Climate Policy and Political Viability:
Case Studies in Elite Institutional Support

By Chris J. Miller[1] • March, 2019

Background

If the threat posed by climate change presents a dauntingly complex policy domain rife with inherent challenges to ordinary processes of policymaking and implementation, as indeed it does, the domestic political resistance to addressing the threat only serves to exacerbate those challenges. Political resistance can be a significant cost factor in assessing policy costs and benefits (Richards 2000, Krutilla 2011), yet most scholarship on climate policy focuses strongly on traditional metrics of policy analysis — notably the economic efficiency and/or scientific effectiveness of any given policy instrument or combination of instruments. Political viability — the prospect of a policy proposal actually being enacted and implemented, given the interests motivating those who influence and direct the policymaking agenda — is all too often mentioned only in passing (Fullerton 2001) or not at all.

Climate policy options categorized as "geoengineering" have been observed to elicit less political resistance from the general public than others (Mercer, Keith and Sharp 2011, Pidgeon et al. 2012, Kahan et al. 2015). However, obstacles to the political viability of any given policy option do not exist solely in the form of individual attitudes amongst voters or legislators. There is a rich literature on the influence of organized interest groups, policy entrepreneurs, and other institutional actors, operating in a middle ground between ordinary citizens and formal policymakers. Moreover, this influence is not equitably distributed. While past scholarship often posited a framework of majoritarian pluralism, a "polyarchy" in which a wide diversity of

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interests is represented, Gilens and colleagues (Gilens 2012, Gilens and Page 2014) among other recent scholars find stronger support for "biased pluralism," in which the interests of corporate, business, and professional groups exert a dominant influence.

Accordingly, this paper will investigate the revealed preferences of elite (business and industrial) organized interests, as demonstrated through support for real-world geoengineering research programs and policy initiatives. The approach will be mixed-method, gathering case studies of geoengineering projects demonstrating a broad range of underlying characteristics, and employing qualitative comparative analysis (QCA) to interpret the criteria that drive their support.

This study provides a natural complement to the first part of my dissertation, focused on the individual attitudes of economic elites via a survey experiment, and makes meaningful contributions to the literature in its own right. It supplements the existing research on broad public attitudes toward geoengineering with findings on elite institutional attitudes—an element of political viability no less crucial than individual economic-elite attitudes, per the findings of Gilens and Page (2014). It also adds to the existing literature by compiling a detailed set of examples of geoengineering research proposals and initiatives to date, including relevant variables that characterize and categorize those examples. In so doing, it can not only inform future research, but provide guidance to climate policy advocates on how to shape future geoengineering proposals in a way most likely to attract constructive support.

Research Question

- *Beyond individual attitudes, interest groups and other institutional actors also influence political viability, with the wealthiest and most business-oriented exerting the greatest influence on prospects for agenda-setting and policy enactment. To what extent do geoengineering-related initiatives garner support from economic elites, including institutional actors?*

Relevant Literature

Organized interest groups and other institutional actors do not participate in opinion surveys, and indeed seldom take positions on completely hypothetical policy alternatives, focusing their attention instead on supporting or opposing initiatives with some credible chance of advancing in the policy arena. Fortunately, this does not mean only fully realized policy proposals: the literature reminds us that there is a spectrum of stages through which new innovations and initiatives develop, many of which may attract institutional attention and involvement. Many geoengineering prospects are situated among such developmental stages.

Grubb (2004), for instance, zeroes in on the role of technological innovation in GHG mitigation. He emphasizes that innovation cannot be taken for granted, but that it can be increased with a "push-pull" dynamic, with early publicly funded R&D efforts enabling later market-driven investment, noting that costs decline dramatically as technology improves. Grubb identifies six developmental stages of effective technical innovation: basic research, technology-specific research, market demonstration, commercialization, market accumulation, and diffusion. These stages limn the range of possibilities for one criterion key to distinguishing case studies, as discussed below in the Methodology section.

Current scholarship reflects a broad consensus that geoengineering is worthy of further in-depth research, although this view is not universal or unqualified. Schneider (2008) reviews the state of the literature on geoengineering techniques over the preceding two decades; he concludes that anthropogenic climate change is itself effectively a form of (unplanned) geoengineering, and identifies an emerging consensus that comparably engineered countermeasures are at least worthy of coordinated R&D efforts. He further observes that notwithstanding extensive scientific modeling, when it comes to policy choices "values will dominate the trade-off: for example, risk aversion versus risk proneness or the precautionary principle for protecting nature versus the unfettered capacity of enterprising individuals, firms or nations to act to improve their economic conditions" (Schneider 2008, 3858).

Some have gone so far as to propose recommendations for governance regimes. For instance, Vaughan and Lenton (2011) find existing research (to that date) limited largely to theoretical concepts and computer models, with little experimental work (aside from a few notable exceptions involving afforestation, ocean fertilization, CCS, and atmospheric carbon recapture). They note that field experiments are not always feasible, and emphasize that geoengineering should be seen as a supplement to mitigation efforts rather than a substitute. This is an important concern, as depending on the specific technologies under discussion — especially solar radiation management (SRM) as contrasted with carbon dioxide removal (CDR) — geoengineering efforts may only stave off the effects of climate change, without reducing the atmospheric GHG concentrations that cause those effects. In response, Vaughan and Lenton argue not only that a more ambitious research agenda is needed, but also for some kind of coordinated governance to provide oversight. In its absence, some geoengineering options (most notably stratospheric aerosols and ocean fertilization) could readily be implemented unilaterally by a single state or even a wealthy non-state actor, despite potential ethical and legal issues.

Reflecting similar concerns, Hahn et al. (2011) present an open letter from climate experts that offers a set of design guidelines for policies they deem "credible, easily monitored, and easily enforced." It is written in broad strokes, but echoes the stabilization wedge concept (Pacala and Socolow 2004, Socolow and Glaser 2009, Davis et al. 2013) in some ways—pointing policymakers away from attempts at ambitious "comprehensive" policy solutions, especially in the international arena, and encouraging them instead to take a flexible approach and embrace "all realistic options." In this context, not unlike Grubb and Schneider, Hahn and colleagues underscore the importance of scientific R&D and technological innovation, not just in renewable energy, but also in CCS and more novel forms of geoengineering.

Humphreys (2011) considers the challenges to coordinated governance of such technologies, including variations in comparative technological advantages and potentially differentiated obligations among states, and the possible role of CDR in emissions trading and carbon-offset schemes, and anticipates nearly intractable collective action problems comparable to those that have plagued conventional attempts to negotiate climate solutions under the UNFCCC framework. Similarly, Parson and Keith (2013) lament what they describe as an ongoing "deadlock" on geoengineering governance, and the way the lack of an agreed-upon oversight regime makes research riskier. They propose breaking this deadlock by drawing thresholds between small-, medium-, and large-scale experiments, with a moratorium on the last of these for the sake of risk aversion, but a more ambitious research initiative on the first. Alternately and more ambitiously, Dilling and Hauser (2013) propose a three-pronged framework for governance, focusing on (A) the direct physical risks of the technology being researched, (B) transparency and accountability in decision making, and (C) most abstractly, the social implications of the technology.

Barrett (2014) argues that effective governance of *any* kind could be a challenge, at least in regard to SRM, precisely because (as Vaughan and Lenton (2011) observe) the technologies involved are both relatively inexpensive and highly scalable, and could be deployed unilaterally or by a "coalition of the willing," evading any particular governing jurisdiction. The best-case approach he posits is one analogous to the way global satellite navigations systems are governed: although the now-familiar GPS technology was developed and deployed by the U.S. and made freely available for use worldwide, other regimes, notably Russia, China, and the E.U., have developed comparable systems under their own control. The obvious incentives for interoperability, nevertheless, have led to number bilateral agreements as well as a forum for multilateral interaction, under U.N. auspices, for all countries capable of such systems. Long, Loy, and Morgan (2015) also offer a somewhat optimistic view, tinged with pragmatism, suggesting that it is infeasible to ban or deter research and development until a comprehensive governance regime is in place, and suggesting instead that governance can and will co-evolve alongside research, starting with projects at the smallest scale and lowest risk level.

