dome in British Columbia in 2021 (White et al., 2023).

- Unprecedented temperatures and heat waves across the Northern Hemisphere in 2022 and 2023 (e.g., WMO, 2023b) — many of these events were predicted to occur only after 2050.

- Wetlands are releasing GHGes faster than the projection in the IPCC's most pessimistic emissions scenario (RCP8.5) (Tandon, 2023).

- Antarctica saw record low ice extent in early 2023, caused by warming oceans and winds (Gramling, 2023).

- Earth's oceanic temperatures have reached record highs (Climate Reanalyzer, 2023).

Recent research also warns that the Atlantic meridional overturning circulation (AMOC) may shut down around mid-century—a catastrophic event that would have severe impacts on the climate in the North Atlantic region (Ditlevsen and Ditlevsen, 2023). This study challenges the IPCC's AR6 assessment, based on CMIP6 models, that a collapse in the 21st century is very unlikely. The authors point out that the models are biased toward overestimating the stability of the AMOC, both from the (relatively recent) historic climate record, and from poor representation of the deep-water formation, salinity and glacial runoff. For example, the models largely ignore the rapid melting of Greenland ice and the resulting massive flow of freshwater into the northern Atlantic.

In general, CMIP models are not adept at analysing non-linear processes. Professor Julia Slingo, former head of the UK Met Office, states "We should be alarmed because the IPCC models are just not good enough. [We need] an international centre to deliver the quantum leap to climate models that capture the fundamental physics that drive extremes." To function, the centre will require a dedicated supercomputer (Sommerlad, 2021).

The former IPCC chief, Professor Bob Watson, says, "I am very concerned. None of the observed changes so far (with a 1.2°C temperature rise) are surprising. But they are more severe than we predicted 20 years ago, and more severe than the predictions of five years ago. We probably underestimated the consequences. Scientists are only now starting to understand the response of large ice sheets in Greenland and Antarctica – and it is very disturbing." Watson said at current rates the world would be lucky to get away with an increase of 2.5°C. More likely, we're heading towards 3°C. (Harrabin, 2023).

Scientific assessments tend to be conservative for multiple reasons, including lags due to the time required to publish findings, discuss issues and develop consensus, and the human reluctance to accept that catastrophic outcomes are likely. Nevertheless, "the tone of the IPCC's probabilistic language is remarkably conservative" (Herrando-Pérez et al., 2019), due to factors such as IPCC policy, the complexity of climate research, and political and institutional pressure.

David Spratt and Ian Dunlop point out that scientists are understandably reluctant to issue warnings of potential catastrophic outcomes in the absence of perfect information. However, "Waiting for perfect information, as we are continually urged to do by political and economic elites, means it will be too late to act. Time is not on our side. Sensible risk management addresses risk in time to prevent it happening, and that time is now." (Spratt and Dunlop, 2017, p. 5)

Many senior scientists know that the IPCC is misrepresenting their understandings of the climate crisis, and that this legitimises ineffective responses, ignores the immediate catastrophic plight of hundreds of millions around the world and increases the threat to the rest of us.

The leaders of the climate science community now face an astonishingly significant, ethical challenge. In the absence of a clear understanding of scientific knowledge about the present and future state of the climate, humanity is sleep-walking towards global cataclysm. To prevent this catastrophe, senior scientists must first develop a common understanding of the incredible seriousness of the situation. Then they must impose change on the IPCC, or refuse to be involved in IPCC processes as 'contributing authors' and withdraw their permission for the IPCC to represent them (Damian, 2023).

Irreversible, adverse climate change on the global scale now occurring is an existential risk to human civilisation. We need to pay attention to the Biblical Judgement of Solomon, a parable that challenges the fallacy that equitable solutions require compromise, even if the compromise will kill the baby. While making compromises may help policy-makers reach consensus, it's not possible to bargain with natural laws.

As Hans Joachim Schellnhuber said, "Political reality must be grounded in physical reality or it's completely useless." (Spratt, 2012)

Section 5: We need climate cooling

Fallacy 5. Climate interventions are so dangerous, even research should be banned

Fact 5.1: Because current mitigation methods are failing to prevent dangerous temperature increases, there is an urgent need to develop a supplemental strategy.

The world has only one internationally agreed strategy for climate mitigation—the Paris Agreement. Although this strategy is inadequate and failing, there is no Plan B. There is now an urgent need to develop and implement a realistic supplemental strategy capable of preventing very dangerous temperature increases.

The issue is that while cooling interventions are needed to constrain and reduce rising global temperatures, their deployment is opposed by many scientists and environmentalists. Such interventions, normally deemed "solar geoengineering methods", or "solar radiation modification (SRM)" are probably viable and cost effective (Smith and Wagner, 2018), but opponents are legitimately concerned that lowering temperatures will give fossil fuel producers an excuse to continue polluting ('moral hazard'), and afraid of potentially dangerous side-effects, such as changes to the Earth's hydrologic cycle.

