Foreword

My first encounter with geoengineering was in January 2013, when as a graduate student, I read an article by David Victor and colleagues (2009) titled 'The Geoengineering Option: A Last Resort to Global Warming?' The content of the article provided a striking contrast to the sustainability science literature I was used to. It painted a dramatic picture of how climate change would alter the world, how dangerous tipping points would soon be reached, and how governments would not stop carbon emissions any time soon. For these reasons, the authors argued, it was time to look at technological emergency strategies that could curb the effects of global warming. Their plea for more attention to planetary scale solutions was bold and unapologetic, and at the time, both the technology descriptions as well as the confidence with which they promoted them left me with a feeling of foreboding.

I picked up geoengineering again as a research assistant working for the former executive director of the Earth System Governance project, Ruben Zondervan. Ruben was investigating the governance of geoengineering field experiments, and asked me to pull together background information about ongoing activities. My work there led to a PhD position at the Political Science department at Lund University to study geoengineering in a context of institutional complexity. Yet at the time, there were no dedicated institutions, no agreements, no conventions, and I initially felt that there was not much material for an institutional scholar to engage with.

As a PhD student, I gradually honed in on the observation that despite the many drawbacks described by both proponents and critics, geoengineering seemed to be a highly resilient concept. The critical social science scholars I spoke with described it as a sort of whack-a-mole type topic – no matter how often you hit it on the head, it kept popping up again. This got me interested in the constitution and evolution of the idea itself. Where did it come from? How did it travel? And why was it gaining traction, despite all the contestation that it attracted? I wasn't as convinced of the narrative of crisis and political inadequacy that David Victor and colleagues had outlined in their article. Having studied both political and sustainability science, I was aware that environmental and social movements were using a similar narrative to argue for other 'radical' solutions, which didn't seem to gain as much popularity. What then was the deeper story behind geoengineering's apparent success?

It is now almost a decade since I first read David Victor's article. Since then, I have engaged with researchers, activists, and policymakers from many different countries and contexts in the quest to understand how and why

geoengineering emerged as a governance object. It is their stories, perspectives, and observations that provide the foundations for this narrative.

Before this background, I bring together my earliest empirical research and latest reflections on the emergence of geoengineering. By tracing the history and social dynamics that shaped the idea, I present my understanding of how and why geoengineering became a governance object. I argue that we need to see geoengineering as one puzzle-piece in a wider setting of economic and environmental policymaking that takes place in a world of unequal power and influence. Seeing geoengineering as such an element of broader scientific and political developments makes it clear that it is not only an emergency plan to save the world from dangerous tipping points. It is also the product of an intricate web of social dynamics that includes the influence of a few authoritative voices, the struggle between different communities of knowledge, and the historical foundations of Western technology and resource exploitation.

1 Introduction

In October 2018, I attended a workshop organized by the German Environment Agency to discuss how the German government should position itself towards geoengineering. At this point, a rumour was circulating that Switzerland would introduce a draft resolution on geoengineering governance at the upcoming United Nations Environment Assembly, and Germany wanted to be prepared. Some key questions at the meeting revolved around who was engaging with and funding geoengineering research, how and where geoengineering was relevant to international law, and what strategies might be used at both national and international levels to ensure that geoengineering did not become a default approach to dealing with climate change. Attendants of the meeting included representatives from the government, civil society, think tanks, and research. I myself had been invited to give a presentation on how to critically read authoritative assessment reports on this subject, as the conveners were sceptical of the policy influence that they perceived to be taking place through these types of publications.

My attendance of the meeting showed me a few important things about the state of geoengineering. One, that it had clearly graduated from being a marginal idea shared by a small group of enthusiasts to becoming a cause of political interest and concern. Two, that the normalization of geoengineering as a policy option was already taking place, and that it was happening through the highest levels of scientific engagement. Three, that (some) policymakers were acutely aware of this process, but that it was difficult to address it in a government setting due to the fragmented nature of the ministerial set-up.

And four, that they perceived geoengineering as being actively pushed for by certain actors, and that they understood this as a problematic sort of lobbying.

