CCAG
Climate Crisis
Advisory Group

The Overshoot

Crossing the 1.5ºC threshold – and finding our way back

FOREWORD

Today, the decadally-averaged global temperature has exceeded 1.1ºC above pre-industrial levels.[1] For some time now, 1.5ºC has been regarded as the 'climate guardrail' – the limit beyond which we must not stray if we want to avoid the worst climate impacts. Keeping within this limit has been the driving ambition of global climate action, and world leaders have adopted the 1.5ºC threshold as the critical indicator for a successful response to the threats of climate change.

But international efforts to reduce greenhouse gas (GHG) emissions to date fall well short of what science says is necessary to remain within the 1.5°C guardrail. Global annual emissions have continued to rise, and so too has the Earth's temperature, putting us on a path to 1.5°C global warming as early as 2035 and reaching at least 2°C global warming by the end of the century.[2] While estimates of when 1.5°C will be crossed draw closer, together with colleagues I have argued that ensuring justice, and not just safety, for vulnerable communities requires keeping global warming below 1°C.[3]

There are many scenarios describing how GHG emissions might change in the coming years and decades, depending on the pace and nature of technological, political and demographical transformations. Of those scenarios that see global temperatures stabilising at or below 1.5ºC above preindustrial levels by the end of the century, only those that temporarily 'overshoot' the 1.5°C guardrail remain feasible for up to several decades. Global temperatures will then have to be drawn back down by explicit removal of carbon dioxide from the atmosphere: a momentous task, requiring an unfathomable technological and industrial effort.

The overshoot matters because, as seen in recent years, even a world below 1.5ºC is not a safe place to be. 2023 has continued to bring home the stark implications of climate change, with an increase of even 1.1ºC proving difficult to live with in many parts of the world, breaking many 'all-time' records globally for temperature, wildfires, droughts, rainfall, storms and floods.

Once the world strays beyond 1.5ºC, it enters a realm of unacceptable risk and uncertainty. In addition to the 'incremental' impacts, which rise in tune with average global temperature, the latest science warns of the risk of crossing various 'tipping points'[4] beyond 1.5°C, with potentially devastating consequences for global ecosystems, human health and security, and in turn unleashing further climate change.

Professor Johan Rockström

Director of the Potsdam institute for Climate Impact Research

Given its near inevitably, we cannot stick our heads in the sand about how to manage and mitigate an overshoot. There is absolutely no guarantee we will return below 1.5°C. If the sluggish action on GHG reductions seen to date is simply perpetuated, even an overshoot scenario will rapidly move out of reach.

This report assesses the impacts and implications of a possible overshoot. It considers the state of the planet in 2023 and looks at the likelihood of various overshoot scenarios, drawing on credibility-gap analyses, feasibility studies and other current climate research. It considers national policies and pledges and the shortcomings in global efforts to reduce GHG emissions. And it highlights some of the available options and interventions for tackling the climate crisis.

Ultimately, the aim of this report is not to scaremonger or catastrophise. The world will not end the minute we go beyond 1.5ºC. But the likelihood of an overshoot is real, and passing the threshold of 1.5°C, however briefly, will intensify existing challenges, potentially exposing humanity to new and irreversible harms. If we are to address this reality, major interventions need to be deployed at scale, without delay, not just to reduce GHG emissions, but to safeguard our planet's natural buffering mechanisms against further climate change.

Professor Johan Rockström

Director of the Potsdam Institute for Climate Impact Research

In memory of our CCAG colleague and friend, Professor Saleemul Huq (1952-2023). Saleemul worked and campaigned tirelessly for climate justice and fairness for the poorest and most vulnerable members of the global community. We will miss his generosity and wisdom.

THE 1.5^{0}C THRESHOLD

On 12 December 2015, 196 Parties at the UN Climate Change Conference (COP21) in Paris adopted a legally binding international treaty on climate change. Known as the Paris Agreement, the treaty entered into force on 4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2ºC above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5ºC…"[5]

The Paris Agreement was hailed as "historic, durable and ambitious", underpinned by an obligation that "brings all nations together to combat climate change and adapt to its effects".[67] It also acknowledges the global inequalities that are underscored and exacerbated by climate change, honouring commitments set out in Article 4.9 of the UN Framework Convention on Climate Change (UN FCCC) to "take full account of the specific needs and special situations of the least developed countries…"[8]

Perhaps what no one could foresee was just how quickly the world would be contemplating the crossing of the thresholds and limits set on that December day in Paris.

Crossing the threshold

Already, climate change is causing major social, economic and environmental damage, visibly and in real time. The impacts are inequitably spread around the world, with the poorest and most vulnerable often the most severely affected. Communities most exposed to stress in normal circumstances are pushed into crisis by relatively small climate shifts; and these shifts have become consistently larger, more frequent and more eratic. A widely reported assessment of the costs of extreme climate events puts the figure at US$16.3 million an hour. This draws on the 185 identified extreme events between 2000 and 2019.[i]

[i] Those figures will no doubt be running at even higher levels now, given the continuing run of record-breaking climate events in the 2020s. Nature Communications, Newman and Noy (2023) 'The global costs of extreme weather that are attributable to climate change' https://www.nature.com/articles/s41467-023-41888-1

Ice sheet melt, rising sea levels, storm surges, typhoons, heat stress and other events pose real threats to lives and livelihoods, as demonstrated recently in Greece (wildfires), Libya (flooding) and the US (extreme heat). July and August 2023 were the hottest months ever recorded globally,[9] while temperatures in September 2023 were the highest ever seen for that month.[ii] These and other extreme events will increase in frequency and magnitude as the planet warms further.[iii]

The continued warming increases the likelihood of crossing various climate 'tipping points'. These have the potential to trigger "cascading and potentially irreversible harm to ecosystems, human health, food security, water availability, and social stability".[10] The precise global temperature rise at which any one of these effects will happen is not knowable. But the range of temperature change within which they will fall has been identified using detailed models. Within the field of climate change such models have generally proved reliable – although they are often somewhat optimistic: changes are happening faster and more deeply than scientists' models have predicted. For example, the Greenland Ice Sheet (GIS) and the West Antarctic Ice Sheet (WAIS) are described as 'vulnerable' at an estimated 1.5°C of temperature rise, but that vulnerability could occur at 0.8°C of temperature rise. In reality, both ice sheet environments are already visibly changing, and in a recent study the WAIS is considered to have passed a tipping point. This will commit humanity to many decades of ongoing sea-level rise even if full action is taken to limit warming, leaving many coastal cities potentially beyond rescue.[11]

Over the last two decades, the baseline for a 'typical' temperature in any given region has shifted. For example the 'extreme' central European summer temperature of 2003, which caused 70,000 excess deaths, would register as a 'typical' summer (i.e. comfortably within the expected average summer temperature range for the region) 20 years on.[12] And unusually hot summers can now reach extreme temperatures that would have been impossible before the baseline shift of climate change.

Again, it is worth noting that the current extremes are being experienced at a baseline temperature rise below the threshold set by the Paris Agreement. And these extremes are already proving fatal to vulnerable humans and communities, expensive to the global economy, and remorselessly escalating in severity and frequency. While opinions may differ as to when and by how much we will go beyond a 1.5°C average global temperature rise, one thing is clear: the world cannot afford to stray beyond that threshold for long.

[ii] The UK temperature record in September 2023 broke a record that had stood since 1895 – by over 1°C. Euronews Green (2023) 'October heatwave expected in parts of Europe after countries record hottest ever September: France Germany and UK all recorded their hottest ever September last month' https://www.euronews.com/green/2023/10/09/october-heatwave-expected-in-parts-of-europe-after-countries-record-hottest-ever-september

[iii] For example, the European heatwave of July 2019 was up to 100 times more likely due to climate change according to 'World Weather Attribution' (WWA) working with Oxford University https://www.ox.ac.uk/news/2019-08-02-european-heatwave-made-100-times-more-likely-due-climate-change; the BBC reports that five failed rainy seasons in succession in parts of East Africa between 2020 and 2022 are at least 100 times more likely according to WWA https://www.bbc.co.uk/news/science-environment-58073295; the Indian and Pakistani heatwave of May 2022, seeing record temperatures of 49C in Delhi and 51C in Pakistan, was 'supercharged' by climate change, making such extremes 100 times more likely https://www.theguardian.com/environment/2022/may/18/climate-crisis-makes-extreme-indian-heatwaves-100-times-more-likely-study; South America's winter hot spell was 100 times more likely as a result of climate change according to Scientific American article in October 2023 https://www.scientificamerican.com/article/south-americas-winter-hot-spell-was-100-times-more-likely-with-climate-change/.

Not if but when

In an evaluation of five illustrative scenarios ranging from 'very high' GHG emissions down to 'very low' GHG emissions, in the near term (2021 to 2040) the IPCC reports that the threshold of 1.5°C is likely to be exceeded in all but the 'very low' GHG emissions scenario. In the 'very low' scenario it is 'more likely than not' that the 1.5°C threshold will be reached, emphasising that there is no headroom at all.[13] Either the world shifts rapidly to very low emissions without further prevarication, or the threshold will be passed. In its special report on 1.5°C published in 2018, the IPCC was already anticipating that limiting the temperature rise to 1.5°C would almost certainly involve CO_2 removal from the atmosphere, even with drastic emissions reductions.[14]

If the question is whether the world can go far and fast enough to maintain the 1.5ºC guardrail and, ideally, stay below the Paris Agreement limits, the answer now appears to be 'probably not'. The evidence to date suggests it may be technically possible if every conceivable step to reduce emissions is taken immediately, and if the world also gets lucky. However, the political and policy alignment is not making things happen anything like fast enough.

