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CAHIERS
FRANÇOIS VIÈTE

Série III – N° 9

2020

Vingt ans d'histoire des sciences et des techniques

sous la direction de
Jenny Boucard

Centre François Viète
Épistémologie, histoire des sciences et des techniques
Université de Nantes - Université de Bretagne Occidentale

Imprimerie centrale de l'Université de Nantes
Décembre 2020

Cahiers François Viète

La revue du *Centre François Viète*
Épistémologie, Histoire des Sciences et des Techniques
EA 1161, Université de Nantes - Université de Bretagne Occidentale
ISSN 1297-9112

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www.cfv.univ-nantes.fr

UNIVERSITÉ DE NANTES

ISSN 1297-9112

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Fifteen Years of Controversy on Solar Geoengineering in the United States, Canada, the United Kingdom and Australia

Jean-Daniel Collomb*

Abstract

This article provides an analysis of the academic controversy concerning research on solar geoengineering technologies in the United States, the United Kingdom, Canada, and Australia since 2006. It reviews the main themes in the academic controversy regarding solar geoengineering: risk management, the economics of solar geoengineering, justice and equity, and geopolitics. Further, the article identifies three main groups of scholars: resolute adversaries, reluctant supporters of research, and ecomodernists who are optimistic about the prospects of solar geoengineering.

Keywords: adaptation, climate change, climate management, climate mitigation, climate remediation, risk management, solar geoengineering, SRM.

Résumé

Cet article propose une analyse des controverses universitaires au sujet de la recherche dans le domaine de la géo-ingénierie solaire aux États-Unis, au Royaume-Uni, au Canada et en Australie depuis 2006. L'article passe en revue les thèmes principaux de discussion entre universitaires au sujet de la géo-ingénierie solaire : la gestion des risques, l'évaluation du coût économique, l'équité et la géopolitique. D'autre part, cet article divise les universitaires en trois groupes distincts : les adversaires résolus, les partisans réticents de l'investissement dans la recherche et les éco-modernistes qui affichent leur optimisme quant au potentiel de la géo-ingénierie solaire.

Mots-clés : adaptation, atténuation du changement climatique, changement climatique, géo-ingénierie solaire, gestion des risques.

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THIS article provides an analysis of the academic controversy concerning research on solar geoengineering technologies in the United States, Canada, the United Kingdom, and Australia since 2006. Solar geoengineering (SG) refers specifically to a group of emerging technologies whose purpose is to reflect sunlight back into space in order to limit temperature increases temporarily. Should it prove successful, SG would slow down the rise in temperatures and allow humans to use the delay to decarbonize the world economy and build a more resilient infrastructure. It has garnered more and more attention since the early 2000s as a growing number of policymakers, academics and environmental activists have become frustrated with the relative inertia of most countries regarding human-made climate change (CC). For three decades, most of the public policy discussion about CC has been dominated by mitigation (*i.e.* emissions reduction) and, to a lesser degree, adaptation. This might change in the decades to come. Hopefully, this article will help readers become more familiar with the nature of the controversies over SG in the United States, Canada, the United Kingdom, and Australia, and with what makes them different from or similar to other issues in the larger climate conversation. Its starting point is 2006 because the publication of an article in favor of research on SG by the Dutch geochemist Paul Crutzen led to a dramatic increase in the number of publications about a subject that had received almost no attention before.

The focus on these four countries seems warranted on account of the disproportionate representation of North American, British, and Australian scientists in this controversy. First, academic publications regarding this topic have not been evenly distributed across the continents so far. Most of the deliberations have been happening in the Northern hemisphere. Second, within the Northern Hemisphere itself, scholars from these countries are clearly overrepresented (Huttunen, Skyten & Hilden, 2014, p. 18). Christopher Belter and Dian Seidel also note the prevalence of the United States, the United Kingdom, Canada, and Australia among the countries of origin of publications on SG (Belter & Seidel, 2013, p. 420-421). That is why the article focuses principally on publications from the United States and the United Kingdom, but also from Australia and Canada where notable contributions have also been made. The choice to focus on these four countries is also reinforced by the fact that those scholars tend to respond to one another's works more than to the contributions made by,

for example, French scholars (Bourg & Hess, 2010; Bonneuil & Fressoz, 2013, p. 102-107; Boucher & al., 2014; Larrère, 2015).[1]

It should also be noted that the article analyzes publications by scientists, although a few journalists, such as Oliver Morton and Eli Kintisch, are also included because of their influential contributions to this controversy.[2] The main justification is that SG is still almost unheard of outside academia and largely unknown to the general public (Corner, Pidgeon & Parkhill, 2011; Mercer, Keith & Sharp, 2011; Mahajan, Tingley & Wagner, 2018). Put simply, SG is being discussed almost exclusively by academics and public policy experts. What is more, Stefan Schäfer and Sean Low have claimed that SG has elicited much more interest from social scientists than a comparable emerging technology such as recombinant DNA did in the late 1970s (Schäfer & Low, 2014). Recently, the authors of the Forum for Climate Engineering Assessment have recommended that ethics and the social sciences be fully integrated in the research process on SG.

The aim of this analysis is to present the substance and structure of the controversy. Specifically, I will try and identify the main areas of interest and bones of contention. Then I will attempt to show how academic scholars position themselves in this controversy, the goal being to identify the main types of reactions to SG — from outright hostility to cautious and reluctant support or enthusiasm. Along the way, I will try to set the SG controversy in the larger framework of the climate conversation.

First and foremost, it is worth bearing in mind that, although the conversation about SG is controversial, it does not qualify as a scientific controversy *per se*. According to Dominique Raynaud, scientific controversies are conflicts and disagreements which are about knowledge and the production thereof, and which originate in the scientific community (Raynaud, 2018, p. 17). Several features of the SG controversy actually dovetail with Raynaud's definition of scientific controversies: there are several sides; the participants discuss a topic the contours of which are mutually agreed on and stable; the controversy is public. However, it does not qualify as a scientific controversy because it does not primarily revolve around scientific

[1] For an overview of the German contribution, see the publications on SG by the Institute for Advanced Sustainability Studies (IASS) based in Postdam, Germany: https://www.iass-potsdam.de/de/ergebnisse/publikationen/2017/solar-radiation-management.

[2] I have chosen the term scientist even though most of the participants are social scientists, from ethicists, economists, and political scientists to historians of science and technology. However, a number of natural scientists, such as David Keith, Ken Caldeira, and James Lovelock, have also made substantial contributions, so that it makes more sense to refer to the participants as scientists.

facts. Instead, it largely focuses on how to solve a problem, and, more specifically, on whether SG would be effective in slowing down the rise in temperatures brought about by greenhouse gases.