More recently, some scholars are coming to the conclusion that geoengineering efforts are not only worthwhile but inescapably *necessary*, not least due to past failures at comprehensive mitigation efforts and projected limits on the efficacy of mitigation going forward. In its most recent comprehensive report, the Intergovernmental Panel on Climate Change (IPCC 2014) modeled over a thousand scenarios. Of these, only 116 successfully limit climate warming to no more than the 2°C threshold considered the scientific consensus for safety… and of those, 108 rely on reducing atmospheric GHG concentrations using technologies yet to be developed (Kolbert 2017). Reacting to this, MacCracken (2016) argues that despite governance challenges, the time has come to focus on both atmospheric and surface-based technologies that can reduce climate impacts on a regional scale, if not yet a multinational scale. Honegger and Reiner (2018) argue that in light of current high costs, financial incentives can and should be used to motivate "progressive industrialized countries" to take first steps to deploy "Negative Emissions Technologies" (NETs). (NET is a common alternate term for CDR, especially in more recent literature, because of these technologies' capacity to reduce atmospheric concentrations of GHGs.) Minx et al. (2018) agree that such technologies are only weakly incentivized to date, but argue that a broad portfolio of NETs would be invaluable for staying within either a 1.5°C or a 2°C climate warming goal. Where CDR/NET is concerned, Amador (2016) argues that obstacles (other than cost) may actually be minimal, as extant atmospheric CO_2 is quintessentially a non-rival good; no one benefits from keeping it in the air, and no industry lobby will be threatened by efforts to remove it.

Rayner (2014) takes note of contrarian scholars, on the other hand, who oppose geoengineering R&D as a "slippery slope" on the grounds that the uncertainties and risks are too profound. Gardiner (2011), for instance, posits that even considering geoengineering options involves acknowledging a "moral failure of spectacular scope and import" (Gardiner 2011, p. 168), and hence that moving ahead with such options poses a classic moral hazard, by way of offering seeming quick fixes that tempt decision makers away from more comprehensive mitigation or adaptation efforts. Rayner (2014) posits that he might agree if the situation were constrained only to all-or-nothing action, a choice of extremes — but as it is not (e.g., he emphasizes the asymmetries between SRM and CDR, noting the different ways they can complement other efforts), he too advocates reducing ignorance (and associated risk aversion rooted therein) through a well-designed program of research. Similarly, Cusack et al. (2014) acknowledge the moral implications of geoengineering and agree that traditional emissions abatement strategies remain the most desirable policies, but also emphasize the importance of drawing informed distinctions, and offer several criteria for comparing and evaluating geoengineering techniques, concluding that many are low-risk and deserve immediate further research, while others (particularly SRM) pose more significant risks and, hence, ethical concerns. In that regard, Frumhoff and Stephens (2018) argue that SRM is also worth pursuing, and that despite both its known risks and the current low levels of public awareness, it can (and should) be researched in a way that promotes its scientific legitimacy by engaging multiple stakeholders in open discourse about the risks involved — including the competing risks of severe climate change, and the prospect that traditional approaches may be insufficient to contain those risks.

Merk et al. (2018) confront the moral hazard argument directly and empirically, using professional discourse and interviews to analyze expert opinion about both CDR and SRM, and concluding that experts do not indulge in moral hazard behavior, but instead retain policy preferences for mitigation as a first recourse, and demonstrate high awareness of not just the potential benefits but also the risks of geoengineering strategies. Exemplifying this awareness, an *ad hoc* group of experts (Rayner et al. 2009) had long since developed and promulgated what have come to be known as the "Oxford Principles," proposing five ethical guidelines for geoengineering research: that it be regulated as a public good, that decision-making involve public participation, that research be open and transparent, that impacts be assessed independently from feasibility, and that governance precede full-scale deployments. These principles were endorsed by the UK House of Commons' Select Committee on Science and Technology, and have provided a framework for later scholars (e.g., Corner et al. 2012, Welch et al. 2012, Rayner et al. 2013).

Meanwhile, as this scholarship has developed, a number of public or quasi-public institutions have weighed in on the topic. The Government Accountability Office, in a pair of reports (GAO 2010a, 2010b), finds that the National Science Foundation (NSF), Department of Energy (DOE), NASA, and a few other federal agencies "have funded some research and small demonstration projects of certain technologies related to proposed geoengineering approaches; but these efforts have been limited, fragmented, and not coordinated as part of a federal geoengineering strategy"

(GAO 2010a, 1). Specifically, the GAO finds that of about $4 billion of federal money invested in climate-related research in FY 2009-'10 (NAS 2015b), only $100.9 million was spent on projects potentially "relevant" to geoengineering, and most of that was focused on conventional mitigation research, with only $1.9 million focused directly on CDR or SRM — less than 0.05 percent of the total funds. In an in-depth follow-up report (GAO 2011), the GAO assesses CDR techniques according to a variety of criteria including "technology readiness level" (TRL), and finds none with a TRL above 3 (on a scale of 9), the highest being atmospheric carbon recapture. In that same report, however, it includes survey data indicating that 65 percent of the public would support increased geoengineering research, and about 45-50% would support spending federal money on that research. (It is tangentially noteworthy that a larger share (75 percent) support efforts at emissions reduction and/or increased reliance on solar and wind power as energy sources, but little policy headway has been made along those lines, for reasons that include the political resistance discussed earlier, exacerbated by the representational inequality discussed in the Introduction.)

Funding has been scant from the nonprofit sector as well. For example, a study on private philanthropy conducted by the Center for Carbon Removal, a nonprofit initiative of the Berkeley Energy and Climate Institute (Amador 2016), finds that less than 0.4 percent of climate-related philanthropy in the U.S. from 2008-2014 (a total of $5.3 million) was directly related to carbon removal (CDR) research.

The abovementioned GAO reports were components of a larger research project into the subject by the House Committee on Science and Technology, chaired at the time by Rep. Bart Gordon, in collaboration with a similar committee from the UK's House of Commons. The final report (House 2010) refers approvingly to the National Nanotechnology Initiative (NNI) — an executive-branch project from 2000, made statutory by Congress in 2003 and amended and reauthorized in 2010 — as a model for a cutting-edge interagency research initiative with clear oversight. The Committee observes that like geoengineering, nanotechnology holds the promise of revolutionary advances to the public good, but also faces concerns about uncertain risks. The NNI is a multi-agency initiative that coordinates nanotech research, development, education, and training, and also interfaces with international consortia such as the OECD to address safety concerns. The Committee's report recommends an initiative along comparable lines for geoengineering research. However, the report's recommendation was never realized.

The Congressional Research Service offers a similar overview (Bracmort and Lattanzio 2013), also noting nanotechnology research as an earlier model for successful governmental research (as well as nuclear power and molecular biology). The report takes particular note of inadequate incentives for private investment, including long-term uncertainties about both technical feasibility and the potential for commercialization, and the lack of a price mechanism on carbon emissions, and recommends filling the gap with a coordinated publicly subsidized research initiative, accompanied by a clear oversight regime. However, the recommendation was never realized.

The National Research Council of the National Academies of Sciences, with funding from the NSF, the U.S. intelligence community, and several federal agencies, has produced a pair of detailed reports on CDR and SRM respectively (NRC 2015a, 2015b). They recommend increased public investment in geoengineering research, focusing on CDR and small-scale field experiments in SRM (echoing Parson and Keith (2013)), along with construction of a clear oversight regime. However, the recommendation has not been realized.

