# 3 Renormalising climate intervention

> I don't think we're ever going back to some pre-industrial Utopia of sorts. I'm not sure what the Utopia as we imagined it to be was. Does it require a global scale and ongoing effort in the stratosphere to take us back to that?… There's no way to deploy solar geoengineering to get us back to those 1850 conditions exactly. Warmer but maybe dryer—We hack it differently.
>
> (Researcher 7)

> People say that you should make the distinction [between SRM and CDR] because solar radiation management technologies are so invasive. For instance, the idea of sticking sulphates into the stratosphere is so revolutionary whereas, other CDR technologies are more innocuous. I don't think that's the case. The idea of dumping iron into the oceans is not innocuous [laughs] in any sense of the word. There are proposals in each category that are just as startling and scary. I don't think that there's that differentiation between CDR and SRM.
>
> (Researcher 6)

## Introduction

By the summer of 1988, global warming had become a serious political concern. Scientists worried about anthropogenic climate change for several decades, but other issues, both environmental—such as ozone depletion, the Chernobyl and Bhopal disasters, and the fears of nuclear winter—and non-environmental—such as the taking hostage of American diplomats in Iran, the assassination of John Lennon, the Falkland war, and disarmament negotiations between the United States and the Soviet Union—dominated the public and political interest. When anthropogenic climate change appeared on the U.S. political research agenda in the 1960s, the National Academy of the Sciences (NAS) noted that the prospects of a global warming of a few degrees would not be altogether catastrophic, because 'although some of the natural climatic changes have had locally catastrophic effects, they did not stop the steady evolution of civilization' (National Academy of the Sciences, 1966, p. 88). At the time, the effects of climate change were comprehensively understood in local terms, not a global worry. This view of climate change as a predominantly *local* concern remained dominant until the 1980s, when the National Research Council (NRC) 'once again stressed that climate change not only could, but for pragmatic purposes *should*, be defined "flexibly in local terms"' (Edwards, 2001, p. 32). According to the NRC,

> viewed in terms of energy, global pollution, and worldwide environmental damage, the '$CO_2$ problem' appears intractable. Viewed as a problem of changes in local environmental factors—rainfall, river flow, sea level—the myriad of individual incremental problems take their place among the other stresses to which nations and individuals adapt. It is important to be flexible both in definition of the issue, which is really more climate change than $CO_2$, and in maintaining a variety of alternative options for response.
>
> (National Research Council, 1983, p. 3)

In its report, the NRC stressed that 'rapid climate change will take its place among the numerous other changes that will influence the course of society, and these other changes may largely determine whether the climatic impacts of greenhouse gases are a serious problem' (ibid.). For many people, the idea that human systems can directly influence the *global* climate system remained hard to accept.[1]

In 1988, global warming started making global headlines. Aided by its summer of climate in the United States and a charismatic spokesperson James Hansen, climate change hit the mainstream. By the mid-1980s, 'most conceptions of climate change painted its risks almost exclusively in global terms' (Edwards, 2001, p. 32). Through the increasing prominence of climate modelling, the scientific focus shifted from representing climate through long-term statistical databases to computer-based climate models. The connotation of the word *climate* shifted too. Prior to these global computer models, climate was understood locally, as the average weather one would experience over the months and years.[2] But climate models understood the climate as a global average of important indicators, such as surface temperature, precipitation, and humidity.[3] This global, numerical understanding of climate was key to the development of today's conception of climate change—and for contemporary imaginations of climate engineering as a potential countermeasure. Since the summer of climate in 1988 put climate change in the public eye, it is this global view that has defined climate change science and climate change politics. It has had paradoxical effects on both climate change and climate engineering. As we saw in Chapter 2, the emergence of this global view contributed to the imagined fragility of 'Spaceship Earth', which led to the temporary disappearance of climate and weather modification dreams in the 1970s. Yet the global view also led to the re-emergence of those dreams as part of the climate change portfolio in the 2000s and 2010s. Likewise, it was the global gaze that rendered climate change visible and measurable, allowing it to become a global political concern. As a global political concern, this global view has also served a form of technocratic decision-making that continues to stifle political action on climate change and notions of systemic change (Hajer *et al.*, 2015; Howe, 2014; Hulme, 2009; Swyngedouw, 2010). Fundamentally, it is the negotiation of this global view, in a variety of guises, that gives shape to contemporary climate engineering research. In this chapter, I outline how the interplay between scientific negotiations and political struggle built a fertile soil for the re-emergence of climate engineering. Laying the groundwork for the subsequent empirical chapters, I specifically ask what scientific and cultural conditions allowed the ways of seeing climate engineering *as we know it today* to emerge.

### *Constructing climate knowledge*

Today's climate science relies on four main sources of information (Edwards, 2010). The first source is empirical observations, based on satellite imagery and measurements in various geographical locations and records of daily, monthly, and yearly climatic conditions. The second source is historical climate data that reconstructs the climate of the past by combining historical observations and historical documents with tree-rings, ice-cores, and other natural records of past climates. The third source is theory, which is the theoretical understanding that facilitates a predictive and causal understanding of the behaviour of weather and climate. The fourth source is climate models, which are numerical simulations of the climate that combine the data from the two empirical sources with the theory to reconstruct climate trends in the past and project them into the future. Such models use historical data reconstruction and empirical data to calibrate climate models and to understand whether or not current climate trends are historical anomalies rather than natural oscillations. None of these four sources of climate information are worth much without the others. Scientists calibrate their models using historical data and empirical observations. Only those models, in turn, can make empirical observations legible because the amount of data is too vast to meaningfully access otherwise. Historical data are triangulated with other historical data and historical records. Even historical climate data often needs to be rendered legible (or at least uniform) by models. In Paul Edwards' words,

> climate scientists are historians. Their work is never done. Their discipline compels every generation of climate scientists to revisit the same data, the same events—digging through the archives to ferret out new evidence, correct some previous interpretation, or find some new way to deduce the story behind the numbers. Just as with human history, we will never get a single, unshakeable narrative of the global climate's past. Instead we get versions of the atmosphere, a shimmering mass of proliferating data images, convergent yet never identical.
>
> (Edwards, 2010, p. 431)

In the development of climate science since the 1950s, Edwards shows, models and data have grown up together, allowing models to fulfil four functions. Models *made global data*, by providing the means to compare different data sets. They made *data global*, by rendering it possible to create consistent data from spotty and inconsistent data sets. Through general circulation models, they made it possible to forecast the whole world's weather and climate. And finally, the reanalysis of historical weather data in the 1980s by using models 'reunited forecasting with climate science' (Edwards, 2010, p. 433). For Edwards, this 'climate knowledge infrastructure', in many ways, 'not only accepts the provisional character of knowledge but constructs its most basic practices around that principle' (p. 438). This recursive complexity and the provisional character of climate knowledge make it susceptible to criticism. The use of modelling as a fundamental method of discovery in particular has been controversial. According to Paul Edwards,

> today, digital simulation modeling is virtually a knee-jerk scientific response, the first and most effective tool for analyzing any problem. One can scarcely imagine a scientific life without it. Yet before about 1970 most sciences had barely begun to think about simulation modeling, let alone to accept it as a fundamental method of discovery.
>
> (Edwards, 2010, p. 358)

Within academia, there is a lively debate about the validity of models. Climate models are dependent on the assumptions built into them, and their projections of the future are inherently uncertain. Because of this uncertainty, and the fact that using them has become 'a knee-jerk scientific response', it is important to spend some time on the validity of model criticism here. At the heart of this debate are two connected questions. On the one hand, there are scientific debates about what types of knowledge climate models can provide and how certain this knowledge is. On the other, there are political questions about how models should be treated, given their inherent uncertainty. Doubts about the merits of models are not exclusive to those who wish to deny that climate change is a problem. Social scientists and climate scientists alike have argued that models, like many other forms of knowledge production, privilege known risks over unknown risk (Beck and Mahony, 2018a; Hulme, 2009; Jasanoff, 1994; Saltelli and Funtowicz, 2014). They also create a particularly technocratic form of knowledge, inaccessible to many groups in society and the world (Anderson and Jewell, 2019; Ashley, 1983; Edwards, 1996; Wynne, 1984). At the same time, the validity of the knowledge that models provide *itself* has also been also questioned. Climate models cannot comprehensively represent natural systems. By necessity, they simplify the climate system. There never is perfect data, and running the simulations with all available data is impossible. While this doesn't necessarily disqualify modelling as a viable source of knowledge—'science does not study phenomena in their full complexity' (Norton and Suppe, 2001, p. 70) anyway—it does mean that the type of knowledge that climate models provide is always partial. It should always be scrutinised. Even within the modelling communities, there are serious disagreements about what models can and should do (Anderson and Jewell, 2019; Shackley, 2001; Thompson, 1984). Statistician George Box (1976) probably said it best when he insisted 'all models are wrong but some are useful'.