Raynaud calls such controversies technological controversies (Raynaud, 2018, p. 33) as they center on technological change and many of their participants are not experts in the natural sciences. In short, the SG controversy is about technology, rather than about science, if only because, to paraphrase Raynaud, the latter helps us *understand* the world, whilst the former is meant to empower us to *transform* it (Raynaud, 2016, p. 27). SG techniques are what Raynaud has called "technological processes", *i.e.* a series of operations, either material or intellectual, based on scientific knowledge (Raynaud, 2016, p. 31). To be sure, disagreements over the science that is mobilized to vindicate calls for further research exist and inform this controversy. But the same is also true of other technological controversies referenced by Raynaud, such as the one about GMOs. However, according to Jean Caune, discussions about climate change, nuclear waste disposal, and nanotechnologies often go well beyond the realm of the technical, especially because they have social and political ramifications that necessitate public participation and in-depth contributions from the social sciences (Caune, 2015, p. 143). That is why, to quote Hélène Guillemot, I will call the SG controversy a "socio-technical controversy", rather than merely a technological controversy, because it goes well beyond the boundaries of science and pertains to conflicting sets of values and visions of the best way to inhabit the world (Guillemot, 2014, p. 342).

The controversy over the desirability of research on SG is part of a larger set of socio-technical controversies embedded in the climate change conversation, such as carbon capture, the actual potential of wind and solar energy, the role ascribed to nuclear energy in the effort to decarbonize the world economy, and whether a decoupling of economic growth and carbon emissions is technically feasible. One may wonder, therefore, whether the structure of the SG controversy differs significantly from other controversies over CC mitigation and adaptation, or whether it largely aligns with them. Are the families of stakeholders largely the same, or are they distributed in a very different fashion? Do the recurrent arguments resonate with other socio-technical controversies or do they open entirely new perspectives?

It is worth bearing in mind that my intention is not to provide readers with an exhaustive analysis of all the publications on SG in the four countries mentioned since 2006. Instead, I will try to bring to light the main trends in this debate. Paul Oldham & al. have already produced a wide-ranging list of publications about both solar geoengineering and carbon

capture (Oldham & al., 2014), and Jesse Reynolds has drawn a list of the multiple policy proposals on SG which have been put forward so far (Reynolds, 2019). Considerable resources on geoengineering are also available at the Kiel Earth Institute's Climate Engineering database and at the University of Montana's ethics of geoengineering online resource center.[3]

This article begins with a brief section aimed at clarifying the meaning and contours of SG so that readers will get a clear understanding of what it seeks to do. The second section will focus on the terms of the controversy and will revolve around the uncertainties linked to technological innovation and risk management, the economics of SG, its implications for international and intergenerational justice and equity, and geopolitical risks. I will try to demonstrate that this socio-technical controversy is largely predicated on the terms of the broader climate conversation. In the third section, I will identify three distinct groups of scholars according to their dispositions toward SG rather than their academic fields. The first group, composed of the resolute adversaries of research on SG, view it as an insane continuation of modern technological hubris. The second group includes the reluctant supporters of research who argue that SG could be an imperfect but unavoidable contingency plan given the lack of any good viable alternatives. The third group, composed of eco-modernists, look forward to using science and technology to expand human domination over nonhuman nature in an increasingly enlightened and technologically sophisticated manner. In that respect also, the SG controversy mimics other climate-related controversies insofar as it lies at the intersection of science, technology, politics and ideology.

What is Solar Geoengineering?

According to the British Earth system scientist John Shepherd, SG is "deliberate intervention in the climate system to counteract man-made global warming" (Shepherd, 2012, p. 4166). In a similar vein, Belter and Seidel define it as "deliberate, large-scale manipulation of the earth system with the intention of mitigating the effects of climate change" (Belter & Seidel, 2013, p. 418). Other terms are sometimes used to refer to this set of technologies. In the report of the Committee on Geoengineering Climate of the US National Academy of Sciences, geoengineering is said to fall into the category of "albedo modification techniques" and is called "climate in-

[3] See Kiel Earth Institute (https://www.climate-engineering.eu/home-35.html) and the University of Montana's ethics of geoengineering online resource center (https://www.umt.edu/ethics/ethicsgeoengineering/default.php).

tervention" (Committee on Geoengineering Climate, 2015, p. 1). Central to SG is the notion of an Earth system, which is tantamount to approaching the planet as an integrated whole, the multiple parts of which constantly interact with and influence one another. The existence of such a system, aspiring geoengineers surmise, makes it possible for humankind to initiate sophisticated efforts with a view to manipulating it in a way that will produce beneficial outcomes for humans and ameliorate CC.

Specifically, SG is aimed at reflecting sunlight back into space so as to limit temperature increases temporarily. The downside is that, even if everything goes according to plan — which is far from a foregone conclusion — it could not bring about a lowering of greenhouse gas concentrations in the atmosphere, which is the root cause of CC. To make matters worse, reflecting sunlight back into space would do nothing to ameliorate ocean acidification, arguably one of the most worrying side effects of CC. If it were to be successful, SG would allow several generations of humans in the 21st century to slow down the rise in temperatures, which in turn would give them more time to eliminate their dependence on fossil fuels and to invest in adaptation to a warmer planet.

SG comprises a range of techniques, including marine cloud brightening (Salter, 2018), cirrus cloud thinning (Storelvmo & al., 2013), urban whitewashing (Akbari & al., 2012), and the use of orbital mirrors to reflect sunlight back into space (Kaufman, 2012). Stratospheric aerosol injection, which consists in spraying sulfur into the stratosphere, twenty kilometers above the surface of the Earth, to produce a cooling effect, is by far the most often discussed technique because its promoters view it as the cheapest and quickest way of slowing warming (Ricke & al., 2012).

Of course, the power of the sun has been a feature of discussions and controversies over energy and the environment for a long time. Consider, for example, the fate of the solar industry in the United States, which was singled out by some as a credible alternative to foreign imports of fossil fuels during the 1973 oil crisis, then marginalized by increases in the production of fossil fuels combined with the hostility of the Reagan administration in the 1980s, before being reintegrated into the portfolio of energy sources deemed necessary to decarbonize the world economy today (Perlin, 2013). Genuine interest in research on SG, however, began much more recently and is in no way connected to electricity generation.

The Italian geophysicist Cesare Marchetti coined the word geoengineering in 1977 in reference to the sequestration of carbon dioxide into the ocean although various forms of it had been discussed under other names by the Soviet and US military establishments earlier on during the Cold War (Fleming, 2010, p. 165-188). Geoengineering only began to receive a very

small modicum of attention as a tool to address CC in the 1990s, but it remained largely irrelevant until the 2000s. The turning point for the visibility and standing of SG in the CC conversation occurred in 2006 when a renowned scientist went on record as supporting research on it.