Despite the collective commitments and individual country obligations of the Paris Agreement, all countries are falling short in their contributions to effectively limit global temperature rise to the extent required. As we approach the midpoint to the 2030 deadline to halve GHG emissions, around the world those emissions are increasing, not decreasing.[15] A peak in fossil fuel use around the world is possible before 2030, but the decline thereafter from a high level will not be enough to reach climate goals[16]. The sum of the current Nationally Determined Contributions (NDCs) is not sufficient to stay below 1.5°C or even 2°C, confirming that trajectory.[iv]

External events are exacerbating the situation. Strong post-Covid economic recovery, and the global energy crisis triggered by the war in Ukraine, have led to an intensification of fossil fuel usage across the globe. As a result, global energy-related CO_2 emissions reached record levels in 2022. At the same time, investments in new fossil fuel projects also increased.[v]

To assess progress against the global climate goals of the Paris Agreement, a Global Stocktake process was included under article 14 of the Agreement[17]. This two-year process is required to take place every five years. It provides for a rigorous inventory of climate actions, interventions and their impacts around the world – country by country and cumulatively. The first-ever Global Stocktake began in 2022 and is due to conclude at COP28 at the end of 2023. In September 2023, key technical findings were set out in a Synthesis Report, upon which future actions are to be based. The report reveals just how far the world has fallen behind in efforts to achieve the Paris targets.

[iv] The November 2022 update on Climate Action Tracker website, showing 2100 temperature projections shows that current pledges and targets will give an average global temperature rise of more than 2°C. If current policies and actions are taken as the benchmark for assessment, then the picture is worse: even a low estimate suggests an average temperature rise of 2.6°C. The Climate Action Tracker also shows the trajectory required for emissions reductions to meet various temperature thresholds. https://climateactiontracker.org/global/temperatures/

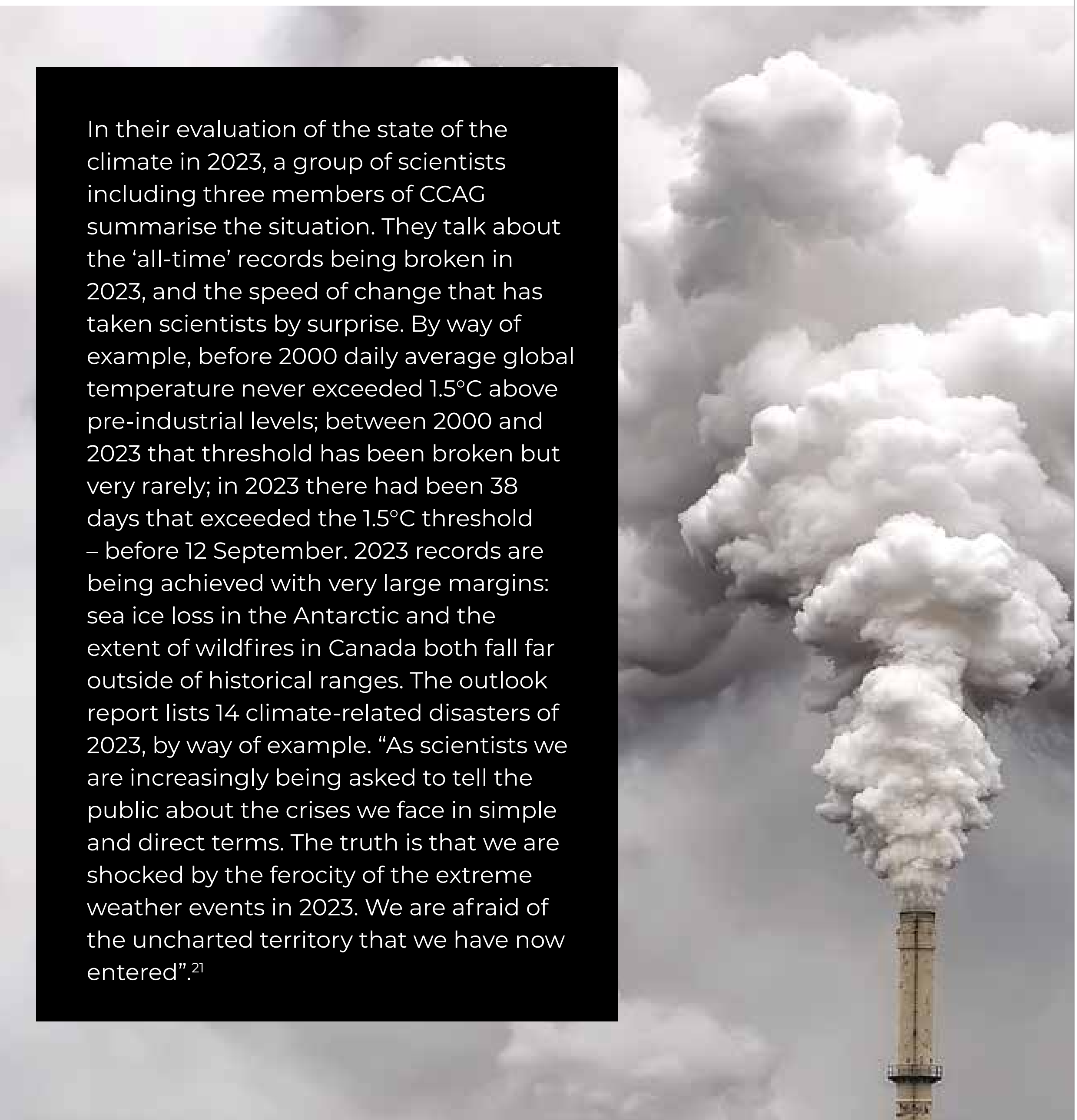
[v] The International Energy Agency (IEA) produced a 2023 update to its 2021 'Net Zero by 2050'. Its executive Summary notes the pressures that challenge meeting the Paris Agreement goals. But it also notes the unprecedented increase in uptake of clean energy during the relvant period, suggesting that this keeps a pathway open to a 1.5°C limit. IEA (2023) 'Net Zero Roadmap: A global Pathway to Keep the 1.5°C Goal in Reach', page 13 https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

Many experts believe the window of opportunity has closed. Despite the rallying cry issued at COP26 to “keep 1.5 alive”, there is growing scientific consensus that the world is on course to exceed 1.5ºC – at least temporarily – in the not-too-distant future. For many, it is no longer a matter of ‘if’ but ‘when’ that threshold is crossed.

In spite of current momentum, and the likelihood of crossing the 1.5°C threshold, there are some helpful trends to build upon for a more hopeful future. Around the world, there is a rapidly accelerating take-up of renewable energy options in the private sector. In 2020, one in 25 cars sold was electric; by 2023 this was one in five.[19] The amount of renewable energy generating capacity added during 2023, at 500 GW, will exceed previous records.[20]

Arising from shifts set in motion years ago, a new, clean energy economy is emerging. At the heart are solar photovoltaics and electric vehicles. The accelerating preference for renewably powered goods is propelled by market realities as well as desires to reduce emissions: the new options are often cheaper and more cost effective than their old fossil fuel predecessors.

“…much more is needed now on all fronts…global emissions are not in line with…the temperature goal of the Paris Agreement, and there is a rapidly narrowing window to raise ambition and implement existing commitments in order to limit warming to 1.5°C…[18]”



In their evaluation of the state of the climate in 2023, a group of scientists including three members of CCAG summarise the situation. They talk about the ‘all-time’ records being broken in 2023, and the speed of change that has taken scientists by surprise. By way of example, before 2000 daily average global temperature never exceeded 1.5°C above pre-industrial levels; between 2000 and 2023 that threshold has been broken but very rarely; in 2023 there had been 38 days that exceeded the 1.5°C threshold – before 12 September. 2023 records are being achieved with very large margins: sea ice loss in the Antarctic and the extent of wildfires in Canada both fall far outside of historical ranges. The outlook report lists 14 climate-related disasters of 2023, by way of example. “As scientists we are increasingly being asked to tell the public about the crises we face in simple and direct terms. The truth is that we are shocked by the ferocity of the extreme weather events in 2023. We are afraid of the uncharted territory that we have now entered”.[21]

Finding a way back

Despite the present situation, the world should not simply accept the inevitable and give up trying. Although 1.5°C is intended to be an absolute threshold, every further fraction of a degree still makes a difference to human lives, and every effort to get back below 1.5°C is worth fighting for. The pressure is not eased by accepting an overshoot; rather, the pressure to restore a safe temperature is intensified. CCAG has not given up on 1.5°C, believing that every effort should focus on immediate implementation of rapid emissions reduction, while acknowledging the likelihood of an overshoot scenario and the additional dangers that represents.

There is no guarantee that exceeding 1.5°C will be followed by a return to safety. This outcome will require massive efforts across the globe, drawing on scientific ingenuity, well-considered experimental testing, rapid technological development, political will, financial investment and public engagement. This is why it is crucial to plan now for a way through any overshoot and back to 1.5°C. Every effort must be ramped up. Arguments about when the boundary will be crossed and whether 1.5°C is even the right boundary for safety should not put any brake on action to reduce emissions deeply and rapidly.

Dealing with an overshoot, wherever the threshold is set, implies that two clear kinds of intervention are fundamental to any climate strategy: emisssions **reductions**; and also effective **removal** of excess GHGs already in the atmosphere. There are many means available for removal of GHGs – ranging from reforestation, land-use change and restoration of other carbon sinks, such as peatlands, to technological efforts to capture and store CO_2 via mechanical means. Reduction and removal form two components of CCAG's 4R Planet Strategy, which addresses problems at the heart of the climate crisis by focusing on action in four key areas:

- Reduction
- Removal
- Repair
- Resilience

More information the 4R Planet Strategy can be found in Section 6, which explores the climate interventions available to help manage and mitigate the overshoot.