Why did geoengineering become an object of governance on the contemporary global science and policy agenda? The most common answer to this question points to the increasing urgency of climate change, the prolonged failure to reduce global greenhouse gas emissions, and the rise in political aspirations (e.g., Parson, 2014; Burns and Nicholson, 2015). While these aspects no doubt played an important role, the question remains why *this* group of techno-scientific approaches seem to have become more mainstream than other 'radical' ideas of addressing climate change (think of a per capita carbon budget, a global carbon tax, or a ban on fossil fuel subsidies). In this Element, I argue that in order to answer this question, we must understand how geoengineering evolved from a marginal idea into a viable policy option discussed in global scientific assessments and political agreements.

Before beginning, I need to point out that many scientists now question the term 'geoengineering' for grouping together technologies that work in fundamentally different ways (see Box 1). In this Element, I nevertheless use it to describe the proposal of addressing climate change by deliberately altering certain components of the Earth's climate system at large scale. Ideas to do this include retroactively removing carbon dioxide and thereby thinning the Earth's layer of greenhouse gases, or actively increasing the Earth's reflectivity in order to reduce the amount of incoming sunlight. Each type of intervention has been proposed as a necessary and feasible mechanism of addressing climate change, and while the procedures of removing carbon or deflecting sunlight are fundamentally different in terms of their physical mechanism, their global orientation, envisioned effect, and design-based perspective can make it useful – from a political perspective – to discuss them under one umbrella term that is seen as separate from conventional mitigation and adaptation.

The emergence of geoengineering on the scientific and political agenda is intriguing for several reasons. First of all, the large-scale modification of natural systems in the name of environmental protection strays substantially from important international norms that have shaped environmental policymaking since the 1970s. In the post-modern era, environmentalism has mostly been associated with reducing human impact, removing man-made sources of pollution, and restoring nature to its 'original' state (Baskin, 2019; Falkner and Buzan, 2019). Most geoengineering technologies, by contrast, aim to strategically increase one human impact on the planet in order to counteract the effects of another. Their normative assumptions about the role and capacity of humankind are thus much more similar to those of the post–world war modernist age, and

Box 1 Geoengineering: A Contested Concept

Geoengineering is usually associated with large-scale and deliberate interventions that aim to moderate climate change. As opposed to conventional mitigation strategies that *avoid* or *prevent* the release of greenhouse gases, geoengineering techniques intend to *reverse* or *counterbalance* the warming effect of emissions that have already been released. In order to achieve this objective, they would need to be deployed at regional or planetary scale.

Ideas on how to do this include removing very large amounts carbon dioxide from the atmosphere and storing it in various forms (carbon dioxide removal (CDR), greenhouse gas removal, negative emissions technologies), or increasing the reflectivity of the planet (solar radiation management (SRM), solar radiation modification, sunlight reflection).

It is important to note that although many small endeavours to remove carbon or reflect sunlight could eventually lead to a reversal or counterbalancing of climate change, the core political concern embodied in the term 'geoengineering' relates to *the idea of being able to engineer planetary systems*. In this Element, geoengineering is thus less about the implications or governance of individual carbon removal or sunlight reflection efforts but more about the consequences of imagining a world in which climate change can be counteracted by deliberate, global interventions.

Still, the wider societal meaning and use of geoengineering has become highly contested. Many scientists nowadays question the use of geoengineering as an umbrella term, seeing it as a diverse set of necessary measures that could help limit global warming, the dangers and merits of which should be discussed individually. For the purpose of designing specific governance mechanisms, this may indeed be true. But for the purpose of a more fundamental discussion of the underlying assumptions that continue to be shared by these measures, I think that the geoengineering umbrella term maintains its merits. In this Element, I thus use the term 'geoengineering' as an anchor with which to trace the evolution of an idea and its relevance to Earth System Governance.

their rise on the agenda reflects a challenge, or 'contestation', of what have long been considered fundamental norms of environmental politics. It thus serves as an interesting case of how this contestation took place.