In 2006, the geochemist Paul Crutzen published an article titled "Albedo Enhancement by Stratospheric Injections: A Contribution to Resolve a Policy Dilemma?" in the journal *Climatic Change*, in which he offered cautious support for research on SG in large part because, he feared, the mitigation policies necessary to avert catastrophic CC were unlikely to be enacted in time (Crutzen, 2006). Crutzen's move was widely seen as consequential on account of his sterling reputation in scientific and environmentalist circles.[4] His endorsement of research meant that the idea could no longer be dismissed as the brainchild of ill-intentioned climate skeptics or of some mad Cold War scientist.

This prompted several of his colleagues to attempt to dissuade him from publishing his paper (Morton, 2015, p. 154). Under pressure from the same academics, the editorial board of *Climatic Change* had hesitated but had eventually not been swayed by the argument that enforcing a taboo on SG would be an effective approach. In their editorial comment to justify their decision, they argue that useful norms could be produced by the national academies of sciences of several countries if they were allowed to engage in research: "[…] geoengineering is being discussed intensely, at least outside of the formal scientific literature, and it is not going to go away by ignoring it or refusing to discuss it scientifically" (Lawrence, 2006, p. 247).

The fact remains that 2006 was a watershed moment in the SG debate. Belter and Seidel have recorded a substantial uptick in the number of academic articles dealing with SG from 2006 to 2009 (Belter & Seidel, 2013, p. 420). The sudden interest in this topic set the stage, in 2009, for the publication of an influential report by the British Royal Society titled *Geoengineering the Climate: Science, Governance and Uncertainty*, which sought to explore the implications of geoengineering. According to the British historian of science Jack Stilgoe, the report did a lot to lend legitimacy and credibility to SG (Stilgoe, 2015, p. 107). Although it remained largely unknown to the general public, SG began to receive more attention in the media and in elite circles. For instance, John Holdren, a distinguished environmentalist and Barack Obama's former Assistant for Science and Technology, has recently stressed the need for "a comprehensive framework for the assessment and

[4] Crutzen had been instrumental in alerting the international community to the risks of ozone depletion in the 1970s. He also won the Nobel Prize in chemistry and performed an important role in popularizing the notion of Anthropocene, which is now regularly invoked in discussions about CC.

governance of geoengineering approaches", recognizing that SG was almost certain to become more and more prominent an issue in decades to come (Holdren, 2019, p. 29).

In addition, prestigious scientific institutions, such as the US National Research Council, the US National Academy of Sciences, and the American Geophysical Union, have recently recommended government support for well-regulated research on both SG and carbon capture (American Geophysical Union, 2018; Briday, 2014, p. 127; Committee on Geoengineering Climate, 2015). At the 2009 Copenhagen conference, the Intergovernmental Panel on Climate Change (IPCC) also decided to investigate the potentialities of geoengineering, which led to the publication of a report in 2012 (Edenhofer & al., 2012). SG also appears in its 2014 Summary for Policy-Makers (IPCC, 2014) though it is argued in the 2018 Summary for Policy-Makers that SG is associated with too many risks and uncertainties to be integrated in the IPCC's portfolio of recommendations to deal with CC (IPCC, 2018, p. 14-15).

Another sign that Crutzen's 2006 article performed a pivotal role was the drafting in 2009 of the so-called Oxford principles, a set of ethical guidelines produced by a group of academics in response to a request by the Select Committee on Science and Technology of the British House of Commons. These principles, which were formally presented at the 2010 Asilomar Conference on Climate Intervention Technologies, bear witness to the growing attention received by SG in the wake of the publication of Crutzen's article.

Finally, it is worth bearing in mind that SG techniques are merely a set of emerging technologies (occasionally also referred to as upstream technologies), which means that they have not been comprehensively tested yet. For the time being, any discussion about SG is therefore bound to be highly speculative, which almost no stakeholder in the debate denies. Advocates of research have to overcome two major hurdles. First, research is by definition difficult to conduct because of the scale required to seriously and effectively assess techniques that are intended to affect entire regions and, in some cases, the Earth-system as a whole. Second, research on SG has already sparked strong resistance from scholars and NGOs, like the ETC Group in Canada, and will almost inevitably continue to do so.

Consider, for example, the cancellation of the 2012 UK Stratospheric Particle Injection for Engineering experiment, which was an attempt to spray water one kilometer into the atmosphere (Tollefson, 2018, p. 614). More recently, the Swiss government and a few other countries introduced before the UN environment assembly a draft resolution to call for an assessment of geoengineering. Because no common ground could be found,

the resolution was abandoned (Harvard's Solar Geoengineering Research Program, 2019). In 2019, the experiment closest to deployment was Harvard University's Stratospheric Controlled Perturbation Experiment, known as SCoPEx, the aim of which is to test the potential impact of stratospheric aerosols injection.[5] In mid-2019, the experiment was still pending because SCoPEx's advisory board had yet to grant authorization.

This account of the inchoate state of research on SG serves to underline that no SG technique is even close to deployment yet. That is why the controversy under study is not about SG *per se*, but about whether research ought to be authorized. In order to make sense of the substance of the controversy, one has to bear in mind that SG has not been tested yet, and that it came to be discussed relatively recently, mainly in reaction to the lack of significant progress in the fight to mitigate CC. Even so, it remains largely invisible to most of the public, and is being discussed almost exclusively by a group of academics and policy experts, which is very small compared to the number of stakeholders involved in controversies regarding climate mitigation and adaptation.

Major Issues in the Solar Geoengineering Debate

It seems useful to probe into the participants' main areas of interest because identifying what they discuss and sometimes disagree on will go a long way toward determining whether the SG controversy conforms to patterns similar to those of other climate-related controversies. It will also make it easier to determine the degree to which this controversy goes beyond the boundaries of scientific disagreement by pitting conflicting sets of values against one another. The arguments for and against support for research fall under four main headings: risk management, cost-benefit analysis, justice and equity, and geopolitical stability. Unsurprisingly, each category encompasses a number of different topics and is also relevant to other aspects of the climate conversation. In this section, I review the main issues broached in each category.

- *Risk Management*

Risk management and the unpredictability of technological change lie at the heart of the deliberations conducted by scientists regarding SG. In their study of the responses of decision-makers to geoengineering, Suvi

[5] For a presentation of SCoPEx, see Carnegie Climate Governance Initiative: https://www.c2g2.net/solar-radiation-management-technology-srm-stratospheric-controlled-perturbation-experiment-scopex/

Huttunen, Emmi Skyten, and Mikael Hilden have found that the fear of unintended environmental side effects topped the list of concerns that are voiced about SG (Huttunen, Skyten & Hilden, 2014, p. 22). The British economist Daniel Heyen marks out the potential use of SG to address CC as a "risk-risk trade-off", by which he means that geoengineering is a highly risky policy to deal with climate risks (Heyen, 2019, p. 91). In other words, resorting to geoengineering amounts to taking risks in order to ameliorate other risks. Such an emphasis on the potential dangers of SG is consubstantial to its status as an emerging technology.