While it could be very dangerous to deploy untested methods that are either ineffective or do more damage than good, if climate interventions are not deployed in time to avert significant overshoot, the consequences are likely to be disastrous. The precautionary principle requires more research before any geoengineering methods can be deployed at climate-altering scales (e.g., Committee on Geoengineering Climate, 2015a; Committee on Geoengineering Climate, 2015b; Climate Overshoot Commission, 2023). However, the precautionary principle also means that the risks of dangerous and potentially catastrophic climate change justify action rather than inaction (King, Schrag, Dadi, Ye and Ghosh, 2015).

The United Nations Framework Convention on Climate Change makes this principle clear in Article 3.3 (UNFCCC, 1992): "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures."

Most scenarios allow climate target overshoot because they focus on reaching climate goals by 2100. To avoid this Rogelj et al. (2019) propose that researchers instead focus on capping peak warming at safe levels. This will require exploring all potentially viable methods for reducing climate risks (Rockström et al., 2016). As the Scientific Advisory Board of the UN Secretary-General (2016) emphasizes, policymakers need to understand climate change as an issue of risk management: since all options involve risks, the challenge is to develop strategies that minimize likely risks and costs while maximizing benefits.

Alarmed by potential risks, some scientists and environmentalists oppose even research on solar geoengineering (e.g., Greenfield 2021; Biermann 2021). Nevertheless, opponents need to recognize that the genie is already out of the bottle: e.g., China is planning to modify weather over an area greater than 5.5 million square kilometers (Griffiths, 2020). Researchers are exploring solar geoengineering methods in Australia, China, India, Russia, the United Kingdom, the U.S, and several EU members (National Intelligence Council, 2021).

As rising global temperatures cause increasingly extreme weather, climate interventions will inevitably be made in order to prevent massive crop failures and other disasters. To forestall the unilateral deployment of untested technologies by individual countries, there is an urgent need to develop an international program to research safe climate cooling methods (Moore, 2023; UNEP, 2023). The issue of governance also needs to be addressed in advance of large-scale testing and deployment (e.g., McLaren and Corry 2021; Feder 2021; AGU, 2022).

Developing safe, effective strategies will require internationally coordinated research on all potentially useful mitigation methods, including large-scale GHG removal technologies and climate cooling interventions (Buck, 2022). The Climate Overshoot Commission suggests that this research should co-evolve with the development of international geoengineering governance. They also recommend that countries should adopt a moratorium on any large-scale solar geoengineering experiment or intervention that could risk significant transboundary harm.

Fact 5.2: While climate interventions will have risks, the risks and moral hazards of not intervening are not only much greater, but also existential.

Global NZE will probably not be reached until after 2050 (UN, 2023). While NZE may stop temperatures from rising further, by mid-century global temperatures will average more than 2°C above present levels. Even an increase of 2°C will destroy coral reefs and other vital ecosystems, doom thousands of species to extinction, cause massive crop failures, and create heat waves that will make many tropical regions uninhabitable. It is also probable that a 2°C increase will pass half a dozen significant climate tipping points, triggering feedbacks that will further raise temperatures. Due to feedbacks and growing radiative forcing, temperatures may rise by 3°C or more by the end of the century. Many scientists believe that an increase of 4°C will threaten human civilization (Lenton et al., 2019; Steel, DesRoches, and Mintz-Woo, 2022).

It will not be possible to stabilize global temperatures at safe levels without lowering CO_2e concentrations to around 350 ppm. This will require large scale CDR geoengineering. However, since existing methods will remove CO_2 slowly, they will not have an appreciable effect on the global climate for decades or more. In contrast, a climate cooling intervention could produce a substantial reduction in radiative forcing in as little as one year (UNEP, 2023).

Opponents of climate geoengineering need to recognise that the alternative to researching and deploying solar geoengineering is to leave almost all efforts to limit temperature increases to reducing emissions, a strategy that would almost certainly fail (Aldy and Zeckhauser, 2020). Because only climate cooling interventions have the potential to rapidly reduce temperatures to safe levels, to oppose climate cooling means to accept global temperatures rising by at least 2°C above pre-industrial levels within a few decades, with catastrophic and irreversible impacts.

Honegger, Michaelowa and Pan (2021) point out that debates on solar radiation modification are based on relatively little evidence, and recommend investigating the potential of SRM to help achieve the UN's Sustainable Development Goals, which are at grave risk from climate impacts. Reynolds (2020) argues that IPCC reports contain many claims about solar geoengineering that are speculative or contrary to existing evidence, and suggests that an IPCC Special Report is needed to accurately assess the advantages and disadvantages of SRM.

