CCAG
Climate Crisis
Advisory Group

Climate Interventions

Exploring sustainable and innovative pathways for humanity

FOREWORD

The world has not gone far or fast enough in its efforts to reduce GHG emissions and is still perilously reliant on fossil fuels in multiple geographies and sectors. Deep and rapid emissions reductions are vitally necessary for a manageable future, but they simply aren't enough. Humanity needn't have been in this predicament, but we failed to act early enough, when things would have been so much simpler.

In 1990 the report from the Intergovernmental Panel on Climate Change (IPCC) showed that relatively modest adjustments to global emissions coupled with sustained effort, versus 'business as usual', would achieve a pathway to safety for humanity. At that point, emissions reduction of 2% per annum would have kept CO_2 concentrations in the Earth's atmosphere below 400 parts per million (PPM), considered a safe threshold.[1] That level of emissions reduction would have protected the world from experiencing most of the acute weather and climate consequences of human activity and fossil fuel consumption.

Of course, that suggested pathway was not adopted. The world delayed, and between 1990 and 2000 the scale of the challenge increased. Even at that time, a sloping reduction to safe levels was still possible, requiring global emissions reductions of about 4% per annum, year on year, with net zero achievable by about 2100. However, because GHGs accumulate in the Earth's atmosphere, the longer the delay, the steeper the fall to achieve the same result. Consequently, the opportunities still available in 2000 have now also slipped out of reach.

By 2020, the world's procrastinations and prevarications were all too apparent. Extremely steep and difficult-to-achieve reductions were now required to achieve net zero by 2050. Most of the work to transition to renewable energy sources, and to adopt new industrial practices, would have needed to be accomplished between 2020 and 2030. And while the changes and transitions have begun, they have not happened quickly or deeply enough.

And so, as I and my CCAG colleagues have long argued, and as this report makes abundantly clear, it is no longer possible to rely on emissions reduction alone to return the world to a safe and just operating space. Quite simply, that ship has sailed. While ongoing efforts to reduce emissions are essential to any future progress, these efforts must now be accompanied by additional climate interventions. Such interventions seek to remove excess GHGs from the atmosphere, repair some of the damage that's already been done, and build resilience to future climate impacts – a pathway CCAG has outlined in its 4R Planet Strategy.

Sir David King
Founder and Chair, CCAG

This report focuses on the 4R Planet strategy, and the processes that could help humanity to tackle the impacts of climate change. As the world moves forward, reaching for greater safety, a further question is raised – to be addressed in more detail in future CCAG reports: is the current globally favoured economics, based on the free market system, fit for purpose as humanity confronts the climate crisis?

Economic growth must be sustainable and inclusive, so tackling the climate crisis and moving to a greener low carbon economy means re-directing all sectors and all actors—public, private and civil society—towards economic growth in a sustainable and inclusive direction. Economic thinking has been shaped for many decades by siloing environmental, social and governance issues into concepts like 'market failures' and 'negative externalities'. It is surely insufficient to describe climate change as the biggest market failure of all, and then to continue exactly as before. What is needed for a green transition is a clear commitment to shape and co-create green markets.[2] The 'common good' includes the state of our planetary climate system, and this presupposes that its protection, along with other common goods, requires public investment and control. Markets will not find the desired green direction on their own, so the climate crisis cannot be left to free market operations alone to resolve them; the situation demands ambitious and flexible mission-oriented public bodies using pragmatic yet radical tools like progressive conditionalities.[3] We are a part of nature, not apart from nature; we are a part of those ecosystems that we are currently destroying.

Around the world, climate interventions are being explored and developed. Some of these interventions are familiar and well understood, such as reforestation, rewilding and mangrove restoration. Others, such Direct Air Capture (DAC), Marine Biomass Regeneration (MBR) and Solar Radiation Management (SRM), are less well known, requiring rigorous testing and ongoing scientific and public debate. As we discuss in this paper, advancing these interventions to a point where they can be safely deployed will require colossal shifts in technological capability and years of research and work. Responsible governance and public engagement will also be critical to making these interventions acceptable and viable.

As outlined in our previous CCAG report, The Overshoot, the world cannot afford **not** to consider all the possible options available to help manage and mitigate the impacts of climate change. Not all of the interventions discussed in these pages will be fully developed or implemented. But some of them might just hold the key to a safer and more sustainable future. It would be wrong, therefore, not to explore their potential further.

Sir David King
Founder and Chair, CCAG

THE 4RS AND CLIMATE INTERVENTIONS

At CCAG, we have developed the 4R Planet Strategy. Through this strategy, CCAG seeks to inform policymakers, governments, civil society and business leaders, so that they are equipped to address key problems at the heart of the climate crisis. 4R Planet Strategy focuses on action in four key areas:

- Reduction: Increasing emissions reduction rapidly to limit the Earth's warming.
- Removal: Developing, researching and scaling techniques to remove greenhouse gases (GHGs) from the atmosphere.
- Repair: Finding solutions that could help repair parts of our damaged climate systems.
- Resilience: Strengthening capacity, especially in vulnerable communities and locations, to deal with the present and future impacts of the climate crisis.

The 4Rs – Reduce, Remove, Repair, Resilience – must all be deployed within a single coherent strategy. The time when reducing emissions alone could be sufficient has passed. There is also no possibility of avoiding massive risk, stress and harm to vulnerable communities. Concerted efforts to support the building of resilience is therefore crucial.

This report focuses in particular on efforts to **remove** excess GHGs from the atmosphere and to **repair** parts of the global and regional climate systems. However, it explores them in the context of the indivisible 4R Planet Strategy.

If we accept that all 4Rs are crucial, then the question becomes how they are tackled and achieved safely. Robust scientific exploration of potential climate interventions is a critical part of this process. Climate interventions take many forms, from tree planting and rewilding to potentially refreezing the Arctic and reflecting sunlight back into space. This paper looks at the interventions that are currently being researched and developed to help address climate challenges and, perhaps, return the planet to more hospitable pre-industrial conditions. Picking up from where our last paper, 'The Overshoot', left off, it discusses the degree to which potential interventions are understood, and the steps available now to secure a safer future.

As a climate advisory body, CCAG does not advocate for any one climate intervention. CCAG advocates for an increased understanding of all proposed climate actions, supporting the scientific exploration of available options. As this paper explains, only through responsible research approaches that engage with local and indigenous communities can we investigate viability and safety for all and find sustainable pathways forward.

1: THE WORLD'S CHANGING CLIMATE SYSTEMS

The world's climate systems are changing surprisingly rapidly, and these changes are being driven by human activity.[i] Human society will not survive without managing the impacts of these changes, firstly to help people around the world to cope, and secondly to stop things from getting worse.

The most important action the world can take to limit global warming is deep and rapid emissions reductions. This is the 'Reduce' part of the '4R Planet' strategy. This reduction process, which has been promoted through the United Nations Framework Convention on Climate Change (UNFCCC), culminating in the Paris Agreement of 2015, requires a mass shift from fossil fuels to renewable energy sources, together with changes to industrial processes and farming techniques. But as things now stand, actions to reduce emissions are not enough on their own.

The concentration of GHGs in the atmosphere is already too high and rising. Around the world, climate impacts are already severe and dangerous. There are more climate changes in the pipeline from historic emissions, heating and lingering concentrations in the atmosphere and oceans. And the natural processes that defend humanity from climate extremes are already damaged - mainly by human activity, and increasingly by the changing climate itself.

Additional measures – climate interventions – on top of emissions reductions, are therefore required to help remove the excess GHGs in the atmosphere; to reverse some of the damage that has already been done to the environment; to strengthen natural defence systems; and to modify local, regional and even global climate change effects.[ii] Indeed, urgent action is needed to relieve some of the climate pressures already presenting massive challenges today, with the global decadal average temperature at 1.1ºC above pre-industrial levels. Action is also needed to mitigate the impact of straying beyond the 1.5ºC threshold, which scientists agree is likely to happen in the not-too-distant future. And finally, action is needed to help bring the global temperature back towards no more than 1°C above pre-industrial levels, where a safe and just climate boundary may lie.