Of paramount importance are the uncertainties typical of a set of techniques that have yet to be tested and the limitations of modelling their putative effects accurately. Modelling the way in which the Earth's climate is going to evolve in the course of the 21st century has been universally recognized as a tremendously difficult task (Leuschner, 2015). Making predictions about the regional and global effects of techniques that have never been tried at scale looks like a fool's errand to most opponents of research on SG. The Australian philosopher Clive Hamilton, arguably one of the most vocal opponents of SG, has urged restraint on his contemporaries and highlighted the need for humankind to come to terms with the limitations of human knowledge (Hamilton, 2013, p. 49). According to this vision, the Earth system is simply too complex to be manipulated in a competent fashion. Too many things can go wrong. Hamilton cites the often-discussed case of the Indian monsoon, which, if it were to be negatively impacted by a geoengineering scheme, could cause substantial human suffering and geopolitical instability (p. 64). This line of argument echoes the controversy about the accuracy of climate modelling. Several climate skeptics have used the limitations of climate models as an argument against strong climate action, claiming that warnings about the effects of CC rest on dubious empirical grounds (Michaels & Knappenberger, 2016). The US political scientist Roger Pielke Jr. predicates his rejection of both SG and vigorous climate action on what he perceives as our inability to model the future of climate accurately (Pielke Jr., 2010).

The British professor of human geography Mike Hulme also bases his opposition to SG on the multiple risks involved (Hulme, 2014, p. 96-98). His line of reasoning bears close resemblance to Hans Jonas's argument in *The Imperative of Responsibility* in which the risks of nuclear technology are front and center. As Hulme puts it, "there are just *so* many things that can go wrong with a system that is global in scale" (p. 99). Put simply, when an emerging technology is surrounded by vast uncertainties and involves potentially devastating risks to humans and their natural environment, inaction is the wiser course of action, even though there are also po-

tential benefits to implementation. Some risks, in other words, are so immense that they just should not be taken. The implication of this position is not systematic opposition to technological innovation, only to change that is seen as too enormous and unpredictable (Hulme, 2014, p. 111-112; Gardiner, 2013). Interestingly, some proponents of climate action often use a similar chain of logic when they refer to the large-scale carbon emissions entailed by industrial civilization as a reckless leap into the unknown that present generations would be well-advised to guard against (Worster, 2016).

Further, critics of SG often fault their opponents with focusing too much on rising temperatures, thus betraying a simplistic understanding of CC. In *Science* magazine, Gabriele Hegerl and Susan Solomon have claimed that the evolution of precipitation patterns was also a major cause for concern (Hegerl & Solomon, 2009, p. 956). This perspective is also central to the thinking of Hulme who bemoans the fact that SG distorts the discussion about CC by ignoring or downplaying regional disparities and risks that do not directly stem from the increase in temperatures (Hulme, 2014, p. 43-55). Another risk that often crops up in the literature is ocean acidification. The US philosopher Dale Jamieson has noted that, even if it were successful in slowing down warming, SG would have absolutely no effect on this major source of climate-related risks (Jamieson, 2013, p. 531).

At the other end of the spectrum, several advocates of research have attempted to reverse the logic of their opponents. To them, risk management is precisely the *raison d'être* of SG. For instance, the Australian climatologist Tom Wigley regards SG as a risk management tool, arguing that, since CC, which is already under way and will inexorably worsen in decades to come, will entail considerable risks, humankind would do well to try to devise instruments that could slow down warming while the world economy gradually shifts away from fossil fuels (Morton, 2012, p. 161).

Likewise, the US economists Richard Zeckhauser and Gernot Wagner take issue with the invocation of the precautionary principle in the case of SG. They do agree with the opponents of research that these techniques are surrounded by great uncertainties, but they go on to state that applying the precautionary principle to SG would be tantamount to emphasizing errors of commission (*i.e.* the negative cost of action) while ignoring errors of omission (the negative cost of inaction). By contrast, they argue that both types of error ought to be weighted equally. By campaigning against funding for research, Zeckhauser and Wagner contend, adversaries of SG act in an irrational manner, foreclosing the possibility of a useful, though certainly imperfect and insufficient, instrument to deal with CC, and increasing rather than decreasing the risks thereof (Zeckhauser & Wagner, 2019, p. 107-111). As early as the 1980s, the US political scientist Aaron

Wildavsky resorted to a similar critique of the precautionary principle on a whole range of socio-technical controversies, from the health effects of the use of chemicals to CFCs and ozone depletion (Wildavsky, 1995).

In order to allay the fears that critics have expressed with regards to the undesirable effects of SG, Ken Caldeira and David Keith, two physicists heavily involved in the social science debate, have put forward what they call a red team/blue team approach "wherein one team is tasked with showing why the approach can be made to work, and another team is tasked with showing why the approach cannot produce a system that can actually diminish environmental risk at an acceptable level" (Caldeira & Keith, 2010, p. 61). Through this proposal, Caldeira and Keith, arguably the most active proponents of research on SG, signal their awareness of the many fears about a Dr. Strangelove scenario among opponents of SG.

Prominent in the risk management debate is the concern that kick-starting research risks propelling humankind onto a slippery slope from which it could not extract itself. That is what prompted Stilgoe to title his book about geoengineering *Experiment Earth*. The British geophysicist James Lovelock also fears the prospect of a path dependency with no easy way out (Lovelock, 2008, p. 3888). The risk, so the argument goes, is that, once under way, an SG program could not be discontinued lest a sudden rise in temperature occurs. Though Lovelock's and Stilgoe's warnings have been echoed by several others (Biello, 2016, p. 224; Jamieson, 2013, p. 555), Keith contends that such a scenario is by no means inevitable since research could be conducted gradually and be discontinued if the risks turn out to be too large (Keith, 2013, p. 77-118). Morton cites the fates of supersonic transport (SST) and of the nuclear industry in Germany as evidence that technological innovation can be called into question and even shelved in some cases (Morton, 2015, p. 358).

The risk of an unending commitment to SG also looms large in the Oxford principles:

> The idea behind the entire process from initial research through development, field trials, and eventual deployment are conducted openly and in the public interest of all affected countries, while also allowing for the development of more flexible technology-specific protocols for the governance of individual geoengineering approaches as their technical contours and socioeconomic implications become clearer through the R&D process. (Rayner & al., 2013, p. 20-21)

Thus, the third principle calls for "disclosure of geoengineering research and open publication of results" (p. 21).