"There is growing scientific consensus that we are on course to exceed 1.5ºC in the not-too-distant future."

1. WHAT IS 'THE OVERSHOOT' AND WHY DOES IT MATTER?

The term 'climate overshoot', or simply 'overshoot', refers to a scenario where the world fails in its efforts to remain within the 1.5ºC Paris Agreement limit, but through various climate actions (reducing emissions and removing excess GHGs from the atmosphere) will rapidly seek to bring the global temperature back down to the Paris Agreement limit or below.

The overshoot therefore describes a temporary period of warming beyond 1.5ºC, rather than a continued rise or higher fixed peak temperature. Following a realtively brief period of cooling, the global temperatures will then stabilise at or below 1.5ºC.[vi]

It is becoming ever more likely that the 1.5ºC limit will only be achieved after a period of overshoot.[22] The IPCC (Working Group 1) adopts the following definition of an overshoot: "For the very low GHG emissions scenario (SSP1-1.9), it is more likely than not that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming."[23]

Of the scenarios considered by the IPCC (which start in 2015) and referred to in their report of 2023, only the two most favourable in terms of low emissions going forward offer any possibility of remaining below 1.5°C without an overshoot. The conditions for those two scenarios would require action to be visible by now; and as yet there is no evidence of any sea change taking place.

Feasibility studies into various emissions scenarios conclude that achieving 1.5ºC with 'no or low overshoot' is only possible if all strategies to reduce GHGs are ramped up to 'challenging' levels.[ix]

In short, the risk of a climate overshoot is 'high and rising'.[24]

[vi] Based on minimising likelihoods of triggering climate tipping elements and preserving other climate functions for a manageable future, an increase of between 1.0°C and 1.5°C exposees the world to moderate risk of passing tipping points and high risk of exposure to additional harms. Even more importantly, a safe and just earth systems boundaries analysis demands a rise no higher than 1.0°C if tens of millions of people are to be protected from dangerous 'wet bulb' temperature extremes at which harm to health and livelihoods occur, with a heightened risk of death. Nature, Rockström et al (2022) 'Safe and just earth system boundaries', pages 103-104 https://www.nature.com/articles/s41586-023-06083-8

[ix] Washington Post, Mooney et al (2020) 'We looked at 1,200 possibilities for the planet's future. These are our best hope.' https://www.washingtonpost.com/climate-environment/interactive/2022/global-warming-1-5-celsius-scenarios/

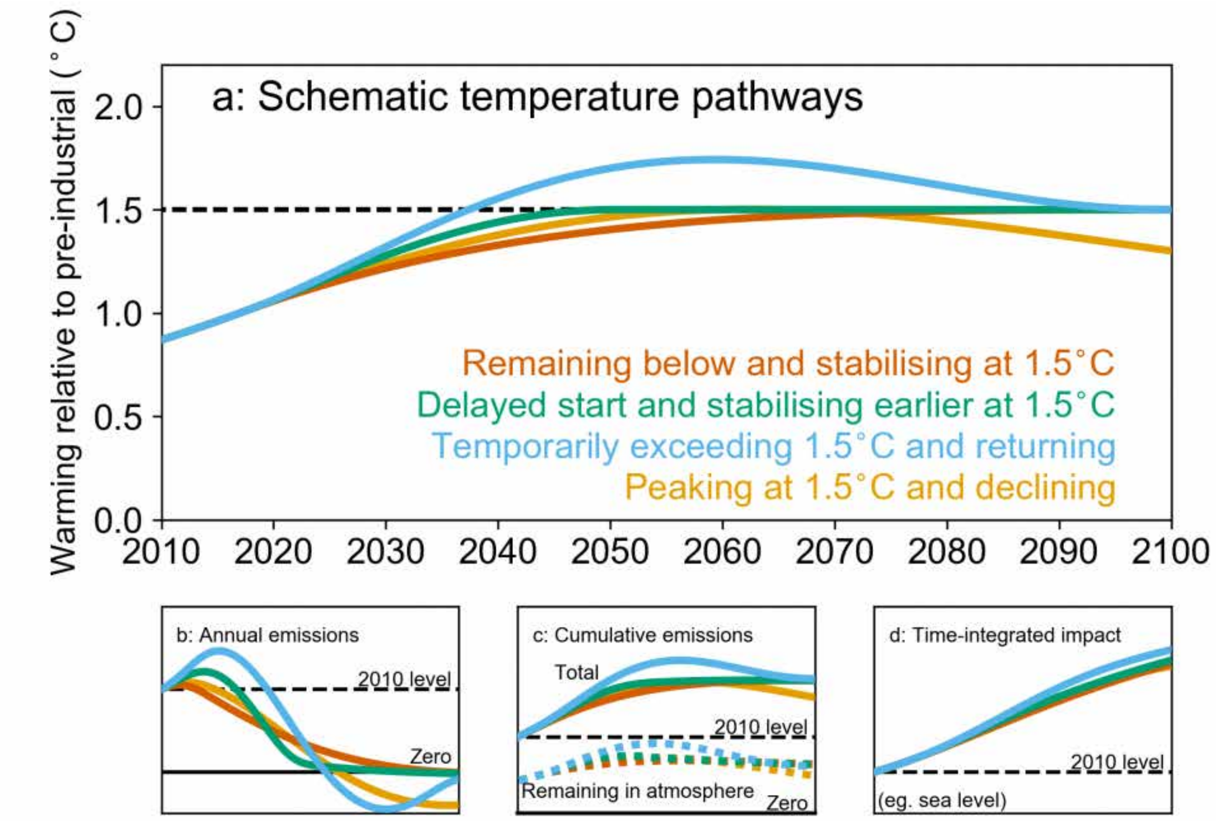


Figure 1: Different 1.5°C pathways schematic: the blue curve shows the overshoot[25]

The overshoot matters because it takes the world over the 1.5°C threshold into levels of temperature increase that will further accelerate all climate change effects and risks, including extreme weather events. According to the IPCC, crossing the 1.5⁰C threshold "risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall".[vii]

In this respect, the extent and degree to which the overshoot occurs is critical. Indeed, "every fraction of a degree matters...the 1.5°C goal is not just a number. The international community set this limit to signal the point beyond which it considers the risks of climate change to be unacceptable."[26]

[vii] The views of the IPCC are paraphrased here by the UN Climate Change website, in its explanation of the Paris Agreement. This quote comes from the response to FAQ 'What is the Paris Agreement?' https://unfccc.int/process-and-meetings/the-paris-agreement. In their Working Group 1 report, the first instalment for the IPCC's sixth Assessment Report (AR6) detailed new estimates of the chances of crossing the 1.5°C (and also a 2.0°C) threshold. At their time of writing, the data showed unequivocal temperature rise of 1.1°C. On that basis the rise would reach or exceed 1.5°C within 20 years.. The IPCC summarises its own report findings on its website post of 9 August 2021. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Acknowledging the overshoot

Lavanya Rajamani is Professor of International Environmental Law at the University of Oxford and a member of the CCAG panel of climate experts. She says that acknowledging the current overshoot pathway is actually vital to managing climate impacts in the short term, and finding a way back to 1.5°C in the medium term:

"We are on an overshoot pathway; the recent IPCC assessment reports say this with a level of certainty. But some vulnerable states are not willing to acknowledge this for fear that the foot will be taken off the pedal if they do. While this is a risk, not acknowledging that we are on an overshoot pathway also carries risks as it means we are not focusing sufficiently on managing the inevitable impacts in the meantime. While the world remains focused on just transitions to a climate-safe world, we also need to navigate the risks of an overshoot, and focus on processes that will bring us back down."

"Every fraction of a degree matters."

Present tense: the impact of over 1.1°C on today's global environment

Something extraordinary is happening on our planet's southernmost continent. As winter falls on Antarctica, the vast wilderness should now be deeply engulfed by ice. But in mid-2023, Antarctica experienced the lowest levels of sea ice ever recorded for that time of year. In fact, the amount of sea ice coverage in the region was 2.3 million square kilometres below the average levels seen between 1981 and 2010.[27]

Nerilie Abram *is a Professor of Climate Science at the Australian National University and a member of the CCAG group of climate experts. Here, she explains how present levels of global warming are already causing extreme anomalies in Antarctic sea ice, driving rapid and damaging change across the southern polar region. Antarctica's collapse is not some distant doomsday scenario. It is already underway.*

"Antarctic sea ice changes have major implications. Firstly, Antarctic sea ice is really important for the climate system and the interaction between the ocean and the atmosphere. It's also an important wilderness habitat and a key landing platform for scientists to access their research stations, enabling us to make studies about sea ice and climate change. But interactions between the oceans and the atmosphere are changing, and this is affecting the global climate.

With the warming that's occurring, Antarctic sea ice is rapidly being lost, changing areas from white ice into darker ocean surface. White sea ice reflects solar radiation back into space, naturally slowing down warming of the atmosphere and the ocean. As this ice melts, accelerated warming occurs, which speeds up the melting, which in turns speeds up the atmospheric and ocean heating. This feedback loop is now well under way.

And the speed at which Antarctic sea ice is declining is honestly off the scale. The magnitude of the sea ice anomaly we're looking at right now is the strongest we've ever seen, and has taken us somewhat by surprise. In the last decade, since 2014, the rate of loss has accelerated, with about 2 million square kilometres lost just in that time. That's even greater than the amount lost in the Arctic over 30 years.[28]

The West Antarctic Ice Sheet (WAIS) has been a particular concern for a long time, and we're now seeing very rapid changes happening there as well. There's a lot of discussion around the potential for passing tipping points even at warming of around 1.5ºC. When that ice sheet destablises we could have a runaway situation, with changes that become effectively unstoppable.