This report will look at the challenges associated with researching, developing and deploying the interventions required to tackle the climate crisis, highlighting different levels of knowledge and familiarity with different approaches. It acknowledges that, whichever pathways are prioritised, these interventions represent a colossal undertaking, drawing on scientific ingenuity, rigorous experimental testing, technological innovation, political will, financial investment and public engagement. Any attempt to repair our damaged climate systems, remove carbon dioxide from the atmosphere and bring global temperatures back down will "require[e] an unfathomable technological and industrial effort", constituting a "momentous task".[4]

[i] Scientists express their surprise as they report on findings. See, for example, the observations of Professor Nerilie Abrams at minute with 6.00 to 14.00 of her CCAG public meeting address in June 2023 https://www.youtube.com/watch?v=O2WRb-MOFD0&t=656s; or 'The truth is we are shocked by the ferocity of the extreme weather events in 2023.' Science, Ripple et al (2023) 'The 2023 state of the climate report: Entering uncharted territory' page 8 https://doi.org/10.1093/biosci/biad080

[ii] Climate impacts are unevenly and inequitably distributed. Those who suffer the greatest impacts have usually contributed the least to global emissions, and have benefitted less than fairly from human development and technological advances of modern society. Temperature rises actually increase as you move away from equatorial regions towards the poles. But impacts on humans are significantly greater in the equatorial areas where temperature levels are already stressful – and small increases makes critical differences. Wealth distribution exacerbates these inequities, and impacts tend to fall more heavily on poorest countries and communities, because they tend to be in equatorial regions. These issues are discussed more fully in previous CCAG reports including: CCAG (2023) 'Risk and Resilience: the role of cities in tackling climate change' https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/65088d392d7aec29238f3697/1695059457088/CCAG+Cities+Report+-+Risk+%26+Resilience.pdf; and CCAG (2023) 'The Overshoot: Crossing the 1.5°C threshold – and finding our way back' https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/6564b3bd04d4bc1ad1245653/1701098431626/The+Overshoot+-digital.pdf

CLIMATE CHANGE: THE BREAKING OF ANCIENT EQUILIBRIA

Ancient climate regulating systems are increasingly well understood. The Arctic, for instance, influences many parts of the global climate system. In the upper atmosphere the Arctic jet stream and polar vortex maintain temperature ranges across the North American continent, thousands of miles from the Arctic; they also affect central European summers and trigger dust storms in sub-Saharan Africa.[5]

At sea level, the Atlantic Meridional Overturning Circulation (AMOC) is driven by the cold waters of the Arctic Ocean. The AMOC governs coastal temperatures in Europe, shifts nutrients and oxygen around the world's oceans, and helps to regulate the Africa Monsoon. However, the AMOC is weakening, as warmer Arctic water reduces the 'sinking' driver of the AMOC conveyor belt, with recent modelling suggesting the AMOC could well collapse this century.[6] As one collapse leads to another – the warming Arctic slowing the AMOC which then fails to regulate climate locally – the domino effects will become increasingly disparate and difficult to manage.[7] Indeed, because of these and other changes, rainforests risk becoming dry savanna, with parts of Amazonia already becoming net emitters of CO_2 and further accelerating climate change.

As these examples demonstrate, the Earth's climate systems are wholly interconnected, stretching across the globe, and feeding back into one another. These feedback loops often accelerate change, with shifts and anomalies in one area driving events in waves across the globe. It is also clear that current climate impacts are pushing these interconnected systems over the edge, leading to irreversible 'tipping points', damage and instability.[iii]

Worryingly, the world has already passed the 'safe and just' limit for global temperature rise, which scientists have identified to be 1ºC above pre-industrial levels. It is now acknowledged that the 1.5ºC limit established under the Paris Agreement would expose "more than 200 million people, disproportionately those already vulnerable, poor and marginalised…to unprecedented mean annual temperatures, and more than 500 million…to long-term sea-level rise."[8] These numbers "vastly exceed the widely accepted 'leave no one behind' principle and undermine most of the Sustainable Development Goals".[9]

So, urgent action is needed. The world's attempts to reduce global emissions have fallen dangerously short. And given the precarious state of our planet's health, the imbalances and instabilities within the Earth's climate systems, and the damage already caused at the decadal average of 1.1ºC above pre-industrial levels, a full range of possible interventions need at least to be critically examined and evaluated.

[iii] By definition, tipping points prevent damaged systems from self-correcting once the pressure of climate change is relieved. If the Amazonian forests all become net carbon emitters, then cooling the earth back to pre-industrial levels will not restore the rain-forest systems. For an explanation of a range of tipping points and their definition see: Science, Armstrong McKay et al (2022) 'Exceeding 1.5°C global warming could trigger multiple climate tipping points' https://www.science.org/doi/10.1126/science.abn7950

Climate change in pole position

Many of the present imbalances in the world's climate systems are caused by extreme anomalies at the Earth's polar regions. Over the last 30 years, the Arctic has been warming three times faster than anywhere else on the planet. This warming reduces the temperature gradient across the globe and is known to slow down the polar jet stream. The jet stream usually keeps weather systems moving. As it slows and meanders, it contributes to 'blocking' effects that cause weather systems to get stuck – giving rise to persistent and often unusual extremes.[10]

Meanwhile, a disrupted polar vortex (between 10 and 30 miles above the Earth's surface) can cause a sudden stratospheric warming (SSW) event. In February 2023, an SSW event occurred high above the Arctic, the fourth such event in the last six years. This compares with four events of this kind in six decades of stratospheric observations.[11] These events all triggered extreme cold across different regions of the planet. At time of writing, in late Autumn 2023, dramatic weather pattern shifts and 'cold air outbreaks' are predicted over north America, linked to stratospheric disruptions above the Arctic.[12]

These polar impacts are replicated and exacerbated at the South Pole, where studies predict that current rates of Antarctic ice melt could lead to a dramatic decline in the overturning ocean circulation generated from that region.[13] The overturning ocean circulation is driven by the very cold 'bottom water' of the Antarctic. Studies have confirmed a 30% reduction in the formation of Antarctic bottom water since 1992.[14] Its decline has major implications for multiple ecosystems around the world. To quote Nerilie Abram, Professor of Climate Science at the Australian National University and a member of the CCAG group of climate experts, the changes occurring in the northern and southern polar regions "could have major global consequences, and they're happening here and now".[15]

EMISSIONS REDUCTIONS: THE CONSEQUENCES OF DELAY AND PREVARICATION

The current global climate trajectory has already brought extreme weather, threats to biodiversity, and unmanageable sea-level rise. Behind this trajectory is a 300-year history of GHG emissions: the burning of fossil fuels, especially in the now wealthy developed nations, but rapidly followed in recent decades by the emerging economies of the world whose people aspire to the lifestyles and living standards of the developed Global North.

Geopolitical tensions around who should act first and who is contributing most to the current crisis have provided grounds for endless negotiations. Over the years, these discussions have been accompanied by a collective failure to reduce emissions when the need to do so was clear. Of course, things are not as bad as they would have been under a 'business-as-usual' scenario; the energy transition is underway, and emissions will peak in the next decade and reduce thereafter. However, the pace of change is too slow and climate impacts are happening more quickly than expected.

"Without deep and rapid emissions reduction, there is no safe future for humanity; but emissions reductions alone are no longer enough."

It therefore follows that all sensible climate interventions must be considered, including (but not limited to) an intensified effort across the globe on emissions reduction. Removing excess emissions from the atmosphere; supporting environmental arrangements that, in turn, support vulnerable communities and countries; considering interventions that protect or repair parts of the climate system while the world is brought back to a safer state – these are no longer 'either or' options. Without deep and rapid emissions reduction, there is no safe future for humanity; but emissions reductions alone are no longer enough.

IDENTIFYING THE NEED

The need to research, fund, develop and deploy climate interventions alongside emissions reduction has been clearly identified in various scientific papers and policies. Back in 2018, in its Special Report on Global Warming of 1.5ºC, the IPCC was already anticipating that carbon dioxide removal (CDR) should form part of the adaptation choices for mitigating climate change.[16] Although the focus for mitigation will emphasise the need for greater ambition in emissions reduction, it seems clear that 'negative emissions', meaning removal of carbon dioxide from the atmosphere, will be acknowledged as a crucial strategy for stabilising the global climate.

