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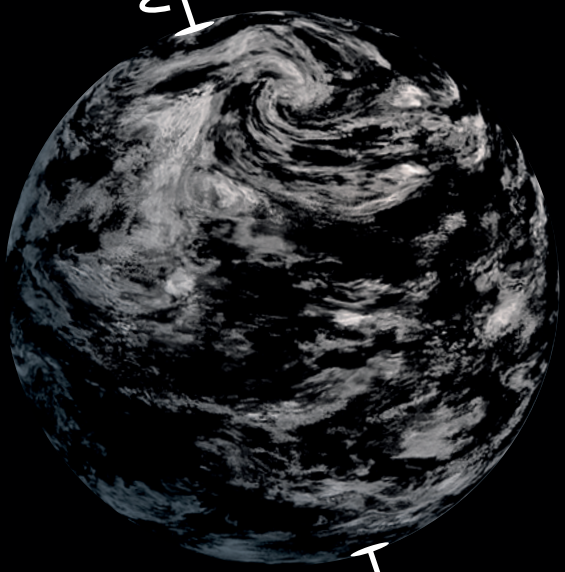
Engineering the Climate



Science, Politics, and Visions of Control

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INTRODUCTION

IN NOVEMBER 2018, *NATURE* FEATURED SOME SENSATIONAL NEWS: 'FIRST sun-dimming experiment will test a way to cool Earth'. The article talks about a project called *Stratospheric Controlled Perturbation Experiment* – ScoPEx, for short – a scientific experiment in development at Harvard University. Underneath the headline, the story is illustrated by a photograph. The picture invites us into a Harvard lab to meet ScoPEX's creators. Our view of the team of researchers is partially obstructed by cables and machinery, literally framing the scientists with techno-scientific hardware. The story begins:

> Zhen Dai holds up a small glass tube coated with a white powder: calcium carbonate, a ubiquitous compound used in everything from paper and cement to toothpaste and cake mixes. … The question … is whether this innocuous substance could also help humanity to relieve the ultimate case of indigestion: global warming caused by greenhouse-gas pollution. The idea is simple: spray a bunch of particles into the stratosphere, and they will cool the planet by reflecting some of the Sun's rays back into space.[1]

The article introduces us to 'a broader class of planet-cooling schemes … that have long generated intense debate and, in some cases, fear': so-called *climate engineering* or *geoengineering* measures.[2] The text quickly pushes us down the rabbit hole that lingers beneath this controversial set of labels. On the one hand, the article is about a balloon that would squirt out a substance, usually found in 'everything from paper […] to cake mixes'. It describes a harmless scientific experiment, exploring an 'innocuous' chemical substance. On the other hand, the text suggests quite the grand mission. It promises the first 'sun-dimming

experiment', testing nothing less than a way 'to cool Earth'. It talks about a 'thermostat' to counteract dangerous global warming. It discusses a new remedy against global warming, offering some much-needed relief for the future of humanity by tackling one of the most pressing challenges of our time.

This *Nature* feature thus confronts us with two somewhat conflicting faces of climate engineering – one light-hearted, one grave. These two faces of climate engineering are further illustrated by the self-descriptions of the researchers, as featured later in the article. Dai, on the one hand, is quoted as 'not stress[ing]' about the critique of this research: 'I'm studying a chemical substance [...] It's not like it's a nuclear bomb'. Frank Keutsch, in contrast, is described as 'a reluctant geoengineer'. He engages with climate engineering research as 'he worries about where humanity is heading, and what that means for his children's future'.

If we dig a bit deeper into the world of climate engineering, the picture only gets more complicated. Almost a decade prior to the publication of the *Nature* piece, in October 2010, the public was similarly prepared for 'the first field test of a geoengineering technology' – this time in the UK.[3] Back then, it was the *Stratospheric Particle Injection for Climate Engineering* project – SPICE, for short – which had sought to 'move solar geoengineering out of the lab'.[4] The project proposed a small field study to test the technical feasibility of a balloon deployment system which was initially scheduled for 2012 in Norfolk, England. In this case, too, two seemingly contradictory perspectives clash in an effort to make sense of the planned experiment: In one version, SPICE would have been the first climate engineering outdoor experiment; in another, it would have entailed pumping 'some water – no more than it would take to fill a child's paddling pool' through a kilometre-long hose and produce a cloud of fine mist.[5] Due to public protest and internal issues, the experiment eventually had to be cancelled.