It is undeniable that climate models give important insights into the climate system. Without them, we would know much less about climate change. Climate change might not even have been a political concern. Climate models and their gradual acceptance as tools of scientific discovery played a major role in the 'discovery' of climate change as a major political concern. Over the course of the 1970s, 1980s, and 1990s, as models became an increasingly central part of climate science, they fuelled concerns about climate change. Through them, scientists first started to think the climate might already be changing noticeably. But knowing that climate models are debated, sometimes rightfully, sometimes disingenuously, helps to understand why neither scientist nor policymaker should take model data at face value. At the very least, it should be clear that 'model output should not be viewed as an accurate prediction of the future state of the system' (Oreskes, 2003, p. 13). Models may give insights into natural systems and 'generate "what-if" scenarios that can help to evaluate alternative courses of action (or inaction)… but scientists should eschew long-range deterministic predictions, which are likely to erroneous and may damage the credibility of the communities that generate them' (Oreskes, 2003, p. 13). This knowledge is important, because models and their projections of the future have political effects (Andersson, 2018; Beck and Mahony, 2018a; Geden, 2016; Oomen, 2019). They provide useful insights in the behaviour of climate systems and climate, but this knowledge is always partial and the performative effects of models in the climate change debate can at times be detrimental. Models may be good science; they can also ask the wrong kinds of questions (Saltelli and Funtowicz, 2014), depoliticising political questions to a 'technocratic managerialism' (Swyngedouw, 2011) in which all decisions are made by experts from a cockpit. This is why is important, as Paul Edwards reminds, to remember that 'data are never an abstraction, never just "out there"':

> 'We speak of "collecting" data, as if they were apples or clams, but in fact we literally *make* data: marks on paper, microscopic pits on an optical disk, electrical charges in a silicon chip. With instrument design and automation, we put the production of data beyond subjective influences. But data remain a human creation, and they are always material; they always exist in a medium' (emphasis in original) (Edwards, 2010, p. 109).

At the same time, knowing that there is a strong consensus on the capacity of models to accurately represent certain trends, and to improve their predictions over time, helps to understand why denying of climate change is intellectually dishonest. And, as I show later in this chapter, denial *is* a major part of the story of climate change. In the subsequent chapters, the question what models mean for climate engineering will return more extensively. Disagreement about to what extent climate engineers can rely on their models continues to fuel the controversy around climate engineering.

## Global environmental change

As Stephen Schneider recounts in his memoir *Science as a Contact Sport*, as late as the 1970s scientists weren't fully sure about global warming (Schneider, 2009). They had become certain that human systems were already changing the climate, but they weren't sure in which direction. Were global temperatures rising due to increased greenhouse gas emission? Were they dropping due to aerosol emissions by airplanes and factories reflecting sunlight back into space? Should people fear an Ice Age? Or should they fear rising sea levels, storms, droughts, and floods due to global warming? Might these two fears even cancel each other out? Despite the fact that the principal mechanism of climate change had been known since the late 1900s and that rising greenhouse gas levels had already broached the policy agenda in the 1960s, it took until the late 1980s for climate change to definitively break into public discourse as a pressing political concern. This had several causes. For one, it should not be overlooked that the shift to a global conception of climate as an interrelated global system required a considerable change in the public and scientific imagination of the climate and the environment. The move from a static climate to an interconnected global system, whose complex systems interact with a wide variety of environmental triggers—and that, importantly, could be influenced by human systems, was a vast shift in the cultural imagination of the climate. A second, loosely connected, reason is that in the years after the Second World War, the dominant paradigm of industrialism, extractivism, and economic growth existed virtually unchallenged. In both the Soviet bloc and the U.S. sphere of influence, extractive, militaristic growth was the norm (Baskin, 2019; Geiger, 2004). Economic growth became a central paradigm of the 20th century, the main driver of politics. Climate change was not just an *inconvenient truth*, as Al Gore would later describe it,[4] it also contradicted deep-seated cultural beliefs about both the environment and the industrial systems. The thought that industrialisation *at large* might be an environmental problem on a global scale (rather than a local or regional one) simply did not fit the scientific and political imagination. Not until the deleterious effects of human industrial systems on nature had become part of the common imagination in the 1970s and 1980s could anthropogenic climate change become a major political concern. The confluence of the risks of industrialisation and a pervasive *experience* of them in the collective imagination redefined the ways people experience risks and human systems (Beck, 1986, 1995). As a 1988 report Earth System Sciences Committee, initiated by NASA Advisory Council in 1983, recognised, 'most of [the] knowledge about the earth has been assembled within historically distinct Earth-science disciplines'. 'Within the past several decades,' however, '…three momentous developments have converged to reveal to us … a new view of the Earth as an integrated system'. According to the report, the first of these developments was 'the maturation of many of the disciplines themselves'. Although 'global connections among the Earth's components began to be recognized in the last century', it was 'only relatively recently that scientists in one discipline have had to confront the need for major contributions from other disciplines in order to achieve substantial research advances'. The report underlined—and this marks the second development—that 'we now have access to a new view of the Earth from space that is both global and synoptic'. Thirdly, from their point of view, 'the past several decades have brought into sharp focus the role of increasing human activity—demographic, technological, and economic—in the generation of global change' (National Research Council, 1988, pp. 12–13).

Within the scientific communities itself too, concern over global climate change was slow to develop. Climate change was mostly ignored until Hans Suess, Roger Revelle, and Charles Keeling started their research. Moreover, the scientific debate over global warming did not really start until Syokuro Manabe and his colleagues constructed global climate models to project future climates in the 1970s. Even then, there was no immediate consensus over whether or not global surface temperatures were rising (Hansen, 2009; Mann, 2012; Schneider, 2009). While scientists believed in the greenhouse effect, many found it difficult to believe that human systems could influence the climate (Howe, 2014). As a result, anthropogenic climate change remained a curiosity rather than a serious concern. Even when scientists *did* agree that humans could influence the global climate, they might still disagree about whether the Earth was heating or cooling. In the 1970s, for example, S.I. Rasool and Stephen Schneider speculated that aerosols injected into the stratosphere by industrial systems might lead to a cooling of the global climate (Rasool and Schneider, 1971). Schneider, eventually one of the most prominent climate scientists in the climate change debate, and Rasool, worried that 'an increase by only a factor of 4 in global aerosol background concentration may be sufficient to reduce the surface temperature by as much as 3.5°K. If sustained over a period of several years, such a temperature decrease over the whole globe is believed to be sufficient to trigger an ice age' (Rasool and Schneider, 1971, p. 138).[5] Clearly, even when comprehensive climate change due to human influence was imaginable, it was far from self-evident what such climate change would mean.

By the 1980s, human influence on the global climate became a more prominent feature of the cultural imagination. Several scientific and political developments in particular contributed to this change. The first was the fear of a 'nuclear winter'. Nuclear war had been a prominent fear since the 1950s but intensified when Carl Sagan published an article that asked 'Would a nuclear war be the end of the world?' (Howe, 2014; Sagan, 1983). Sagan, arguably the most famous scientist in the United States at the time, referred to a study he had done with James Pollack, Brian Toon, Tom Ackerman, and Rich Turco. In the study, the authors suggested that the fallout from a nuclear war might significantly reduce the amount of sunlight that would reach the lower troposphere (Turco *et al.*, 1983). As a result, for several years or even decades, the dust blown into the stratosphere by the nuclear explosions might create an artificial winter, year-round. The results of this would not be unlike the asteroid impact that might have led to the extinction of the dinosaurs (Alvarez *et al.*, 1980) or the eruption of Mount Tambora, in Sumbawa, Indonesia, which led to the 'year without summer' in 1816, resulting in the worst famine of the century (Oppenheimer, 2003). The study was controversial but alarming. It resonated widely throughout the world, reigniting anti-nuclear activism and environmentalism.

The second critical moment arrived shortly after. In 1985, Joe Farman, Brian Gardiner, and John Shanklin discovered that the ozone layer, a stratospheric layer of ozone preventing the influx of dangerous UV light, was damaged (Farman, Gardiner and Shanklin, 1985). The depletion of the ozone layer was the direct result of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), used in refrigerators, in air conditioners, and as solvents. Paul Crutzen, Mario Molina, and F. Sherwood Rowland, who would share the 1995 Nobel Prize in Chemistry for their work on ozone depletion, had previously shown that these substances could damage the ozone layer (Crutzen, 1970, 1979; Molina and Rowland, 1974), but few had expected the effects to be so severe. Few scientists had believed the early speculations of Crutzen and other scientists. When ozone layer depletion was first measured, scientists literally threw out the readings of severely depleted ozone because they were convinced these readings had to be outliers (Sparling, 2001). Such a severe influence of human industrial society on global processes was scarcely believable. Once the evidence was indisputable, however, the 'hole in the ozone layer' became a major global policy concern. In March 1985, the United Nations agreed to protect the ozone layer, via the Vienna Convention for the Protection of the Ozone Layer. In 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer followed. In 1989, just four years after ozone depletion had become a global issue, the Montreal Protocol went into force. CFCs and HCFCs were phased out and replaced. The Montreal Protocol itself became the first global environmental treaty, creating an imaginative framework for later discussions on climate change.