The current situation is a bit of a Catch 22. In Michael Weisberg's words, "We're in a bind because part of the reason that people have been reluctant to do a lot of research about solar geoengineering is because of the uncertainty, but the reason there's so much uncertainty is because there's very little research that's been done." (Schipani, 2023)

To date, there is little evidence that climate cooling methods pose unmanageable risks: e.g., at present, GHG warming is partially offset by the annual discharge of millions of tonnes of anthropogenic aerosols into the atmosphere. While these dirty emissions need to stop as they have serious health and environmental impacts (Lelieveld et al., 2019), it should be possible to replace their beneficial cooling effects with a wide range of smaller, cleaner, targeted interventions designed to maximise benefits and minimise risks. The ethical priority is to urgently research all potential technologies to ensure that cooling interventions can be safely deployed in time to prevent catastrophic outcomes.

Moral hazard is a real risk—that the promise of quick, cheap geoengineering fixes to global warming will reduce political pressure for decarbonization (Asayama and Hulme, 2019, Wagner and Merk, 2019). This is a serious issue as solar geoengineering will not prevent rising levels of atmospheric CO_2 from acidifying the oceans with catastrophic impacts on marine life (Eyre et al., 2018).

To evaluate these risks, we need to weigh the risks of solar geoengineering against the risks of further climate deterioration in a world without solar geoengineering (Goklany, 2002). Benefits have to be assessed as well as risks. Apart from preventing dangerous climate change, geoengineering approaches also have co-benefits. Climate models indicate that a well-designed SRM deployment would not only reduce surface temperature increases, but also reduce some changes to the hydrological cycle associated with climate change across most regions (Irvine et al., 2019). Other methods, such as afforestation and ocean fertilization, may have co-benefits such as reversing desertification, improving water quality, promoting biodiversity, improving fisheries, enhancing food security, and reducing climate inequity.

Because there are still many unresolved questions about CDR and SRM (Fuss et al. 2014; Vaughan and Gough 2016; Zarnetske et al. 2021; Crutzen 2006; Visioni et al., 2021), research is urgently needed on the relative feasibility, benefits, risks and costs of all potential approaches. International Risk Governance Council guidelines could be used to help evaluate the complex risks presented by these technologies (Grieger, Felgenhauer, Renn, Wiener and Borsuk, 2019). The critical problem that must be addressed is that although CDR methods are safer than SRM, they will act too slowly to prevent dangerous overshoot.

Alan Kerstein points out that the choice is not binary. The potential drawbacks of solar geoengineering strategies should be viewed in the context of growing indications that climate degradation will outpace decarbonization. A limited solar geoengineering deployment that slows the increase of global temperatures might yield benefits that greatly outweigh the associated risks. It would also be wise to begin studying and trialling climate cooling methods in case the rapid onset of extreme climate scenarios accentuates the need for their deployment.

He suggests that “Parallel efforts, analogous to the COVID-19 vaccine development strategy, therefore merit consideration. That would involve initiating long-lead-time substantive preparations for deployment concurrently with scientific evaluation, but not committing to full operational deployment of SRM capability until it has been adequately assessed with regard to its effectiveness and risks. By that or other means, the prioritization of SRM should be aligned with its unique precautionary role.” (Kerstein, 2023) Trials should start with low-risk methods like marine cloud brightening (MCB), and localized reflectivity management solutions.

The climate crisis is the result of massive interventions on the climate by humanity, even if their impacts were not deliberate: by deforestation, desertification and burning fossil fuels. For example, the rise of human civilization has destroyed almost 3 trillion trees--reducing their numbers by 46% (Crowther et al., 2015; Ruddiman, 2007). Now we need to use geoengineering to reduce temperatures to safe levels. While climate interventions will have risks, the risks and moral hazards of not intervening are not only much greater, but existential.

There is a simple way to prevent oil, gas and coal interests from using climate cooling as an excuse to keep polluting. Governments can (and should) pass regulations mandating progressive fossil fuel production reductions.

Fact 5.3: The risks and benefits of climate interventions can only be assessed in comparison to the risks and costs of all possible policy options, including continuing with the current strategy.

The risks, costs and benefits of using various geoengineering approaches can only be assessed in comparison to the risks and costs of other mitigation options, including continuing with the current strategy. “Risk vs. risk” framing is required to provide a necessary context in which policymakers can determine the suitability of different geoengineering methods (OSTP, 2023). For example, the potential risks and benefits of using solar geoengineering need to be considered relative to the risks and benefits associated with plausible trajectories of climate change not involving solar geoengineering (Harding et al., 2022; Felgenhauer et al., 2022; Parson, 2021; Aldy et al., 2021, Visioni et al., 2023).

In order to develop a viable strategy, researchers have to first determine what will be required to prevent dangerous temperature increases and ensure a safe, stable climate. This will enable research on the comparative risks of overshooting safe temperatures versus the risks of various mitigation approaches (Climate Institute, 2018).