Another two years earlier, in 2008, meteorologist Yuri Izrael and colleagues conducted a climate engineering experiment just outside Moscow. The scientists installed generators aboard helicopters to spray sulphuric aerosol into the troposphere. The team then measured 'basic meteorological variables in the surface atmosphere (stratification, temperature, air humidity, and wind

speed) and microphysical and optical characteristics of aerosol particles'. Izrael and his team concluded that they had 'shown how it is principally possible to control solar radiation passing through artificially created aerosol formations in the atmosphere with different optical thickness'.[6] The scientists published their findings in two papers. While the publication that reported the first part of the experiment did not connect the project explicitly to solar geoengineering, the one that reported the second part of the experiments did do so.[7]

Now, if we continue our search a bit further, the picture gets even more complicated. Not only do we find that there have been a bunch of field studies, experiments, and demonstration facilities that are directly relevant to climate engineering research – some of which date all the way back to the 1990s. But we find that there is, in fact for years now, a variety of research projects being conducted on the potential to deliberately intervene in and control the Earth's climate. These projects range from modelling studies and computer simulations to social scientific, economic, and ethical research. Part of this research attracted little in the way of controversy as it was simply conducted under different labels; it was not called climate engineering. And part of this research was deemed unproblematic as it was theoretical and conducted 'inside'.[8] Phil Willis, Chairman of the UK Science Committee illustrated this latter point in 2009 when he stated that the British government 'wholeheartedly supports' any 'research that uses computers to model the impact of geoengineering technologies'. That research, with '*a real impact on the wider climate',* however, should be subjected to international regulation.[9] This implicit heuristic of climate engineering research raises the question of exactly what ontological line is crossed between lab and field, between 'indoor' and 'outdoor'? How is 'curiosity-driven indoor research' unproblematic, irrespective of its particular intent or purpose, and yet, 'outdoor research' is deemed 'unethical' without the necessary regulation?[10] Where does climate engineering move from theory to 'real world'? How can one even conceive of the 'real impact' of research?

These questions and examples begin to show just how difficult it is to precisely grasp what climate engineering *is*. The current status of climate engineering, particularly as it is portrayed to the public, seems to oscillate between two

extremes. On the one hand, climate engineering is presented as 'just' research: it is not really existent yet, and therefore seems harmless. On the other hand, it is envisioned in its future reality as a 'global thermostat', a serious and almost miraculous tool, bringing about grave societal consequences and therefore raising fundamental normative questions.[11]

These two extremes seem to neatly separate the science of climate engineering from its politics, giving each its own place in time: *today*, climate engineering extends to nothing more than harmless science, but *in the future,* it will fundamentally change the politics of climate change. Narratives that use these extremes separate science and politics, only to connect the two in a linear fashion: scientific research supposedly creates the base for political decisions that might then be taken at some point in the future. The director of a national research laboratory in the United States which was recently awarded federal funds to explore the merit of climate engineering told the *Scientific American*, 'one of the things I'm interested in doing is let's separate the science out'. The director engages here in what Stephen Hilgartner (referring to Bruno Latour) has described as a key role of science advice. That is, he seems to be seeking to 'purify' the issue of climate engineering from its political components.[12] Following this line of reasoning, the director emphasised that the support for this research should not be mistaken with policy-level approval of such measures. According to the magazine, the goal is rather 'to give policymakers a clear view of how a hurry-up bid to save the planet would work'.[13]

Typically, the questions that dominate public debate around climate engineering, therefore, go something like this: will it actually be possible? What is the research that we will need to be able to answer this question? How could we 'test' this technology without actually deploying it? Would such a thermostat be ethical? Who would control this thermostat? Which regulatory frameworks are in place to govern it and with which consequences?

With this book, I want to suggest a change in perspective. While questions like these are obviously important, they run the risk of steering attention away from what is at stake, which is the very essence of the proposed technology. To use the often-invoked metaphor of the global thermostat, what is at stake here is not merely the shape and form, but the very existence, the making and

assembling, of this thermostat. Instead of debating the implications and consequences of this techno-political project, this book unpacks its genesis and seeks to understand how we got here in the first place. This book traces how we got to make sense of and problematise climate change in this particular manner; it unpacks how this vision to engineer the climate has and continues to unfold its saliency and meaning.[14]

Climate engineering is not a sun shield, ready to be wielded by politicians. Most of the approaches being discussed do not exist as ready-to-be-deployed or even ready-to-be-tested tools, as technologies merely awaiting the push of a button. Notions such as 'global thermostats' or 'sun dimming experiments' are problematic in this sense and have been rightfully criticised in recent years. Yet, the alternative suggestion – that climate engineering is 'just research' – equally misses the point.

Since at least 2009, climate engineering has incrementally arrived on political agendas at local, national, and transnational levels.[15] State and non-state actors around the globe have begun to consider such measures in various ways. Private investors and energy companies, too, have pushed the development of approaches to effectively remove carbon dioxide from the atmosphere and are seeking ways to commercialise such technologies. In a widely-publicised move, Elon Musk, for example, announced 'the largest incentive prize in history' in January 2021 – the XPRIZE Carbon Removal initiative. With this initiative, Musk is promising $100 million for whomever can come up with 'real systems' that are able to permanently remove CO_2 from the atmosphere. XPRIZE describes its efforts as seeking to 'tackl[e] the biggest threat facing humanity – fighting climate change […]'.[16]

Aside from efforts to commercialise and develop climate engineering technologies, we can observe how these approaches are beginning to become institutionalised as standard means to counteract global warming at the international level. Since 2018, the United States, for example, initiated efforts to integrate 'climate coolants' into the International Standardization Organization (ISO) as a way to offset greenhouse gas emissions. This was a highly controversial effort to normalise solar climate engineering measures in order to mitigate global warming. In addition, the United Nation's Intergovernmental Panel on Climate

Change (IPCC) increasingly incorporates climate engineering approaches into its climate change scenarios.[17]

Finally, and maybe most significantly, governments around the world have begun to establish research and development programs for a number of years now. The United Kingdom, the United States, and Germany have been most active in this context with government authorities conducting official inquiries into the issue of climate engineering since around 2009. As we will see in more detail in Chapter 2, the United States initiated its official exploration of the controversial topic in 2009 together with the UK, and shared witnesses and insights about their respective assessments. Germany followed suit when representatives brought the issue up during parliamentary debates in 2011 and 2012. Since then, climate engineering has spread into policy agendas around the globe.