The increasing prominence of environmentalism tied into a complicating view of ecology and natural systems. The discovery of non-linearity in complex systems, at the heart of modern climate science, connected with an increasing recognition of the complex interactions that make up the biosphere. Traces of such a complex system view had already appeared in the 19th century and early 20th century. Climate scientists like Svante Arrhenius, Nils Ekholm, and Guy Stewart Callendar had speculated about the effect of $CO_2$ emissions on the global climate, and naturalists such as Alexander von

Humboldt (Wulf, 2015) and Vladimir Vernadsky (Vernadsky, 1945) pointed out the complex interplay between biological organisms and their environment. At the heart of their theories was the idea that living organisms could affect their environments, influencing the climate and conditions in which they lived. In the early 1970s, James Lovelock and Lynn Margulis built on this idea by presenting the biosphere as a dynamic system. In this system, 'life' played a formative role, co-creating the circumstances for the biosphere to develop as it did[6] (Lovelock and Margulis, 1974). Throughout the existence of complex life on the Earth, Lovelock and Margulis recognised, temperatures and other critical conditions have remained within the narrow bound that allows for complex life to exist. Although it was possible that blind chance kept the surface conditions of the Earth amenable to life, Lovelock and Margulis favoured the 'alternative explanation that, early after life began it acquired control of the planetary environment and that this homeostasis by and for the biosphere has persisted ever since' (Lovelock and Margulis, 1974, p. 2). Lovelock and Margulis' theory, the Gaia hypothesis, initially met with animosity. Largely ignored in the 1970s, it gathered more attention and criticism after Lovelock published *Gaia: A New Look at Life on Earth* in 1979 (Lovelock, 1979). W. Ford Doolittle, a prominent evolutionary biologist, called the book a 'little book' (Ford Doolittle, 1981). Richard Dawkins ridiculed the Gaia hypothesis in his landmark book *The Extended Phenotype* (1982). Both thought that Darwinian natural selection would make the self-stabilising system of Gaia impossible. To James Gould (1988), Gaia provided no new insights, never providing a convincing mechanism by which Lovelock's proposed stabilisation would work. By the end of the 1980s, however, scientific support for the Gaia hypothesis started to grow. In the 1980s, Lovelock and Andrew Watson had built a simple model, Daisyworld, proving that basic feedback loops can have a stabilising effect on a system's climate (Watson and Lovelock, 1983). Daisyworld provided scientific evidence for the mechanism by which system's stabilisation would work. Its success coincided with increasing attention of the complexity of the Earth's systems and the steadily increasing recognition of human influence on the biosphere and climate systems. By the early 2000s, (parts of) Gaia theory had become a commonplace scientific assumption. In 2001, the European Geophysical Union's Declaration of Amsterdam, for example, opened with the manifestly Gaian statement that 'the Earth System behaves as a single, self-regulating system with physical, chemical, biological, and human components' (Pronk, 2002).[7]

Such stabilisation of the Earth's climate is not inevitable. Neither is it bound to result in ever more complex forms of life. Indeed, life's forces have pushed the climatic equilibrium out of place more than once, leading to several mass extinction events (Watson and Lenton, 2011). Gaia theory does not preclude Ford Doolittle's assessment that the Earth's climatic systems are fragile. It does, however, stress the complex relationship between natural and geological systems—and now also *technological* systems. Between them Gaia theory, the closely connected ecological and earth system sciences, and chaos theory fundamentally altered the scientific view of the Earth's system. Chaos theory rendered detailed and reliable predictions about complex systems almost axiomatically impossible (see chapter 2). Gaia theory and ecology further amplified the complexity and the *fragility* of the Earth's system. These changing conceptions of the role of biological organisms altered the way people imagine the metaphysical position of humanity as a part of nature. As I show in Chapter 6, this still affects climate engineering research today. It has also influenced the ways that scientists can conceive of climate change and the types of solutions they are willing to entertain. This increasing acceptance of human influence on the Earth's systems coincided with the increasing recognition that anthropogenic climate change was not only possible, but it was probably already *there*. In the 1980s, it became clear that global warming was much more likely than global cooling. Some still point to the 'global cooling consensus' in the 1970s as proof that climate change is a scientific hoax, but concerns about cooling at the time were genuine worries of scientists in an immature field of research. These concerns were quickly displaced by a growing consensus that human influence on the greenhouse effect is much stronger than aerosol cooling.[8]

## The multiplicity of climate change

By 1988, global warming had become such a prominent public and scientific concern that the United Nations established the Intergovernmental Panel on Climate Change (IPCC). As the Cold War was coming to an end, political bandwidth opened up for a new 'enemy' to rally to: preventing the destruction of the environment as the new collaborative effort of humankind. International cooperation on environmental concerns, under U.S. leadership, suddenly *seemed* possible. Designed as a collaboration between the WMO and the United Nations Environmental Program (UNEP), the IPCC was to 'provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts' (IPCC, 2018b). Two years after its establishment, in 1990, the IPCC published its First Assessment Report. It stated that 'emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases' (IPCC, 1990, p. xi). According to the IPCC, 'these increases will increase the greenhouse effect, resulting on average in an additional warming of the Earth's surface' (p. xi). In response, the World Climate Programme, set up as a research programme into climate change a decade earlier, declared at their second conference that global warming would be a significant future problem. Although this second World Climate Conference[9] was politically disappointing to many scientists, it did call for a global treaty on climate change. Two years later, the United Nations established their Framework Convention on Climate Change (UNFCCC), which aimed to stabilise 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (United Nations, 1992: article 2). It opened for signatures at the Rio de Janeiro Earth Summit, the United Nations Conference on Environment and Development (UNCED). One hundred and fifty-four nations signed it. Only two years later, the treaty reached its threshold for ratification and entered into force. In the years since, the UNFCCC has become one of the most influential and controversial UN treaties. To date, the treaty has been ratified by 197 parties, comprising 196 countries and the European Union. All these countries accept the need for greenhouse gas stabilisation, at least nominally, and, more recently, also for climate adaptation.[10] The IPCC has also grown into one of the most influential scientific organisations globally, as the most authoritative voice on climate change.

Optimism among environmentalists grew further when Bill Clinton and his running mate Al Gore defeated George Bush Sr. in the 1992 presidential elections. Despite his promises of being an environmental president (Bush, 1988) and his insistence on U.S. global environmental leadership (Bush, 1992), Bush had refused to commit the United States to international obligations in terms of environmental protection.[11] The Democrats Clinton and Gore seemed to promise more environmental decisiveness. Al Gore in particular, as a former student of Roger Revelle, flouted his environmental credentials.[12] Hope for decisive action on climate change, however, dwindled as climate change became one of the most divisive political and cultural debates. Although the cultural and scientific view of the climate had shifted towards the perception of a fragile earth, many people, corporations, and institutions were not willing to accept climate change. The political prominence of environmental concerns often directly countervailed corporate interests. As a result, the environmental debate politicised along the lines of 'business and the economy vs. the environment'. In climate change, this divide is obvious. Climate change fundamentally challenges the energy and industrial systems of the modern world. It was, to many businesses, a *very* inconvenient truth. In response, they attempted to discredit climate science in order to foment partisanship on the issue. As long as climate change was uncertain there was no reason to act, climate change deniers insisted. Although energy companies such as Shell, Exxon Mobile, and American Petroleum Institute internally accepted climate change at least since the 1980s,[13] they maintained 'that the jury was still out' on climate change—and they would make sure the jury would stay out. Opponents of climate change policy deliberately manufactured scientific doubt about climate change (Oreskes and Conway, 2010). Borrowing tactics that the tobacco industry and the chemical industry had pioneered to defend the environmental and health records of their products, climate deniers learned that 'doubt is our product, since it is the best means of competing with the body of fact that exists in the mind of the general public. It is also the means of establishing a controversy' (Brown and Williamson, 1969, p. 4). Undermining scientific certainty about whether cigarettes caused cancer (or climate change exists) was the best way to delay or scuttle legislation. The deliberate manufacture of doubt played an important role in the polarisation of the climate change debate (Oreskes and Conway, 2010). In 1988, it was unremarkable to Bush Sr. to believe in global warming as a U.S. Republican presidential candidate. A decade later, however, climate change was a partisan issue—a divide that has only widened further since.

### *Halting climate politics*

The deliberate manufacture of doubt about climate change started in the 1990s and has continued since. Initially, these attempts, predominantly in the United States, focused on undermining the United States participating in the 1997 Kyoto Protocol which has to be an addendum to the UNFCCC and the first binding agreement on emission reductions. At the time, the agreement on the Kyoto Protocol seemed a major victory.[15] It mandated that 37 developed countries and the European Community would cut their greenhouse gas emissions. Developing countries, including China and India, were exempt from obligations but were asked to voluntarily comply (UNFCCC, 1997).[14] Attempts to discredit the Kyoto Protocol relied to a large extent on the systematic discrediting of existing climate science—and presenting alternative 'facts' instead. A favourite target for such manufacture of doubt were IPCC reports, the most authoritative voice on climate change. A unique hybrid of science and politics, the IPCC institutionalised concerns about global warming. At its inception, the IPCC had two major prerogatives. Scientifically, it aimed to assess whether or not climate change was actually occurring. Politically, it was to function as an organ of consensus building. In 1995, the IPCC published its Second Assessment Report, solidifying the message that climate change was a real and serious concern. Deniers of climate change immediately pounded on the opportunity to discredit its findings. Because the IPCC was presented and understood as *the* definitive source on climate information, discrediting (parts of) its Assessment Reports was (and remains) an effective way to create doubt about climate change. The drafting of IPCC reports is a highly stylised procedure, which has to be followed to the letter. In the first round, a selection of reputable scientists, all of whose expertise is relevant to the specific subtopic, writes separate chapters on various aspects of climate change. After peer review of these texts, government officials of all 195 countries participate in the IPCC to review the text. Only when all participants sign off on the final text, the report is published. Through this extensive peer review and the wide authorship, IPCC reports have become the most comprehensive overview of climate science available.[16]

The attacks on the report, led by Frederick Seitz, a well-respected physicist, focused on these ritualized procedures, particularly on the writing of Chapter 8. According to Seitz, in what he called 'the most disturbing corruption of the peer-review process' (Seitz, 1996), some scientists in the IPCC had altered the chapter *after* peer review, never giving governments and scientists the chance to review these final changes. Although the attacked authors had good reason for their changes—they were, in fact, *required* to make these changes according to IPCC rules—Seitz's scientific reputation (and a little help from the *Wall Street Journal*) helped spark a controversy that severely damaged the authority of the IPCC, at least where it mattered. Many groups opposed to climate change policy started to criticise the report as unscientific and biased. Parts of the American public started to believe that there was still significant disagreement about climate change and Republican opponents to climate action had the political justifications they needed to refuse the Kyoto Protocol.