Another risk, often invoked through the so-called moral hazard argument, looms especially large in the SG controversy, but also in other climate-related controversies. For instance, the moral hazard argument is also regularly invoked by some participants in the climate conversation who fear that putting adaptation front and center, or embracing natural gas as a bridge fuel to a decarbonized economy, might dampen efforts to accelerate the short-term development and deployment of wind and solar. This risk is inherently political as talk of SG is said to have negative repercussions on the likelihood of strong climate action. Since the late 1980s, governments across the world have essentially failed to put in place strong mitigation policies to cut back on greenhouse gas emissions because of organized opposition from fossil fuel companies and of the reluctance of many citizens to accept substantial lifestyle changes, which a quick decarbonization of the world economy would almost certainly bring about. In the face of such a wicked problem as CC, Jamieson warns, the prospect of SG is likely to create a false sense that CC can be dealt with in a virtually painless way and to induce many decision-makers and citizens to turn away from mitigation policies (Jamieson, 2013, p. 533). One might note that the same kind of warnings are frequently voiced by degrowth advocates about green growth rhetoric and the belief that economic growth and greenhouse gas emissions can be decoupled (Rees, 2020; Jackson, 2017).

Even though it does not make Jamieson's warning irrelevant, it is worth pointing out that the overwhelming majority of those who favor research do insist that it has to be coupled with strong mitigation and adaptation policies, and that SG is not meant to replace mitigation (Keith, 2013, p. 14-15). The few policy experts who differ from this position are to be found in the world of free-market think tanks. For example, Robert Murphy, a US economist at the Institute of Energy Research, has claimed that any serious mitigation effort would turn out to be too economically costly so that geoengineering could be a cheap insurance policy against climate risks (Murphy, 2009). Note that this line of reasoning, which has been echoed by a few others (Schnare, 2008), has been extremely marginal so far (Collomb, 2019).

- *The Economics of Solar Geoengineering*

One of the biggest hurdles facing proponents of climate action is the issue of financial cost. Whether the speedy decarbonization of the world economy can be achieved without a substantial decline in the standard of living is the daunting question that economists and policymakers across the world have to grapple with (Jackson, 2017; Pielke, 2010; Pollin, 2015). To

many of the proponents of research on SG, much of its appeal resides in what may prove to be its comparatively low cost.

In their best-seller *SuperFreakonomics*, the US free-market economist Steven Levitt and the US journalist Stephen Dubner claim that SG offers "cheap and simple solutions" (Levitt & Dubner, 2011, p. 196). Yet their profoundly optimistic perspective is in fact a marginal position (Collomb, 2019). Much more typical is Caldeira and Keith's contention that Solar Radiation Management has the potential to reduce climate risks in the short run while decisive steps are taken to phase out fossil fuels in the long run: "The best of these approaches are shockingly inexpensive (at least with respect to direct financial costs of deployment) and can be deployed rapidly. However, they do introduce unprecedented environmental and political risks, and they pose formidable challenges for governance and regulation" (Caldeira & Keith, 2010, p. 58). In "The Incredible Economics of Geoengineering", the US economist Scott Barrett reviews the literature on the cost of SG and concludes that "the incentive for geoengineering to be tried is very strong so long as the costs are low" (Barrett, 2008, p. 50). To Barrett, the main challenge lies in setting up sound governance mechanisms (p. 53).

Barrett's highly optimistic appraisal has prompted the British historian of technology Gordon MacKerron to issue a detailed rebuttal. MacKerron faults Barrett for having ignored the external costs of SG while focusing exclusively on its potential benefits (MacKerron, 2014, p. 4). Furthermore, he points out that forecasting the real costs of SG at this stage is virtually impossible, which enables its promoters to ride roughshod over technical, social, political, and regulatory influences which are likely to increase costs markedly, if the history of technological innovation is any guide (p. 6). Indeed, historical precedents suggest that the cost overruns of an emerging technology are almost systematically underestimated by the experts tasked with promoting it to the public and policymakers (p. 8). This is, of course, reminiscent of the way in which the costs of nuclear energy were underestimated by its early proponents. This line of argument is also used by some contemporary critics of renewable energies who claim that their actual costs are significantly higher than reported by their proponents (Mills, 2019).

The US economist William Nordhaus, who has also tried to apply a cost-benefit analysis to SG, adopts a more ambivalent attitude with regards to it. Although he is clearly skeptical of its actual potential and nervous about its unintended environmental and geopolitical repercussions, he concedes that "geoengineering could reduce the risks of the most dangerous climate outcomes" and should therefore be viewed as a measure of last re-

sort, to be mobilized if the worst comes to the worst (Nordhaus, 2013, p. 156). Forecasts of the costs of SG are bound to be front and center in the reflections of policymakers as CC continues to affect human communities the world over. Whose analysis will be regarded as more credible will surely be instrumental in determining whether research on SG is eventually funded. The controversy over the cost of using or abstaining from using SG is a continuation of the controversy among economists about the cost-benefit analyses of mitigation and adaptation strategies (or the lack thereof), as illustrated by the participation of William Nordhaus in both controversies. In both cases, issues such as the limits of our ability to model the future in a highly complex manner and intergenerational equity are ubiquitous.

- *Justice and Equity*

There is widespread concern about the effects of SG on poor countries across the world, especially developing nations. In that regard, the SG controversy fits into the larger framework of the CC debate with its emphasis on climate refugees and on the overexposure to climate risks of low-lying coastal areas. In their report for the Forum for Climate Engineering Assessment, Chhetri & al. of the School of International Service at American University insist on the necessity to take into consideration the fate of marginalized communities (Chhetri & al., 2018, p. 32-33). Central to the critique of SG is the fear that a small cadre of engineers and technocrats could impose suffering on the general public, and particularly on underprivileged groups, without accountability. Szerszynski & al. view SG as a threat to democratic governance because launching SG programs could make elected representatives completely irrelevant: "Given the undoubted sensitivities that would underpin its use, and the highly mediated effects of SRM, it could generate a closed and restricted set of knowledge networks, highly dependent on top-down expertise and with little space for dissident science or alternative perspectives" (Szerszynski & al., 2013). This concern about the risks to vulnerable communities, but also to ordinary citizens, lies at the heart of the Oxford principles. The first principle indicates that SG has "to be regulated as a public good" while the second principle stresses the desirability of public participation in the decision-making process (Rayner & al., 2013, p. 21). The underlying assumption behind those warnings is that SG is potentially unethical as it could exacerbate social, economic, and political inequalities.

Interestingly, several proponents of research on SG have attempted to reverse the accusation entirely. For example, Morton's case for funding research is couched in ethical terms. He argues that, since by 2100, 10 bil-

lion humans need to have access to cheap and reliable energy in order to enjoy a modern standard of living, the effort to decarbonize the world economy will not be quick enough to avert significant climate disruption. That is why trying to develop geoengineering tools is a moral imperative as it could give the developing world several decades to grow without having to deal with the worst effects of CC (Morton, 2015, p. 9). Keith makes a similar case when he claims that, if successful, SG would greatly benefit poor and vulnerable communities. The upshot is that, in Keith's scheme of things, it is in fact the opponents of research on SG in developed countries who are taking a selfish and unethical stance: "So we have the ugly prospect of rich people arguing that we should reject the geoengineering Band-Aid — thus denying what may be a large benefit to the poor — in order to goad the rich into cutting emissions" (Keith, 2013, p. 137).