Second, geoengineering as a concept experienced a remarkable increase in attention and status in a very short amount of time. During the 1990s, the concept existed primarily in the form of an idea sometimes mentioned in the

corridors of scientific conferences (Jamieson, 1996).[1] Only few were willing to speak and write about it openly, and those who did expressed their ideas in the form of cautionary 'if', 'should', or 'could' questions (Schneider, 1996). Today, geoengineering policy options occupy central roles in the assessments of many authoritative scientific organizations. Most prominently, they have made it into the projections of the Intergovernmental Panel on Climate Change (IPCC), which include vast amounts of CDR as a way of compensating for anthropogenic greenhouse gas emissions. Even the most controversial form of geoengineering – spraying a layer of reflective sulphur particles across the stratosphere – is openly being considered by renowned scientific bodies like the United States National Academy of Sciences.

Third, the way in which geoengineering technologies are being presented, by some, as feasible and necessary responses to the climate crisis deserves some critical scrutiny. Geoengineering means deliberate intervention into the Earth's ecological systems at planetary scale, and some of the suggestions put forward include degrees of human coordination that have no historical precedent. Deliberately removing atmospheric carbon dioxide at global scale would require nothing less than an industry comparable to contemporary global oil and gas extraction, with potentially enormous consequences for food, energy, and water. Deliberately reflecting sunlight at global scale raises highly complex political questions around decision-making, control, and responsibility in both the short term and the long term. Yet both approaches to global-scale climate management are becoming increasingly discussed as reasonable visions of the future amongst both scientists and policymakers.

In this Element, I examine the trajectory and dynamics that turned geoengineering into a governance object. In Section 2, I trace the origins of geoengineering as a concept and describe the realms of science and politics through which it travelled since the turn of the twenty-first century. In tracing this trajectory, I portray what I see as key moments and debates – sometimes with detailed illustrations, other times with broad brush strokes – while keeping in mind the larger context of ongoing climate politics. In Section 3, I map the knowledge network that evolved around the geoengineering idea. Here I outline the size, shape, and constitution of the network of actors that engaged with geoengineering between 2006 and 2018, highlighting the social dynamics at play in forming, stabilizing, and diffusing it as an object of governance. In Section 4, I reflect on the larger historical and cultural context in which geoengineering arose, discussing how Earth system science, Western colonial

[1] The history of geoengineering is much older than this, as I will explain in Section 2.

legacy, and the concept of the Anthropocene created a context in which geoengineering could emerge as a reasonable response to climate change.

My aim with writing this Element is to provide a fresh perspective on geoengineering. To do so, I conceptualize it not as an inevitable outcome of an otherwise failed global climate policy, but as the product of a medium- and long-term political and social process. I hope that by explaining the emergence of geoengineering, decision-makers can contextualize geoengineering as an idea that developed in a specific political, social, cultural, and historical context and take this into account when deciding how to engage with it.

1.1 Governance Objects and Knowledge Networks

For the purpose of tracing the emergence of geoengineering, I conceptualize the idea as a 'governance object' (Corry, 2013). The term governance object describes an idea or concept (from 'ecosystem services' to 'women's rights') that becomes subject to political decision-making at any level. It highlights how the creation and shape of a politically relevant concept affects the resulting politics around it, and that this shape is itself determined by political processes in which social actors are involved. As Bentley Allan (2017, p. 133) argues, 'the production of governance objects is neither natural nor inevitable and has important effects on how global problems are understood and governed'. In his seminal article, he explains how even the widely taken-for-granted governance object of 'climate change' has been constructed in a social process, highlighting how particular moments of interaction between state and scientific actors resulted in a geophysical definition of the governance object rather than a bioecological one.

Rather than assuming that governance objects are simply out there and waiting to be put onto a global agenda, this perspective emphasizes the discursive and social processes by which a governance object must first be created. Olaf Corry (2013) theorizes the origins of a governance object as a process in which an object is first designated, or defined, as being separate from other objects (distinctiveness), then problematized with respect to globally relevant interests and frames (saliency), and finally translated into a portable, global object that can be used in contexts around the world (malleability). Only after a governance object is thus constituted can it emerge as an issue and be taken up by the agenda-setting actors described in other influential models of the global policy cycle (e.g., Finnemore and Sikkink, 1998).

