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ADVANCING PUBLIC CLIMATE ENGINEERING DISCLOSURE

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The world does not appear to be on track to achieve the absolute greenhouse gas (GHG) reductions needed to avoid the brunt of a dangerous rise in global temperature. Despite a 2.6 percent reduction in global carbon intensity and early signs of a plateau in the absolute growth of global carbon emissions, 2017 was the second-hottest year worldwide on record—after 2016. The global decarbonization rate is projected to be half of what is needed to limit global temperature rise to the two-degree-Celsius target. The United Nations and industry experts are warning that these dangerous gaps need to be filled.

Two main pillars are currently in place to support efforts to address climate change. The first includes concerted commitments by nearly all nations under the Paris Agreement to mitigate their GHG emissions. The second involves national and subnational efforts to build greater resilience to adapt to the impacts of climate change.

Yet, these have not been enough. And gaps in progress are hastening the incorporation of a third pillar into the climate policy architecture: climate engineering, also known as geoengineering. New transparency mechanisms, such as a public clearinghouse, are needed to ensure that societies are fully informed about these new climate techniques, research findings, and their deployment. The central goal of a clearinghouse would be to gather all-encompassing and up-to-date climate engineering data and make it publicly available as the field unfolds.

Such transparency will be integral to managing the addition of a new pillar of climate policy that is simultaneously responsive to broader concerns over its use, such as issues of equity, governance, and geopolitics.

A NEW LINE OF CLIMATE DEFENSE

Climate engineering employs a diverse set of techniques that deliberately alter the climate system on a planetary scale, reversing or interrupting global warming. Private investment, public curiosity, and policymaker involvement in the field are all growing as scientists explore different approaches to climate engineering research, development, demonstration, and deployment (RDD&D).

A public process has been slowly taking shape, but it is lagging behind RDD&D efforts. About a decade ago, the U.S.

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Congress held hearings on the implications of large-scale climate intervention, the Congressional Research Service began assessing geoengineering policy, and then the National Academies of Sciences, Engineering, and Medicine conducted a major climate engineering study. Simultaneous international efforts have also been under way to probe geoengineering, starting with the UK's Royal Society. More recently, in November 2017, the U.S. House Committee on Science, Space, and Technology held a hearing on climate engineering technologies, sparking interest in its development.

The resulting discussion has produced several ways to characterize climate engineering technologies. The most straightforward option is to sort them into two broad categories: carbon dioxide removal (CDR) and solar radiation management (SRM).

Carbon Dioxide Removal

CDR entails removing the buildup of carbon dioxide and storing it in plants, soils, rocks, and building materials and elsewhere, such as under the ground or in oceans. The techniques that rely on plants and soils are assumed to be cheaper and closer to deployment than the others, yet may not be permanent solutions. Storage technologies that sequester carbon elsewhere may be more permanent, but they could be costlier and require continued research and development.

The applications and scale of effective CDR solutions over coming decades are unclear. While the National Academies described CDR as an important part of a portfolio of options to stabilize and reduce atmospheric concentrations of carbon dioxide, and the UN Intergovernmental Panel on Climate Change highlighted the importance of CDR in keeping global temperature rise below two degrees Celsius, there are biophysical limits to the technology's application. Major uncertainties exist about the economic viability and scalability of CDR. There is controversy over certain CDR techniques' effects on food security, biodiversity, emissions, and storage safety. Some analysts posit that impacts could be local, regional, or even global, especially if CDR is applied on the requisite planetary scale. Others argue that CDR is relatively benign.

Solar Radiation Management

SRM seeks to offset GHG-induced warming by either increasing the amount of sunlight reflected from earth into space or preventing radiation from reaching the earth's surface in the first place.

This approach is accompanied by a different set of risks, both climatological and geopolitical. If SRM is not accompanied by effective mitigation efforts to simultaneously cut emissions, it can cause precipitous warming if it is eventually rolled back. The need for perpetual SRM applications, known as lock in, infers that once SRM is deployed, it may be difficult to safely stop. Even if SRM succeeds on a planetary scale, it may lead to local and regional conflicts over real or perceived harms or benefits.

DEVELOPING A GLOBAL PUBLIC REGISTRY

Gathering accurate, complete information on the evolving array of techniques under consideration, development, or application would be critical to safely manage climate engineering. That information would also be vital to communicating these approaches in a real, credible, and detailed manner to policymakers and civil society. Deliberation, not disinformation, should prevail.