The key takeaway from the special 1.5°C report is that, with or without an overshoot, CDR will form a part of the global effort to limit warming to 1.5°C, or to stabilise at that level after temporarily crossing the threshold.[17] And yet, the report emphasises, there is uncertainty around large-scale CDR measures: "Although some CDR activities such as reforestation and ecosystem restoration are well understood, the feasibility of massive-scale deployment of many CDR technologies remains an open question."[18]

Thus, there is an implicit understanding, emerging within the discourse around 1.5°C and the Paris Agreement processes, that during the remainder of this century fighting the climate crisis will involve ever-increasing efforts to remove excess GHGs, at scale, from the Earth's atmosphere.[iv] For example, in September 2023 the Synthesis Report of the Technical Dialogue of the first Global Stocktake provided an assessment of the collective progress towards the long-term goals of the Paris Agreement.[v] The Synthesis Report confirmed major shortcomings in climate action and emissions reduction, asserting that global emissions are "not in line with…the temperature goal of the Paris Agreement",[19] and finding that "much more is needed now on all fronts".[20]

The report goes on to clarify that Nationally Determined Contributions (NDCs) under the Paris Agreement can include GHG removal measures.[21] In fact, it acknowledges that CO_2 removal will be a required component of the global net-zero strategy, making the case for CO_2 removal in the pursuit of net-negative pathways:

> "While CO_2 removal cannot serve as a substitute for deep emissions reduction, methods of CO_2 removal can further reduce net CO_2 or GHG emissions in the near term, counterbalance residual emissions from hard-to-abate sectors and achieve and sustain net-negative CO_2 or GHG emissions in the long term, given sufficient ambition.[22]

[iv] CEEW, Morrow et al (2020) 'Principles…Policy' also includes the following recommendation: "Start research and development on CDR now so that future generations might benefit from large-scale CDR in the second half of this century" https://www.ceew.in/publications/principles-thinking-about-carbon-dioxide-removal-just-climate-policy

[v] The Global Stocktake process was included under Article 14 of the Paris climate treaty. This two-year process is required to take place every five years. It is designed to enable a rigorous inventory of climate actions 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. The Synthesis Report of the Technical Dialogue forms part of the Stocktake process: UNFCCC Subsidiary Body for Scientific and Technological Advice (2023) 'Technical dialogue of the first global stocktake: Synthesis report by the co-facilitators on the technical dialogue' https://unfccc.int/documents/631600

In addition, the Synthesis Report highlights the need for further research into carbon removal and climate adaptation options. It refers to "information gaps" around a possible climate overshoot, calling for "further research on such scenarios [to] determine the extent of CO_2 removal measures needed…and identify proactive adaptation options for managing…potential loss and damage".[23] It also identifies the need for deeper understanding of reversible climate impacts, pointing the way for climate repair interventions.[24]

Elsewhere, the Synthesis Report asserts that major investment will be required to drive "effective climate action at the required scale and speed", with a mass increase in climate finance needed "to fund activities to support a pathway towards low GHG emissions and climate-resilient development." It points to the current shortfall in climate finance, with global finance flows for climate action reaching an annual average of "US$803 billion in 2019-2020". This, the report states, is "31-32 per cent of the annual investment needed to follow global modelling mitigation pathways consistent with the 2ºC or 1.5ºC global temperature rise".[25]

In its observations, the Global Stocktake technical process has begun to mirror elements of the 4R Planet Strategy. It argues for interventions to protect and rebuild carbon sinks in nature, and for interventions that transform land management techniques to change agriculture from a carbon-emissions to carbon-sequestration model. Both of these approaches seek to remove excess carbon from the Earth's atmosphere; this is the second 'R' in the 4R Planet Strategy. These are necessary, not optional:

"Reaching net-zero emissions also requires curbing deforestation and protecting natural terrestrial and ocean-based sinks, restoring deforested and degraded lands, sustainably managing land, and shifting agricultural and food systems."[26]

"There is an implicit understanding… that during the second half of this century fighting the climate crisis will involve ever-increasing efforts to remove excess GHGs, at scale, from the Earth's atmosphere."

2. EXPLORING CLIMATE INTERVENTIONS

Only once rigorous scientific research has been conducted, and safety and efficacy have each been established, will CCAG (or its individual members) begin to advocate for deployment via specific actions and measures. This approach acknowledges that less-well understood climate interventions, designed with the explicit intention of creating large-scale impacts, should be implemented in a deeply thoughtful and responsible way. Human carelessness has created a global climate crisis as a severe and unintentional side effect of global industrialisation built upon fossil fuel consumption. There must be no repetition of such side effects as the world attempts to put things right.

Governance

However, the desire to avoid unintended consequences is not an excuse for inaction. It is in fact a 'call to arms' for a carefully managed science-based approach to climate interventions. Much thought has been given to the governance principles that should be applied to climate action. In the absence of an empowered global governance entity, to whom scientists and policy makers can look for definite leadership, some clear principles have emerged.

For CDR, governance principles must be driven by the likelihood that the world will want to remove hundreds of billions of tons of excess carbon dioxide from the Earth's atmosphere over many decades. The vast scale of the task requires that action be taken now. Policies need to be developed for each phase of CDR: the research; the development of scalable approaches; and the rollout.[27] Policies of this kind allow for the fact that the social, economic and environmental impacts of different CDR approaches will vary, and each must be considered. The policy proposal acknowledges that acceptance of interventions will vary according to all these impacts.

As noted by the IPCC, "some CDR activities such as reforestation and ecosystem restoration are well understood".[28] The governance requirements for these large-scale interventions will be different from those where the pros and cons are less well established. However, there is plenty to learn and consider when restoring ecosystems or seeking to manage wild places differently. Seeking local community consent, knowledge and engagement in the process is likely to be the fastest and fairest way to achieving sustainable change. Indeed, a great deal of thinking has been applied to the challenge of managing common resources, and best practice in climate interventions should learn from what has gone before.

Best practice includes such principles as:

- Matching rules to local needs and conditions
- Ensuring that those affected have a voice in modifying the rules
- Ensuring that the rule-making rights of community members are respected by outside authorities
- Ensuring that governing responsibility is built from the bottom up across the entire interconnected system.[vi]

[vi] These are some of the eight principles for managing a commons identified by the Nobel prize winning economist Elinor Ostrom. Ostrom (2000) 'Collective action and the evolution of social norms' http://www.tandfonline.com/doi/full/10.1080/19390459.2014.935173

Thinking about the governance of shared natural resources and the role of local communities provides a helpful reminder that we all depend on the 'ecosystem services' of water, air, forests and oceans. Irrespective of boundaries and laws, these are all 'common resources' that need to be managed for all of humanity. Water sources and supplies have become less predictable, so that new ideas about how to manage the 'lifeblood of our planet' have an urgency which highlights the threat to humanity.[29]

While the benefits of restoring forests and other ecosystems are clear, the processes for managing them equitably are still hit and miss. Funding is seldom directed to those whose lives are most closely intertwined with the resource in question, and communities go unpaid for the services upon which we all depend. For example, Indigenous Peoples and Local Communities (IPLCs) directly manage around 17% of the carbon stored in forests, and there is good evidence that land-right security enhances forest management by IPLCs.[30] Yet these communities rarely receive direct funding, and there is a significant funding gap around the securing of customary land rights.

All climate interventions are context specific. It is important to recognise the importance of relevant stakeholder engagement to avoid over generalisation, such that regional, local or group differences are missed. Seen from outside, the huge continent of Africa is often treated as an undifferentiated block. In reality, of course, African nations face different opportunities to make an energy transition aligned with development aspirations. Within each country there will be obstacles and uncertainties. Ethiopia, for example, is on a 'green development' trajectory, whilst Mozambique is grappling with a possible future linked to natural gas expansion. 'Country specific evidence' will be essential for determining the optimum pathway of any nation towards its safer, thriving future.[31]

Evaluating different climate interventions

Climate interventions broadly fall into three categories. There is considerable overlap between the categories, with some interventions having a potential impact on more than one category at a time. Primarily, interventions involve CDR, solar radiation management, or the use of natural ecosystems to strengthen resilience to climate impacts. These interventions equate respectively to 'Remove', 'Repair' and 'Resilience' within the 4R Planet Strategy. Examples of each of these interventions, with their pros and cons, will be considered in turn.

REMOVE

Carbon Dioxide Removal (CDR)

CDR is going to be crucial to managing the climate crisis as this century unfolds. The challenge ahead will be to deploy technologies and approaches at sufficient scale to make meaningful progress against ambitious targets for excess carbon removal.

There are two kinds of removal techniques: those that focus on nature-based solutions, and those that integrate with industrial and technological activities.

The nature-based approaches to CDR are easily understood. They involve rewilding and reforestation, and restoring and extending ecosystems that capture and store vast quantities of carbon, such as mangroves and rainforests. Preventing the loss of other natural carbon sinks is also important. Peatland, for example, stores up to 20 times as much carbon in its swampy waterlogged soil, compared to mangroves and rainforests. In fact, peatlands, which cover about 3% of the Earth's surface, store more CO_2 than all other vegetation types in the world combined. When peatlands dry out, they emit vast quantities of GHGs and become liable to burning. So clearly, a nature-based approach to CDR requires accounts to be kept of losses that cause emissions, as well as gains achieved through new sources of carbon removal.