In terms of identifying where such a governance object might originate, I draw inspiration from the many scholars of environmental politics who study transnational knowledge networks. The concept of a knowledge network

marries the literature on 'epistemic communities' (Haas, 1992b) and 'transnational advocacy networks' (Keck and Sikkink, 1999). Diane Stone (2002, p. 2) describes them as networks that 'incorporate professional associations, academic research groups and scientific communities that organize around a special subject matter or issue'. While many such knowledge networks engage in the disinterested pursuit of knowledge, some are also focused on influencing policy and can include actors that range from universities over philanthropic organizations to non-governmental organizations and pressure groups.

The concept of a knowledge network thus explicitly combines the notion of a science and an advocacy network. As Mai'A Davis Cross (2013) notes, most of the literature on science networks or 'epistemic communities' has been unnecessarily narrow in its empirical focus on groups of scientists and their efforts to influence governments. The wider literature on transnational networks shows that different types of expert communities can exist and interact within the same knowledge network, that they have an active role in shaping global governance processes, and that they influence the views of both state and non-state actors. Andreas Antoniades (2003) further explains that rather than just communicating knowledge to power, these communities' principal mode of influence is the *construction of social reality.* Because of their authoritative knowledge basis, they have the power to impose discourses about what should be considered a problem. While the communities themselves are not independent of already existing discourses and structures, their position as recognized makers of knowledge gives them preferential access to the language that shapes social reality. This access to language brings us back to the theory on governance objects described in Corry (2013). Designating a problem, highlighting its relevance, and making sure it is globally transportable is a task tailored to the skills and capacities of knowledge networks.

How do knowledge networks produce global governance objects? The literature provides us with multiple conditions under which different communities within such a knowledge network are likely to influence policymaking, but still struggles with explaining the mechanisms that might lead to these conditions. Thus, Peter Haas (1992a) has highlighted the degree of consensus within a community and its access to policymakers in a phase of political uncertainty as principal determinants of its success. Mai'A Davis Cross (2013) summarizes additional scope conditions that scholars have identified as being likely to increase a community's influence. These include activity in the early phase of the policy process, compatibility with existing institutional norms, study of quantitative data and/or natural systems, and weakness of competing communities. So far, these conditions are mostly treated as exogenous and are rarely linked to internal social dynamics of the community or wider knowledge

network itself. But could it be that they are in fact interdependent outcomes of more fundamental characteristics that define a certain type of knowledge network, namely one that is capable of producing a global governance object?

What happens if, instead of thinking of two separate entities, we conceptualize the knowledge network and the governance object as one co-evolving amalgam of community and discourse? If we re-imagine knowledge networks as the *source* of global governance objects, then the facilitating conditions of uncertainty and activity in the early phase of the policy process are no longer scope conditions; they are embedded in the fact that the knowledge network itself is creating a new governance object. Also the compatibility with existing institutional norms is not exogenous. Deliberate catering to certain narratives is just as important for the success of a governance object as is the creation of the object itself. This may also explain why the engagement with quantitative data and/or natural systems is considered a facilitating condition. Given the contemporary attribution of authority to numbers and science in Western governance, communities that choose to use quantitative methods may be more successful at catering to the interests and needs of policymakers. The role of competition between communities can also take on new meaning if we see it as adding to increase of distinctiveness, salience, and malleability of a governance object. Rather than just considering the 'strength' or 'weakness' of different communities, we might do well to focus more on their interaction.

1.2 Studying the Emergence of Geoengineering

In studying geoengineering as an amalgam of community and discourse, I focus on the causal mechanisms that characterize the concept's emergence. The study of causal mechanisms is summarized in the book of Alexander George and Andrew Bennett (2005) on case studies as a way to 'open up the black boxes of nature to reveal their inner workings' and 'exhibit the ways in which the things we want to explain come about' (p. 135). To open up this 'black box' around the emergence of geoengineering, I rely mainly on process tracing, supported by document analysis, social network analysis, participant observations, and interviews as input data.

Process tracing amounts to 'the systematic examination of diagnostic evidence selected and analysed in the light of research questions and hypotheses posed by the investigator' (Collier, 2011, p. 823). Choosing what diagnostic evidence to look at is dependent on the researcher's knowledge of the case, including awareness of recurring empirical regularities and the use of an explanatory model. This means beginning with a certain event and tracing the

historical pathway through which the event emerged. It also provides an analytical explanation that is 'couched in theoretical variables that have been identified in a research design' (Bennett and George, 1997, p. 6).