In 2013, the Russian government attracted controversial media attention when leaked documents suggested that it had urged the IPCC to include the controversial measures into the organisation's much-anticipated fifth assessment report on the status of climate change science and expertise. Since 2015, both the Indian and the Chinese government have developed climate engineering programs. Examining both the physical mechanisms and the governance implications of these measures, the Chinese Ministry of Science and Technology initiated what has been characterised as one of the world's largest state-funded climate engineering research programs at Beijing Normal University. And in March 2020, Australia conducted a cloud-brightening experiment off Queensland to test if ocean cooling mechanisms could serve to save the Great Barrier Reef.[18]

In the face of these developments, the question is how might we gain a better and more meaningful understanding of climate engineering, one that goes beyond false dichotomies of science versus politics, theory versus real world, indoor versus outdoor research, and the choicelessness of prescribed futures? As the examples introduced so far begin to show, climate engineering is being developed across a large geographical scale, although not necessarily in oceans and atmospheres (yet), but rather in geographically distant spaces of political decision making. The often-invoked binaries precisely seem to miss this point.

It is not only 'outdoor experiments' that are able to '*change the world*'.[19] Beyond 'just research', beyond particle flows, beyond the mere 'dispersion of material in the environment',[20] climate engineering is gaining political traction and has concrete political impacts. It is beginning to take concrete shape; it is being assembled and installed, fine-tuned and mounted as a potential policy measure, and as a controversial tool for counteracting anthropogenic climate change.

To properly grasp and engage with this reality of climate engineering, we need to understand how it came to be. In other words, to decide if and how to move forward, we need to understand how we got here. Instead of essentialising climate engineering as either 'just research' or a miraculous tool, we need to take a look back. We need to understand how climate engineering became what it is today, how it became assembled in its current form, how it became established as a potential policy tool, and how it became a controversial response measure to the issue of global warming. This book seeks to contribute to current debates over climate engineering by unpacking its genesis. It is about the 'career' of climate engineering in the United States, from curious scientific idea to serious politics.

RE-CONTEXTUALISING THE RISE OF CLIMATE ENGINEERING: THE ARGUMENT IN A NUTSHELL

The current debate over climate engineering generally concerns two broader sets of technological concepts. On the one hand, so-called carbon dioxide removal (CDR) approaches seek to counteract climate change by sucking CO_2 from the atmosphere. On the other, so-called solar radiation management (SRM) measures aim to counteract climate change by reflecting incoming sunlight back to space.[21] We will come back to the technical intricacies and definitional struggles over these approaches in Chapter 2. Exactly how these efforts are categorised and labelled are precisely part of the story of this book. For now, I simply want to emphasise that the umbrella terms of climate- or geoengineering bundle together a wide variety of research contexts in their differently articulated promise to fundamentally alter the politics of climate change. These labels are not primarily 'scientific'; they do not match disciplinary boundaries or follow methodological approaches. In fact, they have been criticised in this respect on

many fronts.[22] Instead, these labels become meaningful and are subject to heated debate as they bind various lines of scientific inquiry to the societal challenge of tackling climate change. The definitional struggles over what climate engineering is, can, or should be, calibrate this relation of scientific inquiry and political intervention, with each emphasising different sides or aspects of this charged relation. Umbrella terms such as climate engineering or geoengineering might not make a lot of sense from a technical point of view, but their controversial status precisely shows what is at stake here. These definitional struggles hint to a relationship between science and politics that is much more complex than what idealist models of advisor and decision-maker would suggest. In the emerging debate over climate engineering, science does not merely figure as a neutral evidence base for politics; it does not simply prepare a difficult political decision with positive facts. Instead, science and politics are coupled 'upstream'. That is, they are linked in the very formulation of climate engineering as a potential measure to counteract climate change.

So, returning to my point from before, the important question then becomes, how did we get here? How did climate engineering earn a spot in climate policy agendas despite enormous scientific complexities and fierce political contestation? And, more generally, what can we learn from this case about the relationship between science and politics in modern society?

This book explains the conflicted status of climate engineering today with historically grown alliances between climate science and politics. It describes the emergence of climate engineering as a story of the political cultivation of climate science for the state. Over the course of the following chapters, I will unpack the historical genesis and 'career' of climate engineering as a controversial policy tool along two dimensions. On the one hand, we will see that the career of climate engineering evolves along historically particular settings of problematising and making sense of climatic change. It corresponds, in other words, to the contingent history of climatic change as a societal problem. On the other hand, we will see how these historically particular settings of problematising climatic change directly relate to shifting alliances between climate science and the state. That means that the career of climate engineering unfolds along respectively changing roles of climate expertise within the state.