Climate warming also has the potential to disrupt deep ocean Atlantic Meridional Overturning Circulation (AMOC). We know about the role of Arctic ice in regulating deep ocean currents, whereby cold water sinks and creates currents that move both warm and cold water around the globe. Antarctica is now understood to be even more important for driving ocean current regulation. Antarctic bottom water is the coldest, saltiest and heaviest in the global climate system. This is really important for the way heat is moved around the planet, the way oxygen is moved into the deep ocean, and the way nutrients are cycled through the ocean, which supports multiple ecosystems.

Two very recent independent studies have confirmed about a 30% reduction in the formation of Antarctic bottom water since 1992.[29] A further recent model suggests that at current GHG global emissions rates, almost half of the bottom water will be lost (and that may not be the full story, given what we're now seeing with observed changes to date). This represents a huge decline in something that's a fundamental part of how our oceans and climate operate. And in the North Atlantic the same experiment design predicts a 19% decline in AMOC by 2050, given current rates of melting. These are changes that could have major global consequences. And they're happening here and now.

A further concern is loss of ice from the continent itself – from land, rather than sea. This kind of ice loss directly raises sea levels as water flows into the ocean. We used to think the ice sheet on land was relatively stable, but now there are worrying signs of instability going into the future. The instability in East Antarctica becomes critical if global warming rises to 2.0°C. In Western Antarctica, the instability is happening at current global temperatures.

One important area of ice on Antarctica fills a canyon some 3.5 kilometres deep, placing massive volumes of ice below sea level. The Denman Glacier, as it's known, contains enough ice to raise global sea levels by 1.5 metres if it was to melt. I'm currently involved in a programme of work focused on the Denman Glacier. It's a very difficult place for scientific study because of its remoteness and environmental conditions. I will be spending three months there, starting later this year."

2. TRANSGRESSING PLANETARY BOUNDARIES: THE HEALTH OF THE WORLD IN 2023

With climate change already presenting massive challenges at 'just' 1.1°C or 1.2ºC above pre-industrial levels, what is the current state of the planet we inhabit?[viii] One climate model suggests that Earth's average temperature rise across 2023 is likely to exceed the 1.5°C threshold, though "...to breach the Paris agreement's limit" the heating of 1.5°C would have to "be sustained for many years".[30]

In 2023, scientists conducted a complete 'scientific health check' of planet Earth.[31] The assessment was based on the concept of 'Planetary Boundaries', first described in 2009.[32] Nine interlinked Planetary Boundaries define "a safe operating space for humanity". By staying within these boundaries, it is possible to "prevent human activities from causing unacceptable environmental change".[33] The focus was explicitly on parameters that would keep humanity safe from the worst kinds of global change, with the poorest and most vulnerable setting the baseline for what is deemed 'safe'.

In geological terms, the Holocene period on Earth began over 10,000 years ago. During this stable period, "change occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development".[34] Since 1950, humanity has triggered the new Anthropocene period, ending the stability of the Holocene. Human actions are now the main driver of global environmental change. These human actions threaten to shift the planet beyond the stable environment of the Holocene, with severe consequences for humanity and all life on Earth.

The Planetary Boundaries framework offered an approach to defining the biophysical preconditions under which human wellbeing is known to be possible.

[viii] Scientists agree that the decadally-averaged global temperature rise has exceeded 1.1 0 C above pre-industrial levels, with some, such as the EU's 'Copernicus' website, showing that global warming reached 'an estimated 1.21°C in December 2022', and 'an estimated 1.24°C in September 2023' (the latest date available). Climate Copernicus (2023) 'How close are we to reaching a global warming of 1.5°C?' https://climate.copernicus.eu/#:~:text=If%20the%2030%2Dyear%20warming, Climate%20Change%20Service%20information%202023.3. '

The identified boundaries are:

- Climate change
- Change in biosphere integrity
- Biogeochemical flows (nitrogen and phosphorous cycles)
- Stratospheric ozone depletion
- Ocean acidification
- Freshwater change
- Land system change
- Atmospheric aerosol loading
- Novel entities[35] (includes, amongst the many entities introduced by humans to the Earth system, synthetic substances and chemicals such as microplastics)

In 2009, three out of the nine Planetary Boundaries had been transgressed. Fourteen years later, many earlier predictions have come to pass. The same boundaries have been more severely transgressed, and a further three boundaries have also been crossed, taking the total to six out of nine. Of the other three boundaries, ocean acidification is close to being exceeded. And although the 'atmospheric aerosol loading' boundary is not yet transgressed, regional transgressions are found.[36]

Overall, the 2023 planetary health check shows that most of these critical global systems are beyond the stable range in which modern civilisation emerged".[37] Earth is now evidently outside of the safe operating space for humanity. Professor Johan Rockström, Director of the Potsdam institute for Climate Impact Research, and a member of the CCAG group of climate experts, is the lead author of the original Planetary Boundaries framework.

"If you want to have security, prosperity and equity for humanity on Earth, you have to come back into the safe space and we're not seeing that progress currently in the world."[38]

Given these findings, and given that the world is unlikely to remain below 1.5°C of global temperature rise, it seems that emissions reductions alone will not secure a safe future for humanity. 1.5°C is not the only threshold humanity needs to be mindful of crossing. Only by respecting every one of the nine Planetary Boundaries will we ensure a resilient, inclusive and liveable planet. A holistic plan for humanity to continue living well on planet Earth is urgently required.

The weakening of planetary resilience

As the impacts of crossing Planetary Boundaries are observed, the resilience of planetary systems is stretched to breaking point. Four biological boundaries – change in biosphere integrity, ocean acidification, global freshwater change and land system change – are in the 'high risk zone', meaning the Earth's natural life support systems have been severely compromised.[39]

The ecosystem services performed by, for example, rainforests, mangroves, urban green spaces and inland wetlands provide natural resilience to climate change. These services include sequestering carbon and protecting against flooding, erosion and saline incursion into farmland in coastal areas. Rainfall regulation and the provision of shade and cooling are other key examples of natural services. But the planetary boundaries assessment shows how these ecosystem services have been weakened, and Earth's natural defences damaged, meaning its capacity to withstand and recover from climate impacts is diminished.[ix]

Professor Rockström and his team have warned that "the rising signs of dwindling planetary resilience"[40] bring the world even closer to pivotal 'tipping points' (see page 22), which makes the overshoot an even more daunting prospect for humanity.

[ix] Much of this harm is reversible. Reforestation, reinstatement of mangrove forest, tree planting in rural and urban areas, and terracing and greening of eroded hillsides are all demonstrably capable of bringing immediate and significant environmental change for the better.

3. DEGREES OF UNCERTAINTY

Eight years after the signing of the Paris Agreement, global warming continues at an alarming rate. Yet there is a lack of clarity about future emissions reductions and temperature increase.

As the overshoot consensus is building, the IPCC has declared it "almost inevitable" that the world will temporarily exceed 1.5ºC.[41] The UN's World Meteorological Organization offers a "50:50 chance of global temperature temporarily reaching the 1.5ºC threshold in the next five years".[42] Meanwhile, analysis suggests current policies will take the world beyond 2.0ºC.[43]

No one can be sure when and to what extent an overshoot will occur, which has led to increased scrutiny of current policies and pledges. In particular, an analysis on the credibility of the climate targets and commitments of individual nations reveals more about the likelihood of an overshoot.

The credibility gap

Estimations of the effectiveness of global action and its impacts on climate projections can produce polarised results. Some say the world will meet the Paris Agreement ambitions, others say the world is a long way off. Arguably the difference between such analyses arises from a 'credibility gap' at the heart of global targets and policies: should countries be evaluated by what they say, or by what they do? Some targets are short to medium term, and can be evaluated by what is happening right now. But some commitments – to achieve net zero by a particular date, for example – are longer term and harder to pin to current action.[44] This credibility gap has been scrutinised and a lack of 'explicitness' in NDCs is noted, with a variety of proxy measures used to estimate future emissions. Adopting this approach, a 2023 credibility analysis finds:

"More cautious analyses that only look at the current status of domestic policies and their influence on emissions in the medium term project global warming centring somewhere between 2.5° and 3°C in 2100 – and continuing to increase thereafter… [However], analyses that factor in international commitments in NDCs and long-term pledges – taking them at face value regardless of how credible they are – suggest that global warming will stabilise between 1.5° and 2°C and even gradually reverse toward the end of the century."[45]

By determining the quality and credibility of net-zero targets in particular, greater clarity can be achieved around the world's projected emissions trajectories and temperature increase. The credibility analysis adopts three measures for evaluating all pledges and commitments country by country:

- Whether a target is legally binding
- Whether a target is accompanied by a clear implementation plan
- Whether a country's current policies are already putting its emissions on a relatively downward path when compared with a no-target pathway

Against these criteria, targets are assessed and given a 'higher', 'lower' or 'much lower' credibility rating. Based on these credibility assessments, the analysis finds a very wide range of possible outcomes depending on how widely targets and commitments are included:

- In the most conversative case, where only the current climate policies in play country by country are accounted for, global warming may still rise 2.6ºC by the end of the century
- Even in the best-estimate emissions path, assuming further policies will be implemented as promised, uncertainties mean there is still a 10% chance that warming ends up at 3.3ºC
- If all current pledges are assumed to be duly implemented, 1.7ºC emerges as the best mid-estimate of global temperature rise
- Where only higher credibility net-zero targets are included, current evidence puts global warming outlook at 2.4ºC.[46]

Overshoot scenarios

In late 2022, to "see what hope remains" The Washington Post initiated a review of "over 1,200 different scenarios for climate change over the coming century."[47] These scenarios were based on models considered in the IPCC 2022 report on mitigation of climate change.[48] The evaluation process was designed and had been implemented in an earlier 2021 study by a team from the Potsdam Institute for Climate Impact Research.[49] The 2021 study categorised climate scenarios according to the kind of mitigation 'levers' they relied upon. The use of or reliance on these mitigation levers was classified as 'reasonable', 'challenging' or 'speculative' based on availability of relevant technology,
roll-out plans for reduction of global energy demand and so on.[50]

Applying the 2021 study approach, The Washington Post review showed that only 230 scenarios out of the original 1,200 would leave planet Earth at or below 1.5°C by the end of this century. Within these 230 scenarios, more than half depended on rapid near-term emissions reductions that "increasingly conflict with reality" (meaning they were unlikely to be achieved).[51] Removing these scenarios from the assessment, The Washington Post found 112 remaining pathways to 1.5ºC by the end of the 21st century, from which two key pathways emerge:

- 'High overshoot', where the Earth's temperature rises well over 1.5ºC before cooling back down.
- 'No or low overshoot' where, in most cases, the world goes far beyond net-zero targets by 2050 to attain 'net negative' (i.e. removing more CO_2 from the atmosphere than it is putting in).