This evaluation of countervailing risks needs to take into account not only linear developments and their impacts, but also likely non-linear developments since climatic tipping elements, climatically sensitive social tipping elements, and climate–economic shocks may be the largest contributors to the costs of climate change (Kopp, Shwom, Wagner and Yuan 2016). The economist Nicholas Stern (2016) argues that while these estimates are difficult to quantify, it’s imperative that future IPCC reports take them into account as they have the most troubling potential consequences.

Another area that deserves more attention is the higher-risk scenarios, which are less predictable but also hold more devastating implications. A new approach is needed that explicitly embraces deep uncertainty, and in which modelling exists in an iterative exchange with policy development (Workman, Dooley, Lomax, Maltby and Darch 2020).

The research should support public dialogue on the relative costs and risks of using or not using various types of climate engineering (Honegger et al. 2017; Lawrence et al. 2018; Buck, Geden, Sugiyama and Corry 2020). The goal should be to both strengthen the Paris Agreement, and develop a supplementary, overshoot risk management plan.

European Union climate policy chief Frans Timmermans suggests that the United Nations should convene talks on the risks and possible use of geoengineering. “Nobody should be conducting experiments alone with our shared planet. This should be discussed in the right forum, at the highest international level." (Abnett, 2023)

While establishing global geoengineering governance is a priority, we are in the midst of a climate crisis, and time is of the essence. Research is needed on potentially useful climate intervention approaches (AGU, 2023). Over regulation could slow down the development and testing of safer, cheaper and more effective technologies, and deter potential investors. Lab experiments do no harm, and small field trials have negligible risks.

Fact 5.4: Many potentially safe, viable geoengineering approaches merit attention. All options should be explored for their capacity to safely offset dangerous warming.

There are two main categories of climate intervention technologies. These are (1) negative emissions (NET) technologies designed to draw down the GHGes trapping heat in the atmosphere; and (2) direct climate cooling (DCC) technologies designed to reflect sunlight and cool the climate.

Mitigation efforts need to focus on accelerating the global transition to a net-zero carbon emissions economy: it is much cheaper and less risky to avoid GHG emissions than to emit them with the expectation that they will be later removed from the atmosphere. In addition, climate cooling interventions are urgently needed to prevent temperatures exceeding safe limits during the long period that it will take to transition to an emissions-free global economy, reduce atmospheric carbon dioxide concentrations and re-establish a safe and stable climate.

Negative Emissions Technologies/Carbon Dioxide Removal

To achieve the Paris targets, in addition to rapid emissions reductions, IPCC pathways rely on removing 6 billion tons of CO2 from the atmosphere per year by 2050 (Hausfather, 2022). However, as we explained in section 2.4, this massive expansion of carbon sinks will not happen for multiple reasons, including the constraints imposed by available land, water, nutrients, and materials, by political resistance and environmental concerns, by cost, and by the time required to develop and scale up new technologies. Additionally, since proposed methods would only remove CO2 slowly, even in the most optimistic scenario, NET methods will take decades to lower global temperatures.

Approaches for removing CO2 have mostly focused on afforestation, large-scale bioenergy with carbon capture and storage, and carbon capture and storage. These have been supported by climate governance strategies designed to generate carbon credits, repurpose existing carbon infrastructures, and maximize energy security. The Paris Agreement’s REDD+ framework (for ‘Reducing emissions from deforestation and forest degradation in developing countries’ and enhancing carbon stocks) is closely tied to emission credit trading. These approaches have been politically acceptable because they help to maintain fossil fuel infrastructures and use (Røttereng, 2018). Nevertheless, they have failed to deliver meaningful climate mitigation. Sean Low and Miranda Boettcher conclude that “While emerging climate strategies ostensibly present new tracks for signalling ambition and action, they functionally permit the delaying of comprehensive decarbonization." (Low and Boettcher, 2020)

In reality, there is no chance that Paris targets can be met with current negative emissions methods. Little land is available for increasing forest cover (already under threat from deforestation, droughts and increasingly devastating fires), and it will be difficult to get support for the large-scale deployment of (currently) inefficient, uneconomical and geographically limited CCS and BECCS methods (e.g., Fajardy et al., 2021). Recently, direct air capture (DAC) technologies have attracted interest and investment, but these are also uneconomical (Young et al., 2023). These approaches may become more viable in the future—e.g., if diets change, permitting the reforestation of the vast tracts of land used to feed livestock; if breakthroughs raise efficiencies and reduce costs; and/or if much higher (i.e., realistic) carbon prices increase the cost competitiveness of these technologies.

Sekera et al. (2023) argue that biological sequestration methods, such as the restoration of forests, grasslands, and wetlands and regenerative agriculture, are more effective, resource efficient, and cheaper ways to achieve large-scale CO2 removal than techno-mechanical methods. Moreover, the co-impacts of biological methods are largely positive, while those of mechanical methods—which use machinery and chemicals to capture CO2—are largely negative. But despite their repeated failures, mechanical CDR methods continue to receive US government subsidies, while biological sequestration is largely ignored. Marine plants can also be used to sequester carbon (e.g., Wang et al., 2023).