Marine Biomass Regeneration (MBR)

MBR, which is discussed in more detail on page 15, involves exploring opportunities to regenerate biodiversity in the deep oceans of the world. It seeks to restore plant and animal life to pre-industrial volumes and conditions, thereby enhancing the ocean's potential for carbon capture and storage.

Other marine-based CDR approaches are also being considered around the world. These include up-welling to shift nutrients around marine habitats; regenerating sea grass; and establishing and extending Marine Protected Areas, all of which offer chances for different habitats to thrive. Protected areas of oceans can enable sustainable fishing to be maintained for local communities, while prohibiting industrial fishing practices. The logic behind these approaches is clear: over 70% of the Earth's surface is covered by ocean. If this area can be harnessed to accelerate CDR, the removal of excess carbon from Earth's atmosphere could be significantly scaled.

Marine Biomass Regeneration (MBR) is an active area of scientific research. MBR links ocean fertilisation studies with a growing understanding of the role of whales in marine ecosystems. The programme demonstrates best practice in scientific exploration of natural, especially marine, habitats. When volcanos erupt they scatter fertile dust on the surface of deep oceans; something magical then happens. Barren marine landscapes come alive, and a rich biodiversity emerges, lasting for months. The driver is nutrients for phytoplankton growth in volcanic dust. As plankton multiply in this food-rich environment, a new food chain starts to rebuild. When whales surface to defecate a similar effect happens. Their poo deposited at the sunlit ocean surface is consumed by phytoplankton, and the cycle of life is re-invigorated.

Teams of scientists around the world are exploring together the implications for actively regenerating ocean bio-diversity. Whale numbers have been decimated by human activity over the past 400 years, and volcanos do not erupt to order. Can human activity replicate these functions? Some work focuses on the impact of iron in volcanic dust, others on the idea that whale poo, or its nutrient equivalent, can unlock a whole chain of marine life from plankton, back to whales themselves.

'Whale poo' studies are currently examining how rice husks could be used as a buoyancy medium capable of carrying nutrients on the ocean's surface. The nutrients themselves, as well as a medium to hold the mixture together, must all be carefully tested for their ability to replicate the natural functions of whales.

All of this is colourful and exciting. Intuitively, people want living oceans. There are numerous eco-system services linked to ocean wildlife. From the climate crisis perspective, life in the oceans creates new carbon stores, both as living matter, and as whales eventually die and sink permanently into the deepest oceans (known as 'whale fall'). Biodiversity, sustainable protein production and livelihood opportunities are all incredibly valuable products of a healthy ocean biodiversity.

The question is whether humans can strengthen marine biodiversity and do so safely. MBR is a great example of a programme that shows the possibilities but takes each step cautiously. One particular group, called ExOIS (examining ocean iron scattering), is looking at the role of iron as a nutrient, and the possibility of systematically introducing it to imitate the effects of a volcanic eruption. In a conference this year they reviewed the MBR field and its research practices. ExOIS identified work planned or under way in different phases.

MBR research will cover: further field studies; better modelling drawing on global observations; studies of new ways for bringing nutrients to ocean surfaces; strengthening transparent monitoring, reporting and verification; development of governance processes with more diverse engagement around the world to ensure all relevant voices are heard. Phase 1 supports informed decisions about whether, and if so how, MBR should proceed. 'Paramount in the plan is the need to move carefully.'[vii]

The ExOIS review of MBR preparatory work concluded that marine CDR could be essential to help manage the climate crisis.[viii] MBR, via natural nutrient distribution is worth exploring further as a possible part of a global mitigation strategy. Various natural nutrient sources will be examined, including volcanic dust and dust-sized particles. The MBR programme is working in research vessels in multiple deep ocean locations as support to evaluative work. Monitoring and responding to subsequent roll-out of MBR will go on for many decades; durable removal of carbon whilst assessing ecological responses requires long-term engagement.

Multi-disciplinary work on MBR engages atmospheric, oceanographic, environmental law, and social science experts. The ExOIS review promises transparency and easy public access to information generated. The MBR consortium is diverse, based in universities in Southern California, Cambridge UK, Goa India, Hawai'i and Cape Town South Africa. Scientists are showing how careful research can and should be done to help, not damage, global ecosystems, with the potential to make major contributions to marine biodiversity and to carbon capture and storage.

[vii] ExOIS (2023) 'Paths Forward for Exploring Ocean Iron Fertilisation' https://oceaniron.org/our-plan/#pathsforward
[viii] Ibid

Direct Air Capture (DAC)

DAC is an engineered approach to CDR. It seeks to extract CO_2 directly from the atmosphere and store it permanently in deep geological locations or use it in industrial applications. The approach is extremely expensive in terms of energy and implementation requirements, although there is a possibility that using captured CO_2 for synthetic aviation fuels could help to reduce these costs. Currently, there is no large-scale DAC process in action; there are 27 DAC plants commissioned world-wide, altogether capturing 0.01 Mt CO_2 per year. To give context, the USA is counting on developing capacity for 1Gt CO_2 removal per year by 2050. So, DAC is not yet able to contribute meaningfully to global targets. In its overview of DAC, the International Energy Agency (IEA) notes that in its own net-zero- emissions-by-2050 scenario modelling, it counts on DAC deployment achieving just 75 Mt of CO_2 removal per year – a possibility if all 130 DAC plants currently planned were to go ahead with deployment.[32]

An important part of any carbon removal programme is to make sure that the removal is permanent. One suggestion about how carbon sequestration and monitoring could be approached is set out on page XXX.

Storing Carbon Permanently: A suggested framework

Removal of excess carbon from the global atmosphere must be accompanied by the assurance that the carbon will be sequestered permanently. Only then is it effective as part of the global mitigation effort on climate change. Removal of excess carbon and accountably locking it away can be viewed, essentially, as a waste disposal problem.[33] This helps to think about a workable framework for ensuring that sequestration is permanent and genuine. Two principles, recognised in international law and climate treaties, guide the approach. First, the polluter pays; second, intergenerational equity principles must be observed.

One framework (that has been suggested by Klaus Lackner, a CCAG member) suggests 'carbon storage operators' should be made responsible for carbon sequestration. Operators would also issue certificates of carbon sequestration, charging a price that reflects the cost of storage, including monitoring and re-sequestration if needed. This approach treats temporary and long-term storage on an equivalent footing. The operator would be obliged to re-sequestrate carbon where temporary storage ends, and ensure monitoring mechanisms consistent with the particular sequestration method.

The framework proposes an obligation that those releasing excess carbon into the atmosphere must obtain certificates of sequestration from an operator **before** undertaking their activity. Thus, a fossil fuel producer would be allowed to proceed only if they already held a certificate of sequestration of appropriate value. The producer has discharged its duty once it holds the certificate. The practical problems of sequestration remain with the carbon storage operator. No-one else in the life cycle of the fuel produced needs to be involved, though the cost of purchasing the certificate of sequestration will certainly be passed on.

A tonnage allowance to carbon-storage operators could gradually be ratcheted down, so that emissions and sequestration would be systematically brought into line. The system could adjust as needed to secure negative emissions. Again, the detail would be driven through the framework and its carbon storage operators.

This approach makes sequestration permanent (even if that happens via a series of shorter-term storage processes). It stands in contrast to the 'carbon offset' projects and claims which have largely been discredited.[34] The cost of monitoring, enforcing and developing storage solutions would be reflected in the cost of certificates of sequestration. This would lower demand for emissions as sequestration certificate costs would incentivise cheaper energy options – accelerating the transition to green energy and driving demand management.

A clear advantage of giving the job of storage to carbon storage entities rather than, say, fuel producers, is that sequestration need not interfere with the core business of those who continue to release excess carbon. Their only concern will be to purchase certificates of sequestration – and this is a step they will have to take up front, before they do anything else in their business. In principle, the framework removes the need for carbon lifecycle analysis (LCA) which tracks the movement of carbon through industrial processes. The idea of matching every ton of emissions with a certificate of sequestration before emissions happen makes its LCA irrelevant.[35]

The details of this framework have been discussed and deliberated upon by scientists.[36] It is set out here as an example of a pragmatic, considered way to increase momentum on carbon sequestration. The framework is applicable at different scales and could be launched in individual jurisdictions without needing global uptake to make it functional. Its sequestered carbon could be clearly calculated, monitored and offered as part of the climate mitigation strategy of the jurisdiction in which it operated. It offers a place to start.

REPAIR

There is a category of nature-based interventions that could potentially be deployed to repair some of the damage that has been inflicted on climate systems and the environment. Designed to help people and communities to deal with changes that have already occurred, these interventions might also slow down or halt – or even reverse – some of the changes in the pipeline.