Twenty six scenarios were found to allow for 'no or low overshoot' through the widescale deployment of carbon capture technologies, and massive reduction of GHG emissions from energy production and other measures. When The Washington Post invited the Potsdam Institute to assess the implied GHG emissions reduction strategies in these scenarios, they were each classified as 'speculative', 'challenging' or 'reasonable' against five levers or dimensions:

- Carbon dioxide removal and storage underground
- Carbon dioxide removal using land
- Reduction in carbon intensity of energy production
- Changing energy demand
- Fewer methane emissions

The Potsdam team evaluation found no available scenarios to attain ‘no or low overshoot’ relying on only ‘reasonable’ use of these levers. If the levers are used at ‘challenging’ levels, 11 pathways for ‘no or low overshoot’ open up, but these depend on ‘challenging’ scenarios across all five dimensions – i.e. a dramatic scale-up of carbon removal; storage across all available methods; the transformation of energy use; and the reduction of energy demands and emissions. Taking just one of these dimensions, the theoretically workable scenarios imply the ability to subtract “over 7 billion tons [of carbon] per year from the atmosphere by 2050”.[52] Current global capacity is at about 43 million tons per year, showing what a monumental undertaking would be required to adopt such a pathway.

Regrettably, therefore, ‘high overshoot’ scenarios are deemed more feasible. And this, with all levers set to ‘reasonable’, leaves six pathways open. These pathways require lower levels of carbon removal and storage to 2050, ramping up to more ‘challenging’ interventions thereafter to bring global temperatures back down.

Based on these assessments, The Washington Post article concludes that 1.5ºC is most likely not achievable “without a major overshoot first”.[53] The subsequent ‘challenging’ interventions required even to achieve a contained overshoot highlight the urgent need for CDR (carbon dioxide removal) techniques and strategies to be thoroughly explored. They will be greatly needed in the second half of this century in any analysis.

Reality check: assessing the feasibility of future emissions scenarios

The Washington Post article of December 2022 described in this report was inspired by a 2021 research paper led by ***Dr Lila Warszawski,*** *Scientist and Research Analyst to the Directors of the Potsdam Institute for Climate Impact Research.*[54]

In the 2021 paper, Dr Warszawski and her team scrutinised the emissions scenarios described in the IPCC's Special Report on Global Warming of 1.5ºC.[55] *Here, Dr Warszawski explains the methodologies and findings of the 2021 study.*

"We wanted to assess the feasibility of the 1.5ºC emissions scenarios set out by the IPCC, to really understand what kind of global transformation they describe and how this compares to best estimates of what is really possible.

So, we took the emissions scenarios in the Special Report and defined a set of common (but not exhaustive) climate-mitigation levers, which we could calculate for each scenario – those that were subsequently cited in the later Washington Post article. And we asked a series of questions, such as 'How much negative emissions are being assumed per year in 2050?'; 'By how much did total energy demand reduce between 2018 and 2050?' Then we scanned the literature for feasibility limits across all these levers and dimensions, and made an expert assessment within our research team of which two limits (a medium and a high one) we'd like to apply.

Anything below the medium limit was 'reasonable'. Anything between the medium and high limit was 'challenging', and anything beyond the high limit was 'speculative'. We took the emissions scenarios, extracted the relevant data relating to each of the levers, and compared the data to the limits. In this way, we created a robust filtering process.

What we found was that scenarios boasting 'no or low overshoot' do so by using at least two levers at challenging levels. Or, looking at it another way, that 1.5ºC is no longer feasible with 'no or low overshoot' unless you're willing to bet on technological and political/social devlopments that will be challenging to realise. For us it was important to emphasise that there is no silver bullet for keeping global warming below 1.5°C, irrespective of your tolerance for an overshoot: all strategies available to us, be it CDR, decarbonisation of the energy system or transformation of the global agriculture system, will need to be pursued with maximum effort.

What you've got to remember is that this research was conducted in 2019/20, and even just three years ago people were holding on a bit more tightly to 1.5ºC as an achievable target without an overshoot. Since that time, the consensus has shifted as emissions have continued to rise. We've had three more years where demonstrably the action required since the study was done to avoid an overshoot has not been taken. But rather than letting us off the hook, this realisation shows us just how fleeting our chance to secure a safe climate future is.

The ongoing UNFCCC Global Stocktake process, which is looking at what countries have pledged and promised compared to the pathways they are actually on, will be another chance to do a reality check on how well the model-based scenarios represent real-world developments. The results of the Stocktake will surely be new food for thought for the next round of integrated assessment modelling (the source of the scenarios we're talking about here). Of course, the feasibility check we did made use of limits drawn from estimates of what is technologically and economically possible. The social and political realities may look very different."

4. THE RISKS, IMPACTS AND IMPLICATIONS OF A CLIMATE OVERSHOOT

So, what happens to the world beyond 1.5ºC?

First, it is important to stress that if/when the world crosses the 1.5ºC average global temperature rise threshold, the planet will not suddenly implode. Humanity will not suddenly be extinguished. However, by going beyond 1.5ºC we move into a world of increased climate risk and uncertainty; an unstable realm where a range of diverse climate impacts can begin to rapidly escalate and self-perpetuate. One of the risks with greatest potential for harm, post-1.5ºC, is the crossing of various 'tipping points'.

Tipping points

Tipping points, or climate tipping points (CTPs), refer to irreversible shifts in the planet's biological and physical systems that become self-perpetuating, accelerating further change. Examples of tipping points include the melting of polar ice sheets and the transformation of tropical rainforests into less abundant forms of vegetation.

In 2008, nine policy-relevant tipping elements and their CTPs were identified.[56] Since then, there have been substantial advances in scientific understanding, with additional tipping elements added to the list. In 2022 an updated assessment of the most important climate tipping elements and their potential CTPs was reported, including temperature thresholds, timescales and impacts.[57] The 2022 study identifies nine global 'core' tipping elements which contribute substantially to Earth system functioning, and seven regional impact tipping elements which affect human welfare. These include:

- (Loss of) Arctic Winter Sea Ice
- (Collapse of the) Greenland Ice Sheet
- (Abrupt thaw of) Boreal Permafrost
- (Dieback of the) Amazon Rainforest
- (Die-off of) Low-Latitude Coral Reefs
- (Collapse of the) West and East Antarctic Ice Sheets

Crossing the CTPs within these and other tipping elements would have major consequences for people and planet. For example, the collapse of the Greenland and Antarctic Ice Sheets would condemn future generations to more than 10 metres of global sea-level rise. This scenario increases the risk of coastal flooding, which in turn threatens the loss of human habitats, lives, livelihoods and economic assets as large populated areas become inundated or submerged.

Even global warming of 1°C, a threshold already passed, raises the risk of triggering some of these tipping elements, while a rise of 1.5ºC and above risks crossing multiple tipping points. At-best global warming scenarios – which the study sets at just below 2°C, if all net-zero pledges and NDCs were to be implemented – would lower tipping point risks but still leave multiple tipping elements at risk of being triggered.[58]

A major concern related to tipping points is the risk of a 'domino effect', where the crossing of a tipping point in one system could drive further warming, thus triggering further tipping elements. A recent study showed that these 'global cascade' effects, mediated by interactions between tipping elements, could be triggered by even a moderate overshoot of the 1.5°C limit.[59] These findings provide a compelling argument for limiting additional warming as much as possible, and of returning to safety as quickly as possible in the event of an overshoot. Many climate scientists agree that "the consideration of tipping points helps to define that we are in a climate emergency and strengthens [the] chorus of calls for urgent climate action – from schoolchildren to scientists, cities and countries."[60]

What happens in the Arctic doesn’t stay in the Arctic: the interconnectedness of global tipping elements

Over the last 30 years, the Arctic has been warming more than three times faster than anywhere else on the planet. This warming is having a significant impact on our planet’s weather systems[x].

The Arctic is an important part of the Earth’s climate-regulating systems. There is increasing evidence that the Arctic is a ‘ground zero’, connected to many climate tipping elements, through its influence on the monsoon system, ocean circulation, and the functioning of ecosystems around the world.

