4 Ways of seeing the climate

> We use models to build hypotheses to try and understand how processes can work, but we rarely increase scientific knowledge based only on modelling. Usually, there has to be some sort of corroboration by observations and, of course, theoretical understanding. Only when these three aspects come together, we trust [our outcomes]. I think there's a misperception that scientists would 'trust' models. What we do with models is build hypotheses of how a future climate could evolve given a certain scenario. But one rarely sees anyone formulating [these hypotheses] as knowledge.
>
> (Researcher H)

The mutable climate

The winter of 2014–2015 in Washington, DC, was unusually cold. For Republican Senator Jim Inhofe, author of the book *The Greatest Hoax* (2012), this cold weather presented an opportunity. He could definitively prove climate change a fiction. In a memorable performance of scientific ignorance, Inhofe brought a snowball, collected from the steps of Congress, into the U.S. Senate. In Inhofe's view, the snowball proved climate change a hoax, because 'it's very, very cold out. Very unseasonable'.[1] Of course, Inhofe's snowball act was nonsense: it deliberately conflated the weather and the climate. Weather is a snapshot of the atmospheric conditions at a particular time; it can change drastically daily, even momentarily. Temperatures can change as much as 30°C or 40°C in a day, and unseasonably cold days and weeks also exist in a warmer world.[2] Yet this volitality of the weather makes it difficult to accept that a change of only 1°C or 2°C in *global* average surface temperature is importants. Inhofe played to this conflation; if global warming were real, shouldn't that mean unseasonably cold weather should cease to occur? Inhofe's performance was rightly ridiculed, but it spoke effectively to an audience refusing to accept global climate change as a local problem. This muddling of the weather and the climate isn't *just* the consequence of scientific illiteracy either. Disagreement about climate change is, as Mike Hulme (2009) aptly observed, quite understandable. The 'climate' is a complicated thing. It is an abstract concept describing the amalgamate of weather conditions over time, locally, regionally, and globally. Traditionally, 'climate is what you expect, weather is what you get', organising the distinction between weather and climate spatially, temporally, and experientially (Hulme, 2009). The 'weather' describes the immediate atmospheric conditions at any given time, while the 'climate' connotes the expected interplay between atmospheric conditions over time. At the same time, the climate is also a cultural phenomenon (Glacken, 1996; Hulme, 2017). It means different things in every country and community. The 21st-century scientific conception of the climate grew from particular scientific and cultural histories, but throughout history countless other perceptions of the climate have existed. In traditional European societies, for example, people often used climatic conditions to explain and justify cultural differences and hierarchies. The ancient Greeks and Romans thought the harsh climate of Northern Europe turned its inhabitants into uncultured barbarians. Similarly, European intellectuals in the 18th and 19th centuries thought tropical climates made people lazy and mentally retarded, using climate determinism as a justification for colonialism. For most cultures throughout history, climate and weather were *metaphysical* as much as physical, they were manifestations of the divine. In other words, 'the climate', and our perception and imagination of it, is cultural as much as it is geophysical.

Because the climate is so entangled with our collective experiences of the world—and because what it describes is so vague and abstract—it is no surprise there are serious disagreements about what climate change is and about what the response to climate change should be. There *is* no one climate change. To some, climate change means drought and crop failure. To the Dutch, such as myself, climate change is warmer summers, drier springs, less ice skating in winters, and an increased risk of flooding—but also a reminder of the fragility of a country mostly below sea level. To Pacific Islanders and Bangladeshi, the prospect of sea-level rise presents an immediate threat to many people's livelihoods (Brouwer *et al.*, 2007; Mcleod *et al.*, 2019). In other countries, climate change presents the risk of devastating heat waves (Im, Pal and Eltahir, 2017; Kang and Eltahir, 2018; Pal and Eltahir, 2016). For larger countries, the risks of climate change are even specific to particular regions. For some even, climate change is simply an opportunity. Anticipating glacial melt, companies and governments are already prospecting in the Arctic regions for, ironically, fossil fuels and rare minerals (Frederiksen, 2020). Climate change always intersects with sociocultural and political configurations, affecting people differently depending on whether they are a man or a woman, are affluent or destitute, make their living of the land or from service, and depending on the colour of their skin. How people are affected also depends on the meanings they ascribe to weather and climate, whether stemming from culture, education, religion, or personality.

Even within climate science, such cultural specificities play an important role. By and large, climate scientists view the climate as a complex global system. Despite the fact that climate scientists all work within stylised and socially defined epistemologies, their *specific* views of the climate still differ.

Scientifically, the climate describes a complex interplay between different systems, most of which escape direct human perception. No one ever deals with the climate *directly*. It is, in Timothy Morton's (2013) words, a hyperobject, real in its consequences and existence but too vast and viscous to fully comprehend. As a result, researchers interact not with the 'climate' but always with a discursive approximation of what they *define* as the climate.[3] Of course, such a representation of the climate is not unconstrained by reality. As Hans-Jörg Rheinberger puts it, 'in configuring and reconfiguring epistemic things, scientists meet with resistance, resilience, recalcitrance. Not anything goes'. But the fact that scientists deal with a discursive approximation of an abstract concept rather than reality itself does mean that 'if there is a scientific real, it is multiple… the resonances that are built up in a particular historical conjecture are not the only ones that are conceivable' (Rheinberger, 1997, p. 225). Clearly, both the 'scientific real' and the cultural experiences of climate and climate change are multiple. This doesn't mean we have to accept Jim Inhofe's conflation of weather and climate as a meaningful contribution to the climate change debate, but it does mean we should be sensitive to the multiplicity of both climate and weather—including interpretations we may not share.

Sharing historical and cultural backgrounds, co-inhabiting similar epistemic communities, climate engineers tend to share a conception of the scientific real and epistemological assumptions about climate knowledge. This shared vision makes it possible to research climate engineering. Within this shared way of seeing the climate, however, there exist serious disagreements about the appropriate visions and descriptions of the climate. This chapter shows how, in the climate engineering debate, the scientific real around the climate is multiple. It draws out shared perceptions and disagreements in climate engineers' view on the climate to show how belief in climate engineering proposals follows from a trust in certain epistemological conventions in climate science. Specifically, it shows how the global view that reduces the complexity of climate to a 'manageable' level—and makes it possible to address climate change using two *global* indicators in the form of carbon dioxide concentrations and global average surface temperatures—facilitates optimism about the promise of climate engineering technologies. At the same time, this chapter also demonstrates that allowing for the multiplicity of the scientific real decreases such technological optimism. For one, climate engineers disagree vehemently about the extent to which the climate system be known and predicted. Closely connected to these disagreements about *knowability* are disagreements about the appropriate epistemological *scales* to address climate change. Forsaking a global epistemology in favour of geographical and temporal specificity tends to bring into view specific and unpredictable details. Such details lessen scientists' confidence in being able to know and predict the behaviour of the climate.

How one feels about the technological reliability of climate engineering always connects to how one views the climate. Different conceptions of the wilfulness and knowability of the climate lead to fundamentally different views on the reliability and desirability of climate engineering.[4] In this chapter, I outline how different climate engineers view different aspects of the climate. Most fundamentally, climate engineers disagree about the *knowability* of the climate. While there is an agreement that the climate can be changed and manipulated, there are disagreements about to what extent *deliberate* control of this change can be exercised. To some, the climate is dangerous and unpredictable. It is a volatile system, axiomatically uncertain and unpredictable. The climate can be manipulated and altered, but such manipulation cannot be *controlled*, so scientists shouldn't think to try. Others see the climate as reasonably well understood. Given further research, it could be knowable, somewhat predictable, and therefore potentially controllable. This chapter showcases these divergent views on the climate, interpreting them in their institutional, political, and cultural contexts. It presents a lens through which to analyse how climate engineering researchers construct their visions of natural systems, of the uncertainties that may be inherent in these systems, and what this means for their view of the reliability of climate engineering technologies. In this chapter, then, I first outline different views on the predictability and knowability of the climate. Subsequently, I address what these views mean for the respective views on climate engineering. Finally, I turn to the implications that such views have on imaginations of what the possible role of climate engineering can be in relation to climate change.

Narrating climate change

Scientists typically represent climate change using partial projections and interpretations of the (global) climate. The abstraction and varicosity of climate, as well as the timescales that the global climate changes on, make climate change hard to perceive. As one scientist expressed, you wouldn't 'mind if the temperature is increasing in 10 years by one degree', because it 'wouldn't be a big difference, you wouldn't feel it'. Climate change *needs* a scientific construct to become legible. Partial projections of climate change are crucially important. Without them, climate change would drop out of sight, until disruptions of the local and regional climates 'affect every culture, economy, and everything' (Researcher L). Through scientific research, scientists don't just obtain knowledge about the behaviour of the climate, they also create *storylines* about the climate that 'have the functional role of facilitating the reduction of the discursive complexity of a problem and creating possibilities for problem closure' (Hajer, 1997, p. 63). They embed the 'scientific real' that speaks through their empirical findings in particular frames, epistemologies, and imaginaries—allowing their storylines to reduce the complexity of the global system to manageable proportions. Because 'the climate' is an abstract phenomenon, what it describes is conceptual. Of course, climates have real and physical consequences, but what 'the climate' and 'climate change' describe is also a discursive convention. As I have outlined in Chapters 2 and 3, the definition of the climate has changed considerably over the course of the 20th century. In the climate change debate, the climate has become a global phenomenon with local manifestations and damages (Ashley, 1983; Edwards, 2010; Hulme, 2009; Jasanoff, 2001; Miller, 2004). In this global view of climate, two indicators in particular facilitate the discursive view of the climate: global CO_2 concentrations and average global surface temperature. As I explained in Chapter 3, these two metrics are important storylines. They justify both solar radiation management (SRM) research—which directly addresses global average surface temperatures through addressing the energy balance of the climate system—and carbon dioxide reduction research—which promises to lower CO_2 concentrations. Such simplified storylines risk, as I have written elsewhere, 'homogenizing the climate, disavowing multiple and complex relationships between humans and their environments' (Oomen, 2019, p. 8), but simultaneously make it possible to selectively address the particular aspects of climate change deemed important.