Reforestation

Climate repair interventions should give nature a helping hand to recover a lost balance, or to ameliorate environmental changes to weather systems. Such changes might be felt quite locally, such as increased heating or reduced rainfall across a large region because of deforestation. An intervention to restore rainfall – or to enhance rainfall in an historically dry area – is very likely to involve restoring forest (reforestation) or extending forest into new areas (afforestation). The restoration of vegetation on the Loess Plateau in China, for example, resulted in an increase in rainfall, between 2000 and 2015, of some 12% per year.[37] Around 4,000,000 hectares of vegetation restoration was carried out - a large-scale region exceeding the size of Belgium.

Conversely, deforestation is found to warm the climate up to 100km from the location of forest loss, and it has been shown that reducing deforestation in the Amazon could lower future warming in the southern Amazon by 0.56°C.[38] Once a certain threshold is crossed, removing trees reduces rainfall dramatically.[39] The heating and drying effects of such tree-removal reduce regional farm productivity and impose additional burdens on millions of people living within range of these effects.

Reforestation provides a full range of co-benefits. It is an effective means of CDR, with trees locking in carbon as they grow. It also improves soil stability, preventing erosion and increasing resilience to storms and floods. Whereas deforestation is a demonstrably negative intervention in the face of the climate crisis, restoring and extending forests is a distinctly positive action. Further investigation is required into the diverse changes reforestation brings, but on balance this is a well-understood climate intervention.

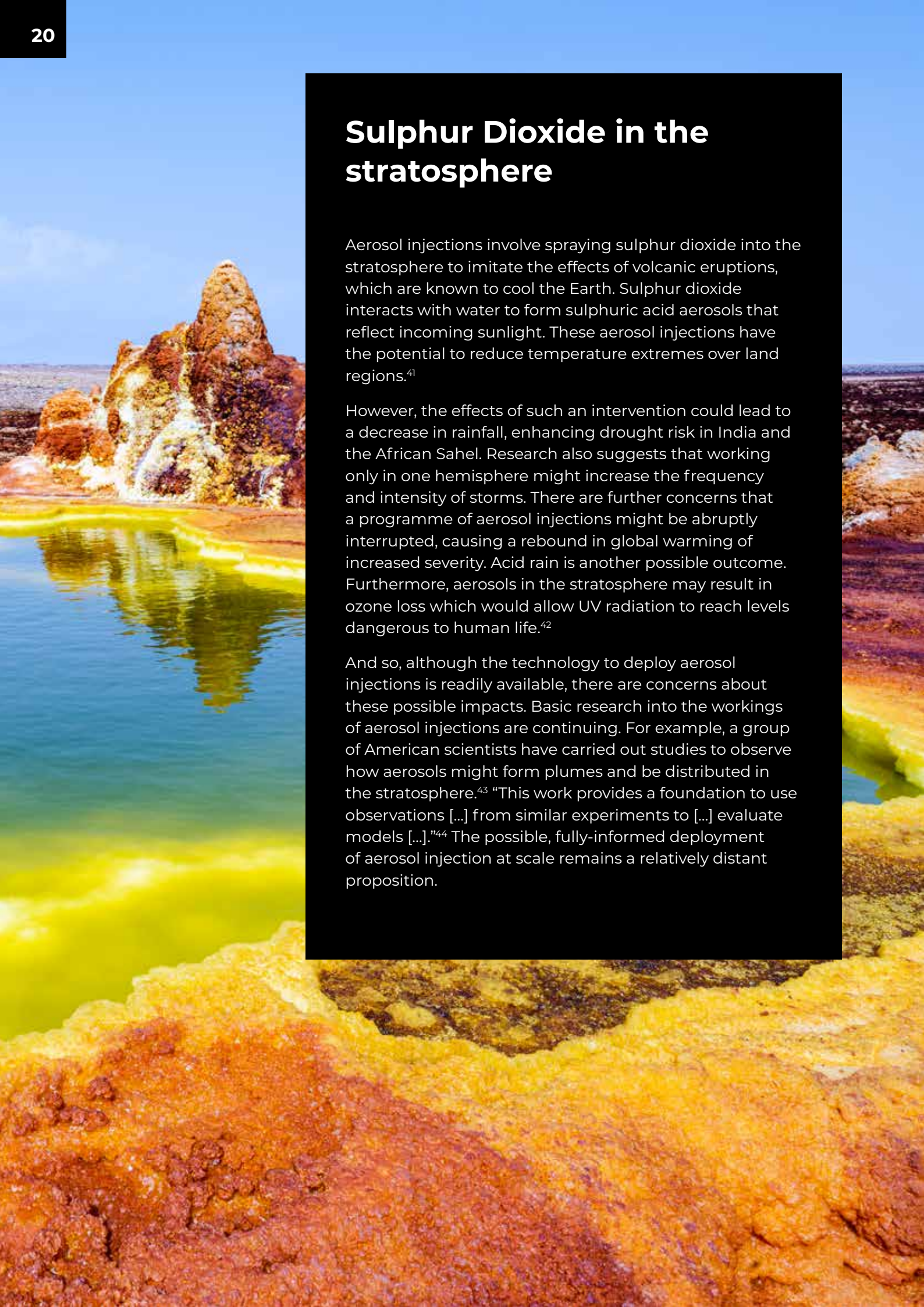
Solar Radiation Management (SRM)

SRM is a different kind of intervention. As yet it has not been deployed at any kind of scale and is currently being studied at laboratory scale in a number of different ways. The objective is simple: to deflect some of the sun's energy (heat) away from regions of the Earth so that regional temperature rise is slowed. The approach is intended for use in areas where the climate is warming faster than the global average, and where damage from heating is seen as particularly intolerable. Such areas include the Arctic Ocean (because of the global impacts on extreme weather and long-term weather patterns), the sea around the Great Barrier Reef (with a view to protecting the reef's coral from bleaching), and glaciers around the world.

In the Arctic, SRM would be deployed to slow down the melting of summer sea ice, in the hope that the runaway changes in the Arctic, and their impacts across the globe, could be slowed down or reversed. Different methods of achieving this goal are being explored.

More extreme ideas for cooling the Arctic have been mooted from time to time. 'Space sunshades', for instance, would involve putting a giant mirror or fleet of mirrors into orbit to reflect more sunlight away from Earth. Such a project would constitute a huge technical challenge, and its impacts would be difficult to manage once underway. While no one is currently planning to implement a 'space sunshade' intervention, this example underlines the importance of a governance code, such as that outlined by the Council on Energy, Environment and Water (CEEW) and described above, to avoid any unintended and damaging consequences. No individual nation, or company, or super-wealthy individual should feel able to try out a 'mirrors in space' implementation without being strictly governed to ensure no damage (judged, particularly, by impacts on the most vulnerable). 'SRM may be able to reduce some climate risks but [could] also introduce new and novel risks of its own.'[40]

In the logical space between forests (mostly a good idea) and mirrors in space (to be approached with infinite caution and probably never to be implemented), lie various techniques considered potentially promising for managing solar radiation. These techniques include stratospheric aerosol injection, marine cloud brightening, high-albedo crops and buildings, ocean mirrors, and cloud thinning. Of these, the most research and debate revolve around aerosol injection and marine cloud brightening; their pros and cons are set out on pages 20 and 21.



Sulphur Dioxide in the stratosphere

Aerosol injections involve spraying sulphur dioxide into the stratosphere to imitate the effects of volcanic eruptions, which are known to cool the Earth. Sulphur dioxide interacts with water to form sulphuric acid aerosols that reflect incoming sunlight. These aerosol injections have the potential to reduce temperature extremes over land regions.[41]

However, the effects of such an intervention could lead to a decrease in rainfall, enhancing drought risk in India and the African Sahel. Research also suggests that working only in one hemisphere might increase the frequency and intensity of storms. There are further concerns that a programme of aerosol injections might be abruptly interrupted, causing a rebound in global warming of increased severity. Acid rain is another possible outcome. Furthermore, aerosols in the stratosphere may result in ozone loss which would allow UV radiation to reach levels dangerous to human life.[42]

And so, although the technology to deploy aerosol injections is readily available, there are concerns about these possible impacts. Basic research into the workings of aerosol injections are continuing. For example, a group of American scientists have carried out studies to observe how aerosols might form plumes and be distributed in the stratosphere.[43] "This work provides a foundation to use observations [...] from similar experiments to [...] evaluate models [...]."[44] The possible, fully-informed deployment of aerosol injection at scale remains a relatively distant proposition.

A brighter future?