Most recently, the U.S. Global Change Research Program (USGCRP), an executive-branch program of the Office of Science and Technology Policy that coordinates and integrates research efforts among 13 federal agencies, in its triennial report to Congress (USGCRP 2017), cites the NAS studies and notes that deliberate geoengineering may be a useful part of a portfolio of tools used to manage climate change, and emphasizes the need to understand both the possibilities and the limits of geoengineering, especially in light of the recognition (as in Vaughan and Lenton 2011) that other countries or the private sector may seek to use such tools to pursue climate interventions unilaterally. It emphasizes attention to the scale and scope of observations and modeling capabilities, in order to "define the smallest scale of [geoengineering] intervention experiments that would yield meaningful scientific understanding" (USCGRP 2017, 37) again echoing the logic of Parson and Keith (2013) and Long, Loy, and Morgan (2015). The steps it recommends, however, have not yet been realized.

In light of inadequate policy formation to date, then, it is instructive to examine the *ad hoc* geoengineering research initiatives that have nevertheless taken place.

Research Approach, Data, and Methodology

The goal of this study is to discern the climate policy attitudes of influential institutional actors — but of course, as noted, it is impractical to conduct an opinion survey of such actors. A different approach is called for, looking to other indicators, seeking revealed preferences in a real-world context. The methodologies employed by Baumgartner et al. (2009) to assess the effect of lobbying activities, and by Gilens (2012) and Gilens and Page (2014) to test theories of Biased Pluralism, although they are not directly applicable, provide guidance and incorporate elements that should be roughly adaptable.

As part of their large-scale Advocacy and Public Policymaking project, Baumgartner and colleagues begin with a random sample of Washington interest groups, weighted by volume of lobbying activity, and then conduct interviews to identify 98 issues on which those groups are active (most of which are very low-salience). They then identify and measure several variables characterizing the groups, issues, and policy outcomes, to facilitate quantitative modeling. They construct a composite index of group resources, comprising ten factors, and determine that comparative advantage on the resource index is (weakly) correlated with policy success. They also note a strong correlation (r=.73) between the resource index and the number of advocates on a given side of an issue from *Forbes* magazine's "Power 25" list, an annual ranking of the most powerful lobbying organizations in Washington. However, they caution against inferring that lobbying is a direct determinant of policy change, not least because policymaking involves a substantial status quo bias: commenting on the successful track record of the banking industry, for instance, they note that "the ability of some groups in society to mobilize more efficiency, and therefore to lobby with a louder and more effective voice in politics, is *already reflected in the status quo policy*." (Baumgarter et al. 2009, 250; emphasis in original.) Keeping a new policy option *off* the political agenda through strategic opposition, in other words, also emerges as an exercise of influence, and often an easier one.

Gilens and Page work with a wide-ranging large-N data set of 1,779 relatively high-salience policy proposals spanning 22 years, and are therefore also able to utilize a predominantly quantitative approach. In conjunction with this they springboard from the findings of Baumgartner and colleagues by compiling a list of interest groups appearing on the "Power 25" ranking over a span of years—including groups they categorize as both elite (business-oriented) groups and (in a few instances) mass-based (i.e., public interest)—supplemented by the ten industries with the highest lobbying expenditures not already represented on the list, as they lobby directly rather than through trade organizations. Gilens and Page code each group/industry for its positions (if any) on each policy proposal in the data set, calculate an index of Net Interest Group Alignments, and analyze the impact of the index measure on each policy outcome. Importantly, they find almost no relationship between interest group alignments and average citizen preferences, but a strongly significant relationship between interest group alignments and policy outcomes — and moreover, the magnitude of the effect for elite groups is almost twice that for mass groups.

The work of both Baumgartner et al. and Gilens et al. provides models to emulate by way of sources, as it makes exemplary use of public-domain information archived online, including organizational statements, government agency activities, legislative bills and statements, committee hearings, and news stories. However, there are also some notable distinctions. Baumgartner et al. focus on traditional lobbying and hence use access to Congress as a criterion for influence; Gilens and Page take a different approach to identifying influential actors, focused primarily on the largest players (as on the *Forbes* list) but emphasizing a distinction between (business oriented) elites and (public interest) mass groups.

The project at hand, although it strives to reflect similar underlying political dynamics, is of course focused much more narrowly than either of these—on a single salient policy domain and a subset of options within it—and certainly isn't intended to occupy a large team of researchers over a period of years. A conventional quantitative-modeling approach would be neither appropriate nor feasible. Accordingly, it becomes necessary to adapt the methodology to employ a case-study approach.

Qualitative Comparative Analysis (QCA)

In the context at hand, where the limited number of cases available makes a large-N approach unrealistic, it seems sensible to invert the analytical approach taken by Gilens and Page, and work bottom-up rather than top-down. The case-study orientation of this research, the small-N data set those cases comprise, the strongly theory-driven nature of the study (with the choice of variables influenced by Gilens and Page's findings concerning biased pluralism), and the defining characteristics of many of the cases, all recommend in favor of qualitative comparative analysis (QCA) as the method of choice.

First developed by political scientist Charles Ragin (Ragin 1987), QCA represents a bridge between qualitative and quantitative methodology, involving both within-case and cross-case analysis. It focuses on first identifying and then minimizing the combinations of underlying conditions contributing to various case-based outcomes, using set theory (based on relationships of necessity and sufficiency) and Boolean logic. Combinations of conditions can be evaluated in terms of both coverage (the percentage of case outcomes they explain) and consistency (the frequency with which a combination is associated with a given case outcome). In other words, coverage is a measure of the extent to which given (combinations of) conditions are necessary, while consistency is a measure of the degree to which they are sufficient.

This is particularly useful for analyses involving a modest number of cases, in which variation in some underlying indicator is less meaningful in precise terms than in how it signifies membership in a set. While QCA was originally developed only for dichotomous variables, it has subsequently been expanded to accommodate multiple-value conditions (mvQCA) and "fuzzy sets" with partial degrees of set membership (fsQCA), allowing even categorical conditions to be weighted by matters of degree. A fuzzy set is one in which membership depends on conceptual boundaries, not precise empirical measurement; for instance, the distinction between a person being bald, mostly bald, partially bald, or non-bald does not depend on knowing the exact number of hairs on the person's head (Schneider & Wagemann 2012).

Discussing the example of economic development by country, Ragin (2008) points out that any given selection of countries will demonstrate wide variation in an indicator such as GDP per capita, and a traditional statistical regression approach will treat the entire range of variation as equally relevant, and do likewise for whatever central tendency it indicates. That can be misleading, however, when what is of more interest to the researcher is membership in the set of "highly developed countries," for which *clusters* of variation in GDP per capita represent categorical degrees of membership grounded in theory (e.g., "mostly but not fully in the target set")… while the central tendency may not represent a meaningful breakpoint, and fine degrees of variation (especially near the extremes) may not be relevant at all. Measures like the mean are mere properties of the data (and subject to being skewed by outliers), and hence devoid of substantive conceptual meaning.

In this approach, it is crucial that values for each indicator condition be calibrated according to theoretically grounded external knowledge, linking that knowledge to the empirical analysis. As Ragin (2008, p. 83) puts it, "After all, it is more common for theoretical discourse to be organized around designated sets of cases (e.g., developed countries) than it is for it to be organized around generic variables (e.g., level of economic development)." Traditional statistical methods rely on correlational analysis which is insensitive to these calibrations, and incapable of assessing set-theoretic relationships. (E.g., it assumes measures vary symmetrically between independent and dependent variables, and cannot identify *asymmetric* relations, such as a combination of conditions that is sufficient but not necessary (or vice-versa) for a specific outcome.) If the researcher is interested in linear additive effects of single independent variables, such methods can be powerful and appropriate, but if the goal is to identify complex causal relationships among specific cases, fsQCA is a more suitable tool. Beyond asymmetry, it also allows for *equifinality* (different, mutually non-exclusive explanations of a phenomenon) and *conjunctional causation* (where the effects of a single condition unfold only in combination with others) (Schneider and Wagemann 2012).

The first step of the QCA in this study is to identify specific geoengineering cases to include in the data set. As noted above, while there has been much scholarly discussion of geoengineering in recent years, there have been relatively few specific policy initiatives to date. Still, it is possible to identify several dozen notable examples of relevant (usually small-scale or early-stage) proposals and initiatives, with (variously) governmental, interest-group, and private-sector financial support. Selected examples of these cases are discussed in the Case Studies section below.