Culturally, these two global indicators are deeply influential. Climate activists, scientists, and policymakers use them to narrate climate change with charismatic storylines. Climate policy revolves around several easily memorable numbers and abstractions. Since the 2015 Paris Agreement, 1.5 °C or 2 °C warming above preindustrial levels is widely regarded as the 'safe' target for climate policy. Rather than being a scientifically agreed upon 'safe limit' of warming, however, these goals are political storylines for people to rally around. As Knutti, Rogelj, and Fischer observe, these targets are

> perceived by the public as a universally accepted goal, identified by scientists as a safe limit that avoids dangerous climate change. This perception is incorrect: no scientific assessment has clearly justified or defended the 2 °C target as a safe level of warming, and indeed, this is not a problem that science alone can address.
>
> (Knutti *et al.*, 2016, p. 13)

For climate scientists, it may be that 'global temperature is the best target quantity', but it remains 'unclear what level can be considered safe' (Knutti *et al.*, 2016, p. 13). The other global indicator, carbon dioxide concentrations, fulfils a similar role. In 2008, James Hansen, the climate scientist who put climate change on the U.S. political agenda in 1988, suggested a target aim of 350 ppm CO_2 'if humanity wishes to preserve a planet to that on which civilization developed and to which life on Earth is adapted' (Hansen *et al.*, 2008, p. 217). Soon, this number became a rallying cry for climate activism, as the scientifically accurate best guess for a safe greenhouse gas concentration.[5]

Both these targets function as a shorthand for a range of expected effects, locally and globally. They homogenise the effects of climate change in favour of a memorable storyline and goal. In doing so, they rely on the conceptual apparatus that developed in the 20th around the notion of the climate as a global mathematical system. Climate engineering, as a possible approach to climate change, deeply relies on this global view. As I have written elsewhere, 'the reconceptualization of the climate from a regional, typically experiential, phenomenon into a scientized, statistical phenomenon based on global models—making possible new visions of control and management—lies at the heart of current climate engineering research' (Oomen, 2019, p. 5). Both carbon dioxide removal (CDR) and SRM are predominantly *global* solutions to the problem of climate change. CDR directly addresses the idea of safe levels of CO_2, based on the idea of a global carbon commons (Bäckstrand and Lövbrand, 2019; Beck and Mahony, 2018a). SRM addresses the idea of safe levels of *warming* by artificially reducing global temperatures.

Narrating climate engineering

By and large, climate engineering researchers share the common understanding that climate engineering research *needs* to be done 'because we all know that the temperature is increasing' (Researcher L). For contemporary climate engineering research, anthropogenic climate change is its *raison d'être*.[6] Scientifically organising climate engineering research around these two global indicators has formative effects on how climate engineers view the role of climate engineering in climate policy. It organises the debate predominantly around the *efficacy* of climate engineering, either SRM or CDR, to bring global surface temperatures down (e.g. Irvine, Sriver and Keller, 2012; Keith and Irvine, 2016) instead of *ethical* or *political* questions (McLaren, 2018; Oomen, 2019). For SRM technologies, the global perspective raises important model-based questions such as the effect of particular technologies on regional precipitation (e.g. Ricke, Morgan and Allen, 2010). In CDR, it highlights issues of land-use pressures due to NETs or the disruption of local ecosystems due to afforestation (e.g. Keller *et al*., 2018; Sonntag *et al*., 2018).

Despite occupying a shared 'ontological playing field', as it were, however, climate scientists continuously have to negotiate the 'right' perspective on climate, climate change, and climate engineering. Some of these negotiations pertain differences in disciplinary epistemology. Meteorologists and climate scientists often prioritise a global (or regional) view because they rely on satellite data and numerical computer models comprising large areas with limited data points. Their climate models, such as general circulation models (GCMs), describe the climate as a *physical* system, as a global system that manifest locally. These models can be operated on various scales, but there are always trade-offs. Detailed regional models that have a high resolution (many data points in a small area) exclude processes that happen just outside the scope of the model, processes 'beyond the border' so to speak.[7] Global models, on the other hand, incorporate the whole Earth, at the cost of detail due to lack of data and processing power. Earth systems sciences and physical geography are likewise bound to a physical, mathematical description of climate systems, but often model human systems (and increasingly, also behaviour) as part of those systems. Their integrated assessment models (IAMs), direct descendants of the IAMs that had started the 'world-modelling' community in the 1980s, describe complex inter-human and organic-nonorganic interactions (Anderson and Jewell, 2019; Edwards, 1996; van Vuuren *et al*., 2011). Even between these two comparable, model-based and global, epistemologies, it can be hard to negotiate the 'right' view of climate. This becomes even more difficult when fundamentally different epistemologies, such as those from economic, law, and philosophy, also become introduced. In some projects such as CEL-ARIT research project in the SPP, an interdisciplinary project investigating legal liabilities connected to SRM, this led to such different interpretations of the (relevant) scientific real that initially 'everybody was doing their own thing' (Researcher C).

Another important site of negotiation is institutional culture. There are considerable differences between different climate engineering research groups and communities, and serious disagreements between them. The David Keith Group at Harvard University and the SPP-1689 in Germany are interesting cases The Keith Group is an issue-driven research group. Its main research focus is to develop a particular type of SRM, stratospheric aerosol injections (SAIs), as a viable climate engineering technology. Focused on this shared goal, Keith Group researchers accept average global surface temperatures as their primary indicator. Regional effects do feature in their work, but their primary concern is limiting the aggregate climate damage globally. In doing so, they rely on global climate models, comparing regional effects of SAI in GCMs. Holding to global temperatures as the main indicator, this view is relatively optimistic about the *knowability* and *controllability* of climate engineering, because it facilitates a problem-solving use of global models—and a well-defined problem to solve. For the German SPP, the climate is less uniform. Being a more diverse research program, the SPP internally negotiates between different perceptions of the climate. Institutionally more sceptical about the potential of climate engineering technologies, the SPP's problem definition of climate engineering is more diffuse. Opening up further layers of complexity, it becomes impossible for the SPP to find a single, problem-solving lens through which to view the climate. Divergent visions and epistemologies make it difficult to find a clear developmental focus, because it starts with negotiations about 'the common thing that we can or can't agree on'.

Such negotiations about the relevant view of the climate are not just a feature of institutional culture, interdisciplinary research, or a priori position on the desirability of climate engineering. They also take place within disciplines, among different 'tribes' of researchers (e.g. Thompson, 1984). A useful example of such negotiations on the preferred indicators and scientific practices are the different *epistemic lifestyles* of climate modellers in the 1990s (Shackley, 2001). At the time, modelling communities disagreed strongly about the 'right' use of climate models. Some, the 'climate seers', used 'model-based experiments to understand and explore the climate system' (Shackley, 2001, p. 115).

Others, 'climate model constructors', focused on 'developing models that aim to capture the full complexity of the climate system, and that can then be used for various applications' (Shackley, 2001, p. 115). These groups disagreed about what models could do, how models can provide new knowledge, and how models should be used. For climate seers, models were a means to learn about the climate system. Using basic comparative models runs would help to understand how the climate system might behave in different conditions. Climate model constructors had difficulty accepting the validity of this 'new knowledge'. They saw these basic models used as crude and unsophisticated. Instead, climate model constructors thought, scientific focus should be on fine-tuning the models, allowing them to incorporate as many interactions and processes as possible.

In the climate engineering research community, there are similar differences of opinion. Here, disagreements about how models should be used also exist, but most disagreements revolve around the extent to which the climate can be known and potentially *controlled*. Such differing opinions tend to be implicit. They underlie scientific work, informing how parameters are chosen and what the most important research questions are, but are rarely clearly articulated. Negotiations over the 'right' way of seeing climate—controllable or volatile, global or local, abstract entity or collection of direct effects on people's livelihoods—and the 'right' indicators deeply influence the imagination of climate engineering as a possible answer to climate change. Fundamentally, it is this choice of indicators that make climate engineering look either feasible and reliable—or wholly irresponsible and unreliable.

Fundamental climate uncertainties

The feasibility and reliability of most climate engineering technologies remain open questions. Within the climate engineering community, fundamental disagreements exist around the 'technical' feasibility of climate engineering. Many of these disagreements derive from disagreements about to what extent climate systems can be known and predicted. Divergent views on the feasibility, controllability, and predictability of climate engineering technologies—in short, in the words of Mike Hulme (2014) its reliability—depend, at least on the technical side, on particular visions of the climate. To many, the global epistemology of climate models obscures, and therefore makes invisible to global policy, the local manifestations of climate (Hulme, 2014, 2017; Oomen, 2019). In this view, climate change is not only a global problem. It is also a local problem that directly affects the lives of humans, animals, and plants. For Mike Hulme, global scales and optimism about the knowability and predictability of climate might make climate engineering computable in a numerical way, but they systematically under-appreciate risks and inequities. Fundamentally preoccupied with *disproving* climate engineering as a viable policy option, Hulme argues that the global epistemology that made climate science possible (see Chapters 2 and 3) also makes climate engineering more appealing than it should. Its global metrics give a false confidence of both the knowability and the controllability of the climate. More techno-optimistic climate engineers, on the other hand, are more optimistic about the reliability of climate engineering technologies.[8]

These fundamental disagreements about climate engineering revolve around the extent which the climate can be understood, predicted, and controlled. To many critics, the climate is and will always remain unpredictable. As one researcher in the German SPP remarked, 'the devil hides in the details' (Researcher K). For opponents of techno-fixing climate change, the problem is that those details cannot be understood well enough to safely promise a measure of climate control. Most climate engineers agree to some degree; they all agree that both the climate and the complex interplay with other Earth systems are not *yet* understood well enough to control. They disagree, however, about whether this scientific ignorance fundamentally precludes reliable climate engineering technologies. Such disagreements occur on a spectrum between two positions on the predictability of the climate: *climate knowledge optimism* and *climate knowledge pessimism*. Climate knowledge optimists think that, in principle, the behaviour of the climate can be understood well enough to consider both temperature modifications through SRM *and* CDR. For these climate knowledge optimists, modifying the climate, especially through directly influencing the Earth's energy budget, certainly presents risks, but it might still be far preferable to 'a climate-changed world'. Even among the most self-assured proponents of climate engineering research, few claim that anyone could reliably engineer the global climate *today*. They are confident, however, that climate understanding could improve sufficiently to safeguard reliable and careful implementation of climate modification schemes. In principle, they insist, the climate is knowable enough to consider both SRM and CDR—especially in the light of the uncertain effects of climate change. Climate knowledge pessimism, on the other hand, views a reliably predictive understanding of the climate as unattainable. To climate knowledge pessimists, the climate remains an unpredictable complex system that behaves non-linearly. As such, invasive modifications such as setting up a stratospheric veil or brightening marine clouds to lower global temperatures are inexcusably uncertain and dangerous. Such interventions might disrupt of global and regional rainfall patterns, not provide the cooling effect people are hoping for, and savagely disrupt local climates. In the eyes of such climate knowledge pessimists, modifying the Earth's albedo will almost certainly only add risks to climate change because the uncertainties of climate change and climate engineering will *compound*. In the eyes of climate knowledge pessimists, the model-based comparisons between 'a climate changed world with and without climate engineering' that optimistic climate engineers conduct are problematic because they remain uncertain projection. Even *if* interventions manage to lower the *global* average temperatures, they might still disrupt local climates severely. Absorbing carbon from atmosphere suffers from similar problems, because most CDR technologies require a significant change in land use—which brings its own unpredictable interactions in ecological systems. Counting on CDR, moreover, is dangerous because it may never work at the required scales.

Optimism and pessimism about climate knowledge are important predictors for both the confidence people are willing to place in climate engineering and the types of research people conduct. Optimists are far more willing not only to accept climate engineering as part of the climate policy envelope but also to do *constructive* research about how to develop climate engineering technologies. In practice, of course, most climate engineering researchers express a mediated form of climate knowledge scepticism, fluidly moving between optimism and pessimism on different occasions. Such climate knowledge scepticism[9] typically abhors what it sees as techno-optimists' hubris but simultaneously warns not to be unnecessarily dismissive about the necessity and feasibility of climate engineering technologies. It argues 'the jury is still out' on climate engineering. Despite the unresolvable uncertainties and risks of climate engineering, development and research is warranted, even necessary. This view is shared widely in the climate engineering research community. In both the SPP and the Keith Group, a large majority of researchers found themselves attracted to such a mediated scepticism. In the Keith Group, scientists who were cautiously optimistic about the controllability of the climate but generally sceptical about the techno-optimism of some of their colleagues argued for such a 'pragmatic' attitude—as they themselves would describe it. In the SPP, most interpreted such pragmatism as too optimistic. In general, SPP researchers remained far more pessimistic about the extent to which the climate can be known and predicted. Yet they too were sufficiently alarmed about climate change to research climate engineering technologies.

In the book *Experiment Earth* (2015), Jack Stilgoe quotes a climate engineering researcher saying,

> when we all stand in that field in Norfolk, all of the engineers will be jumping up and down because they've succeeded in doing something amazing, building the tallest structure anywhere on Earth, and all of the natural scientists will be saying 'Oh shit, we're a step closer to doing something bonkers'.
>
> (Stilgoe, 2015, p. 1)

Engineers, underrepresented in climate engineering research, are trained as problem-solvers and tinkerers. Meteorologists, intimately aware of atmospheric non-linearities, take a different view of the climate and weather. The difference between the 'constructive' research of climate knowledge optimists, aiming to find out how climate engineering could be done, and the 'problematising' research of climate knowledge pessimists, trying to find ways in which climate engineering may go wrong, is reminiscent of the differences between the engineers and the scientists in that field in Norfolk.

Pessimists tend to focus on the ways in which climate engineering could exacerbate climate risks. Often, they choose to model possible risks in the future, such as the possibility that SRM is implemented and then suddenly terminated.[10] Optimist tinkerers, on the other hand, search their models for the optimal ways to implement climate engineering technologies, quite like finding the solution to a puzzle. As both climate knowledge optimists and pessimists realise, such different approaches to research privilege different types of questions. For more optimistic researchers, *disproving* climate engineering technologies is intellectually lazy, because it means you 'don't grapple with the question, "If it works in this way, then what?"'. In their eyes, if you want to understand what climate engineering might offer, 'you should probably presume that it's deployed in a sensible way', 'rather than assuming the worst with every single aspect'. Instead, 'you want to isolate aspects of the problem', 'and then analyse the one you care about'. To do so, 'you've got to accept some of the claims' and 'I think some people are sceptical about doing that' (Researcher 4). Accepting 'some of the claims' means departing from the assumption that climate engineering will be implemented in a sensible manner but it also means assuming that the climate system will—at least to some extent—behave predictably. Climate knowledge optimists are far more willing to depart from those assumptions than climate knowledge pessimists, who do not expect the climate system to behave predictably. Few doubt that climate modification, in the narrow sense of manipulating the climate globally, is possible, as 'technically, of course one could engineer climate'. Yet the real question is, 'will it do what the people doing it intend? I think the problem is that it won't… It would not be easily predictable to say what happens if one puts aerosols in the stratosphere' (Researcher H). To climate knowledge pessimists, technical feasibility alone does not make climate engineering a reasonable possibility, because 'we do not know the climate sensitivity'. This means that 'even if we know how emissions change, and know how CO_2 concentrations change in the future, we do not exactly know by how much the climate warms' (Researcher H). Correspondingly, if we do not know the climate sensitivity, we also 'do not know the response' to climate engineering measures 'very well'.

Such divergent views on the knowability of climate tie into disciplinary epistemologies, cultural background, and institutional norms. Within the SPP, dominated by Europeans, a significant presence of Earth systems scientists, oceanologists, and social scientists—academic disciplines engaging with fundamental uncertainties in knowledge[11]—continually stressed the limits of climate knowledge. In the David Keith Group, institutional culture veers much more strongly to climate knowledge optimism. While individual researchers may be doubtful, the Group generally expresses the potential (safety) of SAIs. Two major factors account for much of this difference. The first is institutional structure. The SPP, funded by the German Research Foundation (DFG), has to be careful to avoid controversy. From the outset, it adopted a critical stance of 'assessment, not development'. As such, they are restricted from outdoor experimentation and the development of climate engineering technologies. In such a sceptical culture, climate knowledge scepticism thrives. Many SPP researchers were attracted to the program precisely because of its institutionalised opposition to most climate engineering technologies. Quite a few only joined the program to *disprove* the viability of climate engineering to begin with. Such climate knowledge scepticism was further aided by interdisciplinary collaboration in the SPP. Experiencing first-hand how difficult meaningfully interdisciplinary communication is, SPP researchers engaged more systematically with *academically* incommensurably different conceptions of the climate and Earth systems. Such collaboration is difficult and wakes many people up to the limitations of their own academic discipline—making the climate seem more complicated and unknowable in the process. The Keith Group's culture was and is fundamentally different. Relying principally on research funding from private donors, Keith and his group are adept marketers of themselves and their research. Through a curated performance of climate fears, technological optimism, and economic arguments, they convince private donors to sponsor their research. This entrepreneurial aspect of the Keith Group inevitably attracts researchers more confident in climate engineering technologies. David Keith himself also forcefully directs his research group to develop climate engineering as a viable policy option. In general, the Keith Group's approach is problem-solving and 'tinkering' (in words of one researcher) to find ways in which climate engineering might work.

The research methodologies used to investigate the possibilities of technologies reflect these differences in outlooks. In the Keith Group, most research consists of atmospheric climate modelling through GCMs and engineering technologies to safely deliver aerosols in the stratosphere. Through such methodologies, the Keith Group thinks, 'we need to develop the idea'. Such GCM and other large-scale modelling facilitate a bird's-eye view of technical and physical feasibility. Projects such as the Geoengineering Model Intercomparison Project (GeoMIP) and the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP)—relied on by all climate engineering researchers—use model ensembles to compare future scenarios with and without the use of SRM, oceanic CDR (oCDR), and terrestrial CDR (tCDR). Using these models, researchers can search for optimal ways to implement CDR and SRM technologies and compare how different components of climate systems such precipitation and temperature react (in the models). Modellers have grown skilful at fitting models to empirical observations and historical analogies. Unfortunately, there are serious drawbacks to such methods. For one, the global scale tends to homogenise many complex relationships across the globe, both socially and climatically. Often, it leads researcher to hypothetically accept climatic trade-offs between different regions across the globe. Such methodologies are great if you want to 'flesh [climate engineering] out in ways that go beyond the idea that "there will be winners and losers because it doesn't reverse the climate change perfectly"', but they also facilitate asking the rather narrow question, '*how much losing would offset all the winning?*' (Researcher 4). Perhaps even more problematic is the false sense of confidence about the climate response that such global models can create. Even though climate knowledge pessimists insist 'we do not know the climate sensitivity', model results are often presented as accurate depictions of what the effects of climate engineering would be. Yet there is no real historical analogy for the current rate of climate change. There are even fewer natural analogies for SRM or even CDR methods, especially when combined with the current rate of climate change. This means that all climate models, historically calibrated as they are, will always have serious shortcomings in terms of their 'model fit' to reality.

Disagreement about climate knowledge leads to major disagreements about the technical 'feasibility' and 'reliability' of CDR and SRM measures. Climate knowledge pessimists, who often also insist on the sociocultural complexity of the climate, almost unilaterally oppose direct interventions in the climate system via SRM. In their eyes, the climate system is too unpredictable and volatile for such interventions. Climate knowledge pessimists might not necessarily oppose CDR as such negative emissions address the root cause of the changing climate, but they are still highly sceptical about the technical feasibility of carbon capture at scale. Most carbon capture technologies do entail interventions in other biospheric processes—and because, as I show in Chapter 6, climate knowledge scepticism ties into a general reticence about technological interventions—climate knowledge pessimism *does* often limit the confidence scientists have in CDR. Clearly, seeing a wilful climate isn't just a vision of climate but rather a vision of unpredictable natural systems.

'A massive difference in motivation'

Views on the potential of climate engineering diverge widely. Between them, prominent climate engineers disagree significantly about the level to which the climate is knowable, predictable, and controllable. As I show in Chapter 5, they also disagree about the (necessary) economic and political response to climate change. For scientists in the Keith Group, by and large quite techno-optimistic, the benefits of climate engineering might outweigh its risks considerably. Because they consistently view the climate as a global aggregate—with local manifestations—they view risks and benefits as a comparison between the global effects of climate change and climate engineering. In this view, the climate is as a resource that needs to be distributed optimally. Some more optimistic climate engineering researchers have even started to discuss climate engineering as a control and design problem (e.g. Kravitz *et al.*, 2016; MacMartin *et al.*, 2013; MacMartin, Kravitz and Keith, 2014). For most SPP members, such a view of the climate is abhorrent. It neglects the vast uncertainties and the specificities of local climates—and it is scientifically hubristic. Nonetheless, because the CE community is still small and the topic feels urgent, the Keith Group and the SPP regularly collaborate. Through these collaborations, it becomes obvious to researchers on both sides of the Atlantic that 'there is a massive difference in the motivation behind the research on climate engineering between [David Keith] and many of the people involved in the Priority Program including myself' (Researcher O). Much of this difference in motivation comes from divergent views on the climate and how it should be treated. Both the SPP and the Keith Group have clearly delineated collective imaginations about what climate is, what climate change will entail, and what climate engineering could do. Of course, individual researchers in these groups often hold different views. The Keith Group's techno-optimist view that sees climate as resource does not sit well with some of the more sceptical researchers, even within the Keith Group itself. Some are uncomfortable with the fact that SRM increasingly treated as a 'design' or 'control' problem, as 'it concerns me that now people are just thinking, "Oh well, this is just an engineering problem now. This is just a control problem"'. The idea of treating SRM as a control problem goes beyond 'dialling in a global mean temperature like a thermostat', because it suggests that 'we have such a perfect tangle on the whole system'. To him, and many others who see the climate as a much more volatile and complex system, this suggests that 'there's some hubris there' (Researcher 8).

Such optimism about climate knowledge often ties into more general techno-optimism. Many techno-optimist climate engineers are self-described *ecomodernist*s who see a wholehearted embrace of science and technology as the best way out of our ecological predicament.[12] For them, optimism about the knowability and therefore controllability of the climate ties into a larger tradition of techno-optimism. The human, they argue, is a *homo faber*, a maker of technology who intervenes in nature for their own benefit. Ideologically, ecomodernists operate in the tradition of the post-Second World War climatologists, chemists, and physicists such as Vannevar Bush, John Von Neumann, Vladimir Zworykin, and John Langmuir. To them, science and technology remain the most promising frontier for improving the human condition. Ecomodernists' optimism about the feasibility of climate engineering technologies, based on a global view in which the climate can ultimately be understood as a control problem, ties into a broader optimism about technology in general. It facilitates optimism (or 'pragmatism') about the potential of climate engineering. As such, they worry less about the uncertainty of climate projections. At times, such technological uncertainty appears to be wholly out of view. For climate knowledge pessimists, on the other hand, those uncertainties are the central focus, the perpetual centre field of vision. They incessantly search for the devil that might hide in the details, aiming to show that however good global projections may look, there will always be unexpected and unwanted effects. They often find those effects at regional and local scales where unexpected and unwanted effects would manifest. The smaller the scales, the more interactions and resistances of reality are thought of as a part of the research discipline and project, the more climate knowledge scepticism grows. Even vehement pessimists admit that both SRM and CDR technically have the potential to bring global surface temperatures down. It's just the question at the cost of what side effects.[13]

Post-Paris: the practical application of climate engineering

As climate change grows more menacing and scientists more worried, the idea of engaging in planetary climate modification re-normalises. Although not yet part of the cultural imagination like it was in the 1950s and 1960s, it is on its way to become a major part of climate policy. With climate modification schemes (re)normalising as a part of imagined climate policies,[14] many climate engineering researchers are becoming more cautiously optimistic about climate modification too. Techno-optimists in particular have in recent years become more outspoken advocates of climate engineering technologies, for example to give 'developing countries' more time to develop their economies.[15] It is likely, they say, that a combination of SRM and CDR could reduce climate risks significantly. Because scientific understanding of the climate response to climate engineering is knowable (enough), engineering the climate may technically be feasible. This re-normalisation of climate interventionist dreams connects strongly to developments in climate politics. In providing clear temperature goals—goals that seem out of reach without at least the use of negative emissions technologies at scale—the 2015 Paris Agreement has provided climate engineering research with political legitimacy. Since 'Paris', the 2°C and 1.5°C goals anchor climate policy. For many climate engineers, these target values justify their research. Carbon capture in its various forms, in particular, enjoys increased attention. As one researcher admitted, 'there is no path seen at the moment that could lead [to the 1.5/2 degree goal] without something like climate engineering' (Researcher B). Of course, the IPCC had previously included NETs as a desirable policy option for reaching the 2°C goal in its Fifth Assessment Report (Beck and Mahony, 2018a). The 2015 Paris Agreement further solidified interest in CDR. In its post-Paris report on 1.5°C of warming, the IPCC stated that 'all pathways that limit global warming to 1.5°C' (IPCC, 2018, p. 17) would to some degree need to rely on NETs, despite the fact that NETs 'deployed at scale is unproven, and reliance on such technology is a major risk in the ability to limit warming to 1.5°C' (IPCC, 2018, p. 96). Many in the climate engineering community simultaneously see their research vindicated and worry about this overt policy reliance on negative emissions technologies. In the aftermath of the Paris Agreement, climate engineers struggled to come to terms with implicit political reliance on negative emissions. In November of 2016, for example, the SPP organised a workshop investigating the relationship climate engineering and the 1.5°C target. In January 2018, a workshop on

CDR went further, asking whether the 1.5°C target could be viable without negative emissions. For many, the conclusion was clear: without stringent mitigation strategies *and* carbon capture and storage at scale, the 'Paris' goals are unrealistic. Hypothetically, of course, '[The 1.5° C target] can be made in these scenarios', 'but [given the lack of mitigation] I think it's really very unlikely'. The '2° C target is another question', but even this 'would be still tough' (Researcher I) without negative emissions.

As a result of the widespread recognition—including from official IPCC reports—that the Paris goals are out of reach without significant negative emissions, the line between conventional mitigation and various forms of CDR is starting to blur. More and more, assumptions about future negative emissions are becoming part of the 'policy envelope' on climate change (Pielke Jr., 2018). Much to the alarm of some researchers, compensation schemes and so-called 'overshoot' scenarios[16] 'may start to allow for some of what we call climate engineering' (Researcher K), because 'most scientists think that you cannot get [to the 2/1.5 degree target] by mitigation only'. Slowly, CDR is becoming a tacit policy expectation. The response to this development in the climate engineering community is mixed. The vast majority of climate engineers are conflicted. Those more sceptical about the extent to which both climate and other natural systems can be understood feel negative emissions projections are wholly speculative. It is unlikely, they insist, that carbon will be captured on the required scales—let alone be politically and ethically defensible. In circles in and immediately adjacent to the SPP program, many researchers sought (and seek) to problematise reliance on NETs in climate policy (Beck and Mahony, 2018a, 2018b; Geden, 2016; Geden and Schenuit, 2020). By modelling how much carbon would to be captured and what trade-offs this would mean in terms of economics and land use, particularly agriculture, for example, they attempt to show that the potential for CDR measures is limited (Lawrence *et al.*, 2018). They also criticise the CDR assumptions hidden in IPCC reports and climate agreements (Beck and Mahony, 2018b; Geden, 2016). At the same time, most SPP members admit current climate goals are unreachable without large-scale carbon capture. Further CDR research, they feel, is paramount, but it cannot get into the way of conventional mitigation—two often conflicting aims no one is entirely sure how to combine.[17] For many of the more techno-optimist researchers, especially in the Keith Group, this is less problematic. For Keith himself, as he states on his website, CDR, especially through high-tech 'direct air capture' (DAC) technologies, more like 'clean energy technologies like wind or nuclear power' that 'also offer the global benefit of reduced emissions in exchange for local costs and environmental risks'. This makes

> DAC, as I see it, more like an energy technology than a form of geoengineering. And, the use of DAC to make carbon-neutral hydrocarbon fuels is an energy technology that competes directly with batteries and biofuels to provide low-carbon transportation.

To Keith, reliance on CDR may not be inherently problematic if CDR is technologically feasible and, this important, *economically* sensible. Although, of course, speculative assumptions about carbon capture should not delay conventional mitigation, most Keith Group researchers feel that carbon dioxide reduction is a reasonable part of climate possible. Many of Keith Group's presentations and discussions even feature carbon capture and negative emissions as way to justify the potential implementation of SRM.

Post-Paris SRM

Like CDR, SRM also enjoyed a boost in attention after the Paris Agreement. By putting temperature goals front and centre, the Paris Agreement provided, at least discursively, a justification for further SRM research. At the same time, SRM remains *deeply* controversial. To most people, managing the Earth's temperature is a 'different story' than capturing carbon. For many climate engineers, SRM is 'more brutal climate engineering' (Researcher H). Most climate engineers view SRM as politically desirable only when catastrophes hit. Prominent SRM metaphors reflect this, as they typically present SRM as a last-ditch effort to stave of climate change, a plan-B, a band-aid, or fever medicine (Lovelock, 2008; Nerlich and Jaspal, 2012). Nonetheless, the 1.5°C goal has legitimised the SRM research of more enthusiastic climate engineers. To some more optimistic climate engineers, such as David Keith himself, stratospheric aerosol veils or brightened marine clouds could potentially become an embedded part of climate policy. Such albedo enhancing technologies can be used to either slow 'the rate of change', giving ecosystems and societies more time to adapt to changing climates, or forestall climate change altogether. Clearly, it is likely that carbon emissions will 'overshoot' safe concentrations. Hypothetically, Keith imagines, the effects of this overshoot could be masked by using SRM technologies, while extensive carbon capture drives atmospheric carbon concentrations back down. In this view, it should be possible to have a carbon-*negative* global economy by the late 21st century. This means that SRM could potentially 'shave the peak' off of global warming. By masking global warming technologically, SRM could safeguard the 1.5 °C or 2 °C target *temporarily*, artificially keeping temperatures down while carbon is captured and stored. For techno-optimists such as Keith, optimistic about both climate knowledge and the potential of science and technology, shaving the peak off global warming might be entirely feasible. For those more sceptical about the possibility to understand the climate, such a proposal simply represents scientific hubris. Cooling the Earth by intervening in the climate would be fundamentally unpredictable. Technically it might be feasible, practically it certainly won't be. A scheme that seriously considers SRM simply cannot be desirable because it will always be unreliable. To some German researchers, this is so self-evident that they insist they 'have never talked to somebody who really thinks it is feasible to implement global climate engineering, I don't know anybody who thinks that one really should do it. I don't think any serious climate scientist would say this is something to consider' (Researcher H). To Keith and others, however, the circumstances may necessitate climate engineering. There may not even be a fundamental reason to oppose SRM. Unlike the far more sceptical SPP program, the Keith Group could imagine climate engineering, both CDR and SRM, as a viable policy option. Climate engineering technologies may be fundamentally uncertain; they are probably better than unfettered climate change. Rejecting climate engineering out of hand is reactionary technophobia. Crazy, because it could potentially prevent so much damage and suffering. This is why, as we have seen above, more techno-optimist researchers insist that 'we need to develop the idea, flesh it out in ways that go beyond the idea that there will be winners and losers because it doesn't reverse the climate change perfectly'. Both SRM and CDR, in this view, are simply necessary fields of research, given not only the political but also *technical* difficulties of conventional mitigation. More than most SPP climate engineers, researchers in the Keith Group view mitigation as an intractable problem. By this they do not just mean politically, which is an attitude that is widely shared within the SPP, but also practically, energetically.

'Climate engineering is undesirable, ungovernable, and *unreliable*'

To Keith and others, climate engineering comes into focus because conventional mitigation seems to be an intractable problem. Wind and solar energy will not prove ready alternatives to fossil fuels. They will probably be much more problematic than people now anticipate—as one of Keith's postdocs also shows in his work (Miller and Keith, 2018). For certain applications, such as air travel and freight, no viable energetic alternatives are within sight, nor does it look like people will be willing to fly less or trade less internationally. Climate engineering, both CDR and SRM, can provide a temporary solution to these problems. Allowing some overshoot in carbon emissions, for example, may buy time to solve these intractable energy problems. Carbon capture can play a role later by reabsorbing these emissions, while SRM technologies keep temperatures down in the meantime. In this view, the climate can be used as a *resource*, measurable by carbon dioxide concentrations and average global warming that can be utilised in the most efficient way. Viewing the climate as a resource makes it possible to view climate engineering as a means to optimise the 'use' of the climate. Like the 1.5°C or 2 °C target as a *global* indicator for climate change, climate engineering comes into view as a global solution to a global problem, reducing the average temperature of the climate. This reduction should ameliorate the worst effects of climate change. This instrumentalised view of the climate becomes possible if one understands it globally, using comprehensive indicators, but it clashes badly with other, more humanistic views of the climate that privilege localism and cultural relationships to the climate.

Often, such differences aren't made explicit. They are the result of tacit epistemologies and ontologies. Instead, they surface through the storylines, metaphors, and discursive frames that organise the climate engineering debate (Baskin, 2019; Hansson, 2014; Huttunen and Hildén, 2014). As we have seen, those who view climate engineering favourably see carbon capture as a possible *augmentation* to conventional mitigation or an *insurance* against insufficient conventional mitigation (e.g. Lackner, 2016; Lackner *et al.*, 2012). In doing so, negative emissions technologies might render unfeasible climate goals feasible (Gasser *et al.*, 2015; IPCC, 2018). Conceptualised in such way, carbon capture could offer developing countries some economic leeway. A combination between SRM and significant carbon removal could even be used to 'shave off the peak' of global warming, limiting global warming while carbon dioxide concentrations are reduced (Keith and MacMartin, 2015). Solar radiation manipulations could also 'slow the rate of climate change', giving both ecosystems and human societies time to adapt to changing conditions—a use David Keith imagines. For economists, climate engineering might reduce the costs of mitigation (Wagner and Weitzman, 2015). Those opposed to climate engineering use fundamentally different storylines for climate change and climate engineering. Negative emissions technologies shouldn't be relied upon because they will be slow, expensive, and are uncertain to work on the scales needed (Anderson and Peters, 2016; Fuss *et al.*, 2014; Geden, 2016). SRM, if used, will disrupt all kinds of climatic processes (Robock, Jerch and Bunzl, 2008). Abrupt cessation of SRM might lead to a catastrophic 'termination shock' (Jones *et al.*, 2013). Climate engineering would be unreliable because the climate is unknowable and unpredictable (according to Hulme, 2014, and many interviewees in the SPP). Climate engineering could be used to the benefit of the powerful at the expense of the poor (Baskin, 2019). SRM would be fundamentally incompatible with democratic systems (Szerszynski *et al.*, 2013). More mixed imaginations about climate engineering might present the climate is unknowable and unpredictable, but still view climate engineering as a way to reduce risks (Arino *et al.*, 2016). In such a view, SRM could perhaps be used in an emergency situation or as a plan-B (Royal Society, 2009). Despite these differences in opinion, however, there are clear boundaries set by the wider cultural and scientific history within which all climate engineers operate. Generally, both SRM and CDR technologies are controversial because they simultaneously represent the failure of climate politics *and* hubristic technological dreams. Outright optimism about the potential of either set of technologies is mistrusted. People who are explicitly optimistic about SRM, such as David Keith, or DAC, such as Klaus Lackner, are always controversial. Most climate engineers are sceptical about both SRM and CDR. Even within the most optimistic climate engineering communities, climate engineering is never considered as a substitute for conventional mitigation. Any suggestion that it *could* be an alternative is seen as baseless and dangerous. Especially in the European research community, and the far more sceptical SPP, optimism about climate engineering is rare.

All of the views above are scientifically weighed and will strike some scientists as wholly reasonable. All of them are also disputed and controversial. These storylines matter. Seeing climate engineering as a way of buying some time for developing economies implies that opposition to the prospect is hypocritical. In other fields, some have even called such rejection of technological promise 'racist' (Mann, 2018)—though not yet in the climate engineering debate.[18] Seeing climate engineering as a means of benefitting the rich over the poor, SRM as a fundamental threat to democracy, or climate engineering as a whole as a means to continue business as usual, on the other hand, leads to fundamentally different conclusions. To a large extent, climate engineering research consists of the negotiation between more optimistic and pessimistic—equally scientific—assessments about the feasibility of climate engineering. This negotiation hinges on how to view (aspects of) the climate and on epistemological questions about what types of knowledge are necessary and sufficient. The debate, then, centres on not just what the climate *is*, or what the adopted lens should be, but rather on how the definitions and approaches for a *desired* climate can be determined. Even to most opponents of climate engineering it seems counterproductive to dismiss climate engineering without research. 'The idea is out there', and climate engineering might be implemented 'in a hurry because that is how they do politics'. This means that extensive, pre-emptive climate engineering research is the prudent thing to do. Otherwise, politicians might see 'do [climate engineering], and not care about evidence'. 'Then, at least', people 'should be thankful that the knowledge about what happens if somebody acts' (Researcher H) exists. Capturing carbon may solve the problem, but it presents a host of other concerns. The role of climate engineering, then, becomes the next major question: what does climate engineering have to offer and how/when does it become acceptable to count on it?

Conclusion: ways of seeing climate as a political determinant

Climate change continues to go unchecked. Despite possessing all required knowledge in the scientific community, including innovative (and invasive) technologies, the changing climate is not a pressing concern of people and politicians. Even as people experience more extreme consequences of climate change—glacial melt continues to accelerate, tropical storms hit harder each year—many refuse to believe climate change is a serious threat. Business as usual is more important, and climate change certainly doesn't warrant a comprehensive re-evaluation of our socioeconomic system. Suddenly, however, climate change arrives in full force. What was merely a projection, a representation on the temperature maps of models, what were mere warnings from scientists in their laboratories, suddenly becomes frighteningly real. Within a few years, devastating winters ravage the East Coast of the United States, large swaths of land become uninhabitable across the globe, and whole islands disappear.

Thermohaline currents are slow, and the Gulf Stream slowly comes to a standstill. What the COVID-19 pandemic did in 2020 happens now: governments panic, trying to find the solution to a problem they should have prevented. Suddenly, all options are on the table. As usual, quick technological fixes garner the most attention. Not a vaccine or medicinal drugs like in 2020 but climate engineering technologies of all kinds, condoned and implemented in order to get the global climate back to some semblance of normalcy. If such a bleak vision of the future sounds eerily plausible, it is because its author Kim Stanley Robinson intended it that way. In his signature style of realist science fiction, based on the best available climate science, his *Science in the Capital* trilogy (2004, 2005, 2007) aimed to project a realistic vision for the future. In the books, increasingly dire (local) consequences of climate change are ignored as long as they *just* threaten the lives and livelihoods of the marginalised, poor, and powerless. But as soon as 'storms and extreme weather are so serious that people are really concerned about that and their livelihoods are severely impacted fairly regular basis' (Researcher 11) in the West, any and all forms of technological interventions become political and practical possibilities.

To many climate engineers, this is the nightmare scenario. Most of them do not expect climate engineering to be implemented in a calm and orderly fashion. Both climate knowledge sceptics and climate optimists agree that there are some consequences of climate change that might warrant the implementation of climate engineering technologies. Nor do they really expect the implementation of climate engineering measures to be an exemplar of democratic deliberation. Instead, they expect CE technologies, especially SRM, to become a political reality in a world much like Kim Stanley Robinson's. They view the most likely implementation of SRM as a panicked reaction to climate catastrophes in part because that is 'how they do politics'. But more importantly, most do not have faith in SRM as a viable policy option. To them, it is uncertain, unsafe, and unreliable, because it suggests 'we have such a perfect tangle on the whole system', while in fact 'we do not know the climate sensitivity'.

To recapitulate, most climate engineers understand the climate numerically and often globally. Such an understanding makes it possible to compute and project climate change and, correspondingly, climate engineering. It helps to quantify how the climate might change and what the consequences might be. It facilitates charismatic storylines about clear temperature goals or 'safe' greenhouse gas concentrations—which, in turn, facilitate both SRM and CDR proposals. Within this historically informed discursive approximation of 'the climate', however, many disagree about what the right lens for climate engineering is. Some, typically more techno-optimistic climate engineers, periodically view the climate as a *resource*, which can be optimally distributed both geographically and into the future. Often, such a view ties into a perspective of the climate as a *global* system with global distributions. Others prefer a more regional and cultural understanding of what the climate means and how it intersects with human societies. In this view, regional specificities are far more important. Most climate engineers mediate between such positions, negotiating the extent to which climate can be known and predicted. The more optimistic climate engineers are about the possibility of knowing, understanding, and predicting climate behaviour, the more amenable they are to the idea of climate engineering as a part of climate policy. Technical concerns about the development of both carbon capture technologies and enhancing the Earth's reflectivity almost inevitably tie into concerns about how to understand the climate system. The way climate engineers see climate—as a cultural phenomenon, as a possible topic of research, as an (un) knowable object of scientific study—co-determines their assessments of the feasibility of climate engineering technologies. Seeing the climate globally, as an 'ontologically unitary whole', facilitates optimism about the knowability of the climate. This, in turn, facilitates optimism about the technical feasibility of both SRM and CDR—in part because it obscures local uncertainties and inequities. For some, it even means it is possible to think about climate engineering as a design and control problem. A global view suggests that, if climate engineering were to be implemented in a reasonable (or even optimal) way, the effects *could* be controlled. Unsurprisingly, such techno-optimist views on the technical feasibility climate modifications tie into particular conceptions of the political feasibility of climate engineering. As I show in Chapter 5, techno-optimism about the climate often extends to optimism about a reasonable or even optimal implementation of climate engineering measures. Likewise, scepticism about the technical feasibility of climate engineering often corresponds to view of its politics as similarly complex. Ways of seeing the climate, then, tie into complex visions of politics and morality—both of which are crucial to the way climate engineering can be imagined.

Notes

1 This weather was, in fact, 'unseasonably cold' only on the East Coast of the United States. Even within the borders of the United States, there were large differences. For instance, at the time of Inhofe's performance, the West Coast was unseasonably warm.

2 Projections show that 'unseasonably' cold and volatile winters on the American East Coast may in fact become *more* frequent rather than less due to changes in air circulation resulting from climate change (Singh *et al.*, 2016).

3 As Mike Hulme says, 'like any interesting word, "climate" defies easy definition' (Hulme, 2017, p. xvii). The 'climate' is a description of physical phenomenon that is invented by the human mind—a discursive approximation of an abstract set of phenomena.

4 For examples of different views, see Ban-Weiss and Caldeira (2010), Govindasamy and Caldeira (2000), Hulme (2014), Keith (2013), Kravitz *et al.*, (2016), and MacCracken (2006).

5 ppm stands for 'parts per million' and describes the relative concentrations of gases in a wider atmosphere. At the time, notably, atmospheric CO_2 had already reached 384 ppm. In 2016 (or 2015, depending on which observational station

and time of year you pick), CO_2 levels passed 400 ppm (Jones, 2017; Thompson and Kahn, 2015).

6 Of course, this is specific to the *current* generation of climate modification research. As I have shown in Chapter 2, early weather and climate modification research did not need such a justification. Lowell Wood and Edward Teller, who brought earlier conceptions of climate modification into the contemporary climate debate, for example, were never fully convinced about climate change. They certainly did not agree with the suggestion that greenhouse gas mitigation would be the desired solution to the problem (Teller, Hyde and Wood, 2002; Teller, Wood and Hyde, 1997).

7 Modellers themselves are intimately aware of these drawbacks, stressing them incessantly. It is when models make their way into public debate that these inherent uncertainties in model projections are often lost.

8 Some climate engineering researchers are not even necessarily interested in the question of reliability. Presenting themselves as 'basic scientists', they are more interested in learning about the climate's behaviour than in making a value judgement about the technical feasibility of climate engineering.

9 Unfortunately, many people who deny climate change also refer to themselves as climate sceptics. Their argumentation and opinions, however, often have nothing to do scientific scepticism, rather with organised climate change denial. I propose to claim the title climate (knowledge) sceptic for those who are *sceptical*, those who sincerely doubt about and reflect on (the limits of) climate knowledge.

10 The idea of termination shock is that if SRM were ever abruptly stopped while carbon dioxide levels are still high, the atmospheric warming that would normally be expected without SRM would come in a very short time span, likely with catastrophic consequences (Jones *et al.*, 2013).

11 Earth systems science and oceanology as academic disciplines are deeply influenced by the complex systems thinking of ecology—and thus also deeply influenced by ideas of inherent non-predictability and mathematical chaos. Social scientists, by and large, are also trained to question epistemology and eye scientific knowledge somewhat more sceptically.

12 Ecomodernism is an environmental movement started by Ted Nordhaus and Michael Schellenberger, which argues for efficient technological progress as the best way to reduce environmental damages. This movement also tends to hold capitalist, liberal, and somewhat technocratic beliefs. For their manifesto (which David Keith has co-signed), see Asafu-Adjaye *et al.* (2015).

13 Such costs can never fully be quantified, but they will certainly include serious economic damages as well as droughts, flood, and general human and non-human suffering.

14 To such an extent that I have, outside of the core climate engineering research communities, attended lectures by biologists who suggested genetically engineering plants so they either (a) would capture more carbon dioxide (which typically means they are darker, and therefore less reflective) or (b) are more reflective (having less leaves of a brighter colour, ideally deliberately angled and distributed to face the most sun). Considering the trade-offs between these two options then becomes, again, a control problem.

15 Importantly, this argument gives no leeway for so-called developed countries to slow their rate of mitigation. If anything, giving developing countries time to develop their economies to post-industrial standards means more rapid and thorough deep decarbonisation for developed countries. To my knowledge, Keith has not systematically thought through this argument yet, and as such it is unclear what countries would be considered developing or developed, nor how this should be practically be implemented. More on the politics of climate engineering will follow in Chapter 5.

16 In which too much carbon dioxide is emitted in the short term, to be compensated by negative emissions later in the century.

17 More on this in Chapter 5.

18 Inversely, climate engineering technologies have been called colonial and imperial (Baskin, 2019) or the 'ultimate expression of all the destructive tendencies of patriarchy' (Shiva, 2013) and as having gender issues (Bronson, no date).

References

Anderson, K. and Jewell, J. (2019) 'Debating the Bedrock of Climate-change Mitigation Scenarios', *Nature*, 573(7774), pp. 348–349. doi: 10.1038/d41586-019-02744-9.

Anderson, K. and Peters, G. (2016) 'The Trouble with Negative Emissions', *Science*, 354(6309), pp. 182–183. doi: 10.1126/science.aah4567.

Arino, Y. *et al.* (2016) 'Estimating Option Values of Solar Radiation Management Assuming That Climate Sensitivity Is Uncertain', *Proceedings of the National Academy of Sciences*, 113(21), pp. 5886–5891. doi: 10.1073/pnas.1520795113.

Asafu-Adjaye, J., Blomqvist, L., Brand, S., *et al.* (2015). *An Ecomodernist Manifesto.*

Ashley, R. K. (1983) 'The Eye of Power: The Politics of World Modeling', *International Organization*, 37(3), pp. 495–535. doi: 10.1017/S0020818300032768.

Bäckstrand, K. and Lövbrand, E. (2019) 'The Road to Paris: Contending Climate Governance Discourses in the Post-Copenhagen Era', *Journal of Environmental Policy & Planning*, 21(5), pp. 519–532. doi: 10.1080/1523908X.2016.1150777.

Ban-Weiss, G. A. and Caldeira, K. (2010) 'Geoengineering as an Optimization Problem', *Environmental Research Letters*, 5(3), p. 034009. doi: 10.1088/1748–9326/5/3/034009.

Baskin, J. (2019) *Geoengineering, the Anthropocene and the End of Nature*. Cham, Switzerland: Springer International Publishing. doi: 10.1007/978-3-030–17359-3.

Beck, S. and Mahony, M. (2018a) 'The IPCC and the New Map of Science and Politics', *Wiley Interdisciplinary Reviews: Climate Change*, 9(6), p. e547. doi: 10.1002/wcc.547.

Beck, S. and Mahony, M. (2018b) 'The Politics of Anticipation: The IPCC and the Negative Emissions Technologies Experience', *Global Sustainability*, 1, p. e8. doi: 10.1017/sus.2018.7.

Bronson, D. (no date) *Geoengineering: A Gender Issue?*, *Isis International*. Available at: http://www.isiswomen.org/index.php?option=com_content&view=article&id=1389:geoengineering-a-gender-issue&catid=162&Itemid=452 (Accessed: 24 August 2020).

Brouwer, R. *et al.* (2007) 'Socioeconomic Vulnerability and Adaptation to Environmental Risk: A Case Study of Climate Change and Flooding in Bangladesh', *Risk Analysis*, 27(2), pp. 313–326. doi: 10.1111/j.1539–6924.2007.00884.x.

Edwards, P. N. (1996) 'Global Comprehensive Models in Politics and Policymaking: Editorial Essay', *Climatic Change*, 32(2), pp. 149–161. doi: 10.1007/BF00143706.

Edwards, P. N. (2010) *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press.

Frederiksen, M. (2020) '4 Ways Climate Change Is Opening the Arctic Up for Business', *World Economic Forum*, 27 September. Available at: https://www.weforum.org/agenda/2019/09/4-ways-climate-change-is-opening-the-arctic-up-to-business/ (Accessed: 4 August 2020).

Fuss, S. *et al.* (2014) 'Betting on Negative Emissions', *Nature Climate Change*, 4(10), pp. 850–853. doi: 10.1038/nclimate2392.

Gasser, T. *et al.* (2015) 'Negative Emissions Physically Needed to Keep Global Warming below 2°C', *Nature Communications*, 6(1), p. 7958. doi: 10.1038/ncomms8958.

Geden, O. (2016) 'The Paris Agreement and the Inherent Inconsistency of Climate Policymaking', *Wiley Interdisciplinary Reviews: Climate Change*, 7(6), pp. 790–797. doi: 10.1002/wcc.427.

Geden, O. and Schenuit, F. (2020) 'Unconventional Mitigation: Carbon Dioxide Removal as a New Approach in EU Climate Policy', *SWP Research Paper*. German Institute for International and Security Affairs. doi: 10.18449/2020RP08.

Glacken, C. J. (1996) *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century*. 7. [pr.]. Berkeley: University of California Press.

Govindasamy, B. and Caldeira, K. (2000) 'Geoengineering Earth's Radiation Balance to Mitigate CO_2-induced Climate Change', *Geophysical Research Letters*, 27(14), pp. 2141–2144. doi: 10.1029/1999GL006086.

Hajer, M. A. (1997) *The Politics of Environmental Discourse*. Oxford University Press. doi: 10.1093/019829333X.001.0001.

Hansen, J. *et al.* (2008) 'Target Atmospheric CO: Where Should Humanity Aim?', *The Open Atmospheric Science Journal*, 2(1), pp. 217–231. doi: 10.2174/1874282300802010217.

Hansson, A. (2014) 'Ambivalence in Calculating the Future: The Case of Re-engineering the World', *Journal of Integrative Environmental Sciences*, 11(2), pp. 125–142. doi: 10.1080/1943815X.2014.921629.

Hulme, M. (2009) *Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge, UK; New York, NY: Cambridge University Press.

Hulme, M. (2014) *Can Science Fix Climate Change? A Case against Climate Engineering*. Cambridge, UK: Polity Press (New Human Frontiers Series).

Hulme, M. (2017) *Weathered: Cultures of Climate*. London, UK: SAGE Publications Ltd.

Huttunen, S. and Hildén, M. (2014) 'Framing the Controversial: Geoengineering in Academic Literature', *Science Communication*, 36(1), pp. 3–29. doi: 10.1177/1075547013492435.

Im, E. S., Pal, J. S. and Eltahir, E. A. B. (2017) 'Deadly Heat Waves Projected in the Densely Populated Agricultural Regions of South Asia', *Science Advances*, 3(8), p. e1603322. doi: 10.1126/sciadv.1603322.

Inhofe, J. M. (2012) *The Greatest Hoax: How the Global Warming Conspiracy Threatens Your Future*. First edition. Washington, DC: WND Books.

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. y* [Masson-Delmotte, V., P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

Irvine, P. J., Sriver, R. L. and Keller, K. (2012) 'Tension between Reducing Sea-level Rise and Global Warming through Solar-radiation Management', *Nature Climate Change*, 2(2), pp. 97–100. doi: 10.1038/nclimate1351.

Jasanoff, S. (2001) 'Image and Imagination: The Formation of Global Environmental Consciousness', in Edwards, P. N. and Miller, C. C. (eds) *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press, pp. 309–337.

Jones, A. *et al.* (2013) 'The Impact of Abrupt Suspension of Solar Radiation Management (Termination Effect) in Experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP): The Termination Effect in GeoMIP G2', *Journal of Geophysical Research: Atmospheres*, 118(17), pp. 9743–9752. doi: 10.1002/jgrd.50762.