For example, evidence shows that a rapidly warming Arctic can cause the polar jet stream to meander in deep curves, leading to blockages of high- and low-pressure systems around the northern hemisphere[xi]. In 2012, Hurricane Sandy, which smashed into the East Coast of America, was proven to have been locked there by such a meandering jet stream. And in 2021, a so-called ‘omega-rich’ meander of the jet stream locked in a very deep high-pressure system, bringing a record setting 49.6ºC of heat in British Columbia, the highest temperature ever recorded in Canada by more than 4.5°C. In fact, only in the southwestern deserts of the US have higher temperatures ever been recorded in the US and Canada.[61]

Arctic ice melt also leads to increased releases of cold fresh water into the North Atlantic, which in turn slows down ocean circulation (the Atlantic Meridional Overturning Current or ‘AMOC’); the slowed AMOC in its turn disrupts the monsoon system in South America, causing droughts and forest fires across the Amazon. It slows down the heat exchange in oceans, too, locking in more warm surface water in the Southern Ocean, which might in part explain the accelerated melting of the West Antarctic ice shelf (see page 12 for further commentary on Antarctica).

In this way, the Arctic is connected in to climate systems across the entire planet. And the dynamics of the physics in the Arctic are very likely connected to extremes which go far beyond what we would expect from today’s 1.1°C or 1.2°C of warming. Stabilising the Arctic is therefore an urgent climate priority. It is another critical reminder of why we need to manage the overshoot and get back to global temperatures which are safe and just.[62]

[x] For a fuller explanation of these links see CCAG Report (2022) ‘Extreme Weather Events in the Arctic and Beyond: A global state of emergency’ https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/6102596bc768697d04731d55/1627543921216/CCAG+Extreme+Weather.pdf

[xi] See the Met Office explanation of the impact of a meandering jet stream: https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/wind/what-is-the-jet-stream And see Nature ‘Research Highlight’ (2022) for link between changes at the Earth’s surface and impacts in the upper atmosphere. https://www.nature.com/articles/d41586-022-02905-3#:~:text=Small%20temperature%20contrasts%20near%20Earth’s,weather%20at%20some%20latitudes1

Impacts of a short-term overshoot

While there are numerous studies that compare the impacts of a 1.5°C global average temperature rise versus one of 2°C, there is little in the scientific literature that looks at the specific impacts of a short-term 1.5ºC overshoot. For a comprehensive analysis of the implications of an overshoot beyond 1.5°C, there are many dimensions to consider: the effects in the coming decades, the longer-term intergenerational implications, the local and regional impacts, as well as the global consequences. The impacts of the costs of mitigation (to stay within 1.5°), and the associated benefits of avoided climate risks and damage, vary widely by region and even at local levels.

A 2023 study set out to begin this analysis, taking account of socioeconomic factors as well as physical and environmental impacts.[63] The analysis considers two key scenarios in detail. In both there is an underlying assumption that global GHG emissions will peak in the near future, and thereafter will fall, reaching net zero well before the end of the 21st century.[64] Within that framework, the two scenarios consider the impacts of a faster or slower rate of change. In the faster rate of change, the focus is on keeping within the 1.5°C global temperature rise of the Paris Agreement. In the second, the focus is on getting back to no more than 1.5°C of temperature rise by the end of the century, with an overshoot beyond that 1.5°C for a decade or so. The scenarios are derived with an Integrated Assessment model, thereby allowing a comparison of the differences in economic efforts involved.

In the **first scenario**, the world adopts very rapid emissions reductions almost immediately, leading to a 'minimum overshoot' beyond the 1.5° maximum target, with a rapid reduction to net-zero global emissions by about 2040. In this scenario there is an emissions overshoot of 50Gt beyond the required 600 $GtCO_2$ carbon budget (for cumulative global emissions between 2010 and 2100).[xii]

The **second scenario** assumes that global emissions remain more or less at current levels for a further decade, until about 2035, with rapid emissions reductions starting from there to reach net zero by 2060. In this scenario there is an overshoot of emissions of 700Gt, over and above the budget of 600 $GtCO_2$.

In both scenarios, the emissions overshoots are dealt with, along with other gross residual emissions, by deployment of carbon removal strategies. In the no (or very low) overshoot beyond 1.5°C scenario, carbon removal efforts are stepped up immediately, giving a potential cumulative removal between 2020 and 2100 of 800 Gt.

[xii] The IPCC explains that 'The term carbon budget refers to the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date.' IPCC WG1 (2021) 'Climate Change - The physical Science Basis: Summary for Policy Makers' https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf . The 2023 study adopts the remaining carbon budget of 600Gt for the defined period of 2010 – 2100, calculated as giving a 66% chance of not exceeding 1.5°C. See Environmental Research Letters, Bauer et al (2023)'Exploring risks and benefits of overshooting aa 1.5°C carbon budget over space and time' https://iopscience.iop.org/article/10.1088/1748-9326/accd83/meta page 2.

The climate target is so stringent that the world has to get to net zero extremely quickly in this scenario. Reducing fossil fuel emissions alone would not do the job – so carbon removal must be 'front-loaded' to support a very rapid shift to net zero. The costs to national economies associated with this rapid deployment are higher than allowing carbon removal processes to be developed and deployed over the timescales of the second delayed scenario.[xiii] Thereafter, the world is assumed to continue at net zero, creating a manageable future for humanity, with little additional risk of reaching tipping points or triggering other irreversible changes to climate systems, compared with prevailing conditions today.

In the second scenario, cumulative carbon removal between 2020 and 2100 reaches 950 $GtCO_2$ – but starting later than in the first scenario, and avoiding additional economic impacts of 'front-loading' removal and faster fossil fuel phase-out. Achieving net zero will not constrain global mean temperature rise to 1.5°C because of the additional cumulative emissions caused by the ten-year delay period. The significant net-negative emissions of 27Gt per year demanded in this scenario to 2100 equate to five times the current level of annual oil extraction.

The study evaluates the economic and social impacts of opting for one or other of the two scenarios. The findings are challenging – especially for non-OECD countries that already bear an increasingly intolerable burden from global temperature rises. In straightforward GDP analysis, the study concludes:

- Accelerating emissions reductions to deliver the first scenario will lead to reductions in global GDP from the current baseline. A rapid reduction in emissions leads to a drop in global GDP of 2.0% to 3.5%. OECD countries would face a decline of about 1.2% per annum; non-OECD countries face a huge drop of 5.9% of their GDP.[xiv]
- By delaying the speed of emissions reductions, and allowing the emissions overshoot to reach around 700 $GtCO_2$ beyond the 600 $GtCO_2$ global budget (a cumulative budget for the period 2010 to 2100), the loss of global GDP falls to just over 1%. In this scenario, global CO_2 emissions could remain constant until 2030 followed by a rapid decline and substantial net-negative emissions in the second half of the 21st century.

Trade-offs: costs and impacts

There are trade-offs between short-term mitigation costs and longer-term impacts and damages, especially for non-OECD countries where the impacts of allowing climate change to run on are most heavily felt, but the adverse impacts on economic development of the most rapid emission reduction policies are more severe.

[xiii] Both scenarios are assumed in the study to be implemented by applying an emissions tax on all greenhouse gas emissions with a uniform tax rate irrespective of sector, source or location. The physical differences between GHG regarding the effect on the climate are considered by applying the Global Warming Potentials for a 100 year time horizon as tax conversion rates. Environmental Research Letters, Bauer et al (2023)'Exploring risks and benefits of overshooting aa 1.5°C carbon budget over space and time' page 2 https://iopscience.iop.org/article/10.1088/1748-9326/accd83/meta Also, Environmental Research Letters, Bauer et al (2023)

[xiv] These figures have high levels of uncertainty especially because it is difficult to know the persistence of certain economic effects. However, the gap between OECD and non-OECD countries and their inevitable economic burden is large and clear. Ibid page 12.

The additional costs to GDP of pursuing a very rapid emissions strategy are sobering – especially for poorer countries, particularly in South and South-East Asia, and fossil fuel-rich middle-income countries.

However, allowing the overshoot to run increases the risk of crossing and locking in global tipping points. It also guarantees the ongoing escalation of extreme weather events being experienced around the world, with even less predictability. Analysis shows, for example, that tropical cyclones can have a negative impact on the GDP of affected countries for more than 15 years.[xv] Perhaps the greatest challenge of all will be more severe heat all over the world, bringing greater heat stress – with the likelihood of catastrophic harm to people, families and livelihoods, especially in already hot countries.

A slight increase in temperature in a very hot country disproportionately harms health and can permanently drag down development, with life-long impacts at the individual, community and state level. Those with very low incomes are often people dependent on subsistence agriculture – a fragile livelihood that profoundly depends on weather, rainfall and human labour all through the year. In such communities, social support systems are put under intolerable pressure when weather events hit.

The economic implications of an overshoot can be seen in the short to medium term. The more tolerant the world economy is of an overshoot, the lower the incentivising carbon price for a rapid energy transition. In order to rapidly limit the overshoot, a carbon tax of around US$550 per ton of CO_2 emissions is implied. If the overshoot is allowed to run to 750 $GtCO_2$ beyond the 600 $GtCO_2$ global budget, the implied carbon tax could be around US$50 per ton of CO_2 emissions.

It is hard to balance global economic impacts against individual costs and struggles. But the intergenerational consequences are already in play: even in the minimal overshoot scenario, a person born in 2020 will experience five times more heatwaves in their lifetime than someone who is 60 years old in 2020. If the second, higher overshoot scenario plays out, this risk increases to six times more heatwaves over a lifetime. In global warming, every fraction of a degree makes a measurable difference.

The painful truth is that poorer nations will face very difficult economic consequences of an immediate reduction in emissions. Their short-term inclination may be to delay. The OECD countries will feel some (though less) short-term economic pressure to delay as well. But the longer-term consequences of an emissions overshoot will be felt much more acutely by the non-OECD countries. The trade-off is a very difficult one, especially where compensation from the wealthier to the poorer countries remains limited.