While data-collection protocols are in place for climate mitigation and adaptation, knowledge-building efforts in support of the governance and implementation of climate engineering RDD&D activities are limited. A number of ad hoc institutions and uncoordinated initiatives have begun to monitor assorted elements of climate engineering activities, but these efforts are limited in terms of their scope, transparency, and/or objectivity.

Once the focus of a handful of scientists, climate engineering RDD&D activities appear to be expanding. More resources are being allocated (publicly and privately), the breadth of approaches being explored is expanding, the number of individuals and institutions conducting research across the globe is increasing, and real-world experimentation is under way.

Despite its global reach, climate engineering RDD&D appears to be dominated at present by U.S. scientists in academia and national laboratories. For example, at a recent distinguished conference on radiation management, presentations were made by twenty U.S. university and government researchers. The remaining thirteen slots on the agenda were spread among EU researchers, NGOs, a Chinese academic, and a journalist.

But it is difficult to know the extent of climate engineering research at present. It may be the case that the U.S. academic community has a higher underlying level of transparency or salience than that in other regions, leading to potential misperceptions. While some researchers believe they have a strong sense of what others are doing, such intimate knowledge likely only applies to a small subset of the broader climate community.

A public repository of climate engineering activities could offer this information to the world, being routinely updated to capture and convey the expanding field of climate engineering RDD&D in a neutral, objective manner. In addition to being informed about what actions are under way worldwide, a registry would facilitate ongoing assessments of the various techniques applied, findings presented, funds expended, permits acquired, collaborations formed, national versus international oversight established, and other relevant facts that would help increase understanding of this emerging field.

The design choices for framing an RDD&D registry are manifold—and consequential. There are more questions than answers:

- How is climate engineering defined, and what should be included?
- Would traditional subcategories (CDR and SRM) be used or would new parameters need to be created?
- How granular is the information, and would the collected information be made available to the broader public on a complete, or partial, basis?
- Should all activities be subject to the same disclosure expectations or requirements?
- Would the explicit permission of researchers and actors be needed for inclusion?
- How would data be authenticated?
- Under the aegis of what institution(s) would such a database be created, maintained, and housed?
- Who has the rights to add, amend, and access it?
- Is a single database most appropriate, or would multiple ones, each catering to the particulars of a given technology set, prove most effective?
- Would the data be interoperable with future national-level databases?

Three distinct approaches to reporting, while not exhaustive of the design choices facing such a registry, illustrate some of the key choices and trade-offs involved. These include full voluntary reporting, incentivized voluntary reporting, and mandatory reporting.

Completely Voluntary Reporting

A completely voluntary reporting approach follows the "if you build it, they will come" philosophy. It convinces climate engineering actors that disclosure and reporting of activities is either in their own self-interest or a requirement due to norms and/or peer pressure. Such a registry could also be populated with research summaries prepared by researchers themselves.

One advantage is that a voluntary approach can have a broad scope in terms of technologies, approaches, and geography. By inviting all involved in climate engineering RDD&D to participate, a successful registry would not be skewed toward a limited number of activities. Voluntary contributions would have to be vetted against real-world activities to identify those actors who are refraining from participation.

The Nanotechnology Clearinghouse serves as a possible model. The Research Triangle Nanotechnology Network, a consortium of universities, is currently compiling information for this database on nanotech and nanoscience. The network collects and organizes published research, news, and multimedia resources in the central clearinghouse, drawing from government- and nonprofit-run voluntary clearinghouses, such as Purdue University's NanoHUB.

Incentivized Voluntary Reporting

An incentivized voluntary reporting approach would build on the completely voluntary system, recognizing that not all actors view disclosure as in their best interest. For example, certain technologies that lower overall GHG concentrations also generate new feedstocks of carbon that can be used in new industrial processes. Direct air capture is but one example of these negative-emissions technologies, whose potential profitability means that private actors may pursue these techniques. Many of these companies may not wish to disclose their structure, activities, and progress for competitive reasons. Additional incentives could take many forms, from custom regulatory relief or guidance, eligibility for certain subsidies or tax benefits, or access to national labs or government RDD&D facilities. While special incentive mechanisms may be useful, the government may find it difficult to gather such competitive information, limiting the scope of data collected.

One example of this kind of setup is the Department of Energy's now-defunct Voluntary Greenhouse Gas Reporting Program, which tracked voluntary emissions from utilities, industry, small businesses, and institutions between 1994 and 2009. It incentivized large industrial emitters to submit detailed emissions data to a public registry by providing credits for registered emissions reductions. It also had special provisions to encourage disclosure by small businesses.