This perspective thus re-contextualises the history of climate engineering within the bigger history of political efforts to cultivate climate science for the state. It suggests that what we today discuss as climate engineering has historically served as a continuous, yet shape-shifting node, effectively linking scientific to political agendas. In so doing, this perspective emphasises just how interrelated efforts to understand and efforts to govern, even control, the climate have been.

I approach this account from two angles by connecting insights from historical scholarship with perspectives from science studies and historical sociology. On the one hand, I draw from historical analyses to demonstrate that the recent rise of climate engineering as a controversial last resort measure or 'Plan B' against dangerous climate change is only the latest chapter in a much longer standing career of efforts to intervene in, modify, and even control the Earth's climate. This career bundles the disparate histories of various technological concepts and scientific insights, sprouting in different contexts and times, under different labels, serving different political purposes. On the other hand, I zoom into the recent debate over climate engineering in US politics. I trace how these measures arrived on the US political agenda around 2009 as a potential approach against anthropogenic climate change. By following these debates through the concrete arenas of climate policy making, I seek to unpack how science and politics precisely connect to one another in the making of this controversial policy tool. With this analysis, the book suggests that what is at stake in this debate over climate engineering is just as much a political vision as a scientific project. Looming large in this debate are thus different visions for the role of science in addressing one of the most pressing challenges of our time. Unpacking the historically grown role of science in both defining and tackling this issue is essential for enabling a meaningful debate over what this role should look like in the future. There was, and there will be, no point zero at which decision-makers will take an informed decision on how to proceed. As much as politics might sometimes allude to external urgencies that force our hands, climate engineering was not infused into the political process by the external urgency of dangerous climate change. It arrived here from within: this particular vision of making sense of and responding to climatic change has a historical legacy and system. It is the result of established and cultivated science-politics alliances.

SCIENCE, POLITICS, AND THE CAREER OF CLIMATE ENGINEERING: THE ANALYTICAL FRAMEWORK

In the following, I briefly introduce the central concepts that guide this book's analysis. I explain what I mean by the notion of the 'career' of climate engineering, what this conceptual take implies for the study of scientific expertise in politics, and what data the following analysis rests on.

Dissecting the 'career' of climate engineering

This book unpacks how we got here. It seeks to understand how climate engineering arrived on mainstream climate policy agendas and how it became established as a controversial policy tool against global warming. To do so, the book follows climate engineering on its turbulent journey at the interface of science and politics; it traces, in short, what I call the 'career' of climate engineering.

This notion of the 'career' of climate engineering, first of all, marks a particular choice of perspective. It suggests a distinct methodological approach to climate engineering as the object of this study. Deciding what climate engineering *is,* is far from straightforward as we have seen at the outset of this introduction. Writing a book on its career in this sense means to work with this ambiguity.

This book chooses as its starting point a set of distinct contexts and arenas in which climate engineering has taken concrete shape as a potential policy tool against global warming to then unpack how it came to be assembled precisely as such: what kinds of experts and actors were relevant in devising this policy tool? What kinds of expertise, what kinds of global political and historical contexts, and what kinds of observational devices and policy programs were at play here? This perspective gives climate engineering a life of its own, so to speak. Connecting to Gil Eyal's call, *For a Sociology of Expertise*, retracing this career of climate engineering entails 'a history without a protagonist'[23] in the sense that it is not primarily the story of a group of individuals or experts, but instead one that places the historical emergence and trajectory of these measures as policy tools front and centre. Instead of asking how a certain group of experts managed to push climate engineering into the political limelight, this

book rather asks how the suggestion of climate engineering managed to push a certain group of experts into the political limelight. The idea, in short, is to give this notion of climate engineering a kind of historical agency for itself and to ask how this notion in its current shape and form has gained political traction, how it has bound scientific to political agendas, and how it has made certain people into experts and certain modes of observing the world into expertise.

The theoretical point, then, is not to contrast real and objective issues with socially constructed ones. I do not wish to show that the issue of climate change or the suggested response of climate engineering is 'constructed' at its core, whatever that might mean.[24] Instead, the point is to qualify *how* climate change came to be seen and understood as an issue that would lend itself to deliberate climatological intervention and control. Following a point made by Bentley Allen, the point is to understand how climate change became 'assembled'[25] in the political realm as an issue of techno-scientific intervention and control and how this particular gaze onto the issue has defined shifting alliances between climate science and the state.

This perspective on the career of climate engineering then secondly implies a particular approach to studying the interrelation between science and politics. The analysis in this book connects scholarship on the emergence of societal issues and the making of governance objects with insights from the sociology of expertise, science studies, and science and technology studies (STS).[26] The book traces the career of climate engineering by asking how these measures have historically linked scientific and political agendas. The career of climate engineering thus serves as a prism for the diverse and historically particular alliances between science and politics that have eventually brought forth this controversial response measure. As we will see throughout the following chapters, the dynamic trajectory of this response measure challenges linear conceptualisations of the science-politics nexus and instead emphasises reciprocity. This trajectory is neither shaped primarily by political will – for example, because politicians decide a certain issue or response measure is, or is not, of particular relevance – nor does it strictly follow the scientific 'discovery' of new puzzles and problems. Instead, the approach developed over the course of this book demonstrates that the recent rise of climate engineering has linked science and

politics *reflexively*; it shows how the formulation of both problem and response has emerged from the mutual interdependence of both societal spheres. The shifting historical contexts of assembling climate change as an engineering challenge thus serve to illustrate just how deeply intertwined efforts to understand and efforts to govern the climate have been.