Potentially viable negative emissions technologies include:

- Afforestation – planting trees in areas that have previously not been forested.

- Biochar – using biomass to create a carbon-rich substrate that supports soil rejuvenation.

- Biological carbon sequestration – storing carbon dioxide in vegetation, e.g., through restoring forests, peat marshes, and coastal wetlands.

- Bioenergy with carbon capture and storage – capturing and permanently storing CO2 from processes where biomass is burned to generate energy or converted into fuels.

- Carbon capture and storage – capturing, transporting and permanently storing GHG emissions from industrial sources.

- Direct air capture (DAC)– CO2 is directly extracted from the atmosphere and then permanently stored in geological formations.

- Direct ocean capture – CO2 is directly extracted from the ocean.

- Deepwater irrigation – regenerative upwelling or deep-cycling can increase the growth of macroalgae, by exposing them to nutrients from the mesopelagic zone.

- Enhanced Atmospheric Methane Oxidation (EAMO) – methods for oxidizing CH4, including adding iron chloride to the atmosphere.

- Enhanced silicate rock weathering – spreading crushed silicate minerals on land and water to increase pH and plant productivity.

- Forest restoration – restoring natural biologically diverse forests to their previous healthy, diverse states.

- Carbon-negative construction – the use of plantation timber, new forms of concrete and road materials, etc. to store carbon in the built environment.

- Ocean afforestation with fast growing macroalgae, seagrasses, mangroves and salt marshes.

- Ocean alkalinization – adding alkaline minerals to seawater to enhance the ocean's natural carbon sink by converting dissolved CO2 into stable bicarbonate and carbonate molecules.

- Ocean Iron Fertilization (OIF)– adding trace amounts of iron-ore dust to iron-poor ocean areas may rapidly increase the growth of phytoplankton, in turn improving fish stocks.

- Regenerative agriculture – practices that limit mechanical soil disturbance, maintain soil biodiversity, and support soils retaining water, nutrients, and carbon.

- Seaweed permaculture – the construction of floating structures to which seaweed can attach in mid-ocean.

- Ocean fertilization to grow diatoms.

- Synthetic limestone manufacture – capturing CO2 and converting it to synthetic limestone.

The National Academy of Science points out that the main barriers to deployment of carbon removal approaches are slow implementation, limited capacity, policy considerations, and the high costs of presently available technologies. Because additional research and analysis is needed to address those challenges, it is critical to embark now on a research program to lower the technical barriers to efficacy and affordability (National Academies of Sciences, Engineering, and Medicine, 2015).

Direct climate cooling/Solar Radiation Management/Solar geoengineering

Supportive policies are needed to develop and implement cost-effective CDR (Honegger, Poralla, Michaelowa and Ahonen, 2021). However, even with strong mitigation efforts, CDR will not act in time to prevent dangerous overshoot. It will be necessary to augment emission reductions and CDR with direct cooling interventions (Baiman, 2022).

At a minimum, climate cooling interventions will be needed to reduce peak temperatures and limit climate damages (National Academies of Sciences, Engineering, and Medicine, 2021; MacMartin, Ricke and Keith, 2018; Tilmes et al., 2020). The methods given the most consideration to date are stratospheric aerosol injection (Keith and Irvine 2016), marine cloud brightening (Wood, Ackerman, Rasch and Wanser, 2017), cirrus cloud thinning (Kristjánsson, Muri and Schmidt, 2015), and changes to land, sea and ice surface albedo (e.g., Johnson et al., 2022).

At present, solar geoengineering is mostly discussed (and opposed) in relation to the risks of a global application of stratospheric aerosol injection (SAI) technologies. While injecting sulphate aerosols into the stratosphere may be a rapid, effective and relatively inexpensive way to cool global temperatures (Smith and Wagner, 2018), it poses new risks, including possible negative impacts on precipitation, ozone loss, ocean acidification, and acid rain impacts on forests and agriculture (Irvine, Kravitz, Lawrence and Muri, 2016; Hornigold and Allen 2021; Visioni et al., 2020; Futerman et al., 2023). Other mineral aerosols may overcome some of these problems (Keith, Weisenstein, Dykema and Keutsch, 2016; Oeste, de Richter, Ming, and Caillol, 2017), but present larger uncertainties (Dai et al., 2020).

Other climate cooling methods, such as marine cloud brightening (e.g., Ahlm et al., 2017) may be much safer. Also, while SAI technologies may not be suitable to offset any amount of warming, they may be safe and economical when used in targeted ways, or to limit some risks. For example, it may be possible to safely reduce climate hazards by using limited albedo modification to halve global warming (Irvine, Emanuel, He, Horowitz, Vecchi and Keith 2019; Visioni et al., 2023), and/or by deploying it only in subpolar regions and only in the spring and summer months with the goal of arresting or reversing ice and permafrost melt at high latitudes (Lee et al., 2023; Smith et al., 2022).

Moreover, there are many more potentially safe and useful direct climate cooling methods. The following may merit early consideration and investigation for possible, carefully monitored implementation (Baiman et al., 2023):

- Bright Water – having travelling ships pump tiny bubbles into the sea to increase the water's reflectivity and lower ocean temperatures.

- Buoyant Flakes – fertilizing the ocean and increasing albedo with floating flakes made from agricultural waste such as rice husks, lignin and mineral tailings.

- Cirrus cloud thinning (CCT) – injecting ice nuclei (such as dust) into cirrus clouds to thin them and allow more heat to escape into space.

- Ice shields to thicken polar ice – building underwater walls and subglacial cooling tunnels to prevent the loss of polar ice.

- Iron Salt Aerosol (ISA) – mimicking natural dust storms with ISA to cool the climate, remove atmospheric CH4, and draw down carbon through stimulating marine algal growth.

- Marine Cloud Brightening (MCB) – mimicking natural processes, seawater and/or other aerosols are sprayed into marine clouds to increase their reflectivity and cool the ocean (e.g., to protect coral reefs).

- Mirrors for Earth's Energy Rebalancing (MEER) – surface solar reflectors made from recycled materials, are used for local heat adaptation and to provide thermal mitigation.

- Stratospheric Aerosol Injection (SAI) – mimicking volcanic eruptions, SAI introduces aerosols into the stratosphere to create a cooling effect via global dimming and increased albedo.

- Surface Albedo Modification (SAM) – proposals for reflecting more sunlight off the Earth's surface include growing crops that reflect more light; clearing boreal forests in snow-covered areas; covering desert areas with reflective materials; protecting glacial and lake ice with reflective materials to slow melting; and whitening mountaintops and roofs with white paint.

- Thermodynamic Geoengineering and Ocean Thermal Energy Conversion (OTEC) –- producing energy by harnessing the temperature differences between ocean surface waters and deep ocean waters.

- Tree planting and reflective materials in urban areas – these proven approaches effectively lower heat and improve health.

All methods need to be evaluated and compared for likely benefits, risks, costs and deployment timelines. There is no silver bullet: multiple approaches will need to be deployed at varying scales, each carefully targeted to minimize negative side-effects. For example, Almarez et al. (2023) have identified a mix of 12 interventions that could be used to achieve net negative emissions in the food system.

Fact 5.5: Termination shock is inevitable if climate cooling is not used to keep temperatures at safe levels.

If solar geoengineering were to be deployed to mask a high level of global warming and then suddenly stopped, temperatures would rise dangerously in the following years. This effect is often referred to as termination shock, as many species could not adjust to the rapid temperature increase.

The possibility of termination shock is one of the key arguments used by solar geoengineering opponents (e.g., Kemp and Tang, 2022). Other arguments are that the risks of solar geoengineering are poorly understood and can never be fully known; that the possibility of future solar geoengineering will be an excuse to delay decarbonization policies; and that the current global governance system is unfit to develop and control solar geoengineering deployment. For these reasons, they call for governments to sign an International Non-Use Agreement on Solar Geoengineering, and commit "to object to future institutionalization of planetary solar geoengineering as a policy option in relevant international institutions, including assessments by the Intergovernmental Panel on Climate Change." (Solar Geoengineering Non-Use Agreement, 2022)

While these are real concerns, geoengineering opponents have the precautionary principle backwards due to badly flawed risk assessments. Deploying solar geoengineering is precautionary as it is needed to prevent rising temperatures causing potentially catastrophic outcomes, e.g., from passing potentially irreversible climate tipping points (how can one replace melted glaciers, dead coral reefs, or submerged islands, or put gigatonnes of CH_4 back in the permafrost?)

The fallacy is assuming that potential future risks are greater threats than actual present risks. While we may not know for sure if different geoengineering approaches will have more risks than benefits (research is needed to determine what methods can be safely deployed), we do know that climate change is already having dangerous, irreversible impacts, and that climate cooling will be required to prevent temperatures from rising to extremely dangerous levels.

Termination shock is inevitable if climate cooling is not used to keep temperatures at safe levels. The large-scale use of solar geoengineering can be likened to prescribing insulin to a diabetic: it would be better if the patient did not need it, but once the disease is advanced, withholding it amounts to a death sentence.

It should be noted that it is highly unlikely that any scientific body would agree to either deploy a risky, untested solar geoengineering technology at a global scale, or to suddenly terminate it. Existing proposals are for careful research, followed by small-scale trials to ensure safety, and only then gradually scaling up with limited, carefully targeted, monitored and supervised interventions.

The goal will be to only use atmospheric climate cooling methods for as long as they are needed to constrain rising temperatures. Regulatory procedures must ensure an orderly exit from the program: the transition will be smooth and safe if solar geoengineering is discontinued at the same rate as natural carbon sinks and negative emissions technologies draw down GHGes and reduce global warming (MacMartin, Caldeira and Keith, 2014).