This strategy soon became a hallmark of climate change denialism. By attacking the science, interest groups could plausibly maintain that there was scientific uncertainty doubt about the occurrence of climate change (Oreskes and Conway, 2010; Singer, 1998). A leaked memo from 1998 road mapped this strategy further. Exemplifying the industry's approach, the memo suggested to 'put $2m behind a plan that would effectively fuel the fires of climate change scepticism in the American people' (Readfearn, 2015). In the memo, written shortly after the adoption of the Kyoto Protocol, Joe Walker and his collaborators state that

> the climate change theory being advanced by the treaty supporters is based primarily on forecasting models with a very high degree of uncertainty. In fact, it is not known for sure whether (a) climate change is actually occurring, or (b) if it is, whether humans really have any influence on it.

Furthermore, the memo notes that the tone of media coverage since the Kyoto negotiations markedly shifted. In just six months, climate change had gone from something about which reasonable scientists could differ to climate change as the position of the overwhelming majority of mainstream scientists. The memo concludes that

> the advocates of global warming have been successful on the basis of skilfully misrepresenting the science and the extent of agreement on the science, while industry and its partners ceded the science and fought on the economic issues. Yet if we can show that science does not support the Kyoto treaty—which most *true* climate scientists believe to be the case—this puts the United States in a stronger moral position and frees its negotiators from the need to make concessions as a defense against perceived selfish economic concerns….

From this, the writers formulated their resolution not to rest until 'a majority of the American public, including industry leadership, recognizes that significant uncertainties exist in climate science, and therefore raises questions among those (e.g. Congress) who chart the future U.S. course on global climate change'. In short, 'victory will be achieved when' 'average citizens "understand" (recognize) uncertainties in climate science'. Uncertainty about climate change should become part of the conventional wisdom, making 'those promoting the Kyoto treaty appear to be out of touch with reality'. In order to achieve these goals, they budgeted an expenditure of $600,000 plus paid advertising for a National Media Relations Program. They also wanted to set up a Global Climate Science Information Source (GCSDC), which was to function as a counterpoint to the IPCC.[17] The GCSDC would provide 'platform for credible, constructive criticism of the opposition's position on the science'. Focusing on, among other things, climate history and the IPCC process, the GCSDC was to 'be a sound scientific alternative to the IPCC'.[18] These attempts to manufacture climate change were strikingly effective. Climate change became an increasingly partisan issue in the Western world. By the mid-1990s, scientific consensus about climate change was overwhelming. Where in the early 1990s dissent or at least uncertainty about whether or not climate change was occurring was still understandable to most scientists, by the second half of the 1990s most scientists considered the evidence incontrovertible (Hansen, 2009; Mann, 2012). By attacking highly visible emblems of climate science as well as discrediting prominent climate scientists by ad hominem attacks, however, these 'merchants of doubt' (as Oreskes and Conway call them) managed to sow public and political doubt about climate change.

Soon after the Kyoto negotiations, it became clear that the criticism of the IPCC's assessment report had been effective. The U.S. Senate refused to consider the ratification of the Kyoto Protocol until further negotiations had taken place.[19] The United States' refusal to ratify the protocol had two main reasons. For one, the Republican Party increasingly bought into the narrative that 'the jury was still out' on climate change. Before it was absolutely certain that climate change was occurring, no invasive climate policy would be justified.[20] They also argued the Kyoto Protocol did not reflect U.S. interests, that it was inherently unfair because it did not demand any contributions from developing countries.[21] This refusal was a serious blow to the Kyoto Protocol. It needed ratification by at least 55 nations, cumulatively accounting for at least 55% of global emissions, to go into force. Because the United States accounted for over 20% of the global carbon dioxide emissions at the time (PBL Netherlands Environmental Assessment Agency, 2016), their refusal to ratify seriously impeded the speed with which the protocol could go into force—in the end, the protocol did not go into force until 2005. The damage to the credibility of the protocol was also serious, as the largest emitter refused to ratify.

Any remaining optimism about global climate cooperation dissipated when George Bush Jr., a politician with an even less convincing environmental record than his father, was elected president in the United States. After years of a political tug of war to get global warming accepted as a pressing issue, Bush Jr.'s administration removed the U.S. signature from the Kyoto Protocol. Then, on the 11th of September 2001, Islamic terrorists flew hijacked airplanes into the World Trade Center and the Pentagon, killing almost 3,000 people. The political effects were enormous, side-lining concerns about global warming for a more militarised vision of the world. In 2001, the United States waged war on Afghanistan. In 2003, they also waged war on Iraq. Where during the 1990s there had been discursive space for global warming in global politics, now the 'war of terror' became the major political focus.[22] The European Union nominally retained its ambition on climate change mitigation but with limited success.[23] The lacklustre mitigation performances of the United States and the European Union did not inspire confidence in other parts of the world. Developing countries expected the rich Western world, responsible for most emissions both historically and at the time, to take the lead in climate mitigation. As they did not, climate politics came to a grinding halt in the early 2000s. Hopes for comprehensive climate policy were dealt another blow in 2007. The subprime mortgage crisis in the United States sparked a financial crisis that rippled across the world. The resulting economic crisis shifted attention once again away from environmental concerns, away even from the war on terror, to 'saving the banks' and 'rebuilding the economy'. By 2007, the majority of the populations of the rich countries were convinced climate change was an urgent political concern, but the recession in the late 2000s decreased the perceived sense of urgency of climate change.

### *Hopenhagen and the vague non-binding memo*

Still, at the end of the 2000s some hope for meaningful climate action seemed to return. Ahead of the 2009 Copenhagen COP-15, political leaders of large industrial nations, such as Barack Obama (the United States), Gordon Brown (the United Kingdom), and Angela Merkel (Germany), had signalled their interest in a binding agreement, as had upcoming nations such as China and India. Scientists, environmentalists, and politicians alike were hoping for a meaningful successor to the Kyoto Protocol, but COP-15 did not deliver significant progress. Developing and developed countries could not agree on the distribution of burdens of climate policy and adaptation (Bodansky, 2010). This has always been a thorny issue, because it relates to fundamentally different conceptions of climate change (Hulme, 2009). For developed countries, climate change is a global issue, a challenge to the global economy that should be addressed globally. For developing countries, climate change represents a direct consequence of the unequal neo-colonial systems that have allowed developed countries to develop their economies at the expense of the environment for over a century. Many of the developing countries are also more vulnerable to the consequences of climate change, a fact they would like to see reflected in the agreements.[24] These disagreements were not helped by yet another controversy about climate science. Leading up to COP-15 emails, in which scientists discussed how to present their findings, leaked. This 'Climategate' presented climate change deniers an opportunity to discredit climate scientists, who they accused of doctoring the data (Leiserowitz *et al.*, 2013). Although the scientists had done nothing out the ordinary (Assman *et al.*, 2010; Oxburgh *et al.*, 2010), climate change deniers presented their discussions on how to present their findings in the most effective way as scientific dishonesty. The Copenhagen COP-15, optimistically campaigned for by the United Nations as Hopenhagen in advance (Sweney, 2009), flopped. Although the countries officially reached an agreement, the Copenhagen Accord was, in the words of Reuters journalist Gregg Easterbrook, a 'vague, non-binding memo' (Easterbrook, 2010). More than 20 years after the 'summer of climate', there had been no real progress in regulating greenhouse gas emissions. The result was that meaningful climate agreements would have to wait another *six* years, until the Paris Agreement in 2015. Between 1997, the year that had seen the adoption of the Kyoto Protocol, and 2015, the year when the Paris Agreement was reached, very little mitigation was achieved politically (Rosen, 2015). Of course, climate policies and laws proliferated in individual states, and there were certainly heartening developments, but overall, $CO_2$ emissions kept rising.