Reflexivity and interdependence, however, should not be mistaken with the dissolution of differences in this context. I do not wish to draw attention to fuzzy boundaries or suggest that science and politics have somehow become the same. By drawing on differentiation-theoretical accounts that have been developed within sociology, my goal is rather to gain a better understanding of how science and politics as two societal spheres interrelate with one another.[27] That means understanding how science and politics latch onto one another in devising this controversial policy tool and how this controversial policy tool matches distinctly scientific to distinctly political struggles. Examining the interdependence of science and politics in this sense importantly contributes to a better understanding of what drives science and politics as distinct spheres of societal communication.

Scientific expertise

Tracing the historical trajectory and career of climate engineering thus requires tracing historically specific modes of problematising climatic change. And this entails looking at distinct groups of people, experts, and institutions as much as looking at particular modes of observing and studying, of knowing and governing climate change. Two concepts therefore guide my analysis of the role of scientific expertise in shaping this career of climate engineering: the concept of the *expert infrastructure* and the concept of *expert modes of observation.*

If we understand science as a system or network of communications, the question of scientific expertise in politics, first and foremost, becomes a relational one: how does scientific expertise become politically relevant? Or, to put it the other way around, where does policy-relevant scientific expertise come from?[28] Who are relevant experts and who decides? The concept of the *expert infrastructure* seeks to capture and build on this relational dimension of scientific

expertise. It seeks to draw our attention to the structures that link scientific expertise to politics, to the institutionalised settings, the advisory panels, the expert organisations, and assessment procedures that effectively bring scientific expertise to bear on politics – whether intended or not. The concept thus seeks to shed light on the empirical diversity of the formal and informal structures, the programs and agencies, and the 'cliques' and networks that have put climate engineering on the political agenda. We may picture a kind of transport infrastructure in this context, an infrastructure that is made up of routes and paths, of bike lanes and motorways, train tracks and shipping routes that each display different modes of transportation yet are all somehow connected.

The concept of *expert modes of observation* marks the epistemological dimension of scientific expertise. This concept understands scientific expertise as a distinctly formalised mode of observing the world, as a particular form of structured observation.[29] It asks empirically for the various ways in which expert observations on engineering the Earth's climate are formalised or structured, and how, in turn, these modes of observation shape the politics of climate engineering. The concept thus seeks to bring into focus questions about the social, historical, and even material preconditions of such expert modes of observing. Speaking with Paul Edwards, we might refer to a 'vast machine' to describe the complex of computers, satellites, measuring devices, theories, models, experiments, threshold values and tipping points that formulated the challenge of governing climate change as a challenge of engineering the Earth's climate.[30]

This reflexive connection of science and politics is illustrated, for example, in the analogous titles given to two accounts on the subject: Jim Fleming's *Fixing the Sky* and Timothy Mitchell's *Fixing the Economy*. Both accounts carve out how different forms of scientific observation – atmospheric and economic – not only provide academic insights, but also transform their respective subjects politically. As a new form of observing, both atmospheric and economic expertise generate new territories of governance and control.[31] Scientific modes of observation in this sense become politically relevant as they make issues politically legible; that is, as they render issues governable and suggest control. Mitchell holds that economics provided 'a new language, in which the nation-state could

speak for itself and imagine its existence as something natural [and] subject to political management'.[32] This formation of economics as a scientific field, in turn, critically depended on the discovery of the economy as a political subject, according to Mitchell. In this sense, the concept of the modes of observations draws attention to the fact that scientific expertise shapes the politics of societal challenges beyond the neat settings of advisory processes or expert commissions. It emphasises the interdependence between observing and addressing societal challenges, such as climate change.

The distinction between expert infrastructure and expert modes of observation thus follows a similar rationale as the distinction between scientific 'expertise' and scientific 'expert', as called for by some authors within the sociology of expertise.[33] It assumes that the relationship between scientific expert and scientific expertise is not unidimensional but runs both ways. It is not only the expert who defines what counts as expertise, but it is also expertise that defines who counts as an expert. Taken together, the two concepts shed light not only on the prominent channels and the hidden byways that bring scientific expertise to bear on politics. They also illustrate the particular distinctions, the methods, theories, or instruments that have cast the challenge of tackling climate change in the terms of scientific intervention and control.

EMPIRICAL APPROACH AND MATERIAL

There are, of course, many ways to approach and study this career of climate engineering as suggested by the theoretical categories and dimensions described above. In this book, I choose a national policy context as the starting of my analysis, namely the policy context of the United States of America. The United States provides a dynamic breeding ground for the exploration of climate engineering as a climate policy tool, and it is therefore an interesting context for studying these measures. For one, climate change remains a partisan issue in the United States. Despite this fact, the United States has played an essential role within global efforts to tackle this issue (for good or ill). And two, the scientific community researching climate engineering is comparatively active here, while the political debate on these measures remains highly contested.