"Analysis shows that tropical cyclones have a negative impact on the GDP of affected countries for more than 15 years."

[xv] It is not only the pure destruction of massive storms, but the longer term effect on economic activity (measured by the differences of GDP with and without the initial shock by the destruction). Ibid page 11 – Figure 8.

***Dr Nico Bauer** is a senior scientist at the Potsdam Institute for Climate Impact Research (PIK Institute). He works on the development of modelling tools in climate studies, also linking climate change to economic pathways. He is the lead author of the 2023 overshoot impacts study.*

“The findings of our study demonstrate how the poorer countries of the world carry more than their fair share of the burden of climate change, in spite of the fact that their activities have contributed so little to the problem. A very rapid global shift to net zero to avoid the overshoot will hurt the economies of poorer countries badly, because their dependence on coal, for example, is disproportionately important to their economic development. GDP loss will be more modest in richer countries, which are already less dependent on fossil fuels for their economic activities and where more financial means are available to make decarbonisation work.

If there is a delay in reaching net zero, all countries see a smaller drop in their GDP caused by mitigation as the transition from fossil fuels is delayed. But climate impacts become more severe, and severe climate impacts hit the hotter, poorer countries and economies harder.

The question in weighing up the trade-off between mitigation and climate impacts is a cruel one: will a country get rich enough to cope before it gets too hot to be sustainable? Heat stress is the greatest threat, and its impacts are immediate. This is not a consequence that rolls out over hundreds of year, as sea-level rise does. Heat stress is killing people now. Whatever pathway the world moves along, these trade-offs will be felt, especially by those who can least afford them.

Waiting also means that later on you need more international cooperation. And the longer you wait, the more international cooperation you need. It’s a strange thing that has not really been analysed yet, but I’m absolutely convinced. With more waiting you need more ambition in the policy, and for that you need tighter institutions and more intensive cooperation to remove carbon and to compensate damages.”

5. THE SHORTFALL: WHAT'S ALREADY BEING DONE AND WHY IT ISN'T ENOUGH

"The emission reductions that high-income countries achieved [between 2013 and 2019] through absolute decoupling fall far short of Paris-compliant rates. At the achieved rates, these countries would on average take more than 220 years to reduce their emissions by 95%, emitting 27 times their remaining 1.5°C fair shares in the process."[65]

Deep and rapid emissions reductions are needed if humanity is to stand any chance of limiting global warming and minimising the impact of a 1.5ºC overshoot. But instead global energy-related CO_2 emissions reached record levels in 2022, while investments in new fossil fuel projects also increased, and no doubt 2023 will be another record year for emissions.[66]

Increases in new projects are in part due to external circumstances, such as the carbon-intensive post-Covid economic recovery, and the global energy crisis triggered by the war in Ukraine. However, these events provided real opportunities for accelerating an energy transition instead of doubling down on fossil fuel consumption. On top of these inappropriate responses to global shocks and pressures all over the world, high-income countries are systematically failing to decarbonise at the rate required and falling short of their responsibilities under the Paris Agreement.

"It is ultimately a question of speed", and many countries simply aren't going fast or far enough.[67] To achieve a fair share of reductions, the rate at which economic growth and GHG emissions need to be decoupled must increase ten-fold by 2025.

In fact, only 11 of the 36 high-income countries recently assessed achieved absolute decoupling of consumption-based CO_2 emissions from GDP. These countries are Australia, Austria, Belgium, Canada, Denmark, France, Germany, Luxembourg, the Netherlands, Sweden, and the UK. And none of these countries achieved emission reductions that are fast enough for a 50% chance of staying under 1.5°C with some adherence to equity principles, where stronger notions are needed.[68]

While the evidence suggests commitments made under the Paris Agreement will likely be missed, some argue that the world requires even greater ambition – that the Paris Agreement does not go far enough.

> **"It is ultimately a question of speed, and many countries simply aren't going fast or far enough."**

For a safe and just outcome the limit may need to be even lower.[xvi] Even where increased ambition has been shown, notably in the US, where plans have been announced to cut emissions by 50-52% compared to 2005 levels by 2030, doubling previous commitments, these efforts are not enough even to reach towards the limits set in the Paris Agreement. The EU has also pledged to reduce emissions by at least 55% compared to 1990 levels by 2030, while China aims to reach peak emissions before 2030. Climate Action Tracker shows that, as of late 2022, the policies of Paris Agreement signatories have the potential to "result in a 2.7°C rise by 2100".[69]

The Global Stocktake Process

The UN Global Stocktake process is designed to "enable countries and other stakeholders to see where they're collectively making progress towards meeting the goals of the Paris Agreement – and where they're not".[70] The Global Stocktake is outlined in Article 14 of the Paris Agreement and detailed in decision 19/CMA.1, a part of what has come to be characterised as the 'Paris Rulebook'. This set of rules operationalises the Paris Agreement. The Stocktake as a whole assesses global progress towards the Agreement's long-term goals, including the 'well below 2°C' and 1.5°C temperature limit on global warming.

Behind the scenes of the Global Stocktake

Lavanya Rajamani *is Professor of International Environmental Law at the University of Oxford and is a member of the CCAG panel of climate experts.*

"I've been involved in an advisory capacity in the Technical Dialogue of the Global Stocktake. The Synthesis Report of the Technical Dialogue that was published on 8 September 2023 ends the technical phase of the Global Stocktake, which spanned some 18 months. The remaining part of the Global Stocktake is the political phase. This phase will conclude at COP28.

Following the technical phase, the political phase evaluates the findings and supporting information from the Synthesis Report. The hope and intention is that the political phase will draw on some of the key technical findings and send progressive political signals at COP28. Although this phase is largely political, it requires decision makers to engage with the technical findings. The technical phase involved a robust process for pulling together and presenting the state of scientific knowledge, so that those involved in the political process know that they are drawing on a reliable source of information.

[xvi] This is the argument about the 'just' outcome being based on the more vulnerable communities of the world, who tend to be most heavily affected by global warming, whilst having contributed the least to it. Nature, Rockström et al (2023) 'Safe and just Earth system boundaries' Page 104 https://www.nature.com/articles/s41586-023-06083-8

The political process should ideally first involve an appreciation of the key findings of the Synthesis Report of the Technical Dialogue, and next a considered response to it. First an understanding of the science, risks and uncertainties – all of which are technical, even if premised in some assumptions. And next, how these risks and uncertainties are managed. So there is an evaluation of what risks matter; how they matter; what challenges there are, and how you might address them. The political choice still remains for states to determine, individually or collectively, what work they're going to do with this information, and how they're going to bridge the gaps that have been identified. It is states that decide which of the key findings, for instance, they're going to highlight in the political outcome.

My sense is that the key finding on the need for the phasing down of unabated of fossil fuels, and scaling up of renewables, is one that states will focus on. Rapid take-up of renewables around the world (via solar power for electricity generation, and via a dramatic market switch currently underway from internal combustion engine to electric vehicles) make this a palatable process that states can get behind, whilst sending clear signals to the fossil fuel industry that they will need to shift their investment focus going forward.

But what else are states going to focus on? And what are they going to actually do with it? The UAE, in the presidency, has been focused on tripling renewable energy goals. So that is something that they might seek to embed in the outcome of the Global Stocktake. We'll have to see how it plays out in the end, but the political process is now ongoing, where they're picking up on particular elements of the technical dialogue, and running with it in different constituencies.

While the world remains focused on just transitions to a climate-safe world, the overshoot pathway clearly should be part of the thinking and planning. Acknowledging the possibility of an overshoot will help focus on the need for resilience and adaptation – since an overshoot will expose vulnerable communities around the world to more extreme climate and weather, however briefly. It would underscore the need for addressing loss and damage. And, it would encourage a conversation on the risks, uncertainties and benefits of deploying CDR at scale to address the overshoot."

6. MANAGING AND MITIGATING THE OVERSHOOT: CLIMATE ACTIONS AND INTERVENTIONS

Accepting that the world is likely to go beyond the 1.5ºC threshold, how do we ensure only minimal excess warming and find our way back to 1.5ºC as quickly as possible? What are the climate actions and interventions that will help us manage and mitigate the overshoot?

4R Planet Strategy

At CCAG, we have developed the 4R Planet Strategy. Through this strategy, we act to move policymakers, government officials and business leaders to address the key problems at the heart of the climate crisis, focusing on action in four key areas:

- Reduction
- Removal
- Repair
- Resilience

To minimise the overshoot and mitigate its impacts, we need to leverage all components of the 4R strategy, with a view to:

- Increasing emissions reduction rapidly to limit the Earth's warming
- Developing, researching and scaling techniques to remove GHGs from the atmosphere
- Finding solutions that could help repair parts of our damaged climate systems
- Strengthening our capacity to deal with the climate crisis

Within the 4R strategy, different strands of our approach involve different levels of challenge and opportunity. For example, when it comes to **reduction**, scientists know what to do and have the technology at their disposal, but face problems around political will and human engagement.

With regard to **removal**, there are not yet definitive technologies in place to extract GHGs from the atmosphere at the scale required. And the longer the world fails to meet reductiorn targets, the more GHG emissions will accumulate, increasing the urgency with which we need to drive technological development. **Repair**, meanwhile, focuses on buying time through efforts to stabilise or reverse local, regional and worldwide impacts of the global average temperature rise. The evidence for building **resilience** is compelling, and the focus must be on a unified global approach to deliver workable solutions. Each of the 4Rs is critical to global efforts to tackle the climate crisis.