For all cases identified as relevant, key defining variables ("conditions") are then coded and calibrated for analysis in "truth tables" reflecting all logically possible combinations. The coding criteria, chosen based on the geoengineering literature, are described in greater detail below. The fsQCA software, designed by Ragin, uses the Quine-McCluskey algorithm (a minimization procedure using Boolean logic) to parse the truth tables, identify necessary and/or sufficient conditions and combinations thereof, resolve contradictions, and report results.

Conditions

There are several types of relevant criteria ("conditions") assessed for each case study and coded into the QCA truth tables. They include the following:

Area of Focus

The case studies analyzed in this study, and exemplified by those described in the section that follows, reflect different areas of focus under the broad umbrella of geoengineering, subdivided into techniques focused on post-emission *carbon dioxide removal* (CDR, more broadly analogous to mitigation, as it targets causes) and those focused on *solar radiation management* (SRM, more analogous to adaptation, as it targets effects) (Royal Society 2009). Within CDR, the focal areas for specific case studies are widely varied, and include carbon conversion technologies shared with carbon capture and sequestration (CCS), a more conventional mitigation technique. SRM likewise encompasses a variety of distinct technologies. There are also broad-based research programs that divide their focus among multiples technologies.

Carbon capture and sequestration (CCS) is not strictly speaking a geoengineering technology, unlike carbon dioxide removal (CDR). It typically involves capturing CO_2 from stationary sources at the point of emission, and can do this from either fossil fuel- or biomass-based energy generation sources, so it doesn't necessarily result in a net reduction of atmospheric CO_2, although as Amador (2016) succinctly explains, it can do so when paired with biomass. The captured CO_2 is typically earmarked for geological (i.e., underground) sequestration, and is sometimes used for "enhanced oil recovery" (EOR), whereby CO_2 is injected into an oil reservoir to help with extraction, so again, the involvement of fossil fuels in the overall system means the total CO_2 reduction may not represent a net negative.

However, certain cutting-edge CCS research initiatives do show significant areas of overlap with geoengineering, especially insofar as some of them involve novel approaches to the "sequestration" part of the acronym, involving efforts to convert captured carbon for other industrial or commercial purposes. This functionality is every bit as useful for direct air capture (DAC) of CO_2 from the atmosphere, one of the prominent categories of CDR. Some of these conversion initiatives are accordingly relevant to this research, albeit tangentially.

More precisely, CDR — also often referred to as Negative Emissions Technology (NET), as noted earlier — refers to any of a number of technological processes for recapturing CO_2 (or other GHGs) from the atmosphere *after* the point of emission. Unlike traditional CCS, which is limited to stationary sources, it can also capture carbon from mobile sources such as motor vehicles, and holds the potential to reduce net atmospheric GHGs below present levels, independent of ongoing emission rates.

Among the different technologies under the rubric of CDR, from the least to the most "pure" in terms of their focus, are production of biochar, a soil additive created by the pyrolysis (high-temperature heating) of biomass, or of algae, which can be used for various purposes including agricultural feedstock (both of which overlap frequently with CCS initiatives); ocean fertilization, which involves either adding nutrients such as iron to the upper ocean to stimulate the growth of phytoplankton (which absorbs CO_2 through photosynthesis, although it can also be used as a means of aquaculture), or upwelling of deep ocean waters that are already nutrient-rich; enhanced weathering, which involves dissolving silicates or other minerals on land or water to increase natural CO_2 absorption (and, incidentally, counter ocean acidification); and finally direct air capture (DAC), which recaptures ambient CO_2 via strategically deployed "carbon sponges" or "artificial trees" using any of several types of chemical processes. Minx et al. (2018) and Fuss et al. (2018), among many others, provide an elegant consensus overview and taxonomy of these techniques.

Meanwhile, where SRM is concerned, the focal areas for specific case studies include stratospheric and tropospheric aerosols, cloud seeding, and oceanic micro-bubbles. While their means differ, all of these approaches share an equal focus on reducing the albedo (i.e., reflectivity) of the Earth system, thereby reducing the radiative forcing effect of solar radiation that is otherwise increased (firstly) by atmospheric GHGS and (secondly) by feedback loop effects such as arctic melting. SRM is substantially different from CDR, not merely in terms of the technologies involved but also in terms of the costs involved (typically lower), the time frames required (typically shorter), and the potential risks (typically higher). Nevertheless, CDR and SRM are conventionally united under the larger rubric of "geoengineering," as what they share is direct intervention into the climate system (Minx et al. 2018).

For purposes of QCA calibration, different technologies' degree of membership in the set of "pure" CDR methods varies: on a scale of 0-1, CCS is coded as 0.2 ("mostly out"), algae and biochar are coded as 0.4 ("more out than in"), ocean fertilization as 0.6 ("more in than out"), upwelling and enhanced weathering as 0.8 ("mostly in"), and DAC as 1.0 ("fully in"). All different SRM technologies are coded as 1.0, as they have no alternative purposes or intended effects.

Economic Elites

As part of the process of identifying relevant cases and developing a consistent coding framework, a key step of the QCA is to investigate the organizations and institutions these cases have relied upon for advocacy, expertise, and most importantly funding. This data has been gathered using resources including (for private companies) CrunchBase, the D&B Global Business Browser, Mergent Intellect and Mergent Online (by FTSE Russell), PrivCo, the Reference USA business database, and S&P Capital IQ, and (for nonprofit entities) GuideStar and the Foundation Center.

The dependent variable, *aka* the "outcome" in QCA nomenclature, is degree of membership in the set of cases with strong support from entities identifiable as economic “elites." I accordingly code the actors involved according to the criteria employed by Gilens and Page (2014) — as either mass-based or elite. It makes sense to take a fairly organic approach to this, identifying leading figures and institutional entities among those who have taken a hand on behalf of (or against) these projects; as the cases include public/private and entirely private ventures as well, recognized lobbying clout may sometimes signify relative status, but is not the most important criterion. Mass-based actors include public-interest-oriented interest groups (nonprofits, NGOs, foundations) as well as public-sector (governmental) entities. Elite actors, with disproportionate economic and political influence, include groups oriented around business, industrial, or financial interests, as well as wealthy private individuals operating as policy entrepreneurs. In instances involving public-private partnerships, the status is weighted by relative degree of involvement. Specific examples are discussed in the Case Studies and Analysis sections that follow.

Degree of Support

For calibration purposes, each case's degree of membership in the set with "strong elite support" is measured by an indexed metric involving two sub-factors. First is the degree of economic eliteness of a case's primary supporters: the public sector is coded as 0.0 (as government agencies are constrained by the need to do as directed by policymakers, and have little ability to exert influence over them); nonprofits (except those founded for the specific purpose of promoting geoengineering) are coded as 0.2, as they may attempt to exert political influence, but it is muted by their public-interest orientation; partnerships between nonprofits and private entities are coded as 0.4; public-private partnerships are coded as 0.6; and private parties (with the exception of universities, which are grouped with nonprofits) are coded as 1.0, as they have the most reliable influence on political feasibility.

Second is the extent of support exhibited by the case's stakeholders, which is based on the conceptual framework utilized by Gilens and Page (2014), considering "both the magnitude of the impact of the policy change on the group or industry in question [i.e., depth] and also the extent to which the breadth of individual members of the group or industry would be affected [i.e., breadth]" (Gilens and Page 2014, Supplementary Materials, 3–Interest Group Alignment Coding). If success of the initiative in a given case would impact stakeholders in a way that was substantially *both* broad and deep, Gilens and Page termed it "strong" (coded here as 1.0); if the impact would be either broad or deep, they termed it "somewhat" (coded here as 0.6); if it was neither, they termed it not favorable (coded here as 0.2).

The product of these two factors is an indexed measure of the outcome variable, "strong elite support," that itself ranges from 0 to 1, with 0.95 counting as full inclusion in the set, 0.05 counting as full exclusion, and 0.5 as the midpoint.

Developmental Stage

Grubb (2004) attempts to debunk the "false dichotomy" between "push" and "pull" theories about innovation in climate mitigation technologies, and in the process lays out a useful incremental taxonomy of developmental stages for such technologies that is easily and logically extensible to the geoengineering cases at hand. He defines these stages as:

1. *basic research and development*
2. *technology-specific* research, development, and demonstration
3. *market demonstration* to potential real-world purchasers and users
4. *commercialization*, involving adoption by established firms or newly created firms
5. *market accumulation*, in which use of the technology expands in scale
6. and *diffusion* to large-scale usage.

Each case study is coded according to these states. For purposes of QCA calibration, these stages are then translated to degrees of membership in the set of "fully developed geoengineering policy options," with stage one = 0.2, stage two = 0.4, stage three = 0.6, stage four = 0.8, and stages five and six both = 1.0 (a level not yet achieved by any case study in this data set).

Scope of Enterprise

The parameters of each case study are analyzed according to understandings gleaned from the literature, and the scope of the project is categorized as either non-state (for the smallest ventures), subnational (e.g., U.S. states and Canadian provinces), national, or multinational. These categories are calibrated for "degree of membership in the set of global-scale solutions" respectively as 0.2, 0.6, 0.8, and 1.0.

Program Origin

Each case study has its origins as either a public project (launched by some branch of government, or a public university), a nonprofit project (launched by a private university or an existing nonprofit organization), a public-private partnership, or a fully private enterprise (also including newly-created special-purpose nonprofits). These categories are calibrated for "degree of membership in the set of private-sector initiatives" respectively as 0.0, 0.2, 0.6, and 1.0.

Locus of Operations

Insofar as this research focuses on political feasibility within the United States, it reflects an understanding widespread in the literature that projects within this country are by far the most salient for policymakers in this country. Each case study under examination has its operations focused primarily on foreign soil, in partnership between U.S. and foreign parties, or entirely in the U.S. These conditions are calibrated for "degree of membership in the set of domestic U.S. operations" respectively as 0.2, 0.6, and 1.0.

Opposition

Interestingly, notwithstanding the scholarly concern over risks, there is little organized opposition to geoengineering. The only substantial entity or initiative staking out a clearly opposed position is Geoengineering Monitor, a nonprofit organization that runs a web site (geoengineeringmonitor.org) dedicated to opposing all forms of geoengineering, on the basis of four expressed reasons: the site contends that it doesn't work, that it would inevitably be weaponized, that it detracts from real solutions (i.e., the moral hazard argument), and that it threatens human rights and biodiversity.

Geoengineering Monitor is a joint project of the ETC Group and Biofuelwatch. The ETC Group (aka the Action Group on Erosion, Technology, and Concentration) is a Canadian nonprofit that focuses on socioeconomic, ecological, and governance issues surrounding emerging technologies, especially in the developing world. Its most recent financial statement shows that its total revenue for FY 2017 was only $813,000, of which slightly more than half was provided by (and spent on) a variety of small projects. This was supplemented by grant funding, the largest single portion of which was slightly over $30,000 from the Heinrich Boell Foundation, a German NGO with close ties to the German Green Party. Biofeulwatch is a UK-based NGO dedicated to opposing all forms of biofuels. It does not have financial statements available, but its web site reports funding from a short list of philanthropic organizations, including the Boell Foundation.

In sum, Geoengineering Monitor is a project with sparse funding and sparser activities. It does not appear to engage in lobbying or activism. Its main avenue of influence is the web site itself, which offers a small assortment of publications and reports, as well as an impressive database and map of the projects and programs it opposes. This database is global in scope but also remarkably indiscriminate, as along with indisputably genuine geoengineering projects it also includes purely academic research and modeling efforts, private ventures that are long defunct, and initiatives related to CCS and other technologies that are related only marginally (or not at all) to geoengineering. Moreover, as its opposition is so indiscriminate, even if it were significant it would present a constant factor with equal impact on any and all case studies worth investigating. Accordingly, it is not treated as a meaningful factor in this research.

Otherwise, the most prominent incident of organized opposition to field research in geoengineering came in response to the UK-based SPICE Project (Stratospheric Particle Injection for Climate Engineering) in 2011. SPICE is a joint project of scientists from Oxford, Cambridge, Edinburgh, and Bristol Universities, one component of which had involved mounting an experiment intended to test the effects of particle injection via a high-altitude balloon. A petition campaign was mounted by the ETC Group and a small group of allies, after which the UK's Engineering and Physical Science Research Council (EPSRC), one of the sponsors of the project, put the experiment on indefinite hold (Ruz 2011).

Beyond that single incident, I have uncovered no organized opposition specifically targeting any project included as a case study in this research.

Exposure to Institutional Constraints

While organized opposition *per se* does not provide any counterweight to organized support of geoengineering (elite or otherwise), there are institutional constraints that can impose limits on certain kinds of initiatives. As the world's oceans are a longstanding subject of international law, they are unsurprisingly the main domain in which these constraints have arisen.

Specifically, the UN Convention on Biological Diversity (CBD) called in 2008 for a halt on ocean fertilization activities, except on a small scale. In 2010 the CBD acted more broadly, inviting parties to the Convention to "consider" a nonbinding moratorium on geoengineering activities "until there is an adequate scientific basis" to justify them, except for small studies conducted in controlled settings (Tollefson 2010, Bodansky 2011). Note, however, that the U.S. is not a party to the CBD.

Similarly, in 2008 the London Convention and Protocol, which regulates dumping of waste at sea, adopted a resolution urging "utmost caution" about ocean fertilization activities. Although this is also nonbinding and includes caveats, both it and the CBD's efforts have been leveraged as rhetorical ammunition against some ocean-based geoengineering experiments. Some analysts have also suggested that the 1987 Montreal Protocol on the ozone layer may pose an obstacle to stratospheric SRM experiments, although this proposition has not been tested (Bodansky 2011).

On the whole, however, while scholars and public officials have issued many calls for various governance regimes to oversee geoengineering research, it remains substantially unregulated. For purposes of QCA calibration of "membership in the set of cases facing institutional constraints," projects involving SRM via stratospheric aerosols have been coded 0.2

(or 0.4 if, like SPICE, they have faced substantial opposition), while projects involving CDR via ocean fertilization are coded 0.8.

Case Studies

In the distinctive policy subdomain of climate-related geoengineering projects, one would be hard-pressed not to detect a pattern among the case studies available for examination: typically small and isolated projects, often accompanying proposals for significant public research initiatives, but with no action from policymakers following up on those proposals. Nonetheless, a number of research projects have been launched in recent years without waiting for public-sector guidance or support. Overall, 53 cases have been identified, coded, and calibrated for QCA. The full table of cases is found in the Appendix. This section discusses a selection of noteworthy examples, arranged by (and chosen to represent) different areas of substantive technological focus. Table 1, below, offers a concise recap of the variety of technologies involved.

The cases identified, and the examples discussed, also represent a range of other defining criteria, including developmental stage, geographic scope, program origin and location, and others, as detailed under Conditions above.

Type	Subtype	Description
CDR (Carbon Dioxide Removal)	CCS (Carbon Capture & Sequestration)*	Captures CO_2 at the point of emission, in various forms suitable either for storage or for commercial usage. **Not* a form of CDR, strictly speaking, but often a complementary or transferable technology.
	Biochar production	Created by pyrolisis of biomass. Can be used as a soil additive. Often overlaps with CCS projects.
	Algae production	Algae consume CO2. Can be used as agricultural feedstock or fuel. Often overlaps with CCS projects.
The following subtypes of CDR are also frequently referred to as ***NET*** *(Negative Emissions Technologies):*	Ocean fertilization	Adding nutrients such as iron increases CO2-absorbing phytoplankton.
	Ocean upwelling	Brings deep nutrient-rich waters to the surface.
	Enhanced weathering	Dissolving minerals on land or water to increase natural CO_2 absorption.
	DAC (Direct Air Capture)	Uses chemical processes to recapture previously emitted CO_2 from the atmosphere.
SRM (Solar Radiation Management)	Micro-bubbles	Increases albedo by creating tiny bubbles on surface water by various means (ships' wakes, etc.)
	Cloud seeding	Increases albedo by increasing cloud cover.
	Stratospheric or tropospheric aerosols	Increases albedo by dispersing reflective compounds in upper atmosphere.

Table 1. Geoengineering Variations Among Cases

Carbon Capture and Sequestration (CCS)

As noted above, CCS is not intrinsically a geoengineering technique, and most research projects and initiatives related to it are not relevant to the research at hand. However, certain innovative techniques for carbon-neutral "recycling" of captured CO_2 into synthetic fuels, chemicals, polymers, or other materials or products, can provide a useful business-case "stepping stone" leading the way to more dedicated CDR activities (Amador 2016). In this context, a small selection of CCS cases stand out as relevant.

Case: Carbon XPRIZE

The XPrize Foundation, launched in 1995, is a nonprofit foundation organized around developing new technologies through incentivized competitions. It is designed to cross national, disciplinary, and industrial boundaries. The first XPrize was a $10 million prize for suborbital spaceflight, and more than a dozen contests have followed, with diverse goals ranging from medical diagnostic devices to clean water generation to educational technologies.

Of relevance here is the Carbon XPrize, a 4.5-year contest launched in September 2015, focused on technologies to convert CO_2 into marketable products, as a means of mitigating climate change (XPrize Foundation 2018). The $20 million prize purse will go to the conversion technology producing the greatest value, as determined by (A) the amount of CO_2 they convert, and (B) the net value of the converted product(s), incorporating economic value, market size, and environmental impact, as judged by a panel of experts.

The Carbon XPrize is perhaps the most noteworthy example in this category, as it has incentivized research by a wide range of project teams. Out of 27 semifinalists chosen in 2016 based on written proposals, ten finalist research teams were selected in April 2018, with conversion outputs ranging from bioplastics to graphitic nanoparticles to concrete alternatives and more. Each finalist won an equal share of a $5 million "milestone" prize. Although the finalists are an international assortment hailing variously from the U.S., Canada, China, India, and Scotland, they will conduct their final-stage research at Integrated Test Centers in North America, with five teams competing at Center located at a coal-fired power plant in Gillete, Wyoming, and five competing at a Center located at a natural gas-fired power plant in Alberta, Canada (Alberta 2017). The winner will be announced in March, 2020.

The XPrize Foundation recruits different sponsors for its various contests. For the Carbon XPrize, there are two sponsors, both corporate. One is NRG Energy, a power generator and retailer that is the corporate parent of Reliant Energy, with operations in Texas and New Jersey; in 2009 NRG started investing in clean energy research, with the announced goal of reducing its carbon emissions 50 percent by 2030 (Cardwell 2014). The other is COSIA (Canada's Oil Sands Innovation Alliance), an industrial association composed of ten companies that collectively account for over 90 percent of the oil sands production in Canada, with a shared charter to improve performance in four environmental areas, one of which is greenhouse gases (COSIA 2018).

Case: Alberta Carbon Conversion Technology Centre

The Alberta Carbon Conversion Technology Centre (ACCTC) was established in Alberta, Canada, in 2017, as a publicly funded test facility for innovative CO_2 capture and conversion technologies. The Centre's primary initial purpose is to provide a home to the Alberta-based finalists for the Carbon XPrize (discussed above). It is owned and operated by InnoTech Alberta, a government corporation financed by the Ministry of Economic Development and Trade. ACCTC received CA$20 million in startup funding, with sourcing evenly divided between the provincial and federal governments (Alberta 2017).

Case: Arizona Public Service Company

In 2009, the Arizona Public Service Company, a private corporation that is the largest public utility in Arizona, received a $70.5 million grant from the U.S. Department of Energy for a project designed to use CO_2 from its coal-fired power plants to feed algae that could be developed into biofuels (John 2009). The company also sought part of a $100 million pool of

DOE funds earmarked specifically for experimental CCS technologies. Like many other algae biofuel projects, this one was cancelled when its technology proved not to be efficient at a commercial scale (Wesoff 2017).

Carbon Dioxide Removal

CDR, as discussed above, is an umbrella terms that describes a portfolio of different technologies. The most focused and ambitious of these involve direct air capture. DAC is at the forefront of current discourse about "negative emissions technologies" (NET), and is the focus of startup firms such as Carbon Engineering (detailed below), Global Thermostat (founded in 2010), and the Swiss firm ClimeWorks AG (founded in 2009), all of which describe their technologies as market-ready or close to it, as well as other cases included in the data set, and think-tanks such as the Center for Carbon Removal (Kolbert 2017, Peters 2017). Other ventures are also exploring related technologies such as biochar production, ocean fertilization, and enhanced weathering.

Noteworthy projects exploring CDR options include the following:

Case: Carbon Engineering

Carbon Engineering is one of the leading private companies in the emerging field of DAC technology. Founded in 2009 by physicist Dr. David Keith (then of Carnegie Mellon and the University of Calgary, now of Harvard), with investments from Microsoft billionaire Bill Gates and Canadian oil sands billionaire N. Murray Edwards (Vidal 2018), the company set up its first pilot DAC system in 2015.

It conducted a new round of private financing in 2016 (McCullough 2016), and in mid-2018 announced that results to date demonstrate the ability to capture CO_2 for as little as $94 per ton (Service 2018, Keith et al. 2018). It has launched plans to validate the scalability of the technology to commercial levels, aiming at large-scale deployment by 2021 (Carbon Engineering 2018). The company also reports that it has led projects funded by various American and Canadian government agencies, including the U.S. Department of Energy. CEO Adrian Corless anticipates that success in this emerging domain could mean "trillion-dollar markets" (Kolbert 2017).

Case: Cool Planet

Cool Planet Energy Systems is a private company founded in 2009. Originally focused on converting biomass to renewable fuel, the firm faced challenges in that market as oil prices fell in recent years, and starting in 2016 shifted its emphasis to biochar production, which it found easier to commercialize (Vinluan 2017). The company conducted more than 70 field trials in its first year of biochar testing, and has aimed strongly at the agricultural market. In 13 successive rounds of funding since its founding, the company has raised a cumulative $261 million of venture capital, from investment firms and familiar corporate names such as BP, UBS, Conoco Phillips, and Google Ventures, as well as individual investment from Mexican retail billionaire Augustín Coppel, who now holds a seat on the company's board (PrivCo 2018).

Case: Ocean Nourishment Corporation

Many ocean fertilization efforts have been stymied in recent years, largely due to the institutional constraints described above. Several firms founded for this purpose have become defunct, even prominent ventures such as Climos, founded in 2006, for which notable technology entrepreneur Elon Musk was a founding investor. However, some remain at least nominally active. Among these is Ocean Nourishment Corporation, a private Australian corporation founded in 2004, which holds three patents pertaining to oceanic carbon sequestration. The company reports that it continues to seek suitable experimental sites, in collaboration with local populations and governments, but acknowledges that commercial implementation will await further research to satisfy regulatory concerns.

Case: Leverhulme Centre for Climate Change Mitigation

The Leverlhulme Centre for Climate Change Mitigation (LC3M) was established in 2015 at the University of Sheffield through a 10-year, £10 million grant from the Leverhulme Trust, a UK charitable foundation. It has a nine-member International Advisory Board composed primarily of scholars, including Dr. Ken Caldeira of the Carnegie Institution and Dr. James Hansen of Columbia University. It supports four multidisciplinary research themes, all of which involve aspects of enhanced weathering as a means of CO_2 removal: Earth Systems Modeling, Fundamental Crop Weathering Science, Applied Weathering Science, and Sustainability & Society. The LC3M is currently conducting applied weathering trials in three locations around the world: Illinois, Australia, and Borneo (Leverhulme 2018).

Solar Radiation Management

SRM, as discussed above, comprises a suite of technologies that together are considered to be less expensive and faster-acting than CDR, but also to pose greater risks of unanticipated consequences. Noteworthy projects exploring SRM options include the following:

Case: Academy of Finland

The Academy of Finland's Research Programme on Climate Change (FICCA), roughly the Finnish equivalent to the NSF, together with the Academy's Centre of Excellence Programme and the Maj & Tor Nessling Foundation (an environmental nonprofit), funded a study at the University of Eastern Finland focused on modeling SRM via the use of atmospheric aerosols into the stratosphere and troposphere. It found that these methods would successfully cool the surface (and that global airline and shipping exhaust could be harnessed for this purpose), but not at a level sufficient to counteract the overall warming effect of current levels of GHG emissions; hence, they would only be useful as a stopgap harm-reduction measure (Laakso et al. 2016).

Case: Keith Group

The Keith Group is a team of researchers at Harvard University, led by Dr. David Keith, focusing on SRM research. While Dr. Keith is a founder of the CDR firm Carbon Engineering, discussed above, and remains its Executive Chairman, he strongly opposes commercial development of SRM technologies, favoring academic research into its potential risks and rewards. In particular, the Keith Group is heavily involved in Harvard's Solar Geoengineering Research Program, a broader interdisciplinary initiative (Keith Group 2018). Its current projects also include the Stratospheric Controlled Perturbation Experiment (SCoPEx), using a propelled high-altitude balloon to test stratospheric aerosols (SCoPeX 2018).

Since its founding in 2011, the Keith Group has received funding from a variety of public and private sources, including the U.S. National Science Foundation (NSF) and Canada's Natural Sciences Engineering and Research Council (NSERC), multiple internal Harvard grants, and a series of gifts from Bill Gates via FICER (described below).

Case: Marine Cloud Brightening Project

The Marine Cloud Brightening Project (MCBP) is a multi-institutional research collaborative housed at the University of Washington. Founded in 2006 with a $300,000 grant from FICER (discussed below), to date its collaborators have produced 16 papers studying the prospects for achieving global cooling by increasing the reflectivity of clouds, a concept first envisioned in 1990 by British physicist John Latham (Latham et al. 2012). It hopes to do this by developing spray technology that can generate microscopic seawater particles and inject them into low-lying clouds. It conducted its first field experiments in 2015 (Krieger 2015).

Case: GeoMIP

The Geoengineering Model Intercomparison Project (GeoMIP) seeks consensus among competing climate models for various scenarios incorporating SRM. (It specifically does not address CDR, for which a similar role is performed by a separate project dubbed CDR-MIP.) It is jointly led by Dr. Alan Robock of Rutgers University and Dr. Ben Kravitz of the Pacific Northwest National Laboratory (an arm of the Department of Energy), and receives funding from both, as well as from the National Science Foundation under grants GEO-1240507 (a cooperative agreement which also funds SCRiM, below, on which Robock is a co-PI) (NSF 2012b) and AGS-1157525 (NSF 2012a). GeoMIP prescribes matching suites of experiments to all its participating modeling teams, from institutions around the world, and also hosts an annual conference at which participants meet in person. It is endorsed by the World Climate Research Programme (WCRP).

Multi-focus

Some broad-based geoengineering research and development initiatives do not confine themselves to a single mode of technology, but instead explore a range of possibilities. For example:

Case: FICER

The Fund for Innovative Climate and Energy Research (FICER) is a project headquartered out of Harvard University, run by Dr. David Keith of the Harvard faculty and Dr. Ken Caldeira of the Carnegie Institute for Science. It is not a research project in itself, but makes grants to climate-related research projects, and since 2007 has funded 13 projects totalling roughly $4.6 million. FICER is funded from the personal resources of billionaire Bill Gates, founder of Microsoft.

In addition to traditional climate modeling and clean-energy research, FICER specifically identifies geoengineering-related areas of focus, including atmospheric carbon recapture ("developing technologies to remove carbon dioxide from the atmosphere") and solar radiation management ("researching approaches to reduce planetary absorption of solar radiation"). It does not fund field testing of SRM, but has done so for CDR. At least nine of its 13 funded projects involve specifically geoengineering-related research projects, to the tune of $3.8 million (FICER 2018).

Case: SCRiM

The Sustainable Climate Risk Management network (SCRiM), centered at Penn State University, is a transdisciplinary team of scholars from across 19 universities and five research institutions in six different countries. Its mission is organized around answering a multi-part question: "What are sustainable, scientifically sound, technologically feasible, economically efficient, and ethically defensible climate risk management strategies?" (SCRiM Overview, 2018) Among its lead researchers is William Nordhaus of Yale, winner of the 2018 Nobel Prize in Economics for his work on climate change (together with Paul Romer of New York University, for his work on the role of policy in fostering technological innovation).

Out of SCRiM's twelve current "transdisciplinary projects," (SCRiM Projects, 2018) at least four directly involve geoengineering. In particular:

Project #2 examines how the high uncertainty of certain climate threshold responses (e.g., in the Greenland ice sheets) affects the efficiency trade-offs between emissions reduction, and other responses such as geoengineering.

Project #3 addresses the potential of solar geoengineering (i.e., SRM) — particularly stratospheric aerosols and cloud brightening — in light of its uneven regional impacts on temperature and other climate variables, using climate modeling to evaluate various combinations of geoengineering techniques and their ecosystem impacts, and examine strategies to minimize those impacts.

Project #5 examines how limits to local adaptive capacity influence the trade-offs with larger-scale efforts at both mitigation and geoengineering, and builds mental models of local decision-making processes.

Project #11 seeks to identify the scientific and ethical criteria necessary to assure effective international governance of geoengineering research and policies.

The SCRiM network is supported by the National Science Foundation under the NSF Directorate for Geosciences' cooperative agreement GEO-1240507 (NSF Award 2012b), an $11 million award dating to 2012 (and still ongoing) focused on climate risk management.

Case: EuTRACE

The European Transdisciplinary Assessment of Climate Engineering (EuTRACE) was a two-year project involving a consortium of independent experts from 14 institutions across five EU countries (Austria, France, Germany, Norway, and the UK), charged with studying and reporting on the current state of both CDR and SRM geoengineering technologies, and assessing their potential, risks, and implications. Related objectives included outreach to and dialogue with the public, policymakers, and other civil society stakeholders, and identifying future policy pathways and critical gaps in understanding (Schäfer et al. 2015).

EuTRACE was launched and coordinated by Germany's Institute for Advanced Sustainability Studies, and funded primarily by the EU's Seventh Framework Programme for research, technological development, and demonstration, which provided roughly €1,000,000 out of the project's overall budget of €1.36 million. In its final report it identified several promising possibilities and just as many challenges, but explicitly declined to reach any clear conclusions as to whether any specific geoengineering technology could be developed, scaled, and implemented in a way that would significantly reduce climate change, nor about what the social and environmental costs of such an effort would be. It recommended a coordinated program of interdisciplinary research combined with stakeholder dialogue.

Analysis

Stated succinctly, the goal of this study is to discern the overall level of support from economically elite private and institutional actors for geoengineering projects to date, contingent on underlying conditions observed in the case studies. The expected outcome was that, as with economic elite individuals, elite interest groups and private actors would show significant openness to geoengineering solutions, with a clear relationship to their potential for commercialization and the degree of risk involved. While the limited sample size may impose constraints on generalizability, fsQCA analysis is designed to accommodate such limits even when they provide an obstacle to traditional quantitative analysis. The results of the fsQCA analysis follows, with corresponding discussion.

Results

After calibrating all the conditions for all the cases, I imported them into fsQCA software and constructed "truth tables." I then conducted analysis of these tables reflecting a variety of scenarios.

The first goal was to determine conditions (and combinations thereof) relevant to an outcome of successful membership in the set of cases with strong economic elite support. To this end, I conducted analyses involving various permutations of conditions, including a focus on either CDR or SRM, a focus on only CDR or SRM, a focus on geoengineering regardless of type, a "maximum" model including all other potentially relevant conditions, a "minimum" model at the opposite extreme, and an "optimal" model containing those conditions considered most likely to be theoretically relevant.

The conclusions were broadly consistent. The inclusion of a generalized, nonspecific geoengineering focus (in addition to the specific degree of CDR or SRM focus) provided no added value to the results; as compared to the optimal model, the most "parsimonious solution" for this model slightly increases the solution coverage (the portion of successful cases explained by the designated combinations of conditions), from 0.644 to 0.724, but the solution consistency score (indicating the extent to which the designated combinations can be relied upon as sufficient conditions leading to the outcome) is dramatically reduced, from 0.875 to a much more ambiguous 0.611. Consistency scores above 0.8 are generally considered substantive enough to establish a set relation. With this confounding condition excluded, the parsimonious solution includes only theoretically sounds combinations, as follows:

```
--- PARSIMONIOUS SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.826087
                                 raw       unique
                               coverage    coverage   consistency
                              ----------  ----------  ----------
CDRfocus*Scope*Origin         0.448276    0.0689656   0.847826
CDRfocus*Origin*Locus         0.528736    0.114943    0.901961
CDRfocus*~DevStage*Origin     0.390805    0.0229886   0.894737

solution coverage: 0.643678
solution consistency: 0.875
```

Table 2: Conditions Sufficient for Strong Elite Support

(Each line represents a "solution term" combining relevant conditions in a way that also includes membership in the outcome set. "Raw coverage" measures the proportion of memberships in the outcome explained by each term in the solution. "Unique coverage" measures the proportion of memberships in the outcome explained solely by each individual solution term, excluding all others. "Consistency" measures the extent to which each solution term is a subset of the outcome, i.e., sufficient to produce that outcome. "Solution coverage" and "solution consistency" represent these measurements for the full set of solution terms.)

It is also possible to visualize fuzzy set relations with a chart. For example, the highest scoring solution term in the set above (representing cases' degree of membership in the combination *CDRfocus*Origin*Locus*) can be charted against the outcome as seen in Figure 1, below. A plot with cases situated predominantly above the line signals a consistent relationship.

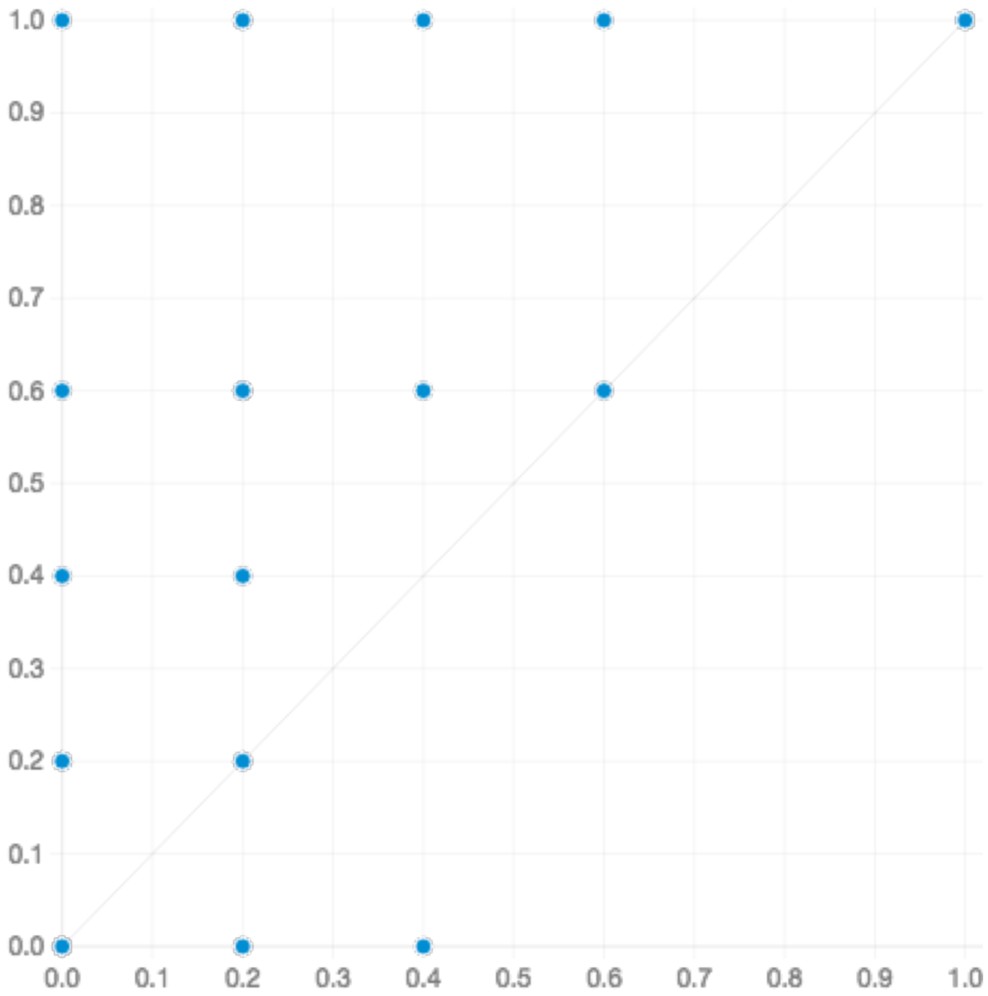

Figure 1: Strong elite support (Y axis) vs. Membership in Solution Set (X axis)

Meanwhile, clearly, projects focused on SRM drop out of the solution. The conditions that are common to each and every solution term are membership in the set of projects related to CDR, together with membership in the set of projects originating in the United States… in combination with any one of three other conditions, specifically a broad geographic scope, an American locus of operations, or an early developmental stage (the ~symbol signifies negation). Interestingly, omitting institutional constraints from the model produced the exact same solution terms and measurements, suggesting that such constraints are simply not (at least, not yet) a relevant factor related to elite support. On the other hand, omitting either CDR or SRM cases only served to reduce the clarity of the solution.

As a complementary analysis, I also modeled scenarios relevant to an outcome *negating* membership in the set with strong economic elite support. With or without institutional constraints included, the optimal model's parsimonious solution was as follows:

```
--- PARSIMONIOUS SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.857143
                        raw       unique
                     coverage    coverage   consistency
                    ----------  ----------  ----------
~Origin             0.769663    0.35955     0.958042
~CDRfocus*~Locus    0.168539    0.0393258   0.9375
SRMfocus*Scope      0.41573     0.0393258   0.891566

solution coverage: 0.85955
solution consistency: 0.916168
```

Table 3: Conditions Sufficient for Lack of Strong Elite Support

The included solution terms appear logically related to the solution terms for the successful cases. Specifically, to be included in the set of cases *least* likely to have strong elite support, it is sufficient for a project to originate outside the U.S., to demonstrate a lack of CDR focus combined with operations outside the U.S., *or* to have a focus on SRM combined with a broad geographic scope.

Discussion

From the analysis of the geoengineering case studies included here, it seems clear that there are important criteria common to the project that attract support from the kind of economic elite individuals and institutions likely to wield significant influence among policymakers.

Specifically, it is important that a project be substantially related to CDR technologies, and that it originate in the United States, together with any one of three additional conditions (U.S.-based operations, an early stage of R&D, or a broad geographic scope). SRM technologies clearly do not attract the same kind of elite support (although they may garner support from government agencies or nonprofit organizations), despite their lower financial barriers to entry and their potentially faster benefits.

The reasons for this are uncertain, but one might reasonably suppose that they include the perceptions of greater risk and the concomitant near-consensus that such projects be limited only to purely scientific research on a small and controlled scale, whereas CDR projects are perceived to be more scalable and present clearer prospects for commercialization.

From these findings, we can draw provisional conclusions for policy entrepreneurs seeking politically feasible policy responses to climate change. It appears that SRM research is likely to be consigned to the back burner for the foreseeable future, while CDR (*aka* NET) becomes more economically and politically salient. Meanwhile, although projects based in other countries may provide guidance as to best practices for American researchers, they are unlikely to catch the attention of domestic elites or policymaker on their own, unless or until replicated in the United States.

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Appendix

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