Effectively, this entire Element relies on process tracing to understand the emergence of geoengineering as a governance object. It starts with describing the historical trajectory of geoengineering since the turn of the twenty-first century, including insights from document analysis, observations, and interviews (Section 2). It then focuses on the analytical explanation of how geoengineering became an object of governance, distilling specific social dynamics by which the geoengineering concept and the community around it co-constituted each other (Section 3). Finally, it reflects on larger contextual factors that facilitated the emergence of geoengineering as a governance object (Section 4).

To support this process tracing endeavour, document analysis served as a way to analyze the evolution of the geoengineering concept. This was an iterative procedure in which I read contemporary studies on geoengineering, identified the studies that were highly cited, reverse-snowballed to sources that those highly cited studies referred to, and assessed the referred studies in comparison to other studies addressing the same issue and published within a similar time frame. This confirmed that authoritative assessment reports act as major influencers on the streamlining of an idea and contribute to ordering a previously contested discussion. For this reason, key authoritative assessment reports are highlighted throughout the analysis in Section 2.

Social network analysis served as a way to draw a boundary around the geoengineering epistemic community, to identify which actors and organizations were actively engaged in the community, and which individuals seem to have played an important role. It is a method used to map actors and their social relations and a way to uncover underlying patterns of interactions and relations in groups (Borgatti et al., 2009). To determine the boundaries of the geoengineering knowledge network, I used the programmes of geoengineering workshops and conferences, reasoning that those who make the effort to repeatedly attend and present at such events demonstrate significant dedication to the group. This kind of event data provides an opportunity to capture those members of the network who are not scholars or academics and provides additional insights to publication-based network analyses, such as those conducted by Belter and Seidel (2013) and Oldham et al., (2014). It can also trace participation and connections over time, providing an advantage over survey-based data. The results of this analysis are reported primarily in Section 3.

Observations and interviews served as a way to gain access to the perceptions of people involved with geoengineering research, both at the core and at its

fringes. Much of the data gathered for this stage can be considered ethnographic, as described by Guest et al., (2013). By getting to know the people in the network, engaging in professional conversations and following the main debates over several years, I developed an in-depth understanding of the language and dynamics used within the community. This helped to gain access to events, researchers, and external observers. I was thus able to share experiences with interviewees and conversation partners, enabling deeper reflexivity and contextualization than if I had stayed completely outside the community and collected data through surveys or structured questionnaires. Furthermore, it helped me understand some of the core conflicts, dilemmas, and motivations that shape the geoengineering community. These insights flow into Sections 2, 3, and 4.

1.3 Reflections on Theory and Method

All studies are subject to theoretical and methodological limitations, and this one is no exception. In the following, I point out some considerations that the reader needs to be aware of when drawing conclusions from this Element.

The first consideration is that because I employ a constructivist perspective, I assume all types of knowledge, including scientific knowledge, are socially constructed. In this perspective, climate science is a knowledge system like many others that is governed by its own rules, norms, and politics (Beck et al., 2014; Lövbrand et al., 2015; Allan, 2017). Studying the social dynamics that govern scientific knowledge production is an enterprise that I share with other scholars of science and society, and that contributes to improving our understanding of why we govern geoengineering in the way we do (Asayama et al., 2019; Low and Schäfer, 2019; Kreuter, 2021; Oomen, 2021; Schubert, 2021). This perspective does not, in any way, intend to undermine or discard the value of science. Rather, it recognizes science as an authoritative and powerful kind of knowledge that, like any other sources of power, deserves critical analysis in order to ensure that this power is used in a reflexive, responsible, and transparent manner.

The second consideration is that in studying geoengineering as a socially constructed governance object, I place more emphasis on its ideational nature and social context than on its underlying materiality. This materiality is, however, an important factor for explaining how geoengineering emerged on the political agenda. It is even more important for recognizing the often unquestioned trajectories that we are on and the alternatives that might exist. For these reasons, I explore some aspects of geoengineering's underlying materiality in Sections 2 and 4, where I briefly discuss the role of scenarios, computers, and