This choice of perspective means that we will begin our inquiry in Part I of this book by asking what the current status of climate engineering is in this particular policy context. In other words, what do 'the politics' of climate engineering look like and what do they amount to? What are the kinds of political decisions that are currently made, the policies that are discussed, the reports that are written up, and the hearings that are being held on climate engineering? What, in other words, is the essence of these emerging politics of climate engineering?

Starting from these kinds of questions, we can then set out to examine throughout the rest of this book how we got here. To do so, this book draws on a variety of empirical material. Most centrally, this includes a corpus of policy documents that spans 30 years, which I will describe in more detail shortly (for an overview of these documents, see Appendix). For the time before the 1990s, I complemented the observations from this document corpus with an analysis of politically commissioned scientific assessments and historical analyses. Furthermore, the book rests on insights from a research stay at the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Boulder, Colorado, as well as participatory observations during three climate engineering conferences and 15 unstructured expert interviews.

The document corpus provides the primary database for my analysis of how climate engineering took shape, and how it unfolded its saliency and meaning, in US climate policy (see Chapters 1, 2, 5, 6). It comprises all federal proceedings, dealing with the issue of climate engineering between 1990 and 2020, as documented in the Federal Digital System (FDsys). FDsys is a public digital archive that preserves official records from the federal government of the United States. It maintains digital access to a vast spectrum of policy documents, from congressional records, appropriations, hearings, to suggested bills, rules, or entries to the Federal Register.[34] With this document corpus, I sought to construct a kind of 'window' onto the US policy process – a window that would allow me to examine the particular arenas in which climate engineering took shape in the US political context over the years and also empirically determine the relevant expert infrastructure and the defining expert modes of observation that defined this process.[35] Let me illustrate what I mean by that.

To begin with, these policy documents bundle the many layers of US federal policy making. This means that they point us not only to the main policy bodies that are exploring and processing climate engineering in some way or another, like the congressional commissions which hold hearings or decide on funds, or the Representatives and Senators who introduce legislation, or the Executive agencies that propose rules. But these documents also track the many different state and non-state actors, the global governance bodies, frameworks, and reports that inform and guide US policy from 'outside' the federal policy process. In her instructive study on *The Politics of Objective Advice*, Ann Keller, for example, illustrates how congressional hearings point to 'scientific findings, shifting analytical uncertainties, emerging regulatory approaches, [...] international negotiations, evolving political positions and arguments' as they all somehow shape legislative politics.[36] Despite choosing a national policy context as the starting point of the analysis, this material also sheds light on the role and relevance of the international and global dimension of climate engineering. The policy documents suggest how the career of climate engineering evolves between the imperatives of national decision-making on the one hand, and the multi-faceted institutions of global climate politics, on the other. We will see how crucial a global understanding of climatic change is to this vision of techno-scientific climate intervention, but also simultaneously how this vision caters to political hopes of national control in the face of this global challenge – how it takes shape, in other words, as a tool for the state.

The emerging politics of climate engineering become visible here as a network of communication. This network comprises all kinds of communicative processes that provide the societal capacity of taking collectively binding decisions, including the individuals or organisations that provide these communications, and the policies, regulations, frameworks, and so on, that stabilise them.[37] The essential role of science in these emerging politics of climate engineering is observed through this lens of the policy-process. It manifests in the experts and modes of observations that effectively shape this policy process.

Furthermore, these policy documents mark the temporality of the career of climate engineering in US policy.[38] Hearings, rules, entries to the federal register, and so forth document policy communications in relation to a particular point

in time. It seems to lie in the very essence of files, and especially the public record, to 'capture' a particular moment. Policy documents thus help us chart the temporal trajectory of this career of climate engineering all the while mapping the many actors and organisations that have stabilised this particular trajectory.

And finally, these documents comprise official and public communication. Congressional hearings, for example, are directed at the general public, a particular committee, an agency, Congress, or the White House. They are held and documented 'to communicate something publicly'. What we see through this window is a 'purposive arena' of political communication.[39] It allows no glance behind closed doors; it does not enable peeking into the minds of policymakers, but it documents how climate engineering has been established in the political arena over the years. The corpus traces shifting discursive frames and arenas of contestation. Just like the status of scientific publications for studying science, the corpus is instructive not despite, but precisely because of its orchestrated nature.[40]

STRUCTURE OF ARGUMENT

The three main parts of this book will guide us through the career of climate engineering by dissecting some of its defining historical settings between the turn of twentieth century and the first decades of the new millennium. Over the course of the following chapters, we will see how each of these historical settings or 'stages' in the career of climate engineering corresponds to a historically particular mode of problematising climatic change as well as shifting alliances between climate science and the state.

We begin this inquiry in November of 2009, in *Part I* of this book. This is our starting point; this is when climate engineering officially arrived in US climate policy as an issue in its own right and assumed the form and status that still defines the debate over these measures today. Chapters 1 and 2 in this sense set the stage and present the basic premise of this book. In Chapter 1, the book contextualises the sudden rise in US political attention to climate engineering around 2009. We will see how climate engineering took shape and gained political traction at this point in time as a 'bad idea whose time has come'.