Intergenerational equity is another fixture of SG deliberations. The US philosopher Stephen Gardiner has warned against "*parochial geoengineering*, where the current generation secures short-term benefits for itself only by passing on much more serious long-term risks to the future" (Gardiner, 2013, p. 31). Such warnings echo concerns about the moral hazard created by SG and by the fear of an endless commitment whereby future generations will be left with no choice but to perpetuate potentially suboptimal, even dangerous, programs. To the US energy law expert William Burns, foisting such a commitment on future generations would be unethical (Burns, 2013, p. 208-213). He goes on to argue that our moral imperative boils down to putting in place strong mitigation policies while staying clear of SG (p. 218). It should be noted that intergenerational equity has long been consubstantial to the broader climate conversation, with the US philosopher Henry Shue echoing Burns's argument (Shue, 2010) and the US philosopher J. Baird Callicott insisting that the moral case for reducing our carbon footprint should rest on the proposition that preserving "global human civilization" for future generations is both necessary and desirable (Callicott, 2013, p. 298).

The terms of the SG controversy echo other well-rehearsed themes in the broader climate conversation. The need to take into consideration the fate of disenfranchised groups, underlined by all sides in the SG controversy, has been a feature of IPCC reports and of policy platforms, such as the Green New Deal in the United States (Gunn-Wright & Hockett, 2019), and the European Green Deal sponsored by the EU Commission (European Commission, 2019).

- *Geopolitics*

International governance is widely regarded by SG proponents as the most daunting challenge to be overcome to start research. In the chapter of their book on CC in which they offer cautious support for research, the US economists Gernot Wagner and Martin Weitzman put strong emphasis on the geopolitical risks surrounding SG (Wagner & Weitzman, 2015, chap. 6). Even more to the point, Keith singles out geopolitical risks as far and away the most formidable challenge ahead of SG deployment (Keith, 2013, p. 156). From the geopolitical perspective, SG is an unattractive proposition as deployment is likely to create regional disparities, which in turn is likely to pit winners against losers (Hulme, 2014, p. 55). The fact that, in a geoengineered world, climate-related disturbances could be wrongly attributed to an SG scheme, might further exacerbate tensions and instability. More broadly, one may wonder where the legitimacy to act may come from if nations disagree about whether SG ought to be implemented or not. Gardiner envisions a world rife with "predatory geoengineering, where one country chooses a particular form of geoengineering mainly to disadvantage its geopolitical rivals" (Gardiner, 2013, p. 31).

Many critics of SG have warned against the danger of unilateral deployment. The US political scientist David Victor cites the possibility of a rogue geoengineer, perhaps a billionaire acting alone, whom he has dubbed "greenfinger" (Victor, 2008, p. 333). Individual states, especially those which are disproportionately affected by CC, might also be tempted to go it alone, which in turn may prompt other states to take counter-measures making conflict all the more likely. Weitzman and Wagner have called this scenario "free driving" (Weitzman & Wagner, 2015, p. 99). The US political scientist Joshua Horton has taken issue with this analysis, claiming that unilateral action is unlikely as decision-makers would quickly realize that their efforts could easily be cancelled by a counter-effort from another nation. Hence the likelihood of multilateralism (Horton, 2013, p. 172-175).

It should come as no surprise that this set of emerging technologies has yet to be subjected to adequate governance mechanisms. Rob Bellamy and Javier Lezaun claim that, in the US, the Long-Range Transboundary Air Pollution Convention and the Clean Air Act could be mobilized to regulate experiments (Bellamy & Lezaun, 2017, p. 600) but it is widely agreed that those mechanisms would be suboptimal at best, if only because they were not devised for the purpose of addressing the challenges of SG. Indeed, the drafting of the Oxford principles stem in large part from the lack of a well-defined international governance regime to regulate SG research and deployment (Rayner & al., p. 13). The final principle stipulates that,

absent a strong governance structure, SG must be abandoned entirely (p. 22). The next question is: what should and can be done?

First, the likelihood of a treaty seems very low at best. Victor believes that it is very unlikely to materialize because diverging perceptions will prompt some key nations contemplating research and deployment to opt out (Victor, 2008, p. 331-332). To make his case, Victor points to the Convention on Biological Diversity which the US refused to sign because the G.H.W. Bush administration thought it would harm US interests. This assessment is largely shared by Robert Lempert and Don Prosnitz, two researchers at the US RAND corporation (Lempert & Prosnitz, 2011, p. 11). More broadly, the travails of the Paris climate agreement of 2015, which, for similar reasons, could not be adopted in the form of a treaty featuring binding obligations, and which quickly came under attack from the Trump administration, seem to corroborate their pessimism.

For the same reason, an effective moratorium seems almost impossible. This recognition has led scholars to set forth more flexible alternatives. Experts at the Bipartisan Policy Center, based in Washington D.C., assert that instead of pushing for an international ban, governments worried about SG would do well to start with a few countries willing to establish strong and credible norms, which could then be adopted by other nations later on (Bipartisan Policy Center, 2010, p. 29-31). Other proposals include the creation of a World Commission on SG under the aegis of the UN on the model of the Brundtland Commission (which made sustainable development more prominent in the 1980s) and intent on bringing about regional coordination and conflict resolution (Chhetri & al., 2018, p. 32-35); the establishment of a sovereign risk pool (Horton & Keith, 2019); and an "active geoengineering research program, that is highly transparent and engages a wide range of countries that might have (or seek) geoengineering capabilities" (Victor, 2008, p. 325).

Difficulties in setting up compelling governance mechanisms for SG stem from the anarchic nature of international relations in that there is no world government capable of forcing compliance on all states (Mearsheimer, 2014), which is one of the main reasons why the UN Conference of Parties have repeatedly failed to produce universally agreed upon and binding mechanisms to reduce carbon emissions. Barrett complains that sound governance of SG is unlikely to materialize "in a world of sovereign states" (Barrett, 2019, p. 35). In his effort to produce a new ethic for the Anthropocene, the Australian utilitarian philosopher Peter Singer also singles out national sovereignty as a formidable obstacle and insists on the necessity to set up a strong governance regime for SG (Singer, 2016, p. 60-68). However, he does not lay out a clear path to it. In the end, all scholars who have

made recommendations as to the proper way to regulate SG have had to grapple with the centrality of national sovereignty in international affairs. Some opponents of SG have seized on this highly unfavorable international environment to argue that SG simply cannot be governed effectively (Hulme, 2014, p. 86).