Conclusion

Direct climate cooling: the crucial missing element of a viable mitigation strategy

The three elements of a realistic climate strategy

The current climate strategy is like a stool with two legs—incomplete, unstable and unsafe.

At present, international mitigation efforts rely on two approaches: sharply reducing emissions by mid-century, and achieving net zero by deploying large-scale negative emissions technologies. Even though commitments to reduce emissions are inadequate, it is conceivable that they will be greatly strengthened in the coming decades. But this will not be enough.

Although the Paris Agreement's NZE goal is an essential part of any realistic climate mitigation strategy, there is little indication that it will be technologically or economically feasible to deploy current CDR geoengineering methods at the scale required to reach net zero. Moreover, because the climate is already unstable and dangerous, and because it will be much more dangerous by the time NZE is reached in mid-century, the Paris Agreement needs to be supplemented with a third strategy: using climate cooling methods to rapidly lower global temperatures to safe levels. New, effective NET methods also need to be employed to draw down GHGs.

Viable, safe climate mitigation requires a triple approach: cooling, reduction, and removal. While in the long-term, cooling the planet is not a substitute for reducing GHGes, in the short-term, the problem is the reverse. Cutting GHGes cannot substitute for direct cooling.

A realistic overshoot risk management plan will have to simultaneously apply three strategies: (a) using climate cooling technologies to keep temperatures within safe limits until GHG concentrations have been reduced to a level that stabilizes the climate; (b) rapidly reducing GHG emissions; and (c) deploying large-scale negative emission technologies to draw down atmospheric carbon (Baiman et al., 2023).

Developing a supplemental climate overshoot risk management plan

A realistic plan has to start with assessing overshoot risks, and then determining the requirements for preventing dangerous climate change and restoring a safe, stable climate. The next step is to assess all mitigation options, and then make a comparative evaluation of the relative benefits, risks and costs of using or not using different mitigation strategies. These assessments are prerequisites for developing a safe, realistic climate risk management plan (Taylor and Vink, 2021). (See Figure 7.)