Chapter 2 complements the general outlook on this historical setting of the career of climate engineering by zooming into the concrete arenas of US policy making in which these measures began taking political shape during these years. We will see how, on the one hand, climate engineering materialised as a matter of fact(s) with policymakers and experts establishing an 'official record' on the issue, engaging them in definitional struggles over what climate engineering is, should, or can be. On the other hand, climate engineering became structurally internalised into the federal infrastructure. We will see how it took shape as a set of techno-scientific challenges that began to guide political efforts at cultivating relevant climate engineering expert capacities.

In *Part II* of this book, we will travel back in time to try to determine the historical roots of this 'bad idea whose time has come'. This move makes it possible for the book to show just how deeply intertwined efforts to understand and efforts to govern climatic change have always been. Chapter 3 sends us on a sweeping journey all the way back to the turn of the twentieth century, when human impacts on the climate were beginning to become systematically explored. We will see how before these initial findings on human impacts on the climate were problematised, they provoked positive techno-scientific visions of targeted modification and control. Climatic change, in other words, appeared as a potentially grand opportunity for humankind during these years. The geopolitical challenges of the first half of the twentieth century would only bring this dynamic into full swing, and, as a result, begin to establish climate science as a critical tool for the state, promising the deliberate modification, even control of climatic conditions for military and national strategic purposes. Chapter 4 traces a fundamental shift to this setup, both regarding this problematisation of climatic change and, correspondingly, in the defining alliances between climate science and the state. The chapter illustrates how the politicisation of global warming as an environmental issue during the 1970s and 1980s drowned out the previous techno-optimism, and with it, political excitement over the potential of deliberate climate modification and control. What we discuss today as climate engineering, in other words, did not gain, but rather lost currency in the face of political concerns over dangerous climate change. The response did not quite fit the problem (yet). We will see how climate science no longer

seemed to promise techno-scientific control for the state, but instead appeared to question the political and economic status quo. The politicisation of global warming, however, not only fractured established alliances between climate science and the state, but it also forged new ones. The chapter suggests how in this particular historical setting, climate science became established as the problem-defining authority for this newly politicised issue.

Part III of the book zooms once more to the exploration of climate engineering in US climate policy, continuing to trace the career of climate engineering from the turn of the new millennium to its first decades, returning to complete the story that began in Part I. We will see how climate engineering re-gained political traction during the early 2000s when the very problem that these measures promised to address was reformulated. Chapter 5 illustrates how climate engineering moved further into the political limelight when climate change became assembled as a challenge that would lend itself to technological intervention and control. Climate science shifted its status in this context from problem-defining to problem-addressing authority. Beginning in 2009, climate engineering then fully arrived on the US political agenda as an issue in its own right.

In Chapter 6, the book comes full circle. Building on the observations from Chapter 2, we will delve further into the role of scientific expertise in the politics of climate engineering, isolating the particular modes of expert observation, as well as the defining expert infrastructure that undergirded this most recent stage in the career of climate engineering. Chapter 6 suggests how the recent rise of climate engineering provides a kind of synthesis that reconciles two historically conflicting roles of climate science within the state. In its outlook as a 'bad idea whose time has come', climate engineering aligns the initial hopes of techno-scientific control over the climate that have shaped political interest in climate modification for the first half of the twentieth century, with the critical positions of climate scientists and environmental movements, emphasising the limits of techno-scientific control during the second half of the century.

The Conclusion provides some reflections on the book's analysis. With the book being finished in the midst of the Covid-19 global pandemic, climate engineering seems to fit eerily well into a world that has turned to scientific expertise

as a tool of crisis aversion. I suggest that this perspective on the career of climate engineering not only sheds light on a highly controversial and somewhat curious debate within climate policy, but that it critically speaks to the status and role of scientific expertise in contemporary politics more broadly.

NOTES

1 Tollefson (2018). For an overview of the ScoPEx project, see, e.g., Dykema and others (2014).
2 I will use the term 'climate engineering' throughout this book as I find that it captures most accurately what is at stake in these debates – namely efforts to deliberately intervene in and potentially control the Earth's climate.
3 Stilgoe (2015).
4 SPICE was a collaboration of the University of Bristol, the University of Cambridge, the University of Oxford, and the University of Edinburgh (see SPICE (2018); see also Hulme (2014: 57) or Stilgoe (2015) for a detailed overview of the planned experiment; see also Doughty (2019)).
5 Stilgoe (2015: 12).
6 Izrael et al. (2009a: 226, 272). It seems surprising how little attention this experiment has received, especially since Yuri Izrael was a renowned scientist, having served as Vice-Chairman to both the World Meteorological Organization (WMO), as well as the IPCC (World Meteorological Organization (2019); see also Doughty (2019: 102)).
7 Izrael et al. (2009b)
8 See, for example, the EPEACE project, which generated relevant insights to SRM research (Russell et al. (2013), but also Russell, (2012)). For the case of ocean fertilisation studies, see Lawrence and Crutzen in Blackstock and Low (2019: 90); Williamson et al. (2012). In addition, *Oceanos*, a marine research organisation lists an overview of ocean seeding experiments on their website (Oceanos 2018).
9 Wills in US House of Representatives (2009: 231), emphasis added.
10 Robock and Kravitz in Blackstock and Low (2019: 97, 98).
11 Holly Jean Buck also speaks of 'binaries' in this context (Buck 2019).
12 Stephen Hilgartner (2000: 4).
13 Fialka (2020).
14 See also Brian Wynne in this context, who stresses the importance to study 'the ultimate contingency of saliency and meaning' for science studies (Wynne 2003: 404).
15 An interactive world map which tracks climate engineering projects around the globe is maintained by the Heinrich-Böll-Stiftung, a German think tank affiliated

with the Greens' Party, together with the ETC Group, a biotechnology watchdog.