## There and back again: from climate change to climate engineering

For climate scientists, this climate inaction presented a growing fear. By the mid-2000s, many were despairing about the lack of progress in combating climate change. Most had started to believe that climate policy would not come, and certainly not in time. Mitigation alone would not be enough to avoid the dire consequences of climate change. This meant that adaptation to the consequences of a changing climate, anathema in the 1990s because it might distract from mitigation, was unavoidable. Some, such as Paul Crutzen (2006), went even further. Because of inaction, Crutzen argued, previously unthinkable climate change measures should get serious consideration. To Crutzen, this included actively intervening in the global climate to counteract climate change. Crutzen's intervention was controversial (Cicerone, 2006; Lawrence, 2006), but his status as 'environmental hero' and esteemed scientist resonated widely. Climate engineering, simmering in the margins of the climate change debate, suddenly found its discursive opening. In the wake of Crutzen's article, climate engineering research exploded (Oldham *et al.*, 2014). As Stephen Schneider told Oliver Morton, 'the messenger was the message' (Morton, 2016, p. 154). It was not just the fact that Crutzen made a cogent argument about the need for climate engineering research, but it was also that *he* had said it.

In the decades prior, climate and weather intervention had never fully disappeared. The Soviet Union secretly seeded radioactive clouds after the Chernobyl explosion to prevent them from reaching Moscow and St. Petersburg[25] (Fleming, 2010). The Chinese government also used cloud seeding in an attempt to safeguard fine weather for the Beijing Olympic Games. In the climate change debate, climate engineering technologies had been one of the first suggested solutions (The White House, 1965). Carbon capture at the source, in various shapes, surfaced periodically as a solution to climate change. So too did solar radiation management (SRM). Researchers like David Keith and Ken Caldeira had been introduced to SRM at the end of the 1980s. 'Weather warriors' Lowell Wood and Edward Teller had championed the practice throughout the 1990s. Yet since the early 1970s, climate and weather modification research climate and weather modification dreams had mostly played second fiddle to increasingly apocalyptic environmental narratives. The understanding of the world as a fragile, complex system had changed what types of interventions were thought possible. Control of the weather and the climate, dreamed of in the 1950s and 1960s, seemed impossible. Still, the inclination to treat climate change as a technological problem never disappeared fully. In 1970s and 1980s, when scientists were first growing concerned about anthropogenic global warming, many scientists investigated the possibility of using climate interventions to counteract climate change. William Kellogg and Stephen Schneider (1974), prominent climate scientists, investigated the use of technological interventions to stabilise the climate, only to conclude it would be 'the height of irresponsibility' (Schneider, 2001, p. 418). Several years later, Freeman Dyson also investigated 'technical fixes for the climatic effects of $CO_2$' with his colleague Gregg Marland (Dyson, 1979). In 1984, Penner, Schneider, and Kennedy, three climate scientists, speculated about the possibilities of using 'active measures for reducing the global climatic impacts of escalating $CO_2$ concentrations' (Penner, Schneider and Kennedy, 1984). An important contribution to these speculations was a proposal by the Italian physicist Cesare Marchetti. Marchetti proposed to inject carbon dioxide into the sinking thermohaline currents. In this way, $CO_2$ could be stored in the deep ocean, which Marchetti thought to have a 'very large equilibrium capacity' (Marchetti, 1977, p. 59). According to Marchetti, 'the Mediterranean undercurrent entering the Atlantic at Gibraltar… would have sufficient capacity to deal with all $CO_2$ produced in Europe even in the year 2100' (Marchetti, 1977, p. 59). In the article, Marchetti was the first to refer to intervening in the Earth's systems as *geoengineering*, saying,

> in our study we take a positive attitude toward the problem in that we look if it can be solved or reduced by taking proper measures in the way of burning fossil fuels. This is done in the spirit of *geoengineering* [my emphasis], which is a kind of 'system synthesis' where solutions to global problems are attempted from a global view.
>
> (Marchetti, 1977, p. 59)

Marchetti's system synthesis tied into the changing conception of the Earth system sciences and oceanology as complex systems of interactions and feedback loops. This 'lifeboat Earth' vision of a global system stimulated thinking about large-scale global processes, how to influence them, and a perception of global systems as vulnerable and changeable. The word 'geoengineering' encapsulated this view and would continue to resonate, both inside and outside of the climate debate. The proposals themselves, both of Marchetti and of the others, did not garner much support. When in 1979 the first World Climate Conference was held, climate intervention was not one of the main interests. Rather, the conference focused on 'climate data, the identification of climate topics, integrated impact studies, and research on climate variability and change' (Information Unit on Climate Change, 1993). In the 1980s and 1990s, the climate science community became increasingly opposed large-scale interventions into the global climate system. To most of them, engineering the climate was dangerous, a *speculative* set of technologies that might distract from emission reduction efforts.

Still, there were always people and interests pushing for further research and possible implementation of climate engineering. Robert Frosch, for example, a vice president of General Motors Research Labs, forcefully opposed carbon cuts if technological solutions could also be possible:

> I don't know why anybody should feel obligated to reduce carbon dioxide if there are better ways to do it. When you start making deep cuts, you're talking about spending some real money and changing the entire economy. I don't understand why we're so casual about tinkering with the whole way people live on the Earth, but not tinkering a little further with the way we influence the environment.
>
> (Frosch, as quoted in Fleming, 2010, p. 246)

In general, corporate and financial actors were sceptical about emissions cuts. Many saw climate engineering as a possible way to reduce mitigation costs—and a way to continue the energy business as usual. William Nordhaus, who in 2018 received the Nobel Prize in Economics for 'integrating climate change into long-run macroeconomic analysis' (Nobel Prize Committee, 2018), speculated that 'geoengineering, would introduce a hypothetical technology that provides costless mitigation of climate change' (Nordhaus, 1992, p. 1317). As Jim Fleming reminds us, it is important to recognise that interest in climate engineering in the 1990s was motivated by a commitment to business as usual; 'it was precisely in this way—as an alternative to reducing emissions—that geoengineering discussions found their way into the twenty-first century' (Fleming, 2010, p. 246). Effectively, Nordhaus argued, the direct costs of certain climate engineering schemes such as stratospheric aerosol injection would be negligible compared to the cost of mitigation. He went on to add that 'geoengineering produces major benefits, whereas emission stabilization and climate stabilization are projected to be worse than inaction' (Nordhaus, 1992, p. 1318). Nordhaus based his ideas on his DICE model, which calculates the economically 'optimal' amount of mitigation based on expected costs of mitigation and damages from climate change[26]—which, to the DICE model, would be a 4°C warming by 2140. Although many are critical of the model's underestimation of climate damages (Hickel, 2018), it has structured economic and political thought since its inception.[27]

Nordhaus and Frosch's insistence on including geoengineering technologies paid off. In 1992, the NAS picked up on 'geoengineering' as climate change-related ecosystem intervention. Its 1992 report on 'Policy Implications of Greenhouse Warming: Mitigation, Adaptation and the Science Base' devoted a whole chapter to 'geoengineering'. Echoing the idea of a 'vast geophysical experiment', the NAS stated that 'our current inadvertent project in "geoengineering" involves great uncertainty and great risk' (National Academy of the Sciences, 1992, p. 433). Geoengineering may, or may not, reduce that risk. For the NAS, three main questions were important:

1 *Does it appear feasible that engineered systems could actually mitigate the effects of greenhouse gases?*
2 *Does it appear that the proposed systems might be carried out by feasible technical means at reasonable costs?*
3 *Do the proposed systems have effects, besides the sought-after effects, that might be adverse, and can these be accepted or dealt with?'* (National Academy of the Sciences, 1992, p. 434).

The NAS report legitimised geoengineering for climate purposes as a feasible field of research. For that reason, many climate scientists had opposed its inclusion. Stephen Schneider (2001), who was in the working group, remembers that

> the very idea of including a chapter on geoengineering led to serious internal and external debates. Many participants (including myself) were worried that even the thought that we could offset some aspects of inadvertent climate modification by deliberate modification schemes could be used as an excuse to continue polluting. Critics instead favoured market incentives to reduce emissions or regulations for cleaner alternative technologies. But Robert Frosch countered as follows: what if a pattern of change currently thought unlikely, but of high consequence, actually started to unfold in the decades ahead? It would take decades to develop the technical and political tools to reverse the risks. We would simply have to practise geoengineering as the 'least evil.'
>
> (Schneider, 2001, p. 418)

Despite its inclusion in the report, the vast majority of climate scientists continued to oppose geoengineering as a possible research avenue. At the time, both adaptation and geoengineering were anathema, widely viewed as distractions from conventional mitigation. As such, the NAS report chapter did not lead to a surge in research. Little was published on climate engineering in the 1990s. Those that did publish on the subject argued that 'we should be very careful, for it can avert disaster but can also cause it' (Matthews, 1996), explicitly against climate engineering as a whole (Jamieson, 1996), or focused on the potential of a particular technology (Stix, 1993).