Marine cloud brightening **(MCB)** involves spraying salt water into the air, using unmanned, solar-powered floating pumps, for example, so that salt particles nucleate cloud condensation and brighten cloud cover over the target area. This mimics the natural formation of clouds over the ocean. The immediate effect is very local, with bright clouds reflecting sunlight and cooling the area directly beneath. MCB could allow the Arctic region to be brought into line with average global warming, for example. To understand how this would play out a programme of research is developing.

A review of MCB research in 2022 identified knowledge gaps in terms of impacts over time and space.[45] However, it identified the 'must haves' for a research programme, starting with continued laboratory work and field studies, together with marine eco-systems studies. Modelling should be undertaken at a large range of scales. Again, scientists are demonstrating a considered and careful approach to their work to be sure that any large-scale implementation of MCB is preceded by a sound scientific understanding of its likelihood of success and possible wider impacts.

RESILIENCE

The resilience of land, people and productivity is greatly affected by climate interventions, whether deliberate or unintended. Around the world, there are opportunities to support and create climate interventions that will strengthen and accommodate local communities, industries and even cities.

As an example, mangrove forests provide great 'services' to the locations in which they are found.[46] They can protect against steady sea-level rise, reduce the impact of storm damage, and absorb energy from storm surges, curbing flooding as a result. They grow in brackish water, and prevent storms at sea from infiltrating coastal farmland, which would leave it unable to support crops. Crucially, mangroves capture carbon at a very high density (three-to-five times the volume, per hectare, of tropical rainforest) and support and regenerate biodiversity. In the Philippines, it has been estimated that US$1 billion of annual property damage is avoided through the services provided by mangroves. Over 7 million people are protected by mangrove forests in Vietnam, where the benefits of mangrove restoration outweigh the costs by a ratio of five to one.[47]

During the second half of the 20th century, about half of the world's mangrove forests were removed, often to make way for coastal fish or shrimp farming. Mangrove now covers just 1% of the world's surface. When efforts to restore mangrove have been made and studied over time, the results have been positive.[48] Communities can manage mangrove planting and restoration management, making this an intervention with strong bottom-up potential.[49]

Mangrove forests illustrate how nature-based interventions can offer highly effective solutions to local challenges, but which cumulatively scale up to provide global climate services via carbon sequestration, prevented losses and flood protection.

Regenerative farming is a similar intervention with potential for even larger scales of global impact; this net-emitting industry, responsible for about 20% of global GHG emissions, has the potential to transform into a largely carbon-sequestering activity.[50] 95% of the world's farmers are smallholders, and these small local farmers provide between 50% and 80% of food eaten in Latin America and Sub-Saharan Africa. Most of these farmers suffer acutely from the impacts of climate change, since they depend on rain and predictable weather patterns for their production. Regenerative farming strategies could be deployed by large and small farmers, but they are not intuitive; systematic training, information sharing, access to finance, insurance and seeds are all required to make a shift happen.[ix]

[ix] For a deeper discussion about agriculture and global food systems in the face of climate change see the earlier report CCAG (2022) 'Climate Change and Food Systems' https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/636ccfd513c34972561b5447/1668075495333/CCAG_Food+Systems.pdf

3: FRAMING INTERVENTIONS: PUBLIC PERCEPTIONS & ACCEPTANCE

Success of any aspect of climate policy depends on it being acceptable; where behaviour change is needed, then people must allow those changes into their day-to-day lives, and incorporate their implications in planning and pursuing their life goals. Behaviour modification must be supported by regulation, investment and clear economic signalling so that the 'right' behaviour brings benefits to the climate and to the consumer. These changes may require pressure from citizens themselves in order to prevent policy makers from sidestepping important changes. Whilst this report has particularly emphasised the importance of 'removing' and 'repairing', these only help the world to achieve its climate goals if 'reducing' – the deep and rapid reduction of GHG emissions – is also continued and intensified. Addressing use of energy and fuel consumption in the UK, for example, if pursued with the ambition of 'transforming' consumption patterns, is shown to have the potential to reduce demand by over 50% by 2050.[51] Such a significant reduction in fuel and energy demand would contribute significantly to emissions reductions. Behaviour change of individuals can aggregate to significant emissions reductions if achieved at scale. Furthermore, individuals who begin to take steps 'for the climate' become more critical and active in voicing their perception that coordinated and comprehensive climate action is needed. Political bodies will only respond if they believe their constituents will not elect them without a commitment to climate action.

Each of the first three 'Rs' of the 4R Planet Strategy depends very much on whether people, groups, societies and nations find them acceptable. It is therefore vital to understand people's perceptions of specific climate interventions, and the importance of how, and by whom, these interventions are framed. Inclusive policy development and implementation, clear and accurate communication and transparent and careful governance are all part of this process.

The experiencing of ecoanxiety

The climate crisis has become profoundly disturbing for ordinary people all over the world. Many want to be part of the solution, to know what to do and to demand action from those who have the power to make a top-down difference. In tandem with that observation, psychologists have insights about what messaging and approaches are most likely to bring about the behaviour changes for the benefit of the climate, and as adaptive responses to the new stresses brought by climate change.[52]

Ecoanxiety is an expression coined in recognition of the worries experienced by individuals who recognise that humanity is confronted with simultaneous environmental crises of unprecedented scale.[53] Young people realise they will be more exposed to climate change harms over their lifetime than older people, and eco-anxiety can cause them real suffering. In contrast to the individual frustrations and suffering, there are recognised benefits in building resilience at community level through environmental activism.[54] Engaging in collective action significantly reduces the association between climate change anxiety and cognitive emotional impairment. Collective action builds a kind of social capital: trust, reciprocity and cooperation generate good ideas and spread them through the group, and from group to group.[55]

For those who are worried about the climate crisis there is a win-win possibility: if they can find a way to take action, to put pressure on those with the ability to change the environment in which consumers make choices, it may improve the world's response to the climate crisis and it will also reduce their ecoanxiety.

Changing behaviours for highest impact

Policy makers have the chance to work with this desire of individuals to become involved. People are likely to be willing to take on changes in their behaviour, and to make collective efforts for beneficial change. It is therefore important to value the response of individual citizens to proposed changes, and to present solutions and strategies clearly and honestly.

People respond positively to suggestions that are presented using a 'solution' framing; they are more likely to accept solutions presented as feasible, desirable and normal. Experts point out the need for 'place-based' contextualised approaches, paying attention to local climate impacts and tailored solutions.[56] Problems and responses are complex and will vary widely for different groups and locations.[57]

As we look at factors that make policy responses to the climate crisis acceptable to the general population, and recognise that acceptability is necessary for many policies to be successful, we also recognise the importance of focusing on the changes that will bring the highest impact; this means addressing high-emitting groups, and looking for approaches that tackle multiple drivers and barriers to win the changes needed.[58] Psychological analysis can help to understand how to bring about desired behaviour change, and this is recognised by the IPCC who draw on psychological input to their reports.

To maximise the value of changes, it is important to know which behaviours bring the greatest cumulative climate-favourable outcomes, and in what contexts. Behaviour change linked to frequently repeated activities (recycling, say) is well-studied; less is known about high-impact but occasional events (investment in cars or heating and cooling systems, for example). Large household investments are driven by price, available information, etc brand perception and availability; regulation, subsidy or other incentives (tax benefits in the production chain, or tax benefits for low-energy devices, or a tax on carbon consumption, for example), public investment in infrastructure, and public information programmes are all levers for change that should be deployed.

Concern about climate change is global and widely shared. Within much of the Global North, climate change can be perceived as a partisan issue. Climate action is placed in opposition to individual choice and freedom. Efforts to reduce emissions in cities are characterised as 'anti-car', rather than supportive of health, for example. America perhaps exemplifies how climate change can fall strictly along party-political lines. It is surprising then to be reminded that there is more wide-spread concern about climate, even in the US, than might be expected.

First, more Americans are concerned about climate change than most Americans believe.[59] In a surprising survey, between 66% and 80% of Americans say they support climate policies; those same respondents to the survey believe that only about 37% to 43% of the population agree with them. A good majority of Americans support climate policy, suggesting that party lines are not as clearly drawn as expected. However, the noise around climate policy is sufficient to distort impressions and whilst 'supporters of climate policies outnumber opponents two to one, Americans falsely perceive nearly the opposite to be true.'[60]

Acceptability and fairness

Across the world a survey of children and young adults aged 16 to 25 years revealed high levels of concern about climate change. They expressed their experiences in emotional terms: sad, anxious, angry, powerless, helpless and guilty. They rated government responses negatively, feeling more betrayed than reassured and those feelings about government correlated with their distress.[x]

These observations demonstrate the importance of getting policy, messaging and communicating about climate right. There is a sense that the children responding to their survey feel they are being treated unfairly by their governments, and probably by the older people around them who have fewer climate impacts to worry about in their lifetime. What does this all say about the need for fair and effective policies that will be acceptable and lead to implementation?