Mandatory Reporting

Mandatory reporting requires buy-in from affected parties to be most effective. Otherwise, parties may try to game the disclosure systems put in place. Historically, such systems that cover global activities end up under the auspices of multilateral institutions, such as the UN, that are equipped to enforce disclosure mandates. Establishing disclosure mandates would take time given parties' varied political and technical interests. At least initially, a mandatory system could be developed by national governments to collect those data that are of greatest domestic interest. However, this also means that there would likely be a balkanization of mandatory, voluntary, and nonexistent disclosure regimes across national borders, leading to significant blind spots and regulatory arbitrage opportunities. Key factors to consider regarding this approach are how to treat different climate engineering actors and which enforcement mechanism(s) would be most appropriate, and how to promote coordination between national or regional disclosure regimes.

The Biosafety Clearinghouse is an example of this approach. Established in 2003 by the Cartagena Protocol on Biosafety to the Convention on Biological Diversity, the clearinghouse governs the cross-border impacts of importing and releasing genetically modified organisms that are alive. Mandatory reporting is required from 171 countries that are party to the protocol. Scientific, technical, environmental, and legal information must be submitted to the clearinghouse within a designated time frame. The database includes standard definitions and categories used by researchers around the globe. A similar "controlled vocabulary" would be useful for a climate engineering clearinghouse because the boundaries around different technologies vary.

QUEST FOR PUBLIC INFORMATION

Yet accumulating information for the clearinghouse is more easily said than done. There is no single source of information. Instead, volumes of currently available data reside in multiple places, each with their own opportunities, obstacles, and insufficiencies. The hunt for data is complicated by today's architecture of information sources (see figure 1). Mining information is currently hit-and-miss. Improvements to this system are possible through the establishment of a more comprehensive climate engineering database structure with proper incentives, mandates, and/or open-source methodologies to enhance the capture of relevant information.

The Cost of Data

Scholarly climate engineering research typically resides in a wide array of academic journals aimed at both science and social science audiences. Accepted articles tend to be high quality; they must be successfully reviewed by academic peers to be published. These articles are mostly behind paywalls, making it costly to access all the information to stay up-to-date in this field.

In addition, there are fee-for-service providers, such as Web of Science and Scopus, that collect metadata and construct search engines for global research articles using keywords, cross-referencing, and other analytic tools. This facilitates research capture but adds an additional cost.

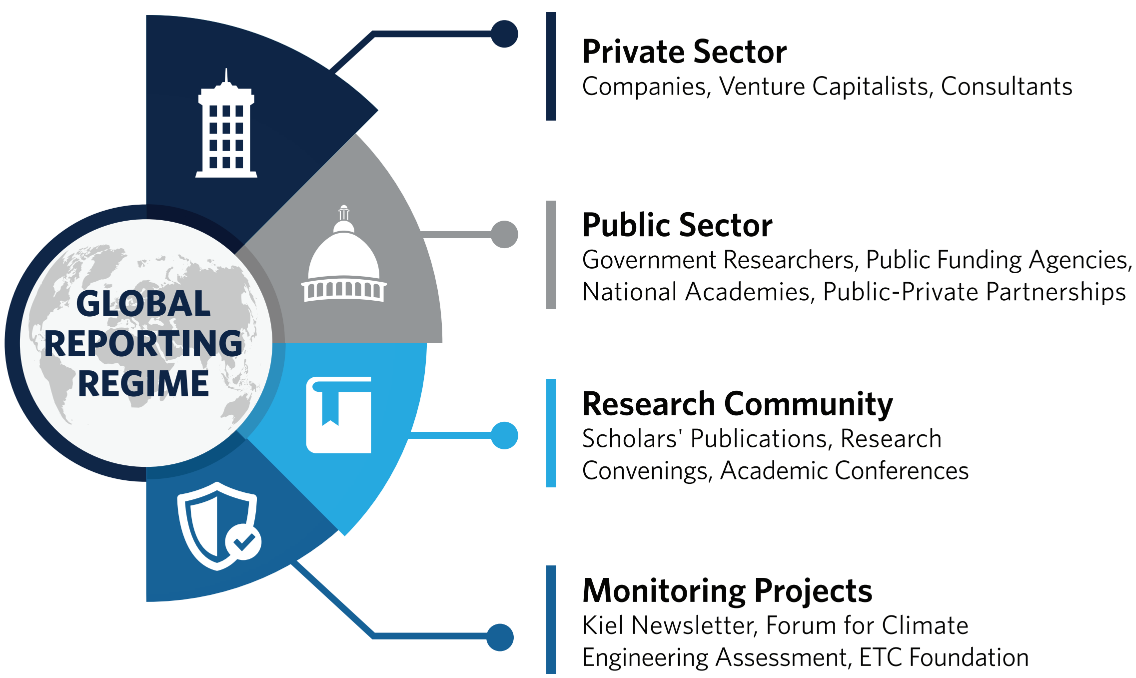
While there are free search engines such as Google Scholar, do-it-yourself data gathering requires time, effort, and expertise. Maintaining an up-to-date database would require essentially nonstop searches, and there would still be no way of knowing if all research relevant to climate engineering was successfully captured.

Even if free data grabs are successful, they only provide bare-bones information, such as a title and an abstract; the rest of the research remains out of reach. Given the increasing influx of climate engineering articles posted year after year and their valuable research citations, funding would be needed to access, analyze, and summarize this information in a database.

Private Intellectual Property

Also hidden are details of private sector climate engineering activities on at least some technologies. Venture capital databases capture some private, for-profit activities that could be considered intellectual property held by private stakeholders who may or may not want to disclose details. Even government databases that track government research and national laboratory activities exist in a gray zone; they can be difficult to access unless policymakers require public reporting. And public-private partnerships can also be partially hidden from view depending on whether they choose to disclose information or not.

Figure 1. Data Sources for Global Reporting Regime



Dispersed Free Data

Journal articles that would otherwise reside behind paywalls can be freely shared with the public if the author purchases open access upon publication. Some authors do, but many cannot afford to.

Beyond this, there are numerous, limited opportunities for public monitoring of climate engineering activities. A search for climate engineering patents can help identify experiments under way. Newsletters from the Kiel Earth Institute, the Forum for Climate Engineering Assessment, and others spotlight a limited scope of current activities and research. And further information can be mined through books (including their bibliographies and endnotes), Twitter feeds, institutions' websites, outreach to individual researchers and companies, and miscellaneous public disclosures and citations provided in reports.

WHY PUBLIC REPORTING MATTERS

Financial, timing, intellectual property, security, and language barriers could jeopardize discussions and consensus building on the myriad of questions regarding climate engineering. As such, public reporting on climate engineering activities can encourage good governance. Direct air capture (DAC), a climate engineering procedure, underscores why public reporting matters.

DAC refers to a diverse and growing set of experimental climate engineering technologies aimed at removing greenhouse gases from the atmosphere to materially reduce their concentrations. At present, a handful of private companies are focusing on removing carbon dioxide. All known undertakings are spin-offs of university research that have successfully raised capital from a variety of venture investors, though this certainly may not remain the case in the future.

The expanding financial interest in these techniques is likely to be further accelerated by the recent passage in the United States of the "45Q" credit, which offers a tax credit of $35 to $50 per ton of captured carbon dioxide, including from direct air capture technologies. Against this backdrop, a wider array of actors may become involved in DAC—from start-ups incubated in tech accelerator programs to larger, established firms with significant financial resources and a nascent interest. And the techniques could evolve if DAC research expands to short-lived climate pollutants, such as methane.

Disclosure mechanisms should be rethought because private climate engineering efforts such as DAC have large growth potential. Such rethinking could include whether a one-size-fits-all approach is appropriate for the loosely defined field of climate engineering, or whether different disclosure or reporting mechanisms (and incentives) could be adapted to best fit the characteristics of varied subfields and technologies. In the case of DAC efforts with broad private sector participation, there should be thoughtful consideration of how to gather this data while avoiding both the disclosure of proprietary, material information and the imposition of undue burdens on small, thinly stretched start-ups.

One possible way governments could augment the information available to policy actors is by offering initial seed funding for DAC and other pre-commercial climate engineering efforts. This mechanism would complement the flow of private capital until technologies have been reported, assessed, permitted, and tracked. An example of this approach is CarbFix2, the world's first negative emissions plant that recently began operation at a geothermal facility in Iceland, which utilizes technology from Climeworks, a Switzerland-based company. Climeworks is the first private company to successfully capture carbon from air at an industrial scale and inject it underground. The project received initial public funding from the European Commission's Horizon 2020 research initiative, which opened the door for data collection.