### *Reimagining geoengineering*

For the most part, climate intervention remained an ignored topic. A few scientists dabbled in it here and there, but it was always a minor interest, a paper or a presentation, never a serious proposal. The only scientists who insisted on climate engineering as a possible solution to global warming in the 1990s were people who didn't really believe in global warming to begin with: Lowell Wood and Edward Teller. Wood and Teller were physicists who had played important roles in the Cold War. Teller had been an intimate part of the early Cold War military machine, part of the Manhattan project and the 'father of the H-bomb'. Wood was an early protégé of Teller's, spending most of his career designing nuclear weapons at the Lawrence Livermore Laboratories. In 1997, Teller and Wood presented a paper on 'global warming and ice ages' with Roderik Hyde. Neither Wood nor Teller, both connected to several conservative think tanks, accepted global warming as a real occurrence, but both agreed that *eventually* climatic change would occur. Ice ages in particular would be unavoidable. By effective use of the scattering of incoming solar radiation, scientists could influence the climate, making it either warmer or colder:

> While the magnitude of the climatic impact of 'greenhouse gases' is currently uncertain, the prospect of severe failure of the climate, for instance at the onset of the next Ice Age, is undeniable. The proposals in this paper may lead to quite practical methods to reduce or eliminate all climate failures.
>
> (Teller, Wood and Hyde, 1997, p. 1)

Their choice of words is highly instructive. Unwelcome climatic changes, to them, are 'climate failures', implying that the climate can be *fixed* technologically. In 1998, Wood presented similar conclusions in Aspen, Colorado (Morton, 2016). David Keith and Ken Caldeira, two relatively young scientists, were also present. Both Keith and Caldeira recall being sceptical about Wood's claims. They thought Wood seriously underestimated the complexity of the climate system. His proposed solutions must be far too simplistic. Nevertheless, they were both intrigued. Caldeira collaborated with Bala Govindasamy, his colleague at the Lawrence Livermore climate modelling division, to compare a Greenhouse Planet, an Engineered Planet, and a Baseline Planet, in an attempt to disprove Wood's claims (Govindasamy and Caldeira, 2000). Instead, Bala and Caldeira found that climate engineering, in the form of stratospheric aerosol veils, might actually merit more serious research. David Keith likewise delved deeper into the subject matter. In 2000, he published the first comprehensive assessment of the 'history and prospect' of geoengineering the climate (Keith, 2000). Both Caldeira and Keith retained their interest in geoengineering, at first only as an important intellectual curiosity. They maintained that without stringent mitigation efforts climate engineering might become important, but neither made it the predominant focus of his own research (yet).

In short, between 1992 and 2006, research efforts focused on climate engineering only sporadically. Climate engineering first made its way into the climate change debate as an alternative to mitigation, but it did not fit the scientific and political culture. Many felt deeply uncomfortable about the prospect of climate engineering. Even those who were intrigued by its promise were careful. In the eyes of David Keith, a 'de-facto taboo against serious work on geoengineering discouraged quantitative work; little was done' (Keith, 2013, p. 92). This is not exactly accurate. Climate engineering may have become unpopular among climate scientists, it was always corporate hope for business as usual.

Both the marked absence of climate engineering in the 1990s and its return after 2006 had much to do with a changing culture. Several changes, both gradual and momentary, in scientific, political, and popular culture were crucial. In the period between 1997 and 2005, it became clear that the Kyoto Protocol was a toothless tiger—which meant there was absolutely no effective climate framework in place. Political focus shifted. The Asian credit crisis of 1997–1999, 9/11, the internet bubble busting, the war in Afghanistan, and the war in Iraq—all shifted political attention away from climate change. People were preoccupied, and the major preoccupation was not the changing climate. The 1990s had been a golden age of neoliberal politics, when even European social democrats had bought into the notions of privatisation, deregulation, and trickle-down economics. The global economy grew explosively. Despite average real wages having stabilised by the 1970s in many parts of the developed world, not significantly growing since then,[28] the 1990s and early 2000s were a time of unparalleled economic optimism. By 2005, the United States still hadn't ratified the Kyoto Protocol, and it was clear it wouldn't do so. Canada, which had ratified the protocol in 2002, had been skirting its obligations (and would withdraw in 2011). Many criticised the protocol—and many started to despair about climate change. Climate change policy delayed time and again. At the end of the 1990s, disagreement about climate change grew, especially in North America. Major political actors denied climate change. Influential radio and television personalities such as Rush Limbaugh made their careers out of discrediting climate science as a 'liberal hoax'. Among those who did believe in climate change, despair was rising. Would there be any significant action in time?

In 2006, Paul Crutzen gave a voice to this scientific despair. Unlike earlier proposals by people such as Frosch and Nordhaus, Crutzen did not propose climate engineering as an *alternative* to mitigation. Rather, he admitted pessimism about the mitigation; 'Reductions in $CO_2$ and other greenhouse gas emissions are clearly the main priorities. However, this is a decades-long process and so far there is little reason to be optimistic' (Crutzen, 2006, p. 217). If political lethargy continued to scuttle serious mitigation, Crutzen thought, alternatives should be researched. Possibly, injecting sulphur aerosols in the stratosphere could lower the average global surface temperature and reduce the damages of global warming. This option should not be rejected out of hand, because 'first modelling results and the arguments presented in this paper call for active scientific research of the kind of geo-engineering' (Crutzen, 2006, p. 217). This led Crutzen to the rather depressing conclusion that 'the very best would be if emissions of the greenhouse gases could be reduced so much that the stratospheric sulphur release experiment would not need to take place. Currently, this looks like a pious wish'. With Crutzen's intervention, climate engineering definitively returned as an object of study.

Many scientists were angry at Crutzen for opening a discussion on climate engineering. They thought scientists of his stature should refrain from normalising controversial and dangerous technologies. Within the group of scientists who collaborated on the special issue of *Climatic Change* in which Crutzen's article appeared there were also disagreements. According to Ralph Cicerone, people 'opposed the publication of Crutzen's paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific' (Cicerone, 2006, p. 221). Mark Lawrence, now a prominent climate engineering researcher, added that 'serious scientific research into geoengineering possibilities, such as discussed in the publications by *Crutzen* [2006] and *Cicerone* [2006], is not at all condoned by the overall climate and atmospheric chemistry research communities' (Lawrence, 2006, p. 245). The 'various and sincere reasons that are not wholly scientific' were often moral and political grounds, combined with fears that climate engineering research would normalise climate non-action. Nonetheless, Crutzen's intervention was influential. In the 1990s, there had been very few climate engineering publications. In the early 2000s, there was some early interest in carbon dioxide reduction (CDR), particularly in carbon soil sequestration and ocean iron fertilisation, but this early peak was the result of 'articles reporting on two 2002 ocean iron fertilization experiments, SOFeX in the southern ocean and SERIES in the Gulf of Alaska, and special issues on soil carbon sequestration in *Climatic Change* and *Journal of Arid Environments*' (Oldham *et al.*, 2014, p. 5). After these projects, the attention had subsided. Crutzen's article brought it back.

In 2016, *Geophysical Research Letters* published a special issue on climate engineering, titled 'Reflecting upon 10 years of geoengineering research'. Seeing Crutzen's article as a new start for climate engineering research, the issue reflected on research since 'Crutzen's paper in climatic change sparked an unprecedented surge of academic, public, and political interest in geoengineering' (call for special issue, 2016). Clearly, there is some merit to the idea that Crutzen's intervention broke a taboo. It was certainly important. But the taboo on climate engineering was never absolute. Climate engineering always existed in the background of the climate change debate. With despair about climate change growing, these ideas seemed more and more attractive. In the mid-2000s, the conversation in the climate change debate had already begun to shift from 'mitigation' to 'mitigation and adaptation', foreshadowing the 'mitigation, adaptation, and carbon capture' approach that has become central to the 1.5- and 2-degree aims after the 2015 Paris Agreement (Anderson and Jewell, 2019; Beck and Mahony, 2018b). In 2001, the Bush White House already held an invitational conference on 'response options to rapid and severe climate change', where climate engineering options were on the table (Fleming, 2010). In 2003, the Pentagon realised a report, 'An Abrupt Climate Change Scenario and Its Implications for United States Security', that recommended that the government 'explore geoengineering options that control the climate' (Schwartz and Rendall, 2003, p. 3).[29] Clearly, climate engineering never fully left the scientific, military, and political imagination.

Crutzen's intervention brought these disjointed engagements into the scientific eye. Quickly, a small climate engineering community formed, discussing the merits and limitations of climate engineering options. This 'geoclique', in the words of journalist Eli Kintisch, argued about the desired shape of climate engineering research. It was by no means of one mind. It consisted of: David Keith and Ken Caldeira who were early adopters and relatively optimistic about climate engineering's potential; Alan Robock, an atmospheric scientist who had been become well known for modelling nuclear winter scenarios, was apprehensive of climate engineering, and wrote the influential 'Twenty Reasons Why Geoengineering May Be a Bad Idea' (2008); Clive Hamilton, a moral philosopher, deeply opposed to the hubris and the injustice he saw as inherent in climate engineering; Steve Rayner, a professor in political and science and technology studies, who worried about possible governance concerns; Jim Fleming, the historian who sees unwelcome parallels between contemporary climate engineering proposals and Cold War militaristic hubris; and Oliver Morton, Eli Kintisch, and Jeff Goodell, three science journalists who went on to write books that would bring further attention to the topic, taking different stances on the desirability of research and possible implementation.[30]

The scientific establishment at large also took note. In 2009, the Royal Society published the first large-scale assessment of possible climate engineering technologies. The report, 'Geoengineering the Climate: Science, Governance and Uncertainty', addressed the economic, scientific, and political feasibility of and concerns about climate engineering technologies (Royal Society, 2009). It was similar to earlier assessments in many ways. It treated, for example, many of the same technologies as the U.S. report in 1992 had done, such as stratospheric dust, reforestation, increasing ocean absorption of carbon dioxide, and space mirrors. The report legitimised climate engineering research and further solidified the position of the geoclique, particularly David Keith, Ken Caldeira, and Steve Rayner, as leading experts in the field. It also confirmed the coupling of CDR and SRM technologies. Both sets of technologies were treated in the report, and although they had separate chapters, 'geoengineering' came to be defined as 'deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change' (Royal Society, 2009, p. ix). This intentionally vague definition leaves space for all large-scale interventions whether they are concerned with sucking carbon from the atmosphere or with enhancing the Earth's reflectivity, to be referred to as geoengineering.