Three factors have been found to be important in citizens assessment of whether they feel they have been treated fairly by government.[61]

- 'Voice'. The belief that decision makers have considered your views (having given you a chance to present them) is important. When voice is denied, then all outcomes can seem unfair.
- Respect and dignity. Citizens who feel they have been treated with respect and dignity in their dealings with government agencies experience the process as fair. Conversely, disrespect leaves people feeling unfairly treated.
- Explanations and information. Adequately informed citizens experience increased levels of fairness.

At the level of objective and subjective fairness (both of which are important), there is a desire for laws and regulations to be administered with integrity and competence.[62] Transparency about the process is important; any hint of corruption or incompetence has an impact on the sense of fair treatment. A belief that those in authority are acting in their own self-interest can negate other indications that a system is fair. People thought to be seeking personal gain are not trusted. Selfless behaviour however builds trust and a belief in fairness.

There is a lot to address and a lot to put right if governments and officials are to try and address climate change with more determination, and to take their citizens with them into the constraints and opportunities that will be presented.

[x] Ten countries were involved in the survey, with 1000 children canvassed in each country. The countries were spread across the global North and South, including developed and poorer countries. The Lancet, Hickman et al (2021) 'Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey' https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(21)00278-3/fulltext

Understanding public perception

Studies of public perceptions have often focused on large-scale efforts to bring about change, sometimes with the assistance of technology. These are often labelled as 'geoengineering'. The label has no defined meaning, and this report has not used it. But the 'mirrors in orbit' solution outlined above would clearly be regarded as geoengineering; large-scale tree planting and creating new forests is not, though both interventions bring climate impacts at scale. We know that people find all interventions more acceptable if they have been framed by analogy with natural processes.[63] These interventions are only a small piece in a big puzzle, and it is important that they are not oversold as a total solution, nor as a complete disaster; in both extremes people engage less willingly with the bigger picture of emissions reductions. Positioning interventions in the middle ground when communicating and developing them conveys the best message.[64]

There are regional differences in what is more readily acceptable – and this heightens the need for local engagement and inclusive conversations about interventions and action. The conversation about SRM has, for example, been somewhat focused in the Global North. There are often deep concerns voiced about aerosol injection, the most discussed SRM strategy. However, the concerns are less deeply felt among young people in parts of the Global South – China India and the Philippines. Young people from all countries strongly support clear governance principles including regulation as a condition of deployment of SRM.[65]

Public perceptions of CDR reveal the need for people to be assured that its deployment is not a failure to get to the 'root cause' of climate problems. The sense of urgency means CDR is seen as too slow, and that it fails to reflect long-term hopes for a sustainable world.[66] CDR research under careful conditions may be acceptable, but at-scale deployment will be unacceptable unless efforts to reduce emissions are demonstrably stepped up as well.

Perceptions are complicated, but some of the implications of these multiple analyses and outcomes are relatively simple to state, though they may present challenges in delivery.

1. Trust and fairness are central to any programme in which action is taken to address climate change. Whether it is low emission zones, airport taxes or incentives to instal heat pumps, there will be better take-up and buy in if there is trust in those leading the implementation. Politicians rank low in the list of who people trust, so some humility from governments will be needed to address this requirement.

2. People tend to trust experts and ordinary people more than they trust politicians. Who is considered a trusted messenger also varies across different groups within the public; people tend to trust those who they share their values with and see as competent and unbiased. So transparent conversations, building of social capital around climate activism, and giving prominence to those experts who understand the technical requirements of climate action could help to make policies and proposed interventions acceptable.

3. Acceptability of large-scale interventions described as geoengineering is likely to be closely linked to the perceived controllability of experiments and scaling approaches. These will need transparency, good governance and good communication.[67]

4. Groups like CCAG can and must 'speak truth to power' - it is important to keep reminding those who make policy what the impact now, and in the future, will be if the difficult issues around climate interventions are ignored.

5. Trust in the storyteller will have an impact on how clearly individuals are able to evaluate and accept climate interventions that may be needed or helpful in the climate crisis.[68] CCAG and other dispassionate experts must remain available to discuss, explain and interrogate interventions to the satisfaction of those who are worried about accepting new approaches and strategies.

ENDNOTES

1 Figure 4 IPCC 1990 page XVII https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_spm.pdf

2 Economic Policy Reform, Mazzucato and Ryan-Collins (2022) 'Putting value creation back into 'public value': from market-fixing to market-shaping' https://www.tandfonline.com/doi/full/10.1080/17487870.2022.2053537

3 IIPP, Mazzucato and Rodrik (2023) 'Industrial Policy with Conditionalities: A Taxonomy and Sample Cases – Working Paper' https://www.ucl.ac.uk/bartlett/public-purpose/publications/2023/oct/industrial-policy-conditionalities-taxonomy-and-sample-cases; Mazzucato (2021) 'Mission Economy: a Moonshot Guide to Changing Capitalism' https://marianamazzucato.com/books/mission-economy

4 CCAG (2023) 'The Overshoot: Crossing the 1.5°C threshold – and finding our way back' page 2 https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/655b0e7666b61f5567ef15e4/1700466296033/The+Overshoot+20.11.23.pdf

5 Nature Communications, Dai et al (2022) 'Stratospheric impacts on dust transport and air pollution in West Africa and the Eastern Mediterranean' https://www.nature.com/articles/s41467-022-35403-1

6 Nature Communications, Ditlevsen et al (2023) 'Warning of a forthcoming collapse of the Atlantic meridional overturning circulation' https://www.nature.com/articles/s41467-023-39810-w

7 Nature Geoscience, Brovkin et al (2021) 'Past abrupt changes, tipping points and cascading impacts in the earth system' https://www.nature.com/articles/s41561-021-00790-5

8 Nature, Rockström et al (2023) 'Safe and just Earth system boundaries' page 105 https://www.nature.com/articles/s41586-023-06083-8

9 Ibid

10 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 and Carbon Brief, Mc Sweeney (2020) 'Is Climate change causing more 'blocking' weather events?' https://www.carbonbrief.org/jet-stream-is-climate-change-causing-more-blocking-weather-events/

11 DOE-NOAA, Di Liberto (2023) 'Disrupted polar vortex brings sudden stratospheric warming in February 2023' https://www.climate.gov/news-features/event-tracker/disrupted-polar-vortex-brings-sudden-stratospheric-warming-february#:~:text=When%20a%20tropospheric%20atmospheric%20wave,vortex%20and%20cause%20r-apid%20warming.

12 See Severe Weather Europe, Korosec (2023) 'Disrupted Stratospheric Polar Vortex sends Powerful Arctic Cold Outbreak to Canada and US over the weekend for Halloween' https://www.severe-weather.eu/global-weather/arctic-cold-outbreak-polar-vortex-2023-2024-united-states-canada-snow-forecast-mk/

13 See CCAG (2023) 'The Overshoot:Crossing the 1.5°C threshold - and finding our way back' https://static1.squarespace.com/static/60ccae658553d102459d11ed/t/6564b3bd04d4bc1ad1245653/1701098431626/The+Overshoot+-digital.pdf

14 Ibid, page 13, citing Nature, Qian et al (2023) 'Abyssal ocean overturning slowdown and warming driven by Antarctic meltwater' https://www.nature.com/articles/s41586-023-05762-w; and Nature Climate Change, Gunn et al (2023) 'Recent reduced abyssal overturning and ventilation in the Australian Antarctic Basin' https://www.nature.com/articles/s41558-023- 01667-8

15 Ibid page 13

16 IPCC (2018) 'Global warming of 1.5°C - An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty' https://www.ipcc.ch/sr15/

17 'All analysed pathways limiting warming to 1.5°C with no or limited overshoot use CDR to some extent to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C following a peak.' Ibid page 96. CDR is mentioned over 300 times in the IPCC 1.5°C report.