16 XPrize (2021).

17 For the ISO case, see, e.g., International Organization for Standardization 2021; Möller 2021. For a critical account of the IPCC case and its consequences, see, e.g., Beck and Mahony (2018).

18 For the case of the United States, see, e.g., US House of Representatives, Committee on Science and Technology (2009); US House of Representatives, Committee on Science and Technology (2010b). For the case of the UK, see, in particular, Science and Technology Committee (2010). For the case of Germany, see, e.g., Deutscher Bundestag (2010); Umwelt Bundesamt (2011); Die Deutsche Bundesregierung (2012). For an account of the Russian case, see, e.g., Lukacs, Goldenberg, Vaughan (2013); Intergovernmental Panel on Climate Change (2013). For an account of Indian initiatives, see Bala and Gupta (2017, 2019). For the case of China, see, e.g., Edney and Symons (2014); Cao, Gao, and Zhao (2015); Temple (2017); see also Bala and Gupta (2019: 24). Moore et al. suggest that many Chinese researchers were introduced to climate engineering measures through a number of scientific meetings that the Solar Radiation Management Governance Initiative (SRMGI) held in 2011 (Moore et al. 2016). For the Australian experiment, see, e.g., Readfearn (2020a, 2020b). For a comparative overview over the debate of climate engineering in international policy contexts, see, e.g., Huttunen, Skytén, and Hildén, (2015).

19 US Senate (2015: 12), emphasis added.

20 Shepherd in US House of Representatives, Committee on Science and Technology (2009: 110).

21 For a general classification of climate engineering approaches, see, e.g., Royal Society (2009: 6); National Research Council (2015a; 2015b).

22 See, e.g., US National Research Council (2015b: vii). Jim Fleming, for example, points out that '[…] an engineering practice defined by its scale (geo) need not be constrained by its stated purpose […]' and 'to constrain the essence of something that does not exist by its stated purpose, techniques, or goals is misleading at best' (Fleming 2010: 228).

23 Eyal (2013: 863).

24 This assumption separates this analysis from the agenda of the social problems literature, which has, for a large part, sought to demonstrate the constructivist core of social problems. For an illuminating critique of this strand of literature, see, e.g., Woolgar and Pawluch 1985. Eyal has instructively criticised the false dichotomy between 'what is real/objective and what is merely attributed/socially constructed' in some of these works (Eyal 2013: 864, fn.2).

25 Allan (2017: 131).

26 For the notion of 'assembling' governance objects, see, e.g., Allan (2017). For scholarship that has developed a concept of expertise in relation to societal problems – that is, asking how societal problems become the objects of expert labour – see, e.g., Mitchell (2002); Eyal (2013; 2019); Abbott (2014).
27 For accounts of the interrelation of science and politics as two distinct social systems, see, especially, Weingart (1983; 2001); Luhmann (1990; 2013); Stichweh (2006; 2015). For accounts on the interrelation of science and politics as two distinct fields of social practice, see particularly, Bourdieu (1998; 2004); Baker (2017).
28 For a relational perspective on scientific expertise, see particularly Eyal (2013, 2019); Grundmann (2017).
29 For this notion of structured observation, see, e.g., Luhmann (1990: 645). The concept of modes of observation also relates to Allan's 'modes of abstraction' or Latour's notion of transcriptions. It is about making an issue legible across a variety of contexts (Allan 2017: 138).
30 Edwards (2010).
31 Mitchell (1998); Fleming (2010). See for this context also Scott (1998).
32 Mitchell (1998: 90).
33 See especially Eyal (2013).
34 See Government Publishing Office (2018) for an overview of all available collections. The document corpus comprises 106 documents (see Appendix: Document Corpus for a detailed list of the included records). This book's analysis places a particular focus on the documents before 2015 as it seeks to explain the controversial arrival of these measures as a potential tool against climate change on the US political agenda.
35 Ann Keller fittingly uses the notion of a 'window' in the context of congressional hearings, which provide insights 'into how events both internal and external to Congress shape legislative debates' (2009: 95).
36 Keller (2009: 95).
37 For this concept of politics, see, e.g., the early political sociology of Luhmann e.g. (2015: 35–44); but also, his later monograph on the topic, (2002: 81–88).
38 For the temporality of hearings, see also Keller (2009: 95).
39 Keller (2009: 95).
40 See also Hilgartner (2000), who examined scientific assessment reports to study expert advice as 'public drama'.