Since 2009, climate engineering has continued to grow as a scientific and political concern. Several major experiments were scheduled or conducted. Ocean iron fertilisation experiments made major waves in Germany, as we saw in Chapter 1 effectively creating a German climate engineering community. The SPICE experiment in the United Kingdom, which was supposed to research aerosol dispersion in the stratosphere by tying a hose to a balloon and spreading water, was cancelled because of public opposition and concerns about conflicts of interests related to patents (Stilgoe, 2015). Several research projects were started, funded by DARPA, by rich philanthropists, and by federal funding agencies. In 2015, the NRC in the United States published a two-volume assessment of climate engineering technologies, in many ways an updated version of the Royal Society (National Research Council, 2015a, 2015b). This assessment was split into two different books, treating CDR and SRM separately. It was titled *Climate Intervention*, rather than Climate engineering or Geoengineering, because many of the authors felt 'engineering' gives a false sense of control.

## An ontologically unitary whole

Since 2006, climate engineering has made a remarkable journey. From being a pilloried moral hazard, a dangerous distraction from more conventional mitigation, some parts of it are now viewed, explicitly or implicitly, as an integral part of the climate policy envelope. Climate knowledge built upon the trifecta of models, empirical data and climate history, dominates in the public debate. IPCC reports, based on climate scenarios and integrated assessment modelling, now fundamentally shape the public, political, *and* scientific imagination of the (climate) future. Increasingly, people are recognising that the 1.5- and 2-degree climate goals might not be feasible, especially given the political climate around the world. As of the Paris Accord in 2015, some climate engineering technologies play a significant role in the political and scientific imagination of *how* to reach the 1.5-degree ambition. Even in the 2-degree goals, most scenarios project the large-scale implementation of so-called negative emissions technologies (NETs) (Beck and Mahony, 2018b; IPCC, 2018a). Yet prior to 2006, and for some years after, scientists and politicians agreed that large-scale climate modification techniques, both technologies intervening in the Earth's solar energy budget and those concerned with industrial carbon capture, could not, would not, and should not be relied on for the mitigation of the climate problem. In the 1990s, even adaptation, meaning accepting a certain amount of global warming and preparing for it by adapting practices and environments, was controversial because it might detract from the political will to effectively mitigate. As three decades of climate politics never managed to lower carbon dioxide emissions, however, views changed. To many climate engineers, the moral hazard argument has lost some of its potency. Even the nations within the European Union that tried to take the lead on climate mitigation did not reduce their emissions significantly. Many emissions reductions have been emissions displacements; carbon-intensive industrial production simply moved to other territories, such as India and China, leading to a perceptual decrease of carbon emissions within the European Union, without de facto emissions reductions (Peters *et al.*, 2011). In fact, the only significant decrease in carbon dioxide emissions came as a result of the global financial crisis in the late 2000s and early 2010s and the COVID-19 pandemic in 2020. When economic growth resumed, so too did emissions growth. Decoupling economic growth from emissions growth, crucial for climate policy as long as economic growth remains a central tenet of the world's political economy, has not been successful. In fact, it is unlikely that sustained global economic growth can be completely decoupled from carbon dioxide mitigation (Ward *et al.*, 2016). If emission reductions don't happen anyway, and climate change continues to exacerbate, why not consider more controversial options?

Most important, however, for the recurrence of climate intervention as a scientific project was an epistemological and ontological change in the way scientists and politicians viewed the climate. Through the development of global models, coinciding with the increasingly prominent global view of the Earth as a 'marble in space', the climate conceptually became an *ontologically unitary whole*. In the political struggle to put climate on the agenda, climate activists and scientists presented a simplified idea of the climate, one based on global aggregate data and easily rememberable targets. As Silke Beck and I have written in an article yet to be published,

> this *simplicity* is mainly aimed for by using *a one-size fits all approach* to assess climate change. Global models have been used as a technique to connect together relatively simple dynamic models of natural resources, population, pollution, capital and agriculture and to aggregate these local trends into a global picture. A key feature of such a one-world, globalist approach is its emphasis on the *universality* of climate risk—climate change is represented as an *ontologically unitary whole* … In the case of the climate debate, the hugely complex challenges posed by climate change are boiled down to a single indicator for risk—the rising concentrations of one single gas: $CO_2$.

Here, I would like to add that for climate engineering, there are in fact *two* major indicators for risk that play a role. Greenhouse gas concentration is one of those indicators. Through it, climate engineering technologies such as NETs and CDR become reasonable alternatives to conventional mitigation, because they directly counteract this indicator of climate change. The other is the global average increase of surface temperatures, which similarly legitimises SRM technologies through the use of a global temperature indicator as the most important indicator for risk. These two indicators have made a reimagining of climate interventions possible. Where the disappearance of climate modification dreams in the 1970s and 1980s was importantly due to the solidification of a global view of the environment and its fragility, now the global view facilitates its reappearance. Uncertainties about the unpredictability of climate interventions, the non-linearity of its effects in a global system, remain, but they can now be imagined in direct opposition to the uncertainties about climate change. And climate engineering, through SRM and CDR, directly addresses the two main indicators of concern: global average surface temperature and greenhouse gas concentrations.

## Conclusion

Different climate engineering technologies have different histories. Some, such as the dream to modify the Earth's albedo, have been present for over half a century. The most prominent example of these dreams, stratospheric aerosol injection, owes much of its prominence to volcanic eruptions. The Mount Pinatubo eruption in 1991 in particular piqued scientists' attention because it lowered global temperatures significantly (Hansen *et al.*, 1992) and affected the global hydrological cycle (Trenberth and Dai, 2007). Other technologies, so as the idea to fertilise oceans with iron particles in the hopes to stimulate algae growth, came up later. Ocean iron fertilisation did so when biochemist John Martin reportedly joked, 'give me half a tanker of iron, and I'll give you an ice age' (Martin and Fitzwater, 1988). Yet others, such as speculations about space mirrors and 'nuking' hurricanes, disappeared from a scientific view almost fully.[31]

Despite their individual particularities, all these technologies share a larger sociocultural history, a similar outlook on nature, and similar metaphors and imaginations. The cultural and political history of climate change and climate engineering between 1945 and the present connects to changing conceptions of the role of humans in their environments and changing visions of international politics and cooperation. It also connects to changing epistemological and even *ontological* scientific ways of seeing climate change and climate engineering. Immediately after the Second World War, technopolitical, geopolitical, cultural, and scientific structures and visions facilitated dreams of weather and climate modification. Increasing meteorological data, political faith in science and technology, and a collaboration between the military and scientists created an atmosphere amenable to 'weather warriors'. A changing cultural imagination of nature combined with outrage about military applications of weather modification to push weather and climate engineering from the political, scientific, and above all public imagination. Through global models, uncertainty and mathematical chaos became a staple of climate change research. Weather warriors became less popular. And human intervention in ecosystems became understood in a different light. Political inaction on climate change since 1988 then gave rise to a form of climate despair that allowed for climate control to be reimagined as climate engineering. Rather than a proactive attempt at the control of nature, climate engineering is now a *reactive* move, an attempt to *restore* or *limit* the damages done by the 'vast geophysical experiment' conducted by industrial societies. Climate despair made it possible to imagine climate engineering as a 'band-aid' or even as a means to restore natural balance. For many, climate engineering should still not have a place in the contemporary climate debate. Most climate scientists are convinced that the climate, a complicated part of a larger complex system, is too unpredictable and unknowable to reasonably consider engineering it. Social scientists and humanists for their part share this conviction, especially as they increasingly view science and technology as sociocultural products that tend to overemphasise the amount of control humans can exert over complex systems. Much of the public is also sceptical about the feasibility of climate engineering. More important, much of the public would not trust the intentions and information of governments, scientists, corporations, or the military concerning the manipulation of the climate—for good reasons and with ample historical precedence.

As the history of climate engineering shows, whether or not to consider interventions in the Earth's climate is not primarily a scientific question. It is a public one. It is both cultural and political. Although the public may not always possess the tools to assess scientific findings, it does have an intimate stake in the proceedings. In the climate engineering debate, this public face of science is important. The fate of current generation of climate intervention proposals will not just be decided on scientific merit, such as feasibility, controllability, and cost, alone. And it shouldn't. As we have seen in the historical view on climate science and climate interventions, it isn't, and shouldn't, only the assessments of the scientists that hold weight. Especially with issues such as climate change and climate engineering, where the actions and social structures of a relative few impact the entire global ecosphere, a broader discussion will be needed.