Overall, one may argue that the issues raised in the SG controversy tend to align with well-rehearsed themes in the larger climate conversation. For all its specificities, its content does not differ significantly from the controversies related to climate mitigation and adaptation.

Types of Responses to Research on SG

Now that I have established that the contours of the SG controversy are largely shaped by the broader climate conversation, it seems useful to draw distinctions between several groups of academics and policy experts involved in this controversy and to determine whether those groups align in ways that differ from other families of players in climate-related controversies. Thanks to an analysis of the positions advocated by the participants, I have identified the three following categories of scholars: the resolute adversaries of research, the reluctant supporters of research, and the eco-modernists. It should be noted that those categories are mine and are not claimed by the participants as their own. Even though most eco-modernists have adopted the name eco-modernist, they did not do so in relation to their views on SG. In this section, I set out to present those categories and analyze the ideological perspectives that undergird them because a scholar's vision of the proper relationship between the human species and the natural world appears to be a strong predictor of their response to SG (Davies, 2013, p. 75). In line with Guillemot's characterization of socio-technical controversies, I find that most of the positions expressed are value-laden and strongly influenced by ideological preferences.

- *Resolute Adversaries*

More often than not, the adversaries of research on SG are highly sensitive to the negative impact of human activities on the natural world. Philosophically, they are prone to see the Cartesian-Modernist project of human mastery over nature as stemming from a fundamentally destructive worldview, which ought to be replaced by a humbler one, placing a premium on epistemological modesty and environmental health. Hamilton best exemplifies this position. In a chapter titled "Promethean Dreams", he writes that geoengineering "dovetails perfectly with the modernist urge to

exert control over nature by technological means" (Hamilton, 2013, p. 107). This, Hamilton adds, betrays a dangerous vision, oblivious to the limitations of human knowledge: "For the true Prometheans it is not enough to regulate today's climate, the goal is to take control of geological history itself. To the Earth they repeat the words of the creature of Dr. Frankenstein: 'You are my creator, but I am your master'" (p. 201).

The indictment of human hubris is consubstantial to most of the opposition to research on SG. Hulme has captured the spirit of this position well: "There are limits to human knowledge; our species is a product of evolution, not its author or controller" (Hulme, 2014, p. 111). The terms hubris, hubristic and Promethean are ubiquitous in Hamilton's book in which he complains that man "is playing God" (p. 177) and "imitates God" (p. 69). The fear of scientists gone mad is conveyed through Dr. Strangelove analogies (p. 108) and phrases like "Frankenclimate" (p. 85). More broadly, most critics of SG find it profoundly perverse that a mindset that brought about CC in the first place should be invoked as a solution to it.

The possibility of a world in which nonhuman nature can no longer exist outside human reach and influence is also deeply worrisome to adversaries of SG. If humans set out to consciously manipulate the world's climate, the entire planet will fall within the human ambit. In the preface of his book on SG, Hulme states unequivocally: "I do not wish to live in this brave new climate-controlled world" (Hulme, 2014, p. 1), a world he also calls "a brave new world of designer-climates" (p. 139). This statement reflects the dominant environmentalist position regarding SG in general.

- *Reluctant Supporters of Research*

The second category comprises scholars who share the concerns of the adversaries of research on SG regarding the unintended effects of a Modernist-Cartesian approach to nature, predicated on growing technological control over biological and physical processes, but also recognize that the reality of human-made CC forces us to consider substantial and imperfect remedial action.

What is especially striking about this group is how deeply uncomfortable with and critical of SG its members are. Most argue that mitigation policies, including the taxation of carbon, ought to be at the top of the climate policy agenda. Yet, paradoxically enough, they have come out in support of research on SG because they have very little confidence in our political ability to do what it takes in a sufficiently diligent manner. The US philosopher Jay Michaelson, for instance, dismisses the possibility of a quick orderly conversion of the US economy to a low-carbon model as "a

pipe dream" and deems it pointless to expect developing nations to refrain from using fossil fuels massively to develop (Michaelson, 2013, p. 108-109).

The recent decision by the US Union of Concerned Scientists to offer conditional support for nuclear energy as a useful instrument to speed up decarbonization after years of opposition bears witness to the existence of a similar group in the controversy over nuclear energy (Union of Concerned Scientists, 2018). The growing saliency of carbon capture as a necessary instrument in the fight against CC is another example of this trend. In both cases, those reluctant supporters have reservations and do not shy away from pointing out the risks attached to those technologies.

This line of reasoning has laid the groundwork for a recurrent pattern in publications about SG in which the author draws a long list of risks before conceding that research is nonetheless necessary in case there is no other option. Emblematic of this mindset is the contribution to the 2008 Royal Society report by the US biologist Stephen Schneider, in which he paints a grim picture of a geoengineered world only to declare his support for research at the end of his article, where he likens SG to "planetary methadone", a suboptimal remedy to an increasingly intractable problem (Schneider, 2008, p. 3858).

Likewise, Jamieson, arguably one of the most prolific critics of SG, is prepared to consider funding for research "as part of the general portfolio of climate-related research, competing with the full panoply of other approaches" (Jamieson, 2013, p. 536). Several prominent economists also fit this mold. Nordhaus compares SG to "a fire truck, not a panacea" (Nordhaus, 2013, p. 154-155) while Weitzman and Wagner also grudgingly support funding for research on SG, which they call "chemotherapy for the planet" (Wagner & Weitzman, 2015, p. 105). The underlying assumption is that given that SG risks attracting the attention of decision-makers if and when CC worsens, we might as well have access to sound data that will inform a rational discussion about the pros and cons of SG (Long & Scott, 2013, p. 48).

- *The Ecomodernists*

The last category is composed of ecomodernists who are more confident about our ability to make good on the promise of SG than the reluctant supporters of research, and who are at loggerheads with the adversaries of SG. Ecomodernism is a word used by a small number of scientists, entrepreneurs and thinkers who strongly believe that what they view as traditional environmentalism has become too hostile to technological change and oblivious to human needs for economic development (Asafu-Adjaye & al., 2015). As Ted Nordhaus and Michael Shellenberger of the ecomodern-

ist Breakthrough Institute put it: "Humans have long been cocreators of the environment they inhabit. Any proposal to fix environmental problems by turning away from technology risks worsening them by attempting to deny the ongoing coevolution of humans and nature" (Nordhaus & Shellenberger, 2011). The Canadian psychologist Steven Pinker, who is sympathetic to the ecomodernist persuasion, points out that "the key idea is that environmental problems like other problems are solvable, given the right knowledge" (Pinker, 2018, p. 121). In this article, a scholar does not have to characterize themselves as an ecomodernist to qualify as one. They only need to adhere to the proposition that it is desirable for humankind to actively reshape the natural world through the use of science and technology and that it is possible do so in a competent fashion.