18 Ibid page 70

19 Subsidiary Body for Scientific and Technology Advice and Subsidiary Body for Implementation (2023) Endnote: 'Technical dialogue of the first global stocktake: Synthesis report by the co-facilitators on the technical dialogue', page 5 https:// unfccc.int/documents/631600

20 Ibid, page 4

21 Ibid page 19

22 Ibid, page 20

23 Ibid, page 40

24 Ibid, page 40

25 Ibid, page 36

26 Ibid page 20

27 These principles are a summary of the key points in the thinking of the Council on Energy, Environment and Water (CEEW). CEEW, Morrow et al (2020) 'Principles for Thinking about Carbon Dioxide Removal in Just Climate Policy' https://www.ceew.in/publications/principles-thinking-about-carbon-dioxide-removal-just-climate-policy

28 IPCC (2018) 'Global warming of 1.5°C - An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty' page 70 https://www.ipcc.ch/sr15/

29 Nature, Rockström & Mazzucato (2023) 'Why we need a new economics of water as a common good' https://www.nature.com/articles/d41586-023-00800-z

30 This is explained in the CCAG report 'Aftermath' following COP26, page 13. https:// www.ccag.earth/s/CCAG_Reflecting-on-COP26.pdf

31 Nature Energy, Mulugetta et al (2022) 'Africa needs context-relevant evidence to shape its clean energy future' https://sun-connect.org/wpcont/uploads/s41560-022-01152-0.pdf

32 IEA (2023) 'Direct Air Capture - Overview' https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture

33 Issues in Science and Technology, Lackner et al (2017) 'Climate Change is a Waste Management Problem' https://issues.org/climate-change-waste-management-problem/; Royal Society, Buck (2020) 'Should carbon removal be treated as waste management? Lessons from the cultural history of waste' https://royalsocietypublishing.org/doi/10.1098/rsfs.2020.0010; Lackner et al (2000) 'Free Market Approaches to Controlling Carbon Dioxide Emissions to the Atmosphere: A discussion of the scientific basis' https://doi.org/10.1007/978-1-4615-1323-0_3

34 See for example, Guardian, Lakhani (2023) 'Revealed: Top carbon offset projects may not cut planet-heating emissions'https://www.theguardian.com/environment/2023/sep/19/do-carbon-credit-reduce-emissions-greenhouse-gases#:~:text=Revealed%3A%20top%20carbon%20offset%20projects%20may%20not%20cut%20planet%2Dheating%20emissions,-This%20article%20is&text=The%20vast%20majority.

35 OSF, Lackner (2023) 'Carbon Accounting Without Life Cycle Analysis' https://osf.io/q9pzb/

36 OSF, Arcusa et al (2022) 'Intergenerational equity and responsibility: a call to internalize impermanence into certifying carbon sequestraton' https://osf.io/b3wkr/

37 Science China Earth Sciences, Zhang et al (2021) 'Feedbacks between vegetation restoration and local precipitation over the Loess Plateau in China' https://link.springer.com/article/10.1007/s11430-020-9751-8#:~:text=Observations%20show%20that%20precipitation%20on,2%2C%20from%202000%20to%202015.

38 PNAS, Butt et al (2023) 'Amazon deforestation causes strong regional warming' https://doi.org/10.1073/pnas.2309123120

39 Nature Communications, Leite-Filho et al (2021) 'Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon' https://www.nature.com/articles/s41467-021-22840-7

40 Carnegie Governance Initiative, Reynolds et al (2022) 'Solar Radiation Modification: Governance gaps and challenges' page 4 https://www.c2g2.net/wp-content/uploads/202203-C2G-GovGaps.pdf

41 Ibid, citing Anthony Jones, University of Exeter

42 See for example Xing et al (2017) 'Impacts of aerosol direct effects on tropospheric ozone through changes in atmospheric dynamics and photolysis rates' https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6104653/#:~:text=Many%20studies%20suggest%20that%20aerosols,2011%3B%20Xu%20et%20al.%2C

43 Geophysical Research, Golja et al (2021) 'Aerosol Dynamics in the Near Field of the SCoPEx Stratospheric Balloon Experiment' https://geoengineering.environment.harvard.edu/publications/aerosol-dynamics-near-field-scopex-stratospheric-balloon-experiment

44 Ibid, final page

45 DOE-NOAA (2022) 'Marine Cloud Brightening (Workshop Report)' https://www.osti.gov/servlets/purl/1902718/

46 Huq et al (2020) 'Adaptation to Climate Change Across ASEAN' Background paper for ASEAN (2021) 'ASEAN Development Outlook' cited at page 116, 117 https://asean.org/book/asean-development-outlook/

47 Ecosystem Services, Menendez et al (2018) 'Valuing the protection services of mangrove at national scale: The Philippines' https://www.sciencedirect.com/science/article/abs/pii/S2212041618301232

48 Aquatic Botany, Bosire et al (2008) 'Functionality of restored mangroves: A review' https://www.sciencedirect.com/science/article/abs/pii/S0304377008000521

49 ASEAN (2021) 'ASEAN Development Outlook' 116 https://asean.org/book/asean-development-outlook/

50 Our world in data, Ritchie (2019) 'Food production is responsible for one-quarter of the world's greenhouse gas emissions' https://ourworldindata.org/food-ghg-emissions

51 CREDS, Barrett et al (2023) 'The missed opportunity – ignoring the evidence on energy demand reduction' https://www.creds.ac.uk/publications/the-missed-opportunity-ignoring-the-evidence-on-energy-demand-reduction/

52 Nature Climate Change, Clayton et al (2015) 'Psychological research and global climate change' https://www.nature.com/articles/nclimate2622

53 Climate Change and Health, Banwell et al (2023) 'Rethinking ecoanxiety through environmental moral distress: an ethics reflection' https://www.sciencedirect.com/science/article/pii/S2667278223000822

54 Current Psychology, Schwartz (2023) 'Climate change anxiety and mental health: Environmental activism as buffer' https://link.springer.com/article/10.1007/s12144-022-02735-6

55 Pretty (2003) 'Social Capital and Connectedness: Issues and implications for agriculture, rural development and natural resource management in ACP countries' page 31 https://cgspace.cgiar.org/bitstream/handle/10568/63614/social%20capital%20wd8032.pdf?sequence=1

56 American Psychologist, Clayton et al (2016) 'Expanding the Role for Psychology in Addressing Environmental Challenges' http://doi.apa.org/getdoi.cfm?doi=10.1037/a0039482

57 American Psychologist, Kristian et al (2020) 'How psychology can help limit climate change' https://psycnet.apa.org/search/display?id=fb0543e1-d3a1-92ca-b606-589b6273bbc5&recordId=1&tab=PA&page=1&display=25&sort=PublicationYearMSSort%20desc,AuthorSort%20asc&sr=1

58 Current Opinion in Psychology, Whitmarsh et al (2021) 'Behaviour change to address climate change' https://www.sciencedirect.com/science/article/pii/S2352250X21000427

59 Nature Communications, Sparkman (2022) 'Americans experience a false social reality by underestimating popular climate policy support by nearly half' https://www.nature.com/articles/s41467-022-32412-y

60 Ibid page 1

61 Lind et al (2016) 'Perceived Fairness and Regulatory Policy: A Behavioural Science Perspective on Government-Citizen Interactions' page 30 https://www.oecd-ilibrary.org/governance/perceived-fairness-and-regulatory-policy_1629d397-en

62 Ibid page 28

63 Climatic Change, Corner (2014) 'Like artificial trees? The effect of framing by natural analogy on public perceptions of geoengineering' https://link.springer.com/article/10.1007/s10584-014-1148-6

64 Environmental Communication, Raimi et al (2018) 'Framing of geoengineering affects support for climate change mitigation' https://www.tandfonline.com/doi/full/10.1080/17524032.2019.1575258

65 Environmental Communications, Sugiyama et al (2020) 'The North-South Divide on Public Perceptions of Stratospheric Aerosol Geoengineering?: A survey in Six Asia-Pacific countries' https://www.tandfonline.com/doi/full/10.1080/17524032.2019.1699137?journalCode=renc20

66 Nature Climate Change, Cox et al (2020) 'Public perceptions of carbon dioxide removal in the United States and the United Kingdom'

67 Global Environmental Change, Bellamy (2017) 'Public perceptions of geoengineering research governance: An experimental deliberative approach' https://www.sciencedirect.com/science/article/pii/S0959378016302230?via=ihub

68 PubMed, Raimi (2021) 'Public perceptions of geoengineering' https://pubmed.ncbi.nlm.nih.gov/33930833/

CCAG MEMBERS

Sir David King

Alice Hill

Dr. Robert W. Corell

Professor Qi Ye

Dr Klaus Lackner

Professor Johan Rockström

Professor Lorraine Whitmarsh

Professor Nerilie Abram

Dr Arunabha Ghosh

Professor Laura Diaz Anadon

Professor Lavanya Rajamani

Professor Mark Maslin

Dr Fatima Denton

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Gustavo Alves Luedemann

Professor Mariana Mazzucato

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