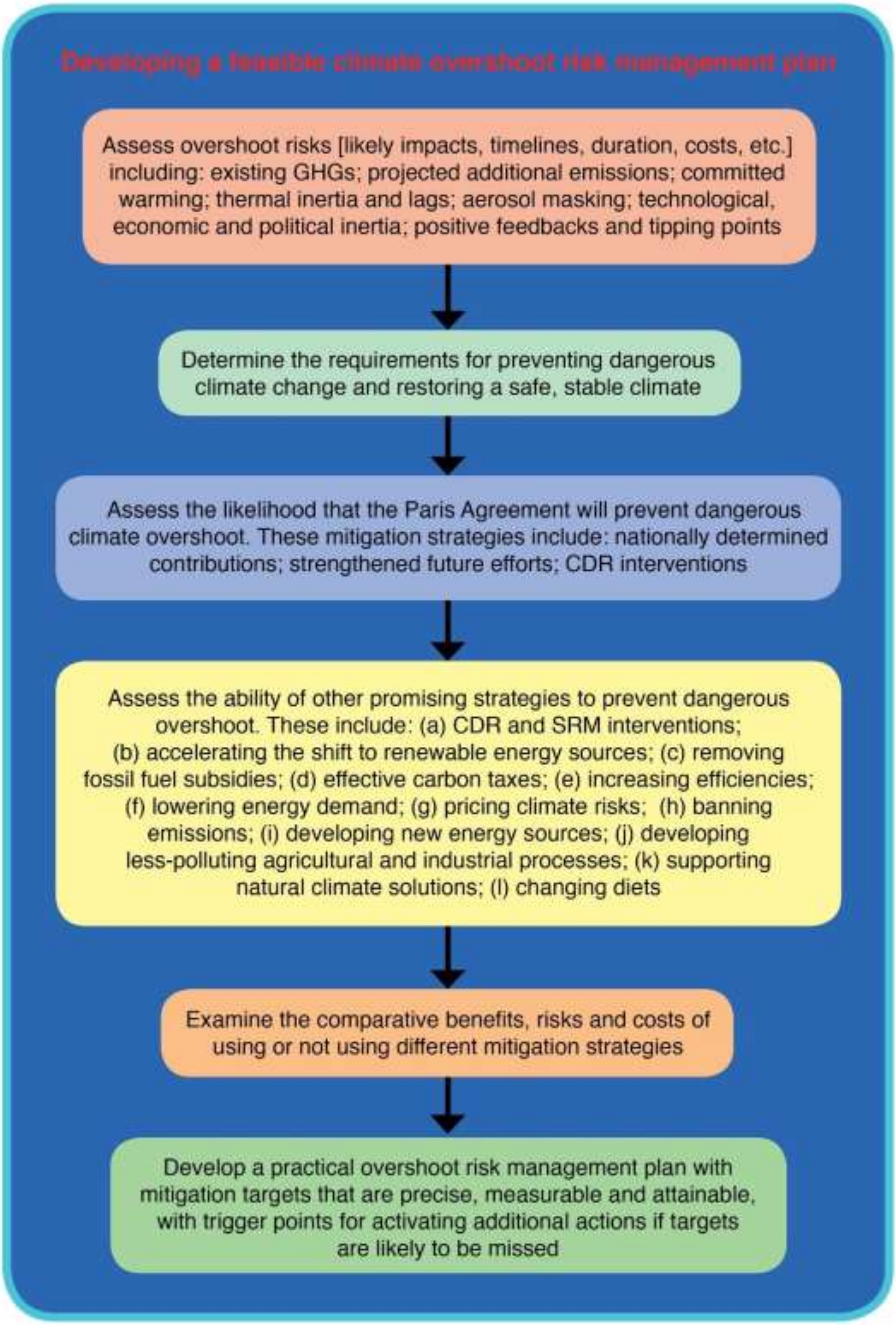

Fig. 7. A proposal for developing a supplemental climate overshoot risk management plan. 🅭 Taylor and Vink, 2021.

A practical risk management plan will need to contain three main elements: metrics, timelines and trigger points for initiating actions. It will have to include a scientifically credible plan for decarbonization (Rockström et al., 2017). In order to challenge policy-makers and hold them accountable, mitigation targets must be precise, evaluable and attainable, with clear constraints on the magnitude and duration of overshoot and the feasibility of mitigation methods (Geden and Löschel, 2017).

Ambitious change is being obstructed by the UNFCCC's requirement for consensus (Verkuijl and Lazarus, 2020). To accelerate change, a two-track approach could be used, with UNFCCC agreements complemented by climate "coalitions of the willing" (Jayaram, 2020; Nordhaus, 2020): e.g., agreements among nations willing to impose meaningful internal carbon taxes matched by tariffs on all imported goods and services (Cramton et al., 2017). A two-track approach will allow the simultaneous application of both the Paris Agreement and a supplemental plan for managing overshoot risks.

The real moral hazard

While there are bad actors, the climate crisis is ultimately a wicked problem: a tragedy of the commons exacerbated by the obsolete, dysfunctional structure of the global system. This crisis has developed because generations of people, businesses, and communities at all scales have created economic and social structures that use the environment, and in particular the atmosphere and ocean, as a free waste dump.

The crisis is not only the product of the duplicity of the fossil fuel sector, and the preference of many states to put the burden of action on others' shoulders, it is also the result of a widespread failure of society at large to understand that there is a cost to maintaining the health and productivity of the environment on which all life depends.

Most policy makers still do not understand the catastrophic risks of rising temperatures. An example of this is that the current carbon price—on average less than $18 per tonne in the 71 countries that tax emissions (OECD, 2022)—is far too low to deter businesses from polluting. In Tim Flannery's words, there is a "kind of madness" to the global approach to carbon pricing. "We know at the moment it costs about $250 a tonne to remove it. In a saner world it would cost more to dump the stuff in the atmosphere than suck it out." (O'Malley and Hannam, 2021)

In practice, most countries are delaying major emissions cuts until closer to their net-zero target year, on the assumption that yet undeveloped technological breakthroughs will sharply reduce the costs of transitioning away from fossil fuels (National Intelligence Council, 2021). Kevin Anderson believes that this approach is dangerously immoral: "It is the reliance on these future technologies that is the moral hazard not the technologies themselves…. But to rely on those, rather than actually reducing our emissions today, that is the moral hazard." (Climate Chat Club, 2021)

Doom is not inevitable: it will only occur if we fail to develop and deploy realistic mitigation strategies. For example, an Oxford University study challenges the pessimistic predictions by the IPCC that the cost of keeping global temperatures rises under 2 degrees would lower GDP by 2050. In reality, switching from fossil fuels to renewable energy could save the world as much as $12tn by 2050. A rapid green transition would also avoid climate damages, reduce air pollution, and lower energy price volatility (Way, Ives, Mealy and Farmer, 2022).

Unfortunately, these analytical errors are not confined to economics. Leading political, scientific and environmental organizations have not only greatly underestimated the benefits of making a rapid green transition, they have also seriously underestimated the dangers of continuing with the current climate strategy (Bawden, 2016).

As we argue in this paper, our failing climate strategy is the result of multiple mistakes, omissions, delays, and compromises. While each of these can be explained and perhaps forgiven, in combination they have created a treacherous collective delusion. Now, reassured that climate change is under control, humanity is staggering blindly towards collective disaster.

Our descendants will pay for these mistakes with their futures—unless we find the courage and voices to demand a new, realistic climate strategy.

At this critical time, the international community must prioritize developing a feasible overshoot risk management plan or risk irreversible, catastrophic damage to the biophysical and physicochemical systems that support human civilization.

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