Unsurprisingly, ecomodernists are involved in other energy and climate-related controversies, in which they also tout their confidence in technological solutions, as illustrated by their unflinching support for nuclear energy, which they portray as an effective means to combine economic development and a lower human footprint on ecosystems and the world's climate (Nordhaus & Shellenberger, 2011). Here, depending on how confident and optimistic they are about SG, ecomodernists are labelled either cautious or gung-ho.

Several cautious ecomodernists have voiced their support for significant effort to fund SG research. In his plea in favor of research on SG, Keith criticizes environmentalist opponents of SG for being too hostile to and pessimistic about technological solutions to environmental problems (Keith, 2013, p. 140-142). Even worse, he argues, they try to cling to a reality that does not actually exist: "With or without geoengineering it's the end of nature with a capital 'N', the romanticized ideal of nature wholly separate from civilization" (p. 172). In Keith's scheme of things, technological risks such as the ones surrounding SG, have to be handled rationally. Research on SG, if subjected to rigorous standards, could greatly benefit humankind so that the indictment of Cartesian-Modernism made by the likes of Hamilton is deeply irrational and dangerous. Enlightenment Modernism, ecomodernists plead, has to be improved, not replaced.

A sub-group of ecomodernists, whom I call gung-ho ecomodernists, differ from their cautious counterparts in that they tend to be a lot more sanguine about the potential of SG. The former usually single out adaptation and geoengineering as the only sound solutions to CC while the latter tend to endorse an all-of-the-above strategy in which mitigation looms large. Most, though not all, gung-ho ecomodernists are to be found in the world of US conservative and libertarian think tanks (Caplan cited in Kintish, 2010, p. 195). Other examples are Levitt and Dubner who devote

an entire chapter of *SuperFreakonomics* to SG (Levitt & Dubner, 2011, chap. 5).

This has led several proponents of strong climate action to claim that US climate skeptics are in the process of transitioning from the denial of the reality of CC to advocacy for SG with a view to preventing emissions reductions (Hamilton, 2013, p. 98; Kintisch, 2010, chap. 10). In reality, support for SG remains a marginal position among free-market advocates in the US (Collomb, 2019). Furthermore, some free-market policy experts interested in SG would qualify as cautious ecomodernists willing to recognize the potential drawbacks of SG and limit their endorsement of SG to calls for funding research (Lane & Bickel, 2009).

The fact that groups and individuals often viewed as climate "skeptics" or "deniers" are perceived as potential players in this controversy serves to underline its political and ideological dimensions. Just as in the case of controversies regarding CC mitigation and adaptation, the SG controversy is viewed by at least some of its participants as an extension of a broader political and ideological battle in which one side seeks to achieve supremacy over the other. As this section makes clear, passions run high and the participants' value preferences are likely to shape their perspectives. The participants' assumptions about the proper relationship between the human species and the natural world, and about the role that technology ought to play with a view to solving environmental problems, seem to determine their stances on SG, at least partially.

Conclusion

Though it has yet to attract significant public attention, the SG controversy bears the hallmark of the broader CC conversation for several reasons. First, it is characterized by a high degree of emotional intensity, as reflected by the polemical tone employed by Clive Hamilton in *Earthmasters*. As one among the multiple battlefields in a so-called "climate war" (Mann, 2012; Pooley, 2010), the SG controversy provides participants with an opportunity to signal which group they belong to in a passionate and high-stakes confrontation centering on the future of the human species. Whether humans manipulate the world's climate unintentionally (in the case of humanmade CC) or intentionally (through the use of Solar Radiation Management techniques), it should come as no surprise that passions run high, as they often do in what Guillemot refers to as socio-technical controversies.

Second, the recurrent themes of the SG controversy also resonate with the other socio-technical controversies embedded in the CC conversa-

tion. The emphasis on the unpredictability of technological change is a feature of the controversies over nuclear energy, and, more broadly, over the effects of the continued use of fossil fuels on the world's climate. Franco Romerio has pointed out that disagreements about the status of technological innovation is consubstantial to all energy-related controversies (Romerio, 2007, p. 36-38).

For instance, discussions about SG have set the stage for a repeat of the already well-rehearsed debate about the precautionary principle. Other issues embedded in the SG controversy also resonate with other climate-related controversies. Consider the moral hazard argument, which is invoked about the use of natural gas as a bridge fuel to reach an economy largely powered by renewables. Likewise, concerns about justice and equity have been part and parcel of international climate negotiations since the late 1980s, the prominence of the notion of "common but differentiated responsibilities" in the international climate regime being a case in point (Aykut & Dahan, 2015, p. 71). As for arguments about the anarchic nature of international relations, they also sound strikingly familiar to observers of the climate controversy as CC is often perceived as an extreme version of the tragedy of the commons (Mingst, 2003, p. 88-91). Note that the geopolitical factor was also relevant, albeit in a less intractable way, in the acid rain and ozone depletion controversies (Vogler, 2014, p. 341-356).

Third, the groups of participants involved in the SG controversy also seem similar to those in other controversies stemming from CC. In his much-discussed 2018 book, *The Wizard and the Prophet*, Charles C. Mann identifies a recurrent pattern in controversies on energy and environmental issues: more often than not, they tend to pit "wizards", prioritizing technological innovation to grapple with environmental problems, against "prophets", calling for a radical shift in our cultural and moral preferences to help humans come to terms with the biological and physical limits inherent to their dependence on the natural world (Mann, 2018). This article tries to refine Mann's typology by singling out an intermediary group.

The line of reasoning of the resolute adversaries of research on SG, who cast doubts over the ability of Modern-Cartesian science to substantively interfere with the natural world without wreaking environmental havoc, is ubiquitous in the statements made by opponents of nuclear energy. As for the reluctant supporters, they recognize both the limitations of Modern-Cartesian science and the uncomfortable fact that SG is likely to become more and more prominent as CC worsens so that responsible research ought to start now. Finally, the so-called ecomodernists are confident, to varying degrees, about the capacity of scientists and engineers to manipulate the Earth-system competently to enhance human welfare.

Ecomodernism is already a structured movement, which tackles many energy and environmental challenges, from decarbonization to GMOs. Their interest in SG aligns perfectly with the technologically informed optimism they exhibit when they participate to a broad range of technological controversies.

Overall, the contours and dynamics of the ongoing controversy about SG look very similar to other socio-technical controversies which are also part of the CC conversation. It differs slightly from discussions about nuclear energy and about the actual cost of decarbonization because of its extremely low visibility and its highly hypothetical nature. Yet, the tone of some of the exchanges, the ideological premises of the participants, and the main bones of contention are bound to sound very familiar to keen observers of the CC conservation.

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