Actions and interventions

As a climate advisory body, CCAG does not advocate for any one particular climate intervention. CCAG advocates for an increased understanding of all proposed climate actions, supporting scientific exploration of options. It also supports responsible research approaches that engage with local and indigenous communities and investigate viability and safety for all. It is clear from the content of this report that safe and innovative pathways will be required to find a sustainable way forward for humanity.

Specific climate technologies and interventions will be explored in greater depth in CCAG's next report, due out in December 2023. Here, we provide a snapshot of some of the options currently being explored.

Technology-based carbon capture – examples under consideration or pilot stage implementation

- **Carbon capture and storage (CCS)**: separates CO_2 from other gases produced in industrial processes, or captures carbon from the burning of fossil fuels in power generation. The captured CO_2 is then compressed and transported to a storage site, where it is injected into subterranean rock formations.
- **Direct air capture (DAC)**: uses sophisticated technology to extract CO_2 directly from the atmosphere at any location. The captured CO_2 can be stored deep underground or leveraged for industry applications – for example, synthetic aviation fuels.
- **Geological sequestration**: converts captured CO_2 into a liquid-like form, which is then injected into rock formations deep underground.

Nature-based solutions/Natural climate solutions – many examples of projects around the world mean that these interventions are well understood, in particular by local and indigenous communities. Here are a few examples of the many approaches available.[71]

Land-use and subterranean carbon capture and storage

- **Land-based reforestation**: carbon emissions are locked into trees and soil as areas are reforested and trees allowed to grow for decades and centuries.
- **Rewilding**: removes carbon from the atmosphere and stores it in undisturbed soils and biodiversity-rich peatlands, while also promoting increased biodiversity.
- **Mangrove regeneration**: supports efforts to manage storm surges and flooding while sequestering extremely large volumes of CO_2, and providing extremely valuable ecosystem services to humans and wildlife. Area for area, mangrove sequesters about four times more than the equivalent area of rainforest.[72]

Low-emissions agriculture

- **Sustainable rice cultivation and livestock production**, as well as methods such as **agroecology** and **regenerative agriculture**: focused on delivering a much-needed shift from high- to low-emissions farming, and enhancing the potential for carbon sequestration through land use and soil regeneration.
- **Intensification of sustainable agriculture:** helps to reduce demand for further land expansion, complemented by rewilding, restoring and enhancing natural carbon sinks.

Increased biodiversity

- **Land-based biodiversity**: encouraged through rewilding and habitat restoration, with 'keystone species' returning to damaged ecosystems to help animate the carbon cycle.
- **Marine-based biodiversity**: boosts oceans' potential for carbon capture and storage. Marine biodiversity depends on the right chemical compositions in our oceans. Currently, many of the surface waters of the deep oceans lack nutrients, including iron, which are vital for plankton growth. Interventions that increase levels of ocean surface nutrients have strong regeneration potential, promoting greening within one month, fish within three months, and big fish within six.
- **Restoration of apex species in the oceans**: restoring whale populations fertilises the oceans, supporting vast biodiverse marine populations.[73]

Solar radiation management (SRM)

- SRM is an umbrella term for interventions designed to reduce global warming by reflecting sunlight away from the Earth's surface. The approach is designed to buy time. There are two principal SRM pathways being explored by scientists:
  - **Marine cloud brightening**: a technique designed to create whiter clouds that can reflect incoming sunlight. It works by enhancing the concentration of smaller cloud droplets, which is achieved by firing large amounts of tiny sea-salt aerosols into marine cloud formations.
  - **Stratospheric sulphate aerosol injection**: an approach that involves using tiny reflective particles or aerosols to reflect sunlight back into space. These particles are either sprayed into the stratosphere using high-altitude planes, balloons and blimps, or dispersed using artillery. The benefits and risks of different SRM approaches will be explored in the next CCAG report on Climate Interventions.

Investing in science: drawing the line

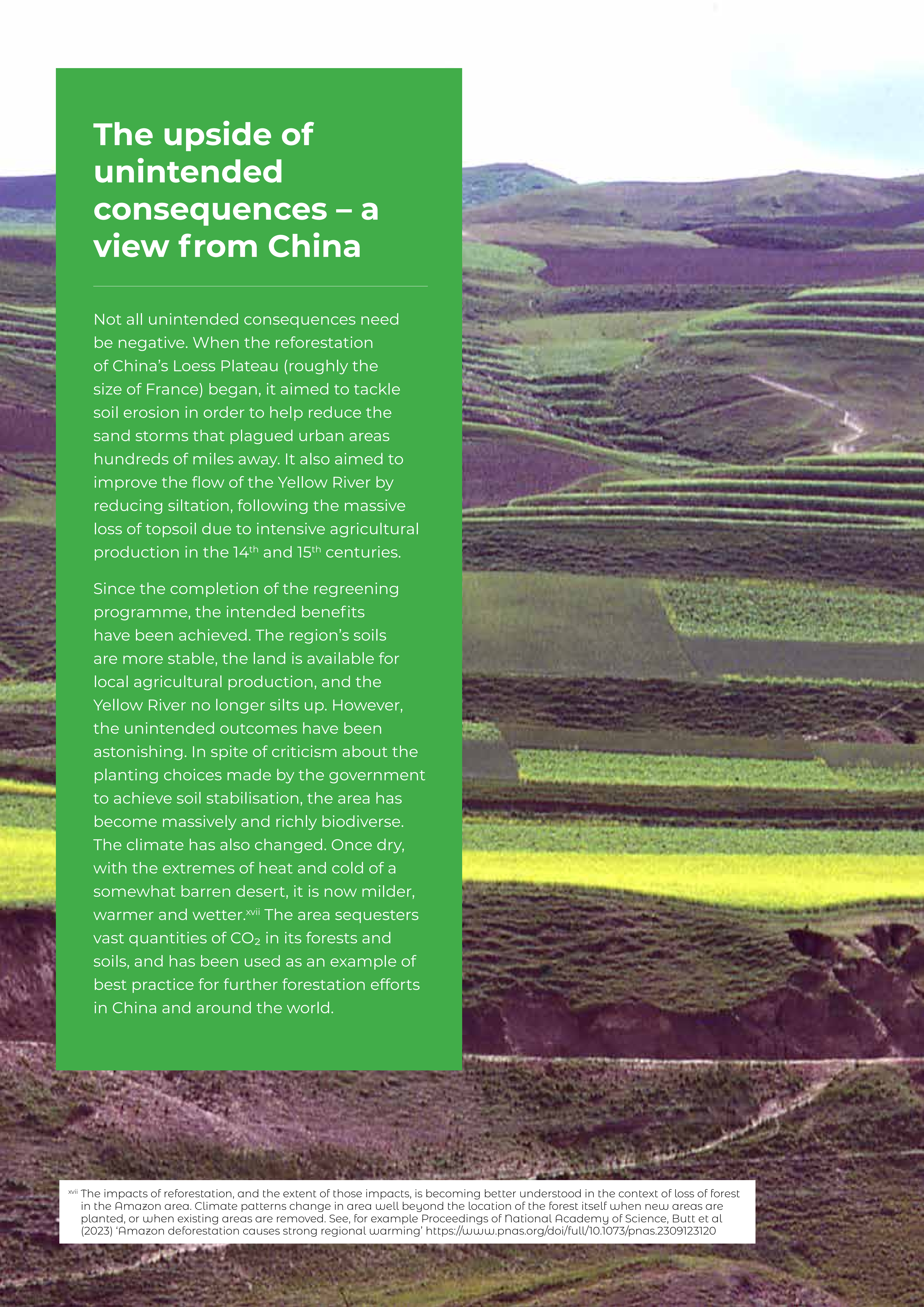
While all the CCAG members are willing to consider the science behind all proposed climate interventions, there is little support for extreme geoengineering approaches to climate repair. The impacts of huge schemes (such as those deployed in space, for example) cannot be foreseen, controlled or readily avoided once deployed. However, CCAG does believe that small-scale experiments can be used to ascertain potential risk levels.

As for other approaches, only once rigorous scientific research has been conducted, and safety and efficacy have been established, will CCAG (or its individual members) advocate for deployment via specific actions and approaches.

Somewhere between clearly controversial methods and readily accepted nature-based practices, CCAG members believe there are strategies where research and considered evaluation must be undertaken, governance principles explored, and clear information made available as outcomes become known.

We believe these tested approaches will enable the world to secure what it needs to secure, and to protect against unintended consequences. The climate crisis itself is an example of the runaway negative consequences of fossil fuel dependency. It is crucial that any response to the crisis does not put in train any further negative runaway events.

Right now, the world cannot afford *not* to consider all its available options. Far better the world understands the science and implications of all potential interventions, rather than deploying them in haste, somewhere not too far down the line, in desperate attempts to reverse global warming.



The upside of unintended consequences – a view from China

Not all unintended consequences need be negative. When the reforestation of China's Loess Plateau (roughly the size of France) began, it aimed to tackle soil erosion in order to help reduce the sand storms that plagued urban areas hundreds of miles away. It also aimed to improve the flow of the Yellow River by reducing siltation, following the massive loss of topsoil due to intensive agricultural production in the 14th and 15th centuries.

Since the completion of the regreening programme, the intended benefits have been achieved. The region's soils are more stable, the land is available for local agricultural production, and the Yellow River no longer silts up. However, the unintended outcomes have been astonishing. In spite of criticism about the planting choices made by the government to achieve soil stabilisation, the area has become massively and richly biodiverse. The climate has also changed. Once dry, with the extremes of heat and cold of a somewhat barren desert, it is now milder, warmer and wetter.[xvii] The area sequesters vast quantities of CO_2 in its forests and soils, and has been used as an example of best practice for further forestation efforts in China and around the world.

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