The question is: on what grounds can we hold such a discussion? What are the epistemological, ontological, and ethical disagreements upon which the (scientific) climate engineering controversy is based? In the coming chapters, I tackle exactly those questions. Through three empirical lenses, I focus on the ways scientists conceptualise the climate and its behaviour (Chapter 4); power, politics, and inter-human relations (Chapter 5); and human-nature relations (Chapter 6) in relation to climate change and climate engineering. All of these components are deeply influenced by the larger sociocultural and scientific histories treated in this chapter and Chapter 2. These histories have created a scientific and discursive 'bandwidth', a shared understanding within which scientists can discuss and conceptualise climate engineering. It has set certain terms of debate—within which people can vehemently disagree.

## Notes

1 The perceived stability or volatility of nature has been a subject of much debate not only in the cultural debate but also the scientific. In sociology and anthropology in particular cultural theories of risk focus on how stable people perceive nature and the environment to be, and how serious environmental concerns should be taken. Different cultural traditions hold to different myths of nature, meaning that they have different perceptions of how capricious nature is (e.g. Douglas and Wildavsky, 1982; Kahan, Jenkins-Smith and Braman, 2011; Thompson, Ellis and Wildavsky, 1990).

2 As Timothy Morton (2013) and Mike Hulme (2017) (among others) have noted, one of the most troubling aspects of climate change is that this adage does not hold anymore. With weather and climate being so deeply embedded into cultures and the personal psyches of people, the global 'weirding' of the weather, in which certainties and expectations are overturned, traded for uncertainty and unknowability.

3 For a fuller understanding of this change, see Edwards (2010), Fleming (2016), and Hulme (2009).

4 In the hit documentary 'An Inconvenient Truth' (Guggenheim, 2006).

5 These fears over a global cooling were subsequently used to paint these climate scientists as 'alarmists', who were just moving from one message of catastrophe to another. Even now, the global cooling theory has some traction under climate change deniers.

6 Famously, Lovelock started conceiving of his Gaia hypothesis while working for NASA, trying to find signatures of life on Mars. By reverse-imaging these signatures, he started to think that if life could be measured from such a distance on the Earth, what processes would make life visible? If life would be measurable from such a distance, this must mean that it *significantly* alters the chemistry and atmosphere of its respective planet.

7 Jan Pronk in the *Declaration of Amsterdam*, 2001, a collaboration between four different research consortia: the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP), and the international biodiversity programme DIVERSITAS.

8 Both processes *do* take place simultaneously (e.g. Andreae, Jones and Cox, 2005; Ramanathan *et al.*, 2001)

9 The First World Climate Conference had been held in 1979 and had essentially been a scientific conference. As the first world conference on climate change, this conference had led to the establishment of the World Climate Programme and the World Climate Research Programme. It had also played an important role in the creation of the IPCC, not least by galvanising political and scientific concern for climate change.

10 Of course, one might question the sincerity of the commitment, as carbon emissions continue to grow.

11 Bush's domestic environmental record seems to have been mixed (but not great). Bush did support some environmental proposals while opposing others. His main aim was always to 'balance environmental concerns with economy'. For a journalistic assessment made of Bush's environmental record at the time, see Schneider (1991).

12 Despite losing the presidential elections in 2000, Al Gore has remained one of the most visible advocates of comprehensive climate policy, starring in and writing two influential climate change documentaries: *An Inconvenient Truth* in 2006 (Guggenheim, 2006) and *An Inconvenient Sequel* in 2017 (Cohen and Shenk, 2017).

13 As shows from leaked internal memos (Readfearn, 2015).

14 Adopted in 1997, the Kyoto protocol already included the idea of carbon sinks – and played a role in normalizing the idea of afforestation and reforestation as one of the imagined mitigation strategies (Bäckstrand & Lövbrand, 2006; Hajer and Versteeg, 2011). After much discussion, however, the sinks included in the Kyoto protocol were restricted to human-induced changes (Boyd, Corbera, and Estrada, 2008; Lövbrand 2009).

15 In retrospect, the Kyoto Protocol certainly wasn't perfect. As 'the wrong solution at the right time' (Rosen, 2015), the Kyoto Protocol has failed to limit greenhouse gas emissions (Prins and Rayner, 2007; Victor, 2001). Modelled on the agreements to deal with acid rain and ozone depletion, it failed to accommodate for the full complexity of the climate change issue. To some, such as Gwyn Prins and Steve Rayner (2007), the Kyoto Protocol even stymied creative thought and initiatives on other fronts, meaning that 'the Kyoto Protocol on climate change is a fundamentally flawed agreement that set back solutions on climate change by two decades' (Rosen, 2015, p. 30).

16 Of course, there is good reason to criticise IPCC reports. Due to their consensus-driven nature, they have serious drawbacks. For one, the IPCC always errs on the side of caution (Brysse *et al.*, 2013; Pearce, 2014). This means that the IPCC may provide a good overview of the available climate science, but it also systematically *understates* the possible risks of climate change. Much of this understatement has to do with the fact that the IPCC cannot publish without political consensus. This means that, in contrast to normal scientific publications, the IPCC has to be approved by emissaries of all participating governments. As a result, many of the more dire warnings of the IPCC are edited out or toned down. Of course, the peer review in the IPCC is intensely political (Edwards and Schneider, 2001; Hulme and Mahony, 2010).

17 As written in 'Global Climate Science Communications Actions Plan', April 1998 (Walker, 1998).

18 The use of the term 'sound science' is important. In the 1990s, climate change deniers used the term to attack the projective model-based science at the heart of climate science. Projective models, according to these critics, are not sound science. They do not operate on the basis of empirical evidence, but on almost speculative projections of a system that is poorly understood. As Norton and Suppe make clear, however,

> the epistemological issues faced by climate modeling are no different in kind than those encountered by traditional experimentation. If contrarian objections had merit, they would impeach all of science, not just complex modeling, forcing the absurd conclusion that science is in principle incapable of producing knowledge.
>
> (Norton and Suppe, 2001, p. 68)

19 As Hovi, Sprinz, and Bang (2012) note, it is likely that President Clinton and Vice President Gore had no expectations of the United States ratifying the Kyoto Protocol, but were rather concerned with at least *appearing* to have a climate-friendly face. At the same time, Europe may have preferred a more ambitious agreement without U.S. ratification rather than a less ambitious accord with that ratification. Clinton's successor Bush Jr. played a similar game regarding international and national opinion, arguing that he could not push for ratification because it did not serve his constituency (Lisowski, 2010).

20 Despite the obvious absurdity of this position—by the same rationale, no army would be needed unless war is absolutely unavoidable and no intelligence services would be needed to guard against terrorism except if it was absolutely certain to occur, many still hold it today.

21 There were (and are), of course, obvious and just reasons to expect far less mitigation efforts from developing countries, since it is precisely past carbon emissions that have allowed for high-income countries to develop their economies. Not only is the vast majority of the current climate change due to the industrialised West, it can also bear the economic burden far better. Nonetheless, the argument that climate change is a global problem, necessitating global effort, is at least somewhat more tenable than opposing any action at all.

22 A painful irony of these wars is the fact that they were importantly strategic. Iraq is one of the main oil reservoirs in the world. So, despite increasing calls for a move away from fossil fuels, the major geopolitical conflicts in the 2000s were still about the control of these resources.

23 Already in the 1990s, the European Union had aspired to impose a carbon tax on itself. Not able to agree on the tax, however, the European Union opted for a cap-and-trade system instead. Such a cap-and-trade system entails a system that provides a mechanism to trade a limited carbon budget, affording countries and companies a finite amount of carbon emissions that can be traded. In 2005, the European Union implemented its European Emissions Trading Scheme (EU ETS), but its carbon price was too low to limit greenhouse gas emissions (Lang *et al.*, 2013).

24 These fundamental differences of opinion remain a major roadblock for climate agreements, especially in terms of what role economic growth should be allowed to take in climate negotiations.

25 To the expense of people in less populated areas, particularly in Belarus, who were not told to expect radioactive rain.

26 This assessment is purely economical, viewing damages economically and neglecting the human suffering that these damages bring. It presupposes a single, global carbon market, where carbon is mitigated where it is least expensive (Bäckstrand and Lövbrand, 2019). Nordhaus' model is highly controversial. Economists are deeply impressed, but many climate scientists and ecologists 'believe that the failure of the world's governments to pursue aggressive climate action over the past few decades is in large part due to arguments that Nordhaus has advanced' (Hickel, 2018).

27 Nordhaus' assertion about the relative affordability of climate engineering for SRM also remains a prominent economic assumption in climate engineering (e.g. Wagner and Weitzman, 2015).

28 See, for example, Piketty (2014, 2020).

29 Yuri Izrael, a pre-eminent Russian climate scientist and vice chairman of the IPCC, also sent a letter to President Vladimir Putin, warning against climate change and suggesting the use of stratospheric sulphur aerosols as a solution (Fleming, 2010).

30 To illustrate the exclusive and lop-sided configuration of the early climate engineering debate, it is worthwhile to note here that these are all white men from Anglo-American institutions.

31 Of course, such ideas surface periodically, but by and large scientists are sceptical about them.

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