In the United States, this niche could also be filled by the Advanced Research Projects Agency-Energy (ARPA-E) at the U.S. Department of Energy, an innovative, early stage energy technology incubator. There's a better chance that the whole development process would be transparent if ARPA-E gets involved in climate engineering, focusing on those technologies that interest the private sector but may be too early stage or upstream to offer sufficiently fast commercialization.

In addition to public grant programs, mechanisms such as reverse auctions could promote public information dissemination. In these auctions, all bidders are required to submit certain data with their bids. Reverse auctions could also be used in conjunction with pre-commercial public procurement programs. Ultimately, the key is to invite disclosure of all climate engineering RDD&D by any actor, to avoid any blind spots as this field evolves.

WHO'S RESPONSIBLE?

While overregulation is indeed a serious risk in many areas, subnational, national, and multilateral policymaking perspectives would be necessary to ensure that climate engineering brings more stability to the climate and society—not less. In the end, ensuring an informed, fact-based public dialogue is also in the interest of investors and researchers, as it reduces the risk of backlash if their efforts are misunderstood or misconstrued. The potential economic, political, and environmental consequences from the variety of techniques aimed at intervening in the earth's dynamic climate cycle call for informed oversight.

Numerous nongovernmental and academic organizations, such as the Forum on Climate Engineering Assessment, the Carnegie Council for Ethics in International Affairs, the Sabin Center for Climate Change Law at Columbia Law School, and others, are analyzing climate engineering technologies and developing governance architectures. While researchers in these institutions would surely benefit from a global database, it would be a heavy lift for them—or any other academic or nongovernmental organization—to assume responsibility for assembling, maintaining, and broadcasting a public database.

The United Nations could be a candidate for assembling public disclosure. If the United Nations' Framework Convention on Climate Change were to assume a new charge at a future Conference of Parties now that the 2015 Paris Agreement has been ratified by most nations, the details for a data collection regime could be hammered out. But the question remains whether the UN is up to the task of creating, gathering, and updating this database from dispersed information sources outside the organization.

The capacity for the UN to take this on is complicated by the fact that no existing UN institution or multilateral agreement has direct responsibility for climate engineering activities. There is no extant treaty that covers all—or, in a real sense, any—of these activities. For example, the London Convention and Protocol, the Convention on Biological Diversity, the European Convention on Long-Range Transboundary Air Pollution, and the Outer Space Treaty do not directly apply nor do they help create a public climate engineering clearinghouse. The only treaty that tangentially relates is the 1976 convention prohibiting the hostile use of environmental modification techniques, ENMOD. But ENMOD encourages peaceful environmental modifications without defining whether this entails climate engineering; it also has no mechanisms to gather data on climate engineering activities.

The lack of comprehensive international governance and data collection mechanisms is mirrored at the national level, where environmental laws relate indirectly but offer no path forward. The chances of a single state successfully regulating this field (or climate engineering research itself) are low given today's dispersed research efforts, multilateral politics, and economic forces. No single national government can successfully manage an international registry. Such responsibility would raise more than just diplomatic issues—certainly, no one government has regulatory authority over other nations' organizations, companies, and governments.

Still, to get bottom-up efforts under way, data collection and oversight could be replicated in different countries through governmental bodies such as the now-defunct U.S. Office of Technology Assessment. Created in 1972, this institution was governed by a bipartisan board of twelve members of Congress and provided policymakers with information and metrics on emerging technologies and scientific trends. Climate engineering, along with numerous other technology efforts (such as synthetic biology and artificial intelligence), would be in the Office of Technology Assessment's clear purview if it were operating today.

NEXT STEPS TO INFORM CLIMATE ENGINEERING GOVERNANCE

Policymakers who have heretofore denied climate change are now speaking in favor of geoengineering as a tool to curb the impacts of the earth's continued warming. The shift appears to be in concert with these policymakers' core beliefs that mitigation is costly, government mandates are unworkable, and technology is the key to address climate change.

The change in U.S. climate policy rhetoric signals efforts to confront global warming with greater bipartisanship. However, the notion that climate engineering provides a proverbial get-out-of-jail-free card is fraught with major risks. These risks are accentuated by the lack of transparency about complex technologies that are in various stages of development amid a backdrop of an already changing climate.

A public registry is a critical step in building out a fully comprehensive system of global climate engineering monitoring and governance. Without such information, it will be difficult to identify real risks, dispel imagined ones, and generally inform policymakers, industry, and civil society as to the current state of research and experimentation.

For source notes, please see the online version of this article in which source material is hyperlinked.