Jones, N. (2017) *How the World Passed a Carbon Threshold and Why It Matters*, *Yale Environment 360*. Available at: https://e360.yale.edu/features/how-the-world-passed-a-carbon-threshold-400ppm-and-why-it-matters (Accessed: 4 August 2020).

Kang, S. and Eltahir, E. A. B. (2018) 'North China Plain Threatened by Deadly Heatwaves Due to Climate Change and Irrigation', *Nature Communications*, 9(1), p. 2894. doi: 10.1038/s41467-018-05252-y.

Keith, D. W. (2013) *A Case for Climate Engineering*. Cambridge, MA: The MIT Press (Boston Review Books).

Keith, D. W. and Irvine, P. J. (2016) 'Solar Geoengineering Could Substantially Reduce Climate Risks-A Research Hypothesis for the Next Decade: Solar Geoengineering Could Reduce Risk', *Earth's Future*, 4(11), pp. 549–559. doi: 10.1002/2016EF000465.

Keith, D. W. and MacMartin, D. G. (2015) 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering', *Nature Climate Change*, 5(3), pp. 201–206. doi: 10.1038/nclimate2493.

Keller, D. P. *et al.* (2018) 'The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP): Rationale and Experimental Protocol for CMIP6', *Geoscientific Model Development*, 11(3), pp. 1133–1160. doi: 10.5194/gmd-11–1133–2018.

Knutti, R. *et al.* (2016) 'A Scientific Critique of the Two-degree Climate Change Target', *Nature Geoscience*, 9(1), pp. 13–18. doi: 10.1038/ngeo2595.

Kravitz, B. *et al.* (2016) 'Geoengineering as a Design Problem', *Earth System Dynamics*, 7(2), pp. 469–497. doi: 10.5194/esd-7–469–2016.

Lackner, K. S. *et al.* (2012) 'The Urgency of the Development of CO_2 Capture from Ambient Air', *Proceedings of the National Academy of Sciences*, 109(33), pp. 13156–13162. doi: 10.1073/pnas.1108765109.

Lackner, K. S. (2016) 'The Promise of Negative Emissions', *Science*, 354(6313), p. 714.1–714. doi: 10.1126/science.aal2432.

Lawrence, M. G. *et al.* (2018) 'Evaluating Climate Geoengineering Proposals in the Context of the Paris Agreement Temperature Goals', *Nature Communications*, 9(1), p. 3734. doi: 10.1038/s41467-018-05938-3.

Lovelock, J. (2008) 'A Geophysiologist's Thoughts on Geoengineering', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 366(1882), pp. 3883–3890. doi: 10.1098/rsta.2008.0135.

MacCracken, M. C. (2006) 'Geoengineering: Worthy of Cautious Evaluation?: An Editorial Comment', *Climatic Change*, 77(3–4), pp. 235–243. doi: 10.1007/s10584-006-9130–6.

MacMartin, D. G. *et al.* (2013) 'Management of Trade-offs in Geoengineering through Optimal Choice of Non-uniform Radiative Forcing', *Nature Climate Change*, 3(4), pp. 365–368. doi: 10.1038/nclimate1722.

MacMartin, D. G., Kravitz, B. and Keith, D. W. (2014) 'Geoengineering: The World's Largest Control Problem', in *2014 American Control Conference. 2014 American Control Conference—ACC 2014*, Portland, OR, USA: IEEE, pp. 2401–2406. doi: 10.1109/ACC.2014.6858658.

Mann, C. C. (2018) *The Wizard and the Prophet: Two Remarkable Scientists and Their Dueling Visions to Shape Tomorrow's World*. First edition. New York, NY: Alfred A. Knopf.

McLaren, D. P. (2018) 'Whose Climate and Whose Ethics? Conceptions of Justice in Solar Geoengineering Modelling', *Energy Research & Social Science*, 44, pp. 209–221. doi: 10.1016/j.erss.2018.05.021.

Mcleod, E. *et al.* (2019) 'Lessons from the Pacific Islands – Adapting to Climate Change by Supporting Social and Ecological Resilience', *Frontiers in Marine Science*, 6, p. 289. doi: 10.3389/fmars.2019.00289.

Miller, C. C. (2004) 'Climate Science and the Making of a Global Political Order', in Jasanoff, S. (ed) *States of Knowledge: The Co-Production of Science and the Social Order*. 1st edn. Routledge, pp. 46–66. doi: 10.4324/9780203413845.

Miller, L. M. and Keith, D. W. (2018) 'Observation-based Solar and Wind Power Capacity Factors and Power Densities', *Environmental Research Letters*, 13(10), p. 104008. doi: 10.1088/1748–9326/aae102.

Morton, T. (2013) *Hyperobjects: Philosophy and Ecology After the End of the World*. Minneapolis: University of Minnesota Press (Posthumanities, 27).

Nerlich, B. and Jaspal, R. (2012) 'Metaphors We Die By? Geoengineering, Metaphors, and the Argument from Catastrophe', *Metaphor and Symbol*, 27(2), pp. 131–147. doi: 10.1080/10926488.2012.665795.

Oomen, J. (2019) 'Anthropocenic Limitations to Climate Engineering', *Humanities*, 8(4), p. 186. doi: 10.3390/h8040186.

Pal, J. S. and Eltahir, E. A. B. (2016) 'Future Temperature in Southwest Asia Projected to Exceed a Threshold for Human Adaptability', *Nature Climate Change*, 6(2), pp. 197–200. doi: 10.1038/nclimate2833.

Pielke Jr., R. (2018) 'Opening Up the Climate Policy Envelope', *Issues in Science and Technology*, 34(4), (Summer 2018).

Rheinberger, H. J. (1997) *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube*. Stanford, CA: Stanford University Press (Writing Science).

Ricke, K. L., Morgan, M. G. and Allen, M. R. (2010) 'Regional Climate Response to Solar-radiation Management', *Nature Geoscience*, 3(8), pp. 537–541. doi: 10.1038/ngeo915.

Robinson, K. S. (2004) *Forty Signs of Rain*. London, UK: HarperCollins.

Robinson, K. S. (2005) *Fifty Degrees Below*. New York, NY: Bantam Books.

Robinson, K. S. (2007) *Sixty Days and Counting*. New York, NY: Bantam Books.

Robock, A., Jerch, K. and Bunzl, M. (2008) '20 Reasons Why Geoengineering May be a Bad Idea', *Bulletin of the Atomic Scientists*, 64(2), pp. 14–59. doi: 10.1080/00963402.2008.11461140.

Royal Society (2009) *Geoengineering the Climate: Science, Governance and Uncertainty*. London, UK: Royal Society.

Shackley, S. (2001) 'Epistemic Lifestyles in Climate Change Modeling', in Edwards, P. N. and Miller, C. C. (eds) *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press, pp. 110–133.

Shiva, V. (2013) 'Terra Futura 2013: Interview with Vandana Shiva about Geoengineering'. Available at: https://www.nogeoingegneria.com/interviste/terra-futura-2013-interview-with-vandana-shiva-about-geoengineering/ (Accessed: 24 August 2020).

Singh, D. *et al.* (2016) 'Recent Amplification of the North American Winter Temperature Dipole', *Journal of Geophysical Research: Atmospheres*, 121(17), pp. 9911–9928. doi: 10.1002/2016JD025116.

Sonntag, S. *et al.* (2018) 'Quantifying and Comparing Effects of Climate Engineering Methods on the Earth System', *Earth's Future*, 6(2), pp. 149–168. doi: 10.1002/2017EF000620.

Stilgoe, J. (2015) *Experiment Earth: Responsible Innovation in Geoengineering*. London, UK; New York, NY : Routledge, Taylor & Francis Group.

Szerszynski, B. *et al.* (2013) 'Why Solar Radiation Management Geoengineering and Democracy Won't Mix', *Environment and Planning A: Economy and Space*, 45(12), pp. 2809–2816. doi: 10.1068/a45649.

Teller, E., Hyde, R. and Wood, L. (2002) 'Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change', in. *National Academy of Engineering Symposium*, Washington, DC.

Teller, E., Wood, L. and Hyde, R. (1997) 'Global Warming and Ice Ages: I. Prospects for Physics-Based Modulation of Global Change', in. *22nd International Seminar on Planetary Energetics*, Sicily, Italy.

Thompson, A. and Kahn, B. (2015) *What Passing a Key CO_2 Mark Means to Climate Scientists*, *ClimateCentral.org*. Available at: http://www.climatecentral.org/news/co2-400-ppm-scientists-meaning-19713 (Accessed: 4 August 2020).

Thompson, M. (1984) 'Among the Energy Tribes: A Cultural Framework for the Analysis and Design of Energy Policy', *Policy Sciences*, 17(3), pp. 321–339. doi: 10.1007/BF00138710.

van Vuuren, D. P. *et al.* (2011) 'The Representative Concentration Pathways: An Overview', *Climatic Change*, 109(1–2), pp. 5–31. doi: 10.1007/s10584-011-0148-z.

Wagner, G. and Weitzman, M. L. (2015) *Climate Shock: The Economic Consequences of a Hotter Planet*. Princeton, NY: Princeton University Press.