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Planetary Power: Geoengineering and the New Geopolitics of Climate Intervention

Olivia Lazard, editor

Mandi Bissett and James Dyke | Olaf Corry | Dhanasree Jayaram, Rucha Shrikant Mapari, and Namrata Kabra | Rod Schoonover Jessica Seddon | Byford Tsang and Yedan Li

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01

Introduction: Anticipating Incomplete Climate Agency

Jessica Seddon

The news about environmental change is invariably bad. The global average temperature is at an all-time high in the modern era, coral reefs are in jeopardy, the Amazon and the Arctic are wobbling on the edge of systemic reorganization, and the Atlantic Meridional Overturning Circulation (AMOC)—the ocean current that regulates the climate of Europe and much of the rest of the world—seems to be slowing down.

Against the backdrop of these physical, chemical, and biological changes, discussions of "geoengineering," also known as climate intervention and defined by the World Climate Research Programme as "deliberate large-scale manipulations of the planetary environment with the aim to counteract anthropogenic climate change," have started to become more common in the media, in national and multilateral scientific assessments, and in the hallway conversations and side events of UN bodies.[1]

This compilation seeks to shift the focus away from evaluating hypothetical technologies and stylized strategic dilemmas and toward an understanding of the countries and actors that are developing, might use, and will have to govern these technologies. As such, the series is an important addition to existing analysis of climate intervention.

The six articles ask what several key actors—nation-states and globally influential industries—think of geoengineering. How do they categorize the various approaches? What are their interests in having these still-hazy technological capabilities available for their own use or that of others? What are their goals and concerns? What interests and abilities do they have as developers, decisionmakers, or instigators of technologies, institutions, or governance approaches?

The authors ask these questions at a time when interests, goals, and strategies are inchoate but evolving quickly. The articles are not definitive statements of national or industry positions but efforts to use publicly available information to infer the stances of some of the economic and political agglomerations that will, deliberately or not, shape whether and how climate intervention evolves.

Geoengineering in the Abstract

The term "geoengineering" is used in various ways. At its broadest, it encompasses a wide range of climate interventions, from carbon dioxide removal (CDR) and removal of other greenhouse gases to deliberate efforts to cool Earth by reflecting sunlight back into space via solar radiation modification (SRM). There is a variety of approaches, with differing scales, impacts, and levels of control within each category.[2] Weather modification is often considered to be distinct from climate geoengineering, since it operates on much shorter time scales.

Current use of CDR is still small relative to the amounts that the Intergovernmental Panel on Climate Change (IPCC) notes would be needed to remain close to the target of limiting average global warming to 1.5° Celsius (2.7° Fahrenheit) since preindustrial times, but the technology is openly discussed as part of many countries' net-zero targets. SRM is more controversial, but it has been the subject of two proposed resolutions (neither of them adopted) at the UN Environment Assembly, national science assessments, reports by the UN Environment Programme and the IPCC, and dozens of articles in the press and across the political spectrum. Dedicated media sites, such as SRM360, have also been established.

National and international assessments tend to present climate interventions as a set of methods to be evaluated.[3] The central questions in policy assessments are often "Does it work?" and "What are the side effects?," while governance is acknowledged as a challenge—and its absence as a risk.

For CDR, the big questions are whether the approaches actually remove carbon from the atmosphere and reliably—or, at least, predictably—keep it away for a reasonably long period of time, ideally with other benefits and few negative side effects. The latter vary widely by approach and scale, as do the efforts to evaluate them.

For SRM, success is frequently defined as limiting or reversing global average temperature increases. It is clear from historical analogues and results across a wide variety of climate models that SRM, particularly planetary-scale stratospheric aerosol injection (SAI), could start to reduce global average temperatures within months of being deployed.[4]

Simulations using some of the same climate models that underpin the IPCC and other global assessments show that cooling is not, however, uniform, nor is it possible to alter temperature without also changing the water cycle.[5] Regional precipitation responses remain uncertain, with models disagreeing on sign and magnitude in some regions and on the various approaches to SRM. Regional impacts on temperature, precipitation, extreme weather, and large-scale circulations such as monsoons, cannot be tightly projected. This is in part due to irreducible internal climate variability (natural chaotic fluctuations in the climate system) and in part due to model uncertainty (differences in how models represent relevant processes). Impacts also depend on what approach to SRM is used as well as where, when, and for how long it is deployed.

There are many other open questions about SRM, such as whether it could delay or avoid the risk of irreversible planetary changes, or tipping points, or how small changes in the intensity or polarity of light might affect ecosystems.[6] The impacts of SRM on atmospheric chemistry and the lifetime of ground-level pollutants and key greenhouse gases, such as methane, are also uncertain.

Much of this work is explicitly or implicitly within the "risk-risk" framework of comparing outcomes under future emissions scenarios with those under some form of intervention. In a loose sense, this is reasonable: Past emissions limit future possibilities, and the world will not return to a preindustrial state. The important and unresolved uncertainties about the ways in which past and present emissions will affect the climate and ecology mirror some of the open questions about the impacts of SRM, such as the timing and pace of tipping points or the way warming will affect clouds.[7] In practice, it is important to be clear that there are a lot of blind spots in both climate change and climate intervention and that the selection of risks to compare is a curatorial choice that shapes conclusions.

Many research efforts also rely on existing climate and impact modeling infrastructure. This approach has limitations. Models are not full representations of complex realities.[8] They often do not fully characterize or replicate the dynamics of the systems in which geoengineering intervenes. They are important sources of insight about global changes and their interrelationships, but they were never meant to be prediction engines or operational management information systems.

In practical terms, much depends on governance. The human choices about how to intervene in the climate will shape the impacts of any climate intervention. In the words of the UK's Royal Society: "If deployed in an informed and globally coordinated way, SRM could ameliorate many, but not all, of the adverse impacts of climate change. However, if deployed without due diligence, SRM could exacerbate regional climate change."[9] Evaluations of efficacy and impacts are based on particular scenarios among a wider design space.[10] Actual choices could be wildly different and depend on differing political motivations. A leader may simply want to look like they are doing something, for example, and since future weather cannot be cleanly attributed to a particular intervention, the act itself might be the main point. Even a deployment that is "successful" in the sense of lowering global average temperature may be perceived as a failure in the sense that most people experience higher temperatures.[11]

There is a growing body of research on the social structures that might shape these choices. Some papers focus on the basic foundations of governance.[12] Others offer more specific proposals, including new institutions and the adaptation of existing environmental governance.[13]

One critique of this analysis is that it legitimizes geoengineering as an object of governance. At this point, however, SRM is an idea with momentum in the world; one way or another, it will be steered. Another critique is that it presumes that steering interventions toward

broadly beneficial outcomes is even possible.[14] It might be; it might not be. Steering geoengineering—whether to ban some or all interventions or to shape how they are used—will require some kind of intentional creation of new social structures.

Much existing research is built on generic assumptions about economic motivations: finding the lowest costs for keeping temperatures stable, for example, or preferring a certain temperature profile over others. (The latter goal, in any case, may be based on an unrealistic sense of control.) Time and time again, these kinds of generalizations have failed to fully explain national or international actions.

The more relevant question, then, is what actual countries, industries, and individuals, embedded in larger geopolitical contexts, might want in terms not only of their climates—much less the trajectory of the global average temperature—but of a more realistic combination of environment, power, respect, and economic advantage on their own and relative to others. More importantly, what might these actors believe about how to achieve these goals?

Understanding Actors' Motivations

Human social dynamics—the aggregate of interacting and evolving decisions, with imperfect information and divergent constellations of meaning—are a significant source of uncertainty about how, where, and to what extent geoengineering will happen. That is where research into national power and industry interest, shown in this compilation, is relevant: Understanding the motivations of real actors is essential for any realistic assessment of how geoengineering might evolve and what governance it might require.

The articles in this compilation cover a range of views.[15]

Olaf Corry's contribution traces the **European Union**'s historical focus on reducing emissions and general caution in allowing promissory technologies to be seen as substitutes for intensive decarbonization. But he also notes the pressure on this position that is now coming from right-wing politics, militarization, energy insecurity, and a volatile United States. On CDR, Corry describes the erosion of lines that EU regulation and diplomacy had drawn to keep carbon removals distinct from emissions reductions. He encourages the EU to resist this trend toward fungibility by treating CDR as a scarce, non-substitutable resource with separate targets. SRM, meanwhile, remains largely outside formal policy frameworks. The renewed policy attention on SRM frames it mainly as an environmental, geopolitical, and security risk, although Corry cautions that SRM, too, could become a substitute for emissions cuts via so-called cooling credits or carbon-accounting standards. He calls on the EU to build a coalition for nondeployment accompanied by carefully governed public research.

Byford Tsang and Yedan Li's description of **China**'s attitudes toward CDR and SRM makes much the same distinction between the two forms of geoengineering: CDR enhances policy flexibility, while SRM is more of a security concern—although for China, that concern focuses on the United States, whose research dominance, defense ties, and fossil-fuel and tech funders could enable unilateral use of SRM. In contrast to the EU, however, China embraces CDR and has invested heavily and visibly in a variety of industrial and ecological approaches for carbon removal. On SRM, however, China is much more circumspect: These technologies receive no explicit mention in Beijing's climate policies, and the country lags behind significantly in SRM research. Tsang and Li argue that although China is often assumed to be a major player in geoengineering because of its history of large-scale weather modification, in reality it has been more reticent about SRM. As in Europe, though, this position may be evolving, with some in China calling for small-scale outdoor experiments.

Turning to the **United States**, Rod Schoonover notes how the country's previous long engagement with geoengineering from a position of scientific authority and cautious inquiry has come to an end. His article focuses on the systemic consequences of the current U.S. administration's approach for the prospects of responsible geoengineering. He describes the administration's systematic dismantling of federal science institutions and argues that this undermines the United States' capacity for responsible engagement, leaves it less able to detect deployment by others, and creates systemic risks for global governance. Domestic politics treat the two technologies in very different ways: SRM is opposed on both the right and the left, while CDR enjoys bipartisan support largely because it serves fossil-fuel interests. As federal oversight recedes, states and tech start-ups fill the vacuum, raising the risk of what Schoonover calls a "desperation pivot" toward poorly governed SRM. He sketches various future geoengineering scenarios, from a cooperative force to a coercive hegemon running a pay-to-participate regime.

The **Global South** as described by Dhanasree Jayaram, Rucha Shrikant Mapari, and Namrata Kabra has mixed feelings and varied capacities to advance CDR and SRM technologies. The authors view geoengineering through a climate-justice lens: Neither approach addresses the root cause of climate change—greenhouse gas emissions—and both risk entrenching North-South power imbalances, which is why many national representatives see SRM in neocolonial terms and have called for its nonuse. The authors emphasize that SRM could create moral hazard by enabling industrialized countries to use it as a substitute for meaningful mitigation, allowing them to evade their obligations to reduce emissions and support the most vulnerable nations. The article also examines South-South dynamics, noting the Global South is not uniform: Higher-emitting, higher-capacity countries, like China, India, Indonesia, and Saudi Arabia, have supported CDR, and China and India fund SRM research, while many least developed countries and small island states reject SRM altogether. The authors see an opportunity for middle powers, including the EU, to devise fair and transparent governance alongside the Global South.

In these descriptions of regional or national positions, CDR and SRM are quite different political objects. Each might, at times, be categorized as the "other" response to climate change, but CDR is essentially a pressure valve for the pace of the energy transition, while SRM is a potential disruptor to keep up with. Neither set of technologies is likely to be the first response to the most visible and immediate impacts of climate change on differences in weather. Weather modification, which is currently focused mainly on enhancing rainfall and suppressing hail but with a renewed interest in preventing hurricanes, might be closer to the first step. In China's case, it is a tool for large-scale water reallocation, while in the United States it is used for agriculture and, increasingly, maintenance of snowpacks in the west.

These positions also highlight two foundational challenges for any form of governance of responsible CDR or SRM: inchoate stances emerging from domestic politics that have not fully absorbed Earth system constraints, and the fundamental absence of a shared sense of these approaches' legitimacy or fairness when it comes to reducing future climate impacts.[16] Removing carbon and/or reflecting sunlight may be necessary for models to generate a trajectory toward a habitable future, but politics remembers history and pushes back.

Among the actors covered in the compilation, **Big Tech** is by far the most enthusiastic. Mandi Bissett and James Dyke argue that Big Tech has become the primary source of geoengineering funding, with nonstate finance now approaching state spending. A relatively small group of individuals in technology and venture capital is associated with a substantial fraction of the philanthropic and investment funding that goes into SRM and CDR. The article sets out what the authors see as Big Tech's incentives: deflecting scrutiny of the rising emissions of AI data centers, influencing and profiting from carbon-removal markets, molding the standards meant to hold firms to account, and treating SRM as a way to protect economic growth—and the expansion of AI. The authors contend that public narratives of humanitarianism and climate leadership obscure these motives. They read Microsoft's April 2026 decision to pause CDR purchases as a sign that the commitment depends on Big Tech's own fortunes. These claims are hard to evaluate given the evidence available.

Olivia Lazard concludes with a discussion of the multiple layers of competitive dynamics that underlie research into geoengineering. In her mapping of the landscape, geoengineering is shaped not only by the environmental and political by-products of U.S.-China rivalry over energy models, critical minerals, and AI but also by a clash between publicly funded, accountable research for common goals and a privately funded, tech-accelerationist ecosystem. She sees this as a shift from techno-solutionism to techno-substitution for nature, with securitized, dual-use experimentation advancing in a governance vacuum. Her article also asks to what extent U.S. positions reflect national strategy rather than the interests of the private tech companies on which the state increasingly depends. Lazard argues the EU must respond with an equally ambitious counter-agenda: championing ecological complex regeneration over temperature-focused fixes, building transition intelligence on how the

United States, China, and tech firms plan to adapt their power to climate disruption, and using the EU's precautionary principle to legally prohibit commercial SRM while retaining public research capacity.

This compilation is a start and hopefully will inspire more researchers and observers to add to the evolving documentation on de facto and potential governance by looking closely at more actors and their interactions. For example, while Big Tech's role in funding and enabling geoengineering is perhaps the most visible, the insurance and finance sectors have obvious interests in any prospects of reducing climate risks. Are they just potential customers for what early investors in private CDR and SRM companies see as an emerging industry—or protagonists?[17]

As for political actors, China, the EU, and the United States are commonly seen as the major players in geoengineering governance, but other countries have prominent roles and interests, too. The UK, for example, is one of the largest public funders of SRM research via its independent public research funder, the Advanced Research and Invention Agency (ARIA).[18] Australia is conducting outdoor experiments in marine cloud brightening as part of an effort to protect the Great Barrier Reef. One of the goals of Japan's new Moonshot Research and Development Program is "controlling and modifying the weather."[19] And one forthcoming study highlights a concentration of states with the motivation and ability to launch unilateral SRM around the Arabian Sea.[20]

Finally, the meaningful involvement of the Global South is widely understood to be essential for any legitimate approach to geoengineering, but one article is hardly enough to cover the range of views within and across a diverse set of places where most of the world lives. Indigenous peoples and their institutions of self-governance are also important actors to understand and involve.

Shaping the Future

The environment is changing. Meanwhile, CDR and SRM are getting more attention and funding, including for moving from ideas to technological realities. What happens next depends on how these two facts intersect in the complex world of political, market, and public interpretations. Who will gain and who will lose in this intersection? Whose demands will be met, and whose needs will be ignored? Who will grow rich from providing solutions, and whose offerings or innovations will be excluded?

Humans have agency over the answers to these questions—if the focus of policy-relevant research shifts toward the social rather than the disembodied technological. The intersection of climate change and geoengineering raises three sets of important research and strategic questions: political, technical, and institutional.

Politics

The first questions are political: How will higher temperatures, new patterns of precipitation and extreme weather, and loss of ecological resilience translate into the self-interest of individuals, businesses, industries, and nations? How will these changes shape political demands and permissions? When, if ever, will real-world politics absorb the temporal, spatial, and sectoral realities of the way the Earth system works?

More and more people are experiencing Earth system change: heat waves, droughts, floods, and previously once-in-a-century storms happening every few years. Coverage of climate research in traditional and social media is growing. Advocacy groups across the spectrum are competing to frame events, and disinformation that seeks to turn instability into blame is increasing. All the while, there is widespread political ignorance of Earth system realities: the accumulated energy imbalances; the time scales between the act of cutting emissions and the surface temperature response; the ecological dynamics that run through species interactions; and the chemical, physical, and biological entanglements that transcend administrative boundaries. What kinds of politics will these pressures and storylines produce as they weave through different cultural, economic, and institutional contexts? Will they have any environmental or climate substrate at all?

There is already research on the political effects of natural disasters and extreme weather and the ways in which these events interact with fiscal systems, political-party systems, regime types, and more. Combining this research with analysis of the information environment could be very useful in anticipating political dynamics and informing public interventions to channel some of the politics of a changing Earth system into actions that meaningfully address the underlying causes of instability.

Technology

The second set of questions is technical, but with a more political and demand-curious frame than past assessments of climate intervention: How does climate intervention compare with other solutions for the range of goals that public actors might reasonably have—from economic security to political longevity to offensive or defensive action? From the perspective of a city or national leader, how do the varieties of SRM or CDR stand up as public health interventions, security technologies, economic developments, or adaptation approaches in comparison with other solutions?

For a subnational or national leader under pressure to do something about extreme weather, heat, rainfall in the wrong place, or the consequences of these changes, what are the options? To the extent that some of the top choices have spillover effects for the collective good, what are those effects, and what are their scales? The existing research has little to say. There is no way of telling whether SAI is better than, say, marine cloud brightening, afforestation,

or crop switching for achieving local goals, such as stable agricultural livelihoods. The approaches to addressing physical risk are evaluated against different metrics. They are rarely, if ever, compared from the perspective of satisfying political constituents.

These questions may not be answerable with current scientific methods. In that case, the uncertainties need to be centrally acknowledged and not secondary to statements about the impact of SRM on global average temperatures. These may be statements of the planetary problem and the root cause of many local impacts—but nobody lives in the world of global averages.

Institutions

The third group of questions is institutional: Which existing or feasible structures have the flexibility, scalability, durability, and legitimacy to be relevant for shaping local to national to regional and global cooperation to balance mitigation, adaptation, and potential additional, more intentional interventions in Earth systems? What systems exist for managing regional environmental externalities, jointly administering infrastructure and services, building trust, and expanding cooperation over time?

Governing—in the sense of building the social structures to steer the political demands and choices that stem from Earth system changes toward collectively preferred outcomes—may be a matter as much of weaving together what currently exists as of creating an entirely new superstructure. What are the promising threads, and where are the holes? What are the lessons from the last few times that humans faced technological and infrastructural revolutions? What steering worked, and what did not? What new analogues are available today? Those are the pragmatic and practical questions—not the binary choice of governable or not.

In short, analysts and practitioners need to step back from narrow debates about technology and governance in the abstract to recontextualize and reflect on how humans can and might use new abilities in a changing world.

02

Europe at a Geoengineering Crossroads

Olaf Corry

The world is rapidly approaching—if not surpassing—the 2015 Paris Agreement's advised limit of 1.5° Celsius (2.7° Fahrenheit) of average global warming since preindustrial levels. But that is only part of what is driving rising interest in novel and, in many cases, speculative geoengineering techniques. Heavy reliance on carbon dioxide removal (CDR) in net-zero plans and the growing allure of solar radiation modification (SRM) must also be understood in the context of a deeper crisis in European and world politics.

Political parties hostile to climate policy have surged in recent European elections. The war in Ukraine and a remarkable remilitarization of EU countries have put security concerns ahead of climate change and other vital European priorities. An erratic United States is openly doubling down on fossil-fuel energy and repealing federal regulation of greenhouse gases, while the administration of President Donald Trump is effectively at war with the rule of law at home and multilateralism abroad.[21]

While CDR and SRM are often framed merely as rational supplements to existing climate policy, context is crucial in understanding what role these technologies will actually play in EU climate politics and what their real implications are for the bloc's overall climate and security strategies. The idea of CDR on the scale of several billion tons is routinely deemed necessary if the overshoot of global carbon budgets is to be temporary. Meanwhile, SRM is similarly pitched as a temperature peak–shaving measure pending decarbonization and eye-watering amounts of carbon removal.[22] Crucially, the scale of CDR needed depends hugely on the success of current and future mitigation. Supposedly temporary SRM usually implies decades, if not centuries, of protracted intervention in the Earth system via securitized infrastructures that will inevitably attract the attention of economic and security interests. And rather than buy time, geoengineering ideas could easily end up *adding* to climate overshoot and delay.

Despite global instability, the EU has an opportunity to step into the breach where the United States absents itself. Europe traditionally championed the mitigation of greenhouse gas emissions and led a precautionary stance globally toward speculative technological fixes. The challenge now is to again prevent unsustainable reliance on dubious carbon-removal techniques and the trading of offsets that erode ambitious mitigation targets, while grasping the nettle of SRM by funding inclusive, well-governed research and building safeguards against premature deployment.

For both CDR and SRM, Europe needs strategies to prevent promissory future technologies from hampering urgent accelerated mitigation or harming Europe's broader interests of tackling the biodiversity crisis, ensuring societal resilience, and reviving global cooperation. How the EU holds the line in the coming years may be critical to whether these techniques become useful additions or unhelpful hindrances.

The Historical Good Climate Citizen

The EU has historically staked a claim as a good citizen or even the climate leader among the world's major economies. Unlike the United States, the former European Community (EC) demanded binding rather than voluntary targets on emissions cuts and a generally precautionary approach to risky technologies. The EC came up with one of the first collective climate targets during negotiations to establish the UN Framework Convention on Climate Change (UNFCCC) in 1990. By the 2015 Paris Agreement, the EU was offering a 40 percent emissions reduction target by 2030, relative to a 1990 baseline.[23]

The 2021 European Climate Law committed the EU to reach "climate neutrality" with net-zero greenhouse gas emissions by 2050; the European Commission proposed a net 90 percent reduction by 2040.[24] Despite doubts about commitments to the 2030 goal of a 55 percent reduction, one favorable review concluded that "EU climate policy development has . . . remained leading by international comparison."[25]

Geoengineering technologies are diverse in technical terms, with variations both between and within SRM and CDR. However, they are crucially similar in terms of their political and governance challenges: Both bear the promise—or imply a wager—that climate harms can be decoupled from greenhouse gas emissions, at least partly. Both rely on a raft of unproven techniques, as yet nonexistent infrastructures, and unsolved societal and regulatory quandaries to manage difficult trade-offs. Future supplies of safe, socially just, and sustainable CDR as well as equitably and carefully governed SRM are likely to be severely limited. Biological capture and storage depend on combinations of land, energy, resources, and finance that potentially threaten other EU policy goals, like biodiversity, food security, and global justice. SRM is at a very early stage and still faces enormous technical uncertainty, profound governance challenges, and geopolitical risks.

So while these approaches may buy time in theory, they could undermine the EU's core strategy of mitigation in practice by making hard limits and targets appear softer, justifying slower or deferred emissions cuts. They also challenge the EU's diplomatic coalitions. Europe's relations with high-ambition and climate change–vulnerable countries in the Global South, many of which already suspect Northern promises of future fixes, are strained by geoengineering—not least when richer countries renege on climate-finance pledges and press on with fossil-fuel exploration.

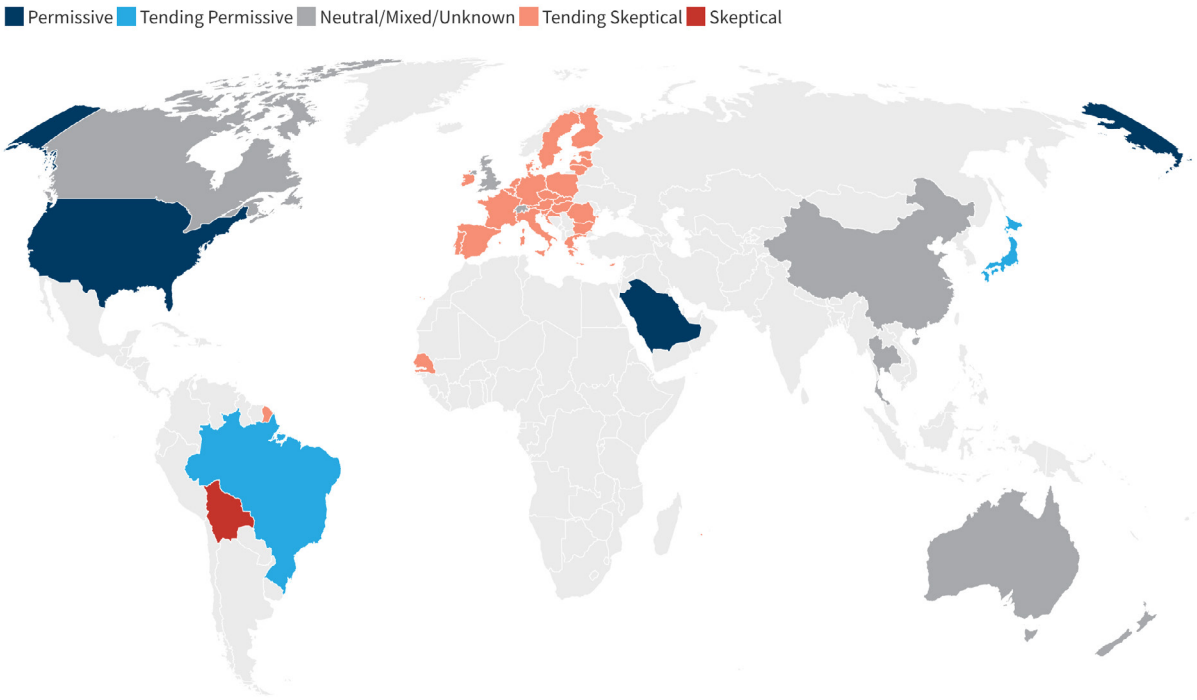
For all these reasons, the EU previously took a precautionary position on CDR. Wording on carbon sinks featured in the UNFCCC treaty in terms of a balance between emissions and sinks, but the EU allied with NGOs and developing nations to resist pressures for a more permissive inclusion of sinks in the 1997 Kyoto Protocol. Canada, Norway, Russia, and the United States—all land- and forest-rich countries with high emissions—pushed to count "avoided deforestation" as mitigation, but EU negotiators rightly feared that including sinks as mitigation could open up loopholes and pose unmanageable accounting challenges. In the end, avoided deforestation was not accepted, but afforestation and reforestation did become normalized as forms of mitigation.[26]

The EU played a more permissive role when CDR emerged in the form of speculative technological ideas for capturing atmospheric carbon dioxide and storing it. Initially considered a backstop risk measure, large-scale biomass energy with carbon capture and storage emerged in models of future policy trajectories.[27] Such hypotheticals quickly became mainstream as necessary forms of large-scale engineered carbon removal, despite consistently underperforming and posing dire feasibility concerns.

With the proliferation of net-zero framing from around 2019, CDR became a staple of national and even corporate climate planning. EU policy on CDR now assumes that in 2050, emissions in the union's entire Emissions Trading System (ETS) will be at minus 50 million metric tons, achieved with CDR.[28]

The lessons for SRM governance are significant. The EU did help shepherd some early international governance of geoengineering, including a de facto moratorium on marine-relevant techniques. At the first UN Environment Assembly (UNEA) negotiations in 2019, the EU, with support from Bolivia, pushed for precautionary wording and the assessment of a broad set of knowledge and concerns (see figure 1). But the resolution failed after countries led by the United States and Saudi Arabia rejected precautionary language. Powerful, fossil fuel–dependent states were eager to avoid governance that might restrict development (or the promise of development), particularly of CDR options.

Figure 1. Country Positions on the 2019 UNEA Draft Resolution on Geoengineering

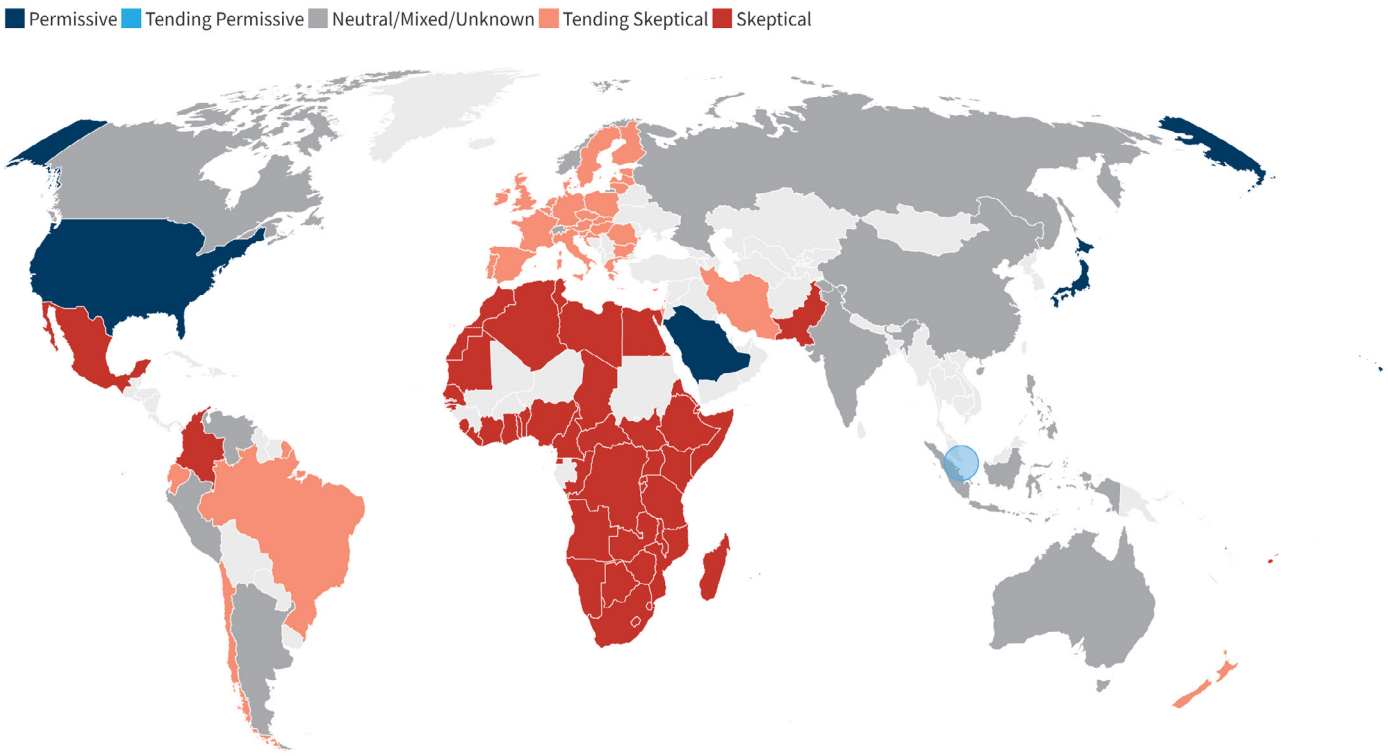


Source: Duncan McLaren and Olaf Corry.

Note: The terms "permissive" and "skeptical" refer to country stances toward the feasibility and value of pursuing research into and possible development of the technologies under consideration. Positions were qualitatively allocated for all countries that submitted views or proposed text. All EU states and all UN African Group members are treated as part of their respective bloc, although African Union members that were suspended in 2019 have been excluded. Countries that attended negotiating sessions, thus indicating interest, but made no interventions are included in the "neutral/mixed" group. This map is illustrative; boundaries, names, and designations used do not represent or imply any opinion on the part of Carnegie or the authors.

Five years later, the United States and Saudi Arabia again led opposition to multilateral governance at the UNEA; but the EU also found itself outflanked by an organized African Group aligned with other skeptical Global South countries, like Pakistan and Mexico, angry at permissive stances and what appeared to be yet another Northern excuse to avoid responsibilities (see figure 2).[29] This placed the EU in a less central role, though the union stuck to its precautionary position and attempted a role of honest broker between opposing blocs clashing over questions of research and governance.[30]

Figure 2. Country Positions on the 2024 UNEA Draft Resolution on SRM



Source: Duncan McLaren and Olaf Corry.

Note: The terms "permissive" and "skeptical" refer to country stances toward the feasibility and value of pursuing research into and possible development of the technologies under consideration. Positions were qualitatively allocated for all countries that submitted views or proposed text. All EU states and all UN African Group members are treated as part of their respective bloc, although African Union members that were suspended in 2019 have been excluded. Countries that attended negotiating sessions, thus indicating interest, but made no interventions are included in the "neutral/mixed" group. This map is illustrative; boundaries, names, and designations used do not represent or imply any opinion on the part of Carnegie or the authors.

European governments are no longer merely exploring positions on SRM, and an explicit EU stance began to form in earnest with a series of scientific advisory reports that concluded that SRM poses significant environmental, geopolitical, and security risks. These reports recommended international coordination and governance of SRM research and a precautionary EU-wide moratorium on deploying SRM, pending adequate evidence and international and just governance.[31] The advice also urged public funding for responsible, broad-spectrum research that would not displace or negatively affect funding for mitigation and adaptation research, provided mitigation remains unequivocally the EU's top priority.

In May 2026, the EU Council embraced the advisory reports' position on the risks of large-scale climate interventions, particularly SRM, and called for the application of the precautionary principle and discussions of international governance arrangements.[32] A 2026 European Parliament briefing put forward an EU-wide moratorium on SRM use while

supporting the development of international governance frameworks.[33] SRM is thus rapidly moving from a specialist scientific concern into a broader field of European policy debate. What is more, governments are increasingly considering not only the environmental risks of SRM but also what position they should adopt on research, governance, and potential deployment.

Rising Pressure on European Climate Policy

Precautionary stances on risky and unproven technologies are coming under increasing pressure from factors beyond climate change, including security, geopolitics, and economics. The EU's share of global greenhouse gas emissions fell from around 15 percent in 1990 to 6 percent in 2023.[34] While the bloc's lower share of global emissions could be cast as proof of concept for ambitious mitigation plans elsewhere, it has instead been weaponized as a reason to cut back on mitigation. In July 2025, the far-right Patriots for Europe group in the European Parliament, which includes climate change–denying members, was given responsibility for negotiations on the European Green Deal. Vocal opponents of the target of a 90 percent emissions reduction by 2040 took charge.

On top of this, concerns of energy security and European competitiveness mean the EU faces a European energy trilemma: the need to decarbonize, boost competitiveness, and lessen dependence on Russian gas.[35] Investments in renewable energy potentially alleviate dependence on Russia, but under pressure from right-wing political forces and a troubled European motor industry, European Commission President Ursula von der Leyen agreed in early 2025 to water down a 2023 agreement to end sales of fossil fuel–powered cars by 2035.[36]

Compounding all this, particularly outside the EU, climate change has been increasingly defined in terms of geopolitical and national security agendas, notably in the United States. In 2025, even the bipartisan Council on Foreign Relations came out seemingly resigned to failing mitigation policies and pivoting to climate security.[37] In such discourse, disadvantaged groups like climate migrants—not climate change itself—appear as the vector of chaos. Shifting attention to preparing for climate wars—a classic trope about poorer populations heading to richer countries—signals that climate change is in danger of either disappearing from the global agenda or being turned into a homeland security issue.

The 30 percent surge in European military spending from 2021 to 2025 illustrates how badly integrated climate policy is with other areas.[38] European rearmament makes up a major contribution to NATO's military emissions, which are projected to rise by 200 million metric tons of carbon dioxide a year as a result.[39] For its part, the current U.S.-dominated security order Europe hopes to rely on involves a vast apparatus of bases and military infrastructures that are deeply dependent on fossil fuels. But the entanglement of fossil energy and U.S. geopolitics goes beyond fueling the military. The petrodollar system is part of the reason the U.S. dollar remains the global reserve currency, supporting the United States' global economic leverage and strategic primacy. This creates tensions between elements of the Western security order and the EU's decarbonization agenda.

CDR and SRM in a Climate Change–Skeptical World

If climate change mitigation is under severe pressure from securitization, economic interests, and rising tech accelerationism among billionaires and politicians, this is also crucial context for CDR and SRM as real policy options.[40] The rollout of both categories of climate intervention would rely on a raft of unproven techniques, nonexistent infrastructures, and unsolved societal and regulatory quandaries, with even so-called nature-based solutions posing serious risks and demands for land, energy, resources, and finance. Pledges on different environmental issues, such as climate change or biodiversity, tend to be oriented around policies as opposed to fully mapped out, and little work is done to understand how all pledges fit with physical and social constraints.

In this context, it was a worrying sign that the European Commission proposed allowing a proportion of the 2040 goal of cutting emissions by 90 percent to be achieved by buying carbon credits abroad. Though the proportion appears small, at 3 percent, this could result in up to 30 percent higher net EU emissions in the period up to 2050.[41] What is more, this share could be revised upwards—a loophole that would allow an escalating substitution of removals for cuts.[42] In addition, the commission's proposal lumped together gross emissions reductions, permanent removals, and land-based removals in a net target, which increases this risk further.

During negotiations on the Paris Agreement's Article 6 rules, which allow countries to pay for emissions reductions abroad as part of fulfilling their commitments to the accord, the EU campaigned to keep carbon removals out of the international credit trading. However, the EU also bought into arguments that such market mechanisms could "facilitate further ambition" by reducing the near-term costs of mitigation, and the eventual agreement failed to include key transparency requirements needed to verify whether projects work or have even happened.[43]

On SRM, the EU's earlier precaution is also under pressure from external geopolitical developments. Though SRM cannot replace emissions cuts, some methods appear to offer cheap options for reducing the costs of elevated levels of atmospheric carbon and, at the very least, would provoke a debate about how rapid decarbonization needs to be and how urgent the development of carbon removal is. At worst, SRM becomes another spurious means of delaying emissions cuts.[44]

In models that allow cost-benefit methods to identify optimal pathways to staying within temperature targets, SRM displaces huge emissions cuts and CDR.[45] In the real world, a start-up called Make Sunsets sells what it describes as "cooling credits" in exchange for lofting small amounts of aerosols that, the company claims, offset the warming from carbon dioxide. The firm's customers are overwhelmingly Global North carbon dioxide emitters.[46]

Alarm that SRM could enter Article 6 markets through a similar route arose when a proposal was submitted for radiative forcing management to be codified in the International Organization for Standardization (ISO) system. This technicality would risk putting

sulfur injections on a par with carbon emissions, with the two made comparable in terms of their net impact on overall temperatures, or radiative forcing effects. In this case, SRM deployments might be accounted as substitutes for emissions reductions or carbon dioxide removals, even though greenhouse gases last much longer and have many other effects beyond warming.[47] This proposal was opposed by European organizations that "feared that such a standard would legitimize solar geoengineering projects and undermine existing metrics for emissions accounting."[48]

Security actors and private money are beginning to flow into the field of research and advocacy for SRM as a policy idea. According to the nonprofit SRM360, itself funded partly by former tech entrepreneurs, "five of the top 10 funders of SRM are philanthropic."[49] Interest among tech investors is ballooning, which risks aligning SRM more closely with security actors. Stardust Solutions, an Israeli-U.S. venture that develops proprietary aerosols for SRM, is part funded by Awz Ventures, which specializes in security technology and whose founder previously led the security team of the Israeli prime minister.[50] Stardust's chief executive is "a former deputy chief scientist at the Israel Atomic Energy Commission, which oversees the country's clandestine nuclear program," according to the *Bulletin of the Atomic Scientists*;[51] the company has been quietly lobbying policymakers in Washington.[52]

Scientists see potential in SRM's speed and leverage as a cooling measure, but security experts assess that countries could seek to acquire the technology for geopolitical reasons.[53] Having a planetary lever on the climate would be a strategic asset or, at least, involve a presence and stake in contested spaces like oceans, the Arctic, the stratosphere, near-Earth orbit, or even the Moon. Ominously, SRM is gaining attention among conservative U.S. think tanks that link it to security and weather sovereignty.[54]

European Strategies on Geoengineering

How can Europe not only protect its cornerstone policy of emissions mitigation but also, potentially, set the international agenda and standards on CDR and SRM technology and governance? Given the fraught context, it is dangerous for the EU to assume CDR and SRM will neatly supplement mitigation. Whether these technologies buy time or the opposite, and how much to trust future solutions over available ones, depends on wider political questions, not just on whether current mitigation is woefully insufficient.

Solar Radiation Modification

On SRM, the EU still has potential to shape global governance before unilateral research, commercial incentives, and security logics crowd out scientific and collective aims. The risk of a small set of powerful states and private actors shaping the field is already acute, with players in Israel, the UK, and the United States advancing more assertively. Without early coordination, EU regulatory and sustainability preferences may lose field-defining potential.

The most immediate signal the EU can send to both profit-seeking actors and states inclined to securitize or commercialize SRM is to build a coalition around the position expressed by the EU Council in 2026.[55] The council's endorsement of precaution, SRM monitoring, and a deployment moratorium for the foreseeable future provides the start of a distinct European approach to SRM governance. This approach aligns with calls from the African Ministerial Conference on the Environment for a global nonuse framework[56] and with advice from EU scientific bodies to halt large-scale outdoor testing.[57] The EU should translate this emerging convergence into a proactive diplomatic initiative aimed at preventing premature deployment and discouraging an uncontrolled technological race.

In doing so, the EU should act while the window for consensus remains open. A coordinated framework is most feasible while there is still near-global reluctance about deployment. That window may narrow quickly as private and security-linked actors begin to mobilize around large-scale experiments or deployment scenarios. For now, however, the EU position remains aligned with the prevailing international stance: No state has formally endorsed deployment, and unilateral initiatives continue to face strong criticism. This creates a narrowing but still-viable opportunity for EU leaders to consolidate and institutionalize a nondeployment norm.

The EU needs to pair this nondeployment stance with support for carefully governed research. EU-funded programs, clearly distinguished from development and deployment, can set international benchmarks for transparency, multilateral oversight, and public accountability. The EU Council has already endorsed further discussion of international governance arrangements and more proactive EU funding for multilaterally governed research. These pledges should be put into operation in ways that reduce the risk of private capture and technological escalation. This means building on ethical frameworks for SRM research and demanding these be applied to all legitimate research assessed by the Intergovernmental Panel on Climate Change and others.

Another priority is to rebalance the knowledge base of SRM research. EU research funding should avoid replicating trends toward narrowly technocratic or engineering-led approaches. Recent funding patterns elsewhere have been heavily weighted toward natural scientific modeling and experimentation, sometimes involving commercial partners. By contrast, EU programs should foreground interdisciplinarity by incorporating social science, law, and broader forms of knowledge. Modeling alone is insufficient to guide decisions amid deep uncertainty and contested societal implications.

Last but not least, the EU must maintain a clear boundary between research and deployment. This will be politically and institutionally difficult, but it is essential. The criteria for public funding should explicitly prioritize projects that minimize pathways to rapid commercialization or deployment, and instead support forms of inquiry that enhance collective understanding without accelerating technological lock-in. If funding agencies can accelerate innovation and diffusion elsewhere, they can also be directed to contain escalation risks in the SRM field.

Carbon Dioxide Removal

As for CDR, a more coherent EU doctrine is also possible: This technology should be governed as a scarce, tightly constrained, and nonsubstitutable resource, used only to address clearly and equitably defined residual emissions and never as a flexible and futurist alternative to near-term emissions reductions. To this end, the EU should focus on six steps.

First, the union should sharply limit its reliance on CDR. As a historically high-emitting region, Europe should avoid drawing on scarce global supplies of just and sustainable carbon removal. EU policy should reflect this scarcity explicitly, rather than assume future abundance. Allowing emissions, especially from commercially hard-to-abate sectors, to be compensated through removals risks weakening incentives for structural decarbonization and slowing innovation, where advanced economies have a particular responsibility to lead.

Second, the EU needs to anchor its climate targets in domestic mitigation. The EU and its members should maintain clear commitments to meet their nationally determined contributions and the 2040 target primarily through emissions reductions within their borders, and resist integrating international CDR credits into compliance frameworks. Questions about the risks of carbon leaking—for example, when it is captured in trees or soils—and the quality of carbon-credit projects remain unresolved. More fundamentally, replacing planned cuts in fossil-fuel emissions in Europe with land-based carbon removals elsewhere transfers environmental and social risks to vulnerable communities. Europe needs a robust principle of territorial responsibility to avoid externalizing costs or generating new pressures on biodiversity, food systems, or human rights.

Third, the EU should move from net targets to institutional separation. Composites such as climate neutrality and net zero easily blur the boundary between emissions reductions and removals. To avoid implicit fungibility, the EU should establish separate, legally grounded, and politically transparent targets for emissions reductions and for distinct categories of removals. This would help ensure that CDR is used narrowly to address clearly defined residual emissions, rather than as a general balancing mechanism.

Fourth, Europe must place strict limits on the use of removals. CDR should be confined to demonstrably residual emissions identified by a combination of technical challenge (emissions that are hard to abate) and social profile (those that it would be unjust to abate). Limits on the share of emissions that can be offset through removals can be lowered over time. In particular, integrating CDR into the ETS—where substitution would be driven primarily by price—risks undermining mitigation incentives and should be tightly constrained. Support for restoring ecosystems in poor countries harmed by historic resource extraction should not count as carbon credits.

Fifth, the EU should guard against speculative reliance and policy hype. Assumptions of large-scale removals, drawn from exploratory model scenarios and corporate wishful thinking, risk creating a false sense of future flexibility. The EU should adopt more

conservative approaches to CDR availability in policy design, strengthen regulatory measures against greenwashing, and require greater transparency and independent scrutiny of removal claims.

Finally, the EU needs to treat CDR as a constrained and exceptional instrument. Even when acknowledged as part of the policy mix, CDR should not be a routine offsetting mechanism embedded in carbon markets. This implies maintaining separate governance frameworks, ensuring political visibility and oversight, and including explicit safeguards against mitigation deterrence in the design of EU climate policy.

Pursuing such options would meet resistance but could strengthen the EU's alliances with high-ambition developing and climate change–vulnerable countries on the basis of a comprehensive climate agenda that provides clear leadership in the vacuum created by petrostate obstructionism. A moratorium on deployment starting in the EU and aiming for global reach, coupled with the promotion of responsible research, could enable and extend such alliances.

Conclusion

If the United States withdraws from and continues to actively undermine climate governance, and geopolitical constraints mount, the EU faces a strategic quandary: Can it play a more assertive global role in addressing growing risks of climate overshoot and despair without weakening its central priority of rapid emissions reductions or generating new social, environmental, and geopolitical harms?

The challenges posed by CDR and SRM pull in different directions, but they converge on the underlying risk of erosion of the EU's precautionary and mitigation-first climate strategy. Within the EU, CDR is already embedded in long-term targets and regulatory thinking, with pressure to scale it. SRM, by contrast, is largely outside formal policy frameworks. A more coherent strategy would involve tightening constraints on CDR and treating it as a scarce and strictly supplementary resource while engaging much more proactively in shaping international norms, research, and governance for SRM to stem its uncontrolled proliferation and securitization.

Recent developments reinforce the urgency of this shift. In the United States, the convergence of tech capital, geopolitical competition, and narratives of so-called climate realism is beginning to normalize geoengineering as a strategic need rather than a complex challenge, particularly in the case of the comparatively low-cost, high-leverage SRM.[58] Deployment timelines for stratospheric aerosol injection are already emerging in policy-adjacent circles, while skepticism of precautionary or restrictive governance is growing. In this context, EU preferences for safeguards and prudent oversight will carry little weight unless backed by credible policy instruments, research, and diplomatic initiatives, especially when parts of the U.S. debate increasingly frame geoengineering in terms of strategic competition, weather sovereignty, and technological advantage.[59]

On CDR, this proactive posture entails resisting the drift toward substitution through target separation, strict limits on use, and a renewed focus on domestic decarbonization. On SRM, it involves using the EU's regulatory, diplomatic, and research capacities to slow the onset of unilateralism and technological lock-in by sponsoring a nondeployment mechanism combined with carefully governed public research.

These approaches seek to preserve political and economic pressure for emissions reductions, even as the policy landscape becomes more complex through mounting security, geopolitics, and environmental risk. If pursued consistently, this path would allow the EU to address overshoot risks without relinquishing its role as a driver of mitigation ambition, international legitimacy, and collaborative climate action.

03

The Development and Geopolitics of China's Geoengineering

Byford Tsang and Yedan Li

China's geoengineering efforts are in their early stages and characterized by a research landscape led primarily by national institutes and universities, with enterprises participating as key partners. A growing number of start-ups are further enriching the ecosystem, although they remain relatively small in scale and have yet to achieve the prominence seen in more established tech sectors.

The main sources of investment in China's geoengineering sector are national research funds, private companies, and state-owned enterprises. Notably, funds such as the National Natural Science Foundation of China and the National Key Research and Development Program provide substantial backing for climate and environmental research. Meanwhile, private companies are increasingly focusing their efforts on carbon dioxide removal (CDR) through land- and ocean-based projects, such as afforestation, grassland restoration, desert management, and marine aquaculture. State-owned enterprises, by contrast, play an important role in large-scale carbon capture, utilization, and storage (CCUS) initiatives and in the management of extensive forest carbon sinks.

Despite these activities and investments, China does not explicitly recognize geoengineering as a distinct category in its climate policies. Instead, it incorporates CDR strategies into its wider climate objectives, particularly those associated with Beijing's goal for China to be carbon neutral by 2060. While China has embraced clean technologies as significant drivers of modernization and as a means of building an alternative development model to that of the West, research into frontier technologies, such as solar radiation management (SRM), is more limited. Nevertheless, discussions of SRM governance and potential testing are starting to emerge, reflecting an evolving stance toward these more controversial interventions.

Geoengineering in China's Climate Policies

While the term "geoengineering" does not feature in China's climate or environmental policy lexicon, various approaches commonly associated with geoengineering, especially carbon removal, have been integral to China's climate change mitigation strategy. Terrestrial ecosystem-based carbon sequestration, such as large-scale afforestation, grassland restoration, and wetland protection, as well as industrial carbon removal methods such as CCUS, play prominent roles. SRM technology, by contrast, receives no explicit mention in these policies.

Within China's climate policy landscape, these approaches are considered fundamental to achieving the country's goal of carbon neutrality. Experts and policymakers often describe carbon removal as the "ballast" or "stabilizer" of China's climate strategy.[60] This framing underscores the importance of these techniques in providing a critical buffer period, allowing for the gradual phaseout of fossil fuels and the staged introduction of clean-energy technologies. China sees such a transition as essential for ensuring the country's energy security and a stable, low-carbon economic transformation.[61]

In 2022, China published the Fourth National Assessment Report on Climate Change, a comprehensive analysis produced jointly by key national institutions, such as the Ministry of Science and Technology, the China Meteorological Administration, the Chinese Academy of Sciences, and the Chinese Academy of Engineering.[62] This and other reports aim to capture the latest developments in China's climate change research, support the formulation of domestic and international climate policy, and offer strategic guidance for technological research and development in related fields.

Carbon Removal Targets

Conventional CDR approaches, such as afforestation and reforestation, have long been integral to China's climate change mitigation strategy. In its initial international climate pledge under the UN Framework Convention on Climate Change (UNFCCC), submitted in 2015, China committed to increase its volume of forest stock as part of its broader endeavor to reduce emissions by 2030.[63] In 2021, the State Council set a forest coverage target of 25 percent by 2030.[64]

China's overarching carbon sink target informs national policies and planning related to reforestation and afforestation. As with most quantified policy objectives in China, this goal is supported by a national implementation plan, which requires provincial governments to develop localized strategies with specific measures to meet national targets. To put this objective into operation, the National Forestry and Grassland Administration has developed a five-year plan that outlines a series of initiatives, including afforestation and reforestation programs, improved forest management, stronger wetland protection, and enhanced carbon sink measurement and monitoring.[65] These efforts are designed to ensure steady progress toward China's long-term carbon sequestration goals.

Carbon Removal in Climate Policies

Most emissions pathways consistent with limiting the average global temperature rise to 1.5° Celsius (2.7° Fahrenheit) or 2°C (3.6°F) since preindustrial levels—whether modeled by Chinese or international research institutions—incorporate both industrial carbon removal technologies, such as bioenergy with carbon capture and storage (BECCS) and geological sequestration, and enhanced terrestrial carbon sequestration in agriculture, forestry, and other land-use sectors.[66]

Notably, research led by Professor He Jiankun at Tsinghua University, which has served as an intellectual foundation for China's carbon neutrality target, highlights the essential roles of carbon capture and storage (CCS), BECCS, and agroforestry carbon sequestration in meeting climate goals.[67] His 2022 study estimated that achieving a 2°C-aligned emissions trajectory would require an additional 700 million metric tons of carbon sequestration from agriculture, forestry, and other sectors alongside the storage of 510 million tons of carbon dioxide (CO_2) through industrial CCS.

Carbon removal technologies are embedded in China's strategy for achieving carbon neutrality by 2060. Indeed, carbon removal is a key component of the Chinese government's high-level design of its climate policy framework, guiding actions at different levels of governance. Notable among these actions are the 14th Five-Year Plan and the 2035 Long-Term Vision Outline, the central government's opinions on achieving carbon peaking and carbon neutrality, and the State Council's Action Plan for Carbon Peaking Before 2030. These policy frameworks collectively define the role of carbon removal in China's pathway toward carbon neutrality.

The main approaches in China's climate policies are carbon removal via natural ecosystems and industrial methods such as CCUS.

Carbon Removal in Terrestrial and Marine Ecosystems

Enhancing carbon sink capacity is listed as one of the ten major actions in the Action Plan for Carbon Peaking Before 2030.[68] While this plan does not specify the approaches to be taken to enhance natural carbon sinks, it does cover the types of ecosystem involved, including both terrestrial and blue carbon.

Industrial Carbon Removal

For industrial CCUS, the focus in China's policy documents is on investing in technological breakthroughs, scaling up technologies, and promoting demonstration and commercialization. Fossil-fuel power is likely to remain part of China's energy system through 2060, making CCUS necessary for maintaining a zero-carbon trajectory. In the power sector, CCUS also enables coal-fired plants, of which China owns the biggest fleet in the world, to support stability in a renewables-dominated grid.[69] For heavy industries, such as steel and cement, CCUS provides a feasible decarbonization solution.

Since 2011, China has developed a CCUS Technology Road Map, which identifies CCUS as a strategic technology for the large-scale, low-carbon use of fossil-fuel energy.[70] By the end of 2022, the Chinese government had issued over seventy policy documents related to CCUS, covering areas such as planning, standards, and technical guidelines.[71] Beijing has also established financial mechanisms to incentivize investment in CCUS. Policies such as the Climate Investment and Financing Pilot Program and the Green Bond Endorsed Project Catalog explicitly include CCUS, enabling funding opportunities for research, demonstration, and deployment.

Geoengineering Research and Development in China

China's geoengineering readiness shows a clear distinction between CDR and SRM technologies. In CDR, China has research capabilities on a par with international standards for land-based technologies and leads in certain ocean-based approaches, such as artificial upwelling and downwelling and blue carbon, which have reached the stage of commercial deployment in China despite remaining at the prototype verification stage internationally.

In contrast, China lags significantly in SRM research. There is a notable absence of activity in key SRM technologies, such as stratospheric aerosol injection (SAI), surface albedo augmentation and modification, and marine cloud brightening, all of which are more actively explored in other countries.

Overall, China's geoengineering research is conducted primarily by state-run institutes under the Chinese Academy of Sciences and the Ministry of Natural Resources as well as leading universities, such as Zhejiang and Xiamen. The research landscape is highly state controlled, with funding and priorities closely aligned with national strategies and five-year plans.

Perceptions of Risk

Chinese scholars have conducted extensive research on the risks associated with geoengineering, particularly SRM. Many of these studies have been supported by the National Key Basic Research Program, launched in 2015 as China's first national research program on geoengineering. The five-year project involved leading academic institutions, such as Beijing Normal University, Zhejiang University, and the Chinese Academy of Social Sciences.

A primary concern identified in these studies is the potential for disruptions to the climate and ecosystems. For instance, research on "cocktail geoengineering," which combines SAI and cirrus cloud thinning to stabilize global temperatures and precipitation, suggests that while this approach shows promise in mitigating some risks, it also results in uneven precipitation patterns and highlights the persistent challenges of regional inequalities in climate outcomes under geoengineering scenarios.[72]

Other studies have examined the interaction between SRM and the carbon cycle. The findings suggest that while SRM increases terrestrial carbon storage, as its cooling effect reduces soil respiration by reducing CO_2-induced heat stress, lower atmospheric CO_2 in turn reduces how much SRM is needed, creating a stabilizing feedback loop.[73] Research on extreme temperature and precipitation under solar dimming and SAI suggests that both methods generally moderate temperature and precipitation extremes relative to global warming by reducing the intensity of extreme heat and heavy rainfall.[74]

Additionally, studies simulating the effects of SRM on ocean acidification suggest that while SRM might mitigate temperature rises, it does not address CO_2-driven acidification. This issue disproportionately affects marine ecosystems in coastal regions, particularly in developing countries.[75]

The risk of termination shock is another critical issue identified in these studies. Simulations of long-term climate responses to idealized SRM scenarios highlight the consequences of a sudden cessation of SRM efforts, which could lead to rapid warming, severe ecological disruptions, and societal instability, especially for vulnerable populations least equipped to adapt to abrupt climate shifts.[76]

As of this writing, there is no real-world experiment or large-scale deployment of SRM technologies in China. Leading scholars in the field urge caution in managing the risks of geoengineering but are also calling for China to give these technologies a more formal role in the country's climate policies and to expand research in this area.[77] Some Chinese scholars, however, advocate the application of SAI in small-scale outdoor experiments to position China at the forefront of international research.[78]

Perceptions of Governance

China's relatively limited research efforts on geoengineering mean that Beijing lacks discourse power in international governance.[79] Indeed, less than 10 percent of all authors of major geoengineering proposals come from the BRICS group of countries.[80] Despite this, China is often mischaracterized by Western observers as a major player in geoengineering, largely because of its extensive weather-modification programs and a track record of engineering nature, from the Grand Canal system of interconnected waterways in northeast China to the Three Gorges Dam on the Yangtze River in central China.

Leading Chinese scholars on geoengineering believe there should be a distinction in the approaches to governing CDR and SRM technologies. The governance of CDR revolves primarily around issues such as safety and efficiency, as it is often integrated into existing climate change mitigation strategies. In contrast, SRM poses greater uncertainties, and its governance should take into account the risk of uneven regional impacts, environmental and human health effects, and ethical considerations.[81]

Domestically, there are existing legal frameworks that could apply to geoengineering research.[82] The Chinese government's 2019 Provisions on Handling Misconduct in Scientific and Technological Activities explicitly prohibit research and development activities that "endanger national security, harm public interests, pose risks to human health, or violate ethical principles."[83]

At the international level, China has taken a measured stance on SRM governance. During discussions at the UN Environment Assembly in 2024, China neither actively supported nor opposed a proposal to establish an expert panel on SRM governance. While Beijing did not align with the African Group's call for a nonuse policy, it also refrained from championing new governance mechanisms under the UN Environment Programme, arguing that existing international bodies, such as the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Organization, already undertake similar efforts.[84]

Key Research Institutions

China's geoengineering research landscape is shaped by an array of institutions, spanning national institutes, public universities, state-owned enterprises, and private or start-up ventures. National research funds underpin the work of universities and national institutes in basic and applied geoengineering research. State-owned enterprises take the lead in large-scale deployment and industrial application, often forging partnerships with other enterprises or international companies. The private sector complements these efforts by scaling up natural carbon removal solutions and engaging in partnerships with research bodies.

Bringing these various stakeholders together, collaborative networks are often built between universities, research institutes, and enterprises to tackle technical bottlenecks. All actors operate within a framework in which their research and development are aligned with China's national strategic needs and climate goals.

National Institutes

National research institutes play a leading role in China's geoengineering research and often set the strategic tone for scientific advancements in the field. At the forefront are the Chinese Academy of Sciences and its subsidiary institutes for geography, environmental science, oceanology, and atmospheric physics. These institutions conduct extensive research into land- and marine-based carbon removal and contribute to SRM understanding through specialties such as space-based carbon monitoring, AI-driven climate modeling, and the study of atmospheric aerosol interactions.

The Ministry of Natural Resources oversees several prominent institutes of oceanography that provide vital research infrastructure for developing and evaluating ocean-based climate intervention strategies. These institutes specialize in a variety of oceanographic research areas, including blue carbon, marine ecological dynamics, and deep-sea biology, as well as advanced marine-based techniques, such as artificial upwelling and downwelling.

The China Meteorological Administration's Weather Modification Center is another key player. The center's work is relevant to SRM and atmospheric interventions, specifically through cloud seeding and other weather-modification techniques. The center conducts large-scale field experiments to investigate the impact of aerosols on cloud formation and precipitation. By integrating satellite-based monitoring, AI-driven climate modeling, and advanced meteorological instrumentation, the center enhances China's capacity to manage atmospheric processes and explore climate intervention strategies on national and global scales.

Overall, these national institutes focus on large-scale, long-term research projects, often in collaboration with universities and state-owned enterprises. Their work plans and research priorities align closely with China's five-year plans, showing a high level of state involvement and coordination in their geoengineering research. These institutes are the primary recipients of major research funds. They operate under performance-based funding metrics and can receive additional targeted grants for specific research projects.

Universities

Leading Chinese universities contribute significantly to geoengineering's technological development and theoretical frameworks. Zhejiang and Xiamen Universities are at the forefront of ocean-based carbon removal technologies, having pioneered the concept of the "artificial upwelling carbon sink"—achieved by pumping cold, nutrient-rich water from the deep ocean up to the surface to enhance marine carbon sequestration—and developed innovative gas-injection lifting technology.[85]

The Ocean University of China further contributes to ocean-based solutions by serving as a global pioneer in blue carbon research, establishing national accounting standards, and advancing carbon capture through algal cultivation and microbial carbon fixation. Other relevant academic institutions include the China University of Geosciences and Tsinghua University's Institute for Carbon Neutrality.

University research tends to concentrate on basic scientific research, nurturing young talent and pioneering theoretical breakthroughs and exploratory technologies. However, it still feeds into state-led priorities, operates within a state-controlled framework, and relies on major state funding. In sum, China's universities leverage their specialized expertise and collaborative networks with other public and private institutions to drive the country's early-stage geoengineering efforts.

State-Owned Enterprises

State-owned enterprises constitute a significant force in China's geoengineering efforts, particularly in carbon removal. Rather than invest primarily in start-ups, these large enterprises tend to favor developing and operating their own extensive projects. Their involvement spans multiple categories, with energy companies having the most wide-reaching initiatives. These entities operate under national strategic directives and align their work with the state's overarching climate goals.

Major players in this space include the China Forestry Group Corporation, Fujian Jinsen Forestry, the Shandong Marine Group, the China National Offshore Oil Corporation, and China's two largest oil companies, the China National Petroleum Corporation and Sinopec Group.

The Private Sector

Finally, the private sector in China contributes to geoengineering research and deployment primarily through a growing but still small number of start-ups that develop and operate their own carbon removal projects. This approach contrasts with that of state-owned enterprises, which have a more extensive focus on industrial CCUS. Private companies' efforts are concentrated predominantly in land- and marine-based carbon removal, with minimal presence in SRM or industrial CCUS.

Investment data from 2019 to 2024 show over ninety funding transactions for geoengineering-related start-ups, primarily in land-based carbon removal, with the focus shifting from wood construction before 2022 to afforestation and carbon sequestration in 2022–2024. The frequency of funding for geoengineering-related start-ups peaked in 2023 before declining the following year, and overall funding amounts are significantly underrepresented, as only about a third of transactions disclosed their values.[86]

The Geopolitics of China's Geoengineering

China's weather-modification projects, while not considered geoengineering in a strict sense, have sparked concerns about weather wars. Beijing's long-standing application of these techniques, which are usually deployed on a large scale, has been criticized because of the risks of undesirable weather impacts for China's neighbors, such as disrupted monsoon patterns or reduced water availability downstream.

For example, the 2017 Sky River Project involved deploying tens of thousands of fuel-burning chambers designed to release silver iodide into the atmosphere to seed clouds and generate artificial rain.[87] This system could increase precipitation across an area about three times the size of Spain by up to 10 billion cubic meters (353 billion cubic feet) annually, which amounts to 7 percent of China's water consumption.[88] The project raised concerns from Indian observers, as the Tibetan Plateau is a critical source of water for India's major rivers, including the Brahmaputra, which starts in southwestern China.

Tensions surrounding large Chinese infrastructure projects and their regional impacts are long-standing. China's construction of a hydropower dam on the upper Brahmaputra (known as the Yarlung Zangbo in Chinese) has been a source of friction with India.[89] New Delhi accused Beijing of inadequate transparency in its hydrological data, which contributed to flooding on Indian territory.[90] In response, the two countries signed a series of memorandums of understanding aimed at improving data transparency and providing advanced flood warnings during the monsoon season.[91]

But concerns remain that such environmental engineering could be weaponized. China has reportedly stopped sharing hydrological data, despite the memorandums of understanding, citing technical reasons after a 2017 standoff in the border area of Doklam.[92] The involvement of the state-owned China Aerospace Science and Technology Corporation, a defense contractor, in the Sky River Project further fueled these concerns.[93] China's weather-modification development plans, which include quantified targets to generate artificial precipitation and suppress hail, have sparked new worries over China's geoengineering ambitions and their impacts on the region.

At the same time, Chinese researchers have voiced significant concerns about the potential weaponization of geoengineering technologies by other major powers. Leading experts on Chinese climate policies, such as Chen Ying at the Research Institute for Eco-civilization of the Chinese Academy of Social Sciences, have warned that the military, intelligence, and foreign policy agencies of powerful nations—particularly the United States—are already involved in SRM research and governance.[94]

Chen noted that the United States has a complex position on geoengineering. On one hand, the country is highly engaged in active scientific research and is acutely aware of the potential impacts and risks of geoengineering. On the other hand, it has shown strong resistance to international discussions of geoengineering governance—a stance that fuels speculation that the United States may be pursuing a unilateral path, leveraging its scientific and technological advantages as a major power.[95] Chen further cautioned that in the absence of a broad consensus, or if a partial consensus is achieved under duress, SRM deployment could be perceived as an act of war, potentially intensifying existing conflicts or sparking new ones.

Other scholars, citing the close ties between key geoengineering research institutions and the U.S. defense and intelligence community, have expressed concerns that technologies such as SRM could be developed or deployed within a military framework. For example, they have highlighted the personnel and funding links between the Harvard Solar Geoengineering Research Program and the Belfer Center for Science and International Affairs as well as the Weatherhead Center for International Affairs—the latter two of which have long-standing connections with the U.S. military apparatus—and the involvement of defense contractors such as Raven Aerostar in the Harvard program's research and experiments.[96]

Furthermore, Chinese researchers emphasize that the extensive infrastructure required for geoengineering inherently limits governance and equitable participation by weaker states. This concentration of capabilities in the hands of major powers or alliances risks turning geoengineering into a tool for preserving what one study described as a "military hegemony based on fossil-fuel power": By offsetting greenhouse-gas emissions in the short term and preventing other powers from challenging the existing fossil fuel–based energy hegemony, U.S.-led geoengineering could reinforce geopolitical and economic inequalities.[97] The fact that major oil and gas companies, such as Chevron, Shell, and ExxonMobil, and Big

Tech philanthropists, including Bill Gates, Dustin Moskovitz, and Richard Branson, are significant funders of SRM research in the United States reinforces this critical view of the country's geoengineering ambitions.[98]

There is also a strong concern that more technologically advanced nations are likely to gain an advantage in geoengineering research and development because of their superior resources. Some researchers have underlined the risk of intellectual property abuse, whereby countries that can develop geoengineering technologies further and faster could establish patent dominance over weaker nations, widening the existing knowledge and governance gaps in the field.[99] According to a 2025 study, there were fifty-two patent applications in SRM technologies, nearly half of which had been submitted by patent holders based in the United States.[100] That said, in terms of CDR innovation, China and the United States are both leading countries, together accounting for over 13,000 patents filed from 2004 to 2023.[101]

At the same time, geoengineering itself appears to be becoming more visible in China's academic climate discourse. For example, the 2026 International Conference on Climate Change and Carbon Neutrality, held in Xi'an in April, listed geoengineering as a dedicated research theme alongside negative-emissions technologies, carbon capture and storage, climate policy and governance, and climate justice.[102] While this does not indicate that geoengineering has been institutionalized as a distinct category in Chinese climate policy, it does suggest that the concept is becoming more visible and normalized in academic discussions of climate technology and governance.

More broadly, the Chinese research community is actively tuning into international debates on the implementation, theorization, and governance of geoengineering to establish a comprehensive understanding of the technologies' challenges, ethical risks, and geopolitical implications. Recognizing that China is not yet a prominent player in the field, particularly with regard to frontier technologies, such as SRM, Chinese researchers are raising concerns, first, about the legitimacy of large-scale geoengineering conducted by developed powers without an effective international governance framework and, second, about the dangerous power imbalances that such unilateral climate interventions could create. Many Chinese scholars caution against the aggressive acceleration of geoengineering research and advocate a stronger voice for China in the design of a fair and robust multilateral governance mechanism.[103]

04

The United States and the Geoengineering Conundrum

Rod Schoonover

The United States finds itself at a moment of profound discontinuity in its political and scientific trajectory, despite long-term energy expansion and technological competition. The climate math is unforgiving. Humanity has effectively committed the Earth system to exceeding the 1.5° Celsius (2.7° Fahrenheit) threshold for average global warming since preindustrial levels; warming is now well on its way toward a 2°C (3.6°F) rise by the end of the century, and will almost certainly go beyond it. This physical reality intensifies the need to manage the consequences of a changing climate as conventional mitigation and adaptation efforts continue to fall short.

Debates over geoengineering have accelerated and grown increasingly polarized. One pole, largely anchored in Europe, emphasizes precaution and advocates strict moratoriums or outright nonuse agreements, particularly for methods that seek to disrupt incoming solar radiation.[104] The other pole resists any restraints on research or deployment, often rooted in national sovereignty or techno-optimism.[105] Between them lies a risk-balancing middle ground: The view that humanity must prepare scientifically for the possibility of geoengineering deployment, even though it remains deeply contested. Some proponents argue that the risks of deployment must be weighed not against a pristine Earth but against the real-world risks of accelerating climate disruption; under those conditions, advancing scientific understanding itself becomes a form of prudence.[106]

The U.S. political environment under the second term of President Donald Trump adds a destabilizing element: a governing posture that actively denies and distorts climate science. In practice, that position is dismantling the agencies and expertise the United States would need for any responsible engagement in geoengineering. By defunding climate monitoring and hobbling analyses such as the National Climate Assessment, the administration is widening the gap between growing planetary risk and the government's ability to manage it.

Historically, the United States has engaged in geoengineering discourse from a position of scientific authority and evidence-based inquiry. It has supported expert assessments and governance frameworks while deliberately avoiding firm commitments to either deployment or outright prohibition. That era of cautious stewardship has ended. Amid sharpening geopolitical rivalries and a federal government entrenched in climate change denialism, the United States is, for now, no longer a stabilizing force, and it risks becoming the kind of "rogue actor" U.S. intelligence assessments once warned about.[107]

This article defines responsible geoengineering as any pathway grounded in scientific integrity, supported by transparent governance, aligned with considerations of global equity, and pursued through legitimate democratic processes. Such a pathway may ultimately lead to prohibition, governed research, or even deployment. Arguments that treat geoengineering as inherently dangerous rest on scientific uncertainty and on normative judgments about acceptable risk and human intervention in Earth systems. By this standard, the current trajectory of U.S. domestic politics and institutional decay threatens the nation's capacity to engage responsibly. It also weakens the broader international system's ability to manage planetary risks.

The U.S. security community has long recognized that climate disruption and poorly governed geoengineering pose destabilizing risks from migration shocks to interstate tensions. Intelligence assessments have even warned that unilateral deployment by a state or nonstate actors could become a source of conflict.[108] However, the United States is currently undermining its own ability to heed those warnings. The decline of U.S. scientific institutions and governance capacity is now eroding the pillars of cautious engagement, and narrowing the strategic choices available to U.S. decisionmakers in the near and medium terms.

Before and After the Rupture

Before 2025, the United States approached geoengineering from a position of cautious engagement. Federal agencies and scientific and advisory bodies sustained research capacity, and commissioned expert studies, while the monitoring agencies kept watch on the Earth system. Political leaders, however, largely avoided committing to either deployment or prohibition. Federal funding for geoengineering research was modest and typically incorporated into broader climate science programs, reflecting an exploratory approach that stopped short of endorsement.

U.S. caution varied by technology. Research funding and policy formulation were relatively more open to carbon dioxide removal (CDR), often within wider climate science and innovation efforts. Solar radiation modification (SRM), however, was confined to modeling and assessment work, reflecting greater concerns about these technologies' governance and equity.

Security actors occasionally raised concerns about potential unilateral deployment by foreign powers, but the prevailing U.S. stance stayed grounded in scientific assessment. In international forums, this caution translated into a reputation for being laissez-faire or uncooperative on governance issues, complicating cooperation with partners that sought stronger regulatory frameworks. Such caution was less disengagement than a deliberate attempt to preserve freedom of action and avoid constraints on a technology still in its infancy.

The Federal Science-Policy Apparatus

Behind this cautious posture stood a complex science-policy architecture. Effective U.S. engagement on geoengineering depended on this ecosystem of agencies and institutions, whether the goal was research, regulation, negotiation, or prohibition. Key players included:

- **National Oceanic and Atmospheric Administration (NOAA):** This agency is the lead entity for understanding and predicting changes in climate, weather, oceans, and coasts. NOAA's monitoring networks and models provide essential baseline data and were foundational for assessing how geoengineering interventions might perturb ocean-atmosphere systems.

- **National Aeronautics and Space Administration (NASA):** Beyond space exploration, NASA is a world leader in Earth observation. Its satellites provide global data on the atmosphere, oceans, and ice sheets, and they are central to monitoring climate variables and detecting signals of large-scale interventions.

- **Department of Energy, Environmental Protection Agency (EPA), National Science Foundation (NSF), and U.S. Geological Survey:** Together, these agencies provide research expertise and infrastructure across energy systems, environmental risk assessments, Earth sciences, and land and water resources. Through NSF's support of major atmospheric research institutions, the United States maintains core capabilities in climate modeling and atmospheric chemistry that are essential for evaluating the potential impacts and risks of geoengineering.

- **Office of Science and Technology Policy (OSTP):** Situated within the Executive Office of the President, OSTP coordinates science policy across agencies and provides direct advice to the White House, and ensures coherence on cross-cutting rules for research and transparency.

- **National Academies of Science, Engineering, and Medicine (NASEM):** Although nongovernmental, NASEM advises policymakers through independent, evidence-based assessments

- **Intelligence community:** With its unique monitoring and analytical capabilities, the intelligence community tracks foreign research and assesses risks arising from weaponization and unintended consequences. It would also support the verification of any international agreement.

This science-policy architecture represented the nation's primary capacity to understand climate change and its risks, and to engage credibly in international debate. While imperfect, the apparatus enabled the United States to ground its cautious stance in evidence and participate in global governance conversations with a measure of authority.

From Strength to Incapacitation

Beginning in 2025, this foundational architecture came under assault. Early actions by the second Trump administration started dismantling the institutions that had underpinned cautious engagement. The cumulative impact of budget cuts, ideological loyalty tests and personnel purges, regulatory rollbacks, and a narrowing of mandates has been significant technical and institutional incapacitation across the federal government's climate and science infrastructure.[109] Five specific consequences stand out.

Erosion of Expertise

Many senior scientists and climate policy experts from agencies such as NOAA, NASA, the EPA, and NSF have been driven out of government service or seen their entire climate-relevant offices closed. Hiring freezes and potential loyalty tests further impede recruitment and retention of talent. The result is a significant brain drain.[110]

Gaps in Data and Monitoring

Budget reductions have impacted the continuity and reliability of long-term climate-monitoring systems, including satellite missions and ground-based observational networks. Restrictions on data access and the public communication of climate-related findings by federal scientists further obscure understanding of ongoing environmental changes.[111]

Degradation of Research and Modeling

Federal funding for climate science, particularly large-scale Earth-system modeling, which is critical for assessing both climate change and potential interventions, has been curtailed. Resources for high-performance computing are being reallocated, and grant programs that support university research in climate science are facing cuts or redirection.[112]

Weakening of Assessment and Policy Functions

Independent scientific advisory panels on climate change have been sidelined or disbanded and regulatory processes have been streamlined in ways that reduce consideration of climate impacts. The EPA's capacity to develop and enforce regulations has been significantly weakened.[113] OSTP's role in coordinating climate science and policy across agencies has been refocused entirely away from climate concerns.[114]

Conflicting Policy Direction

Beyond specific institutional impacts, the administration's overarching policy commitment to maximizing fossil-fuel extraction works against efforts to address the climate crisis. This creates a policy environment in which even theoretical considerations of climate impacts or complex interventions, such as geoengineering, are systematically deprioritized and undermined.[115]

Some counterweights remain. Certain states, notably California, continue to pursue ambitious climate programs, and career scientists in agencies like NOAA and NASA strive to preserve data continuity and expertise.[116] Yet, these efforts are fragmented and resource-constrained. They slow the erosion of capacity but cannot offset the scale of federal dismantling.

The Domestic Political Crucible Around SRM and CDR

The domestic political context that surrounds geoengineering in the United States is deeply fractured and shaped by localized concerns of environmental justice, conspiratorial paranoia, and heavy industrial lobbying. The political treatment of SRM and CDR is highly divergent, because the two carry very different perceived risks and very different economic incentives. Across the United States, opposition to and support for these interventions are emerging as potent, cross-cutting forces in climate politics. Neither fits the left-right political divide.

SRM: The Conspiratorial Right and the Resistant Left

Opposition to SRM unites much of the conspiratorial right and the progressive left, albeit for different reasons. On the right, antigovernment paranoia and chemtrail conspiracy theories have infiltrated mainstream discourse, prompting several state legislatures to pursue outright bans on atmospheric aerosol dispersal. Conversely, the political left often frames SRM as a moral hazard that distracts from emissions reductions and poses inequitable risks to the Global South.

This deep polarization paralyzes federal policy, leaving a governance vacuum in which subnational entities are left to handle the conundrum alone. Localized resistance has already become a material constraint on geoengineering research. In 2022, Alaska Native organizations challenged the Arctic Ice Project, which sought to slow climate change by restoring sea ice, over inadequate consultation; a lack of free, prior, and informed consent; and potential ecological harms.[117] In California, the Alameda City Council blocked the resumption of a University of Washington experiment into marine cloud brightening after local officials raised concerns about transparency, authorization, and public oversight.[118]

CDR: The Bipartisan Bastion and Industrial Capture

Unlike SRM, CDR (specifically, direct air capture and point-source capture) enjoys broad bipartisan support, largely because it strongly aligns with the economic interests of the legacy fossil fuel sector. This dynamic was solidified in 2025 by the One Big Beautiful Bill Act, which established fiscal parity under a federal tax credit for permanent geological storage and enhanced oil recovery. While this move ensures short-term longevity and funding for CDR technologies, it exacerbates the central climate conundrum. By heavily subsidizing carbon capture as a supply chain for further oil extraction, the act's provisions severely undermine the net-negative emissions potential of CDR. This dynamic deepens progressive skepticism. Many on the left now see the technology as a publicly funded lifeline for extractive industries.

The Second Trump Administration: Continuity and Discontinuity

Paralyzed SRM research and the industrial capture of CDR feed directly into the broader strategic and institutional shift of the second Trump administration, and that shift in turn makes both worse. Trump's second term deepens structural continuities in U.S. geoeconomics and technological competition while producing sharp, politically driven discontinuities in the country's science governance and international posture.

The effects compound: When enduring drivers, such as energy expansion and tech competition, intersect with institutional dismantling and conspiratorial politics, the United States becomes far more likely to follow hazardous, poorly governed pathways on geoengineering.

Continuities: Strategic and Technological Drivers

Trump's second administration amplifies each of these long-running drivers. They embolden the structural incentives for geoengineering, even in the absence of governance or scientific capacity.

Enduring U.S.–China Strategic Rivalry

Strategic competition with China remains the dominant axis of U.S. foreign policy, sustained by geopolitical analysis and by persistent domestic narratives that cast China as an inherent adversary. This blend of structural rivalry and ideological framing is a significant impediment to global climate cooperation. Mutual suspicion blocks joint initiatives and knowledge sharing while dampening the emergence of trust-based governance. For geoengineering, the implications are particularly severe: Without a baseline of U.S.-China cooperation, efforts to establish credible rules or verification systems, let alone a moratorium, are unlikely to succeed.

An Energy Emergency and an Energy Footprint

The administration's declaration of a national energy emergency accelerates fossil-fuel production and associated emissions. This trajectory increases the likelihood of high-end warming scenarios, which heightens political pressure to consider drastic interventions. Deregulated, energy-intensive industries, such as cryptocurrency mining, further compound this footprint. This trajectory also creates a classic moral hazard, as expanded fossil-fuel output today increases the likelihood that leaders will later advocate emergency SRM as a rapid cooling stopgap rather than cut emissions.

Fossil-Fuel Exports as Leverage

The United States is doubling down on fossil-fuel production and exports, using them as instruments of diplomacy and economic competition. Because China is the world's largest energy importer and increasingly seeks to shape global supply chains through its own partnerships, this strategy directly challenges Beijing's influence and intensifies the rivalry.[119]

Technology and AI as a Security Edge

The administration prioritizes AI and other advanced technologies as pillars of national competitiveness and security. This orientation fosters an appetite for rapid, high-tech fixes that could make techno-solutions, such as geoengineering, seem more appealing, even when their risks are poorly understood.

Discontinuities: Institutional and Political Breaks

Under the second Trump administration, several breaks have been introduced that directly undermine the possibility of a responsible U.S. approach to geoengineering.

Withdrawal from Cooperative Governance

The United States has moved from disengagement with climate institutions to a posture of selective participation, prioritizing narrow national interests over collective rulemaking. This shift erodes allies' trust in U.S. reliability and makes it far more challenging to establish international governance on geoengineering.

Dismantling of the Scientific Architecture

Budget cuts and narrowed mandates have hollowed out federal monitoring and modeling, leaving a weaker evidence base for policy and verification. The brain drain of scientists compounds the problem. The federal government is now far less able to assess geoengineering risk or anticipate side effects, and it may not even detect deployment by others.

Conspiratorial Influence and Legal Bans

Political factions have increasingly conflated geoengineering with conspiratorial narratives such as chemtrails, producing pressure for outright bans or heavily politicized prohibitions. A 2024 controversy in which then representative Marjorie Taylor Greene suggested that the government was maliciously engineering hurricanes exemplifies how fringe theories can move into mainstream discourse.[120] This environment of distrust risks producing inconsistent, reactive domestic policies that do not align with international verification or governance needs. It also undermines U.S. credibility in global forums when domestic debates are distorted by conspiracy theories.

Lobbying Pressures from Big Oil and Big Tech

Two powerful but divergent lobbies shape outcomes. Big Oil pushes for expanded fossil fuel production and regulatory rollbacks, exacerbating emissions and increasing the likelihood of pressure to pursue emergency interventions. Big Tech, with growing investments in climate-tech and SRM-relevant start-ups, may quietly advance research outside federal oversight. The effect is bifurcation where fossil-fuel interests deepen the problem and tech interests increase the capacity and incentives to pursue unaccountable solutions.

Policy Incoherence and Legal Fragmentation

Federal retreat has created a patchwork of initiatives. Some state governments, universities, and private firms continue to pursue CDR or small-scale field trials of SRM. At the same time, federal capacity to coordinate or regulate remains weak or nonexistent. This lack of coherence raises the risk of unmonitored experiments. It also fuels perceptions abroad that the United States is unable or unwilling to manage geoengineering responsibly.

Fragmentation has uneven consequences. CDR can be piloted in subnational contexts, provided clear permitting and liability pathways are in place. SRM is harder. Its experiments can have cross-border ecological and diplomatic effects, so even small-scale trials would, in principle, require federal coordination and transparent notification. The United States lacks a dedicated federal framework for managing geoengineering, or assigning liability for it, leaving both CDR and SRM in legal gray zones.

How Continuities and Discontinuities Interact

These two sets of trends interact, and this interaction compounds systemic risk in three ways. In each, the temptation to pursue geoengineering grows while the safeguards needed to manage it recede.

First, a capability gap meets an incentive gap. Persistent incentives for technological fixes, such as the U.S.-China rivalry and the bipartisan political appetite for high-tech solutions, collide with an erosion of public scientific capacity and governance structures. While demand for geoengineering options increases, the capacity to evaluate or regulate them shrinks. In a crisis, this mismatch raises the risk of a desperation pivot, in which SRM trials are advanced without the necessary institutions to monitor them or explain them to the public.

The second mechanism is privatized experimentation, which invites misreading at home and abroad. As federal oversight recedes, other actors fill the vacuum. Without statutory authority or national coordination, these actors may pursue carbon removal or SRM trials in ways that are hard to verify internationally, and easy for other governments to take as evidence of U.S. intent. Such uncoordinated activity is also likely to fuel domestic conspiracy narratives, including claims that elites are secretly controlling the weather.

Finally, eroding trust raises the danger of escalation. When conspiracy theories pollute domestic debate, U.S. geoengineering policy, including state bans, rests on claims that other governments know to be false. That makes Washington's commitments on transparency or restraint harder to believe. The distrust can also run the other way. A faction that already sees deliberate malice behind hurricanes, as Greene's 2024 claims showed, is primed to read a rival's SRM activity as an attack. In a crisis, either side may deploy first, or deploy in response, on suspicion alone.

These dynamics create three choke points: a verification gap or weakened capacity among relevant agencies that impairs detection and confidence building; a legal gap, or the absence of a federal framework to control or even track subnational CDR or SRM; and a governance gap, or corporate priorities substituting for public deliberation. Together, these gaps make the United States appear unreliable to allies and competitors, and make it act unpredictably, exactly when credibility is a prerequisite for any global rulemaking.

Divergent Post–Trump Futures for the United States

The institutional rupture and domestic volatility of the second Trump era leave the trajectory of U.S. science and global governance highly uncertain. As the physical realities of a warming planet force interventions such as SRM and CDR into immediate strategic consideration, the United States will face a critical branching point after Trump leaves office in 2029. The choices made in the post-Trump era will extend beyond domestic politics, ultimately determining whether the international community can forge a stable, legitimate governance regime or will fragment into adversarial climate interventions.

Scenario Set 1: Reengaging with Multilateralism

On this scenario track, a post-2029 administration explicitly commits to rejoining UN frameworks, international climate treaties, and multilateral dialogues that include the governance of geoengineering. However, the specific nature of that engagement determines the stability of the global order regarding these technologies.

Scenario 1A: The Cooperative Force

The United States operates as a stabilizing, cooperative force. It leverages its vast financial and technological resources to push for risk-based, equitable approaches to both CDR and SRM, governed strictly through multilateral bodies. The United States comprehensively rebuilds the civilian capabilities of NOAA, NASA, and the EPA, using this expertise to

support global monitoring networks and attribution science. Washington works in lockstep with the EU and the Global South to establish transparent thresholds for research, ensuring that any field experiments are subject to the consent of affected populations and rigorous environmental impact assessments.

While desirable, this scenario requires overcoming an enormous trust deficit. Allies will likely need multiple election cycles to believe that U.S. cooperative diplomacy will outlast the next populist disruption.

Scenario 1B: The Unstable Player

Washington rejoins multilateral forums but behaves as an erratic participant. Polarization (and perhaps radicalization) at home and shifting congressional majorities make U.S. approaches hard to predict, and heavy lobbying from the fossil-fuel and tech industries, pulls them in different directions. The United States sends mixed signals to the international community.

In this role, U.S. diplomats delay or dilute efforts to establish firm multilateral governance. Washington insists on voluntary reporting and nonbinding research guidelines, and on protecting intellectual property for domestic corporations. It has played this part before in the broader climate regime; the United States often watered-down binding emissions targets only to withdraw from agreements and later reenter. This ambivalence frustrates allies. Emergency protocols stall and the international community stays mired in procedural debate as warming continues.

Scenario 1C: The Aggressive Underminer

In this scenario, the United States reengages with multilateral institutions specifically to subvert them. A highly capable, science-literate administration driven entirely by America First security imperatives aggressively undermines multilateral efforts to retain unilateral leverage and absolute freedom of action.

Treating planetary climate control as a zero-sum theater of great-power competition, the United States works to defeat UN resolutions on SRM bans and presses other governments to abandon moratoriums such as the one adopted under the Convention on Biological Diversity. It threatens trade retaliation against nations that try to regulate U.S. geoengineering corporations. Borrowing tactics from global trade disputes, it uses its presence in international forums to block consensus. The goal is to peel countries away from any coalition seeking binding rules, so that no international law can constrain its ability to deploy SRM or dominate CDR markets.

Scenario Set 2: Remaining Outside Multilateralism

In the second set of scenarios, a post-2029 administration declines to rejoin UN climate frameworks, including any on geoengineering governance. It goes further, rejecting the authority of the UN and multilateral environmental agreements altogether. That rejection

could take two forms: isolationism, in which Washington walks away, or transactional hegemony, in which it builds a rival system. The second could do far more damage to the global order.

Scenario 2A: The Inactive and Indifferent Stat

Here, the U.S. federal government remains inactive and indifferent toward geoengineering. Crippled by internal political gridlock or a sustained commitment to climate change denialism, Washington passively cedes the domain entirely to private actors, venture capital–funded start-ups, and foreign competitors. Without a federal regulatory framework, the legal and verification gaps widen dramatically. U.S. borders become havens for rogue experimentation, leading to a proliferation of unauthorized, localized SRM trials that violate international norms.

The federal government refuses to engage in global diplomacy, reacting only after the fact when a catastrophic domestic consequence occurs or when a foreign power's unilateral deployment directly damages the American homeland. This negligence leaves the rest of the world to manage the planetary crisis while constantly bracing for uncoordinated shocks emanating from the U.S. private sector.

Scenario 2B: The Coercive Hegemon

This scenario poses the most systemic threat to established global governance. Remaining outside the traditional UN multilateral system, the United States aggressively establishes its own parallel, exclusionary geoengineering regime. Its structure borrows from the Board of Peace, a body created in 2026 purportedly to oversee Gaza's reconstruction. The charter of that body, as written, gave its U.S. chairman unilateral authority over its membership and agenda, charged member states a $1 billion fee for permanent seats, and drew wide criticism as an attempt to supplant the UN.[121]

Applying this transactional, chairman-dominated model to climate intervention, Washington places itself at the center of decisionmaking. The exclusionary board recruits wealthy allies through a similar pay-to-participate arrangement and authorizes rapid SRM deployment to protect the economic centers of its paying members. International environmental law is replaced by a coercive hegemony in which the right to shape planetary climate interventions becomes a commodity sold to those who can afford a seat, while the consequences of those interventions are imposed on everyone else.

Global Reverberations

The consequences of U.S. policy volatility will not be confined to the United States' own borders. American instability on climate and geoengineering reverberates through the international system, reshaping the strategic calculations of allies, and competitors alike, often in ways that undermine U.S. interests.

When the United States oscillates between engagement and withdrawal, it cedes ground to rivals and weakens the alliances it needs to shape global norms. European governments, already inclined toward precaution, are likely to harden their calls for nonuse agreements or moratoriums on SRM. Such positions may further isolate the United States from cooperative frameworks, even if a more constructive administration returns to power.

Meanwhile, U.S.-China rivalry risks transforming geoengineering governance into yet another arena of strategic competition. A volatile Washington opens space for Beijing to position itself as a more stable partner and norm setter, banking reputational gains by advancing CDR standards while contrasting its steady stewardship with the United States' erratic posture. For vulnerable nations in the Global South, those bearing the severest climate impacts, U.S. instability deepens an already difficult predicament. Fragmented coalitions struggle to secure a voice and safeguards in governance structures dominated by major-power rivalries they cannot control.

The cumulative result is a world in which mistrust flourishes and the governance architecture the United States needs to protect its long-term interests remains fragile. Fragmentation produces blocs with mismatched rules and expectations for carbon removal and sunlight reflection. Opaque private research, whether American or otherwise, leaves publics and governments in the dark. The prospect of unilateral action, especially under crisis conditions, grows more plausible because no stable multilateral regime exists to prevent it. The lesson for the United States is that domestic policy instability erodes the international order on which effective geoengineering governance depends.

Political Stability as a Prerequisite for Planetary Stewardship

The rupture from Trump's second administration compounds long-standing drivers of U.S. competition and technological ambition. The interaction of these forces produces systemic risks, creating an incentive to consider geoengineering while simultaneously diminishing the capacity to evaluate or regulate it responsibly. The United States, once a cautious participant, now risks becoming the very unreliable actor it has long warned against, just when stable governance is most needed.

Whatever path the United States takes on geoengineering, handling it responsibly will require resilient political systems and trusted scientific institutions as well as technology and diplomacy. The United States has long been central to building those foundations. Whether it can reclaim that role or, instead, will exacerbate global instability will shape the rules for CDR and SRM for decades.

The author used an AI plugin for editing assistance.

05

Global South Perspectives on Geoengineering and Climate Justice

Dhanasree Jayaram, Rucha Shrikant Mapari, and Namrata Kabra

Anthropogenic climate change has emerged as an existential planetary challenge that is profoundly disrupting natural ecosystems and the security of Earth's inhabitants. Despite over three decades of international negotiations, global climate action remains insufficient, with current trajectories in a business-as-usual scenario risking a cataclysmic rise in average global temperatures of 4° Celsius (7.2° Fahrenheit) since preindustrial levels.[122] In response to these mounting threats, geoengineering interventions, which aim to further manipulate Earth's natural systems, are being proposed as potential fixes.

The climate crisis is not merely a matter of rising temperatures; it is fundamentally a crisis of justice and equity. While its impacts are now felt across the globe, they are disproportionately borne by the Global South, particularly by marginalized communities: those that have contributed least to the causes of the crisis yet suffer the most severe consequences and are excluded from climate decisionmaking. This imbalance underscores the deeply entrenched inequalities and systemic injustices at the heart of the crisis. Without addressing these structural disparities, no climate action can achieve lasting success.

The geopolitics of climate change highlights stark divides between the Global North and the Global South. The North's dominance of political decisionmaking and the low economic capacity of most of the South pose serious challenges to global climate governance. However, it is crucial to be mindful of the different risks and capabilities among and within the Global South. For small-island developing states (SIDS), climate change is already an existential crisis, with rising seas threatening habitability and sovereignty. By contrast, larger, middle-income economies experience a wide spectrum of risks, which, while severe and potentially destabilizing, may not amount to immediate existential threats.

This asymmetry shapes priorities and politics at both the national and the global level. For example, in 2014, Kiribati bought land in Fiji as a potential relocation site for its population facing climate displacement,[123] while some states have experimented with technological interventions as localized strategies for water security. Most geoengineering experiments in the Global South, such as cloud seeding, have been conducted on a local scale with seemingly limited potential for immediate transboundary harm. However, their wider socioecological, economic, and political implications are insufficiently assessed and poorly governed.

Meanwhile, the July 2025 advisory opinion of the International Court of Justice (ICJ) on climate change highlights the power of intergenerational claims from the Global South. The opinion, which had been sought by a coalition led by Vanuatu and other Pacific youth groups, confirmed that states have due-diligence obligations not only to mitigate emissions but also to prevent foreseeable harm from responses to climate change.[124] This interpretation broadens international law's reach over so-called techno-fixes, such as geoengineering. In effect, states cannot claim legal neutrality if their geoengineering activities threaten rainfall patterns, agriculture, or cross-border ecosystems.

It is essential that the geopolitical and security narratives of both climate impacts and climate action include a climate justice lens. Justice implications are not to be conflated with the ethical or moral concerns about geoengineering that have long dominated discussions of research, development, and potential deployment of these technologies. Going forward, the geoengineering landscape presents an opportunity for middle powers such as the EU to advance a collective governance approach—together with the Global South—by promoting frameworks that ensure transparency, justice, and fairness.

Climate Justice and Geoengineering at a Crossroads

Geoengineering encompasses various methods aimed at reducing global temperatures and mitigating the adverse impacts of climate change. Geoengineering options such as solar radiation modification (SRM), marine geoengineering, and carbon capture and storage (CCS), even at early experimentation stages, are being promoted and explored as solutions to address the climate crisis globally.

However, there are concerns over the legitimacy and sustainability of these options. Without addressing the root cause of climate change—greenhouse gas emissions—solar geoengineering could imply an increase in emissions coupled with unintended social, economic, geopolitical, and security impacts. The battle against the climate crisis is, essentially, a fight against historical injustices as much as preparation for the future through technological interventions.

Some scientists discuss the just and equitable use of geoengineering to protect the most vulnerable populations from climate change impacts. But these solutions may also result in irreversible damage to the environment, such as permanent disruption of regional climate and precipitation systems or long-term harm to biodiversity, while marginalizing those who seek climate action through a human rights and ecocentric perspective. Global power relations and imbalances are most evident in international climate negotiations year after year. Despite three decades of talks, commitments on climate change mitigation and adaptation, technology transfer, climate finance, and loss-and-damage finance have not been achieved, while global average temperatures have continued to rise.

Many countries in the Global South, particularly in the Pacific and Africa, see geoengineering through a colonial lens. After centuries of colonization, these countries now face new forms of colonization through the differentiated impacts not only of climate change but also of climate solutions. Government representatives of countries with colonial histories have used strong statements to reject geoengineering as a climate solution. For example, Ralph Regenvanu, Vanuatu's special envoy for climate change and environment, in 2024 described geoengineering as a colonization of "our atmosphere," calling it a "neocolonial approach to climate action."[125]

Concerns about moral hazard and neocolonial approaches to climate action amplify the various dimensions of climate justice that apply to geoengineering discourses. Climate justice is integral to the international climate regime. According to the UN Development Programme (UNDP), climate justice is about "putting equity and human rights at the core of decision-making and action on climate change." The UNDP has suggested that "the countries, industries, businesses, and people that have become wealthy from emitting large amounts of greenhouse gases have a responsibility to help those affected by climate change, particularly the most vulnerable countries and communities, who often are the ones that have contributed the least to the crisis."[126]

On the one hand, meaningful engagement with marginalized communities, which are often the most directly affected by climate impacts, is limited in most contexts and decisionmaking forums, resulting in policies and interventions that may not adequately address these communities' specific vulnerabilities and needs. On the other hand, with the exclusion of large sections of the Global South and marginalized communities, climate solutions could "entrench gendered, race and class-based historical and contemporary inequalities," in the words of researcher Peter Newell.[127] "Avoiding questions of justice" in climate governance, according to analyst Chukwumerije Okereke, risks forcing poorer nations to sacrifice their "vital interests."[128] It is therefore essential for justice to remain central in deliberations on geoengineering and broader climate interventions.

Geoengineering techniques, whether carbon dioxide removal (CDR) or SRM, require a thorough mapping of the dimensions of environmental and climate justice. These issues have been widely discussed in previous research, but there needs to be a deeper engagement with critical questions of geopolitics and security that are interwoven with climate justice.

Any form of decarbonization raises concerns about affordability, job losses, risks to global cooperation, and the distribution of costs, emphasizing distinct types of justice, such as procedural, distributional, and recognitional.

For example, studies indicate that carbon capture, utilization, and storage (CCUS) may pose significant trade-offs between global climate benefits and costs to local communities, such as environmental and health risks and land dispossession.[129] The use of CCUS in the extractives sector brings to light issues of ecological risk, distrust, socioeconomic inequities, technological uncertainty, greenwashing, resource competition, and operational oversight.

Other issues highlighted in previous research include the need for caution in narratives about the climate emergency to ensure that considerations of fairness and justice are not overlooked. Often, discussions of carbon removal do not go beyond questions of infrastructure ownership, monitoring, and governance. A predominant focus on building a technical case for CCUS projects risks sidelining justice considerations. Critics of CDR and SRM have warned that such exclusion could exacerbate existing socioecological and socioeconomic conflicts globally. Increased dependence on technological solutions may give rise to technocratic political systems and launch a new race for profit and power.[130]

SRM, whether it is characterized as a plan A or a plan B in case mitigation and adaptation fail, essentially curtails any behavioral and structural transformations that are critical for climate justice. What is more, residual responsibility for addressing the risks, unintended consequences, and structural inequities of these technologies will remain. Other responsibilities, such as the supervision and long-term maintenance of SRM, also require further deliberations. In many SRM scenarios, climate change mitigation becomes contingent on another technological intervention in the future. Hence, technological solutions should be pursued only if they effectively address climate change without undermining justice or equity and without serving as a pretext for circumventing mitigation responsibilities.

The Global South's Engagement with Geoengineering

While there is a widespread motivation to include more actors from the Global South in discussions of solar geoengineering, there is no clear direction for how best to do so.[131] Yet, questions of who gets what, who counts, who is heard, what matters, and who does what are integral to addressing justice and legitimacy in discussions of geoengineering governance.[132]

The global North-South divide is reflected in growing calls for the nonuse of SRM. For example, in 2023, Mexico banned solar geoengineering experiments in the country after Make Sunsets, a U.S.-based start-up, sent balloons injected with reflective sulfur dioxide particles into the atmosphere as a cooling experiment without giving the Mexican authorities prior notice.[133]

Meanwhile, the African Ministerial Conference on the Environment has called for "a global governance mechanism for non-use; while cautioning against the promotion of carbon dioxide removal (CDR) in light of a limited understanding of the risks."[134] African ministers have supported a proposed international nonuse agreement on solar geoengineering that would strictly prohibit outdoor experimentation and deployment, public funding, and patent rights for these technologies. This proposal has been endorsed by many academics, scientists, and NGOs around the world, including in the Global South.[135] Other technological interventions, such as marine cloud brightening, that have been suggested by countries including Australia and the United States are fraught with technical and environmental challenges far beyond the question of where they are deployed.

While many countries in Africa and the Pacific have supported a nonuse agreement, the positions within the coalition that consists of the G77 developing nations and China are heterogeneous: Some countries have voiced concerns, while others, such as China and India, have refrained from taking a formal stance. For those in the Global South, the approach to technological intervention is shaped by a need to balance climate action with economic development, among other factors. Pursuing industrial competitiveness in the context of the Fourth Industrial Revolution remains a priority for many countries. From an economic standpoint, then, technological progress can serve as a driver of growth and development.

From a geopolitical standpoint, however, such progress risks reinforcing a divide between the technological haves and have nots, as seen in the case of other regimes, such as nuclear nonproliferation. Some countries, like Saudi Arabia, have actively supported geoengineering, reflecting their national interests as fossil fuel–dependent economies.[136] In other states, such as China and India, governments and other actors have invested in SRM research, but these investments constitute only a small fraction of global SRM funding.[137]

Some studies indicate a greater acceptance of geoengineering in the Global South because of the increasingly severe impacts of climate change. At the same time, concerns about inequities and geopolitical conflicts arising from the deployment of these technologies are also most pronounced in the Global South.[138] The frequent depiction of the Global South through a risk-risk frame—that is, by weighing climate change risks against geoengineering risks—presents a lopsided view, as it fails to capture these countries' systemic vulnerabilities and their lack of agency in shaping technologies such as geoengineering. Not only is knowledge of these technologies low among many Global South countries, but these studies also mostly include emerging economies and exclude least developed countries (LDCs) and other highly vulnerable states.

These gaps in representation and framing become especially salient when specific geoengineering proposals are considered. The potential unintended, adverse, and irreversible consequences of interventions such as stratospheric aerosol injection (SAI) may lead to civil unrest, including protests over perceived or real environmental harms and impacts on livelihoods, as well as heightened social tensions arising from competing narratives of attribution. Such technologies could also raise regional tensions and widen the gap between the Global South and North, reinforcing concerns of climate colonialism.

Many solar geoengineering programs have attracted criticism for disregarding the need for consent and public participation. For example, Harvard University's Stratospheric Controlled Perturbation Experiment (SCoPEx) was abandoned in March 2024 after Sweden's Indigenous Sámi community opposed the solar geoengineering project. The Saami Council, an NGO that represents the community, and the Swedish government raised concerns about the lack of consultations with the Sámi people and the experiment's potential damaging effects, such as a sharp temperature rise—or termination shock—if SAI were suddenly halted, and the potential undermining of decarbonization efforts.[139]

The counterargument that these technologies are aimed at achieving equity by protecting the most vulnerable communities and states also has implications for the climate justice considerations emphasized by the Global South.[140] SAI, in particular, is advocated by some scientists based on the premise that it could be predicted and controlled to a large extent.[141] At the same time, many studies have documented the risks of varied regional impacts from planetary interventions. According to one analysis, "large asymmetric stratospheric aerosol loadings concentrated in the Northern Hemisphere are a harbinger of Sahelian drought whereas those concentrated in the Southern Hemisphere induce a greening of the Sahel."[142] Another study estimated that deploying SAI in the Southern hemisphere, rather than globally, would increase the frequency of North Atlantic tropical cyclones, while limiting SAI to the Northern hemisphere would reduce it.[143]

In light of such uncertainties, the lack of enforceable mechanisms for liability, transparency, monitoring, and compensation raises significant concerns for the Global South. Without robust governance frameworks, these countries may bear disproportionate risks while having little influence over decisionmaking in the event of transboundary harm.

Even if an experiment carried out under present conditions delivered the expected outcomes, a similar experiment in the future could have different results because of climatic changes. The risks for the most vulnerable countries in the Global South would multiply, as they could be forced to tackle the disproportionate effects of both climate change and geoengineering deployment. In this context, the rights of future generations could be violated by the varied, long-term impacts of present actions. Additionally, the hazards of a slippery slope and termination shock could exacerbate existing vulnerabilities in the Global South, where adaptive capacity to respond to sudden climatic shifts is limited.

Beyond physical impacts, the moral hazard that industrialized countries could use SRM, particularly SAI, as a substitute for meaningful mitigation—allowing them to evade their obligations to reduce emissions and provide financial and technological support to the most vulnerable countries—would further entrench the North-South divide.

Geoengineering, Geopolitics, and Security

North-South relations are marked by entrenched power imbalances and structural inequalities between industrialized nations and developing countries or LDCs. Although these terms originated during the Cold War to differentiate countries based on income, technology, infrastructure, and education levels, these disparities are deeply rooted in historical, political, socioeconomic, and colonial legacies.

Countries in the Global South face several structural barriers to governance in discussions of geoengineering, including financial constraints, technological and knowledge gaps, institutional weaknesses, geopolitical limitations, and inequities in risk and liability, all of which reinforce global asymmetries in climate governance. These barriers are central to international climate negotiations, creating an environment of distrust and inertia in climate action. The well-acknowledged moral hazard of geoengineering can deepen the wedge between the Global North and South, as most rich, industrialized countries have fallen short or failed to deliver on climate finance, technology transfer, and emissions reductions. Any lack of momentum from high-emitting, industrialized countries in advancing mitigation, in favor of deploying geoengineering, would risk straining trust among states and weakening the possibility of collective, multilateral climate action.

The politics of climate change permeate its governance—so much so that one cannot be separated from the other. In market mechanisms implemented under the UN Framework Convention on Climate Change, such as the 1997 Kyoto Protocol and the 2015 Paris Agreement, cases of injustice and marginalization are rampant. One such example is the UN's Reducing Emissions from Deforestation and forest Degradation (REDD+) framework, which researchers Emma Jane Lord and Siddharth Sareen have accused of being a "mechanism for offsetting carbon emissions of the global North, by territorializing land in the global South."[144] In Global South countries, forest carbon offsetting schemes have been misframed to exclude some communities from justice.[145]

The continuing debates on the effectiveness of nature-based solutions and the push to complement them with engineered CDR solutions have opened the door to including and legitimizing these technologies as options under Article 6 of the Paris Agreement, which allows countries to cooperate voluntarily to achieve their emissions reduction targets, without necessarily paying much attention to questions of justice.[146]

This does not, however, mean that the Global South is a monolith. There are internal differences on questions of responsibility as well as the costs and benefits of climate impacts and action. There exist differing perspectives between the LDCs and SIDS, on the one side, and the emerging economies of the G20 and BRICS+ countries, on the other. Some countries in Asia, such as China, India, Indonesia, and Saudi Arabia, have shown firm support for geoengineering, especially CDR, CCS, and CCUS, based on their net-zero commitments and their higher emissions and capacities in comparison with other developing countries.[147] Others, because of their lower emissions and lack of finance, knowledge, and technology, have been less enthusiastic or merely passive about these unproven technologies.

On the question of SRM, most countries in the Global South have endorsed a precautionary approach, given the risks involved in the technology, while some LDCs and SIDS have categorically rejected it as a false solution and called for a moratorium. Even those countries that have a geoengineering research program, such as China and India, have highlighted the need for further research on the risks and governance of SRM.[148] Studies have emphasized these differences within the Global South over SRM, arguing that countries with greater scientific capacity and geopolitical influence may have different perspectives on SRM from smaller or more vulnerable states.[149] For instance, in 2026, the National Institution for Transforming India (NITI Aayog), the government's leading public policy think tank, established a working group comprising Indian and international policymakers and experts to assess "SRM's science, risks, and governance frameworks, and make research and policy recommendations."[150]

China seeks to position itself as a leader of the Global South while pursuing solidarity with the rest of the group on many issues of global governance. Yet, Beijing's position in the current world order has evolved beyond that of the Global South because of its geoeconomic and geopolitical interests, its role as a major greenhouse gas emitter, its large investments in research and development, and its status as a global power. This places China in a complex position in debates on climate justice, which extend to geoengineering discussions.

A 2013 study argued that China was unlikely to adopt unilateral deployment and would instead promote a distinctive developing-world perspective that combines concerns over sovereignty and Western imperialism with a strict interpretation of the norm of common but differentiated responsibility.[151] More recently, state-supported SRM research has continued in China, as shown by a 2026 study funded by the country's National Key Research and Development Program that assessed the effects of stratospheric aerosol injection and its termination on extreme climate events.[152] China's future research trajectory on SRM could change given the country's extensive programs on weather modification and other mega-engineering projects. Shifting research priorities in the United States and other Global North countries, increasing U.S.-China technological competition, and changing geopolitical alignments could also significantly affect China's positions and strategies on SRM.

Geopolitics and security considerations shape both North-South and South-South relations. In 2024, many Global South countries that have traditionally demanded ambitious mitigation commitments and climate finance from the Global North rejected a proposed resolution by Switzerland at the UN Environment Assembly (UNEA) to create a UN expert group to assess the risks, opportunities, and impacts of SRM. What is important to note is that this and other attempts to normalize discussions of solar geoengineering within global climate-governance architectures have resulted in both South-South and North-South coalitions. Apart from the Pacific Island states, led by Vanuatu and Fiji, the EU also supported the Africa Group's opposition to the proposed resolution at the UNEA.[153]

Similarly, the fact that the technological wherewithal is restricted to a small group of countries, especially those in the Global North, means that the geopolitical competition for the control and governance of these technologies could intensify, with distinct implications

for the Global South. The ongoing U.S.-China competition in various tech sectors raises concerns about powerful countries using geoengineering for geopolitical leverage or monopolization, shaping governance norms to suit their own interests, and, potentially, marginalizing most of the world from technological access and decisionmaking processes.[154]

In this context, countries' engagement in global techno-industrial competition may inadvertently increase their exposure to the very drivers that make SRM and other geoengineering interventions more likely to be considered or deployed. The lack of coherent and collective strategies limits the Global South's ability to shape the geopolitical dynamics of geoengineering, leading to fragmentation, patchwork approaches, and power asymmetries in global governance deliberations. These piecemeal approaches may take the form of ad hoc coalitions within the G77 or with non-G77 countries; selective participation in certain aspects of geoengineering, such as research; and fragmented national policies that pursue conflicting national interests. This outcome would further dilute the Global South's collective influence in debates on geoengineering governance.

Another issue is the security dimension of geoengineering. Even the use of small-scale, regional geoengineering technologies could have adverse cross-border effects or trigger fears and geopolitical tensions, as seen in India's concerns over China's weather-modification program. Strategic ambiguity arises from differing national priorities. For China, this initiative is a means of adapting to climate change and managing water resources. For India and other downstream countries that depend on the rivers that flow from the Tibetan Plateau, however, these activities present a fresh set of apprehensions in an already geopolitically volatile and heavily militarized region. Hence, even if China does not overtly support SRM deployment, its willingness to roll out large-scale domestic engineering projects without much regard for justice blurs the boundaries between geoengineering technologies that are already geopolitically contentious.[155]

The Future of Geoengineering Governance and Justice Considerations

As the climate and atmosphere fall under the global commons—areas beyond national jurisdiction—geoengineering activities should not be monopolized, controlled, or appropriated by any one country or group of countries. Global South countries have championed a host of principles when it comes to governing the global commons, including the common heritage of humankind; precaution; free, prior, and informed consent; public participation; and transparency.

The Global South has supported the de facto moratorium on geoengineering under the Convention on Biological Diversity, which restricts climate-related geoengineering that could affect biodiversity until robust scientific, regulatory, and risk assessments are in place.[156] Several Global South countries, such as Bolivia and Ecuador, have advanced the Rights of Nature, which recognize rivers, forests, and ecosystems as legal entities.

These legal developments, rooted in Indigenous and ecocentric worldviews, emphasize that human well-being is inseparable from ecosystem health. Such perspectives challenge planetary-scale techno-fixes, advocating instead precaution, the principle of "do no harm," and intergenerational justice.

Looking ahead, a dynamic justice framework is required to ensure that geoengineering discourses recognize considerations of climate justice and keep sight of the geopolitical and security implications of the development and deployment of these technologies. Based on recent developments at the UNEA and individual country positions, it is clear that the North-South binary alone does not offer sufficient context for these discourses, especially on SRM. While CDR technologies are increasingly integrated into national climate policies and regulatory frameworks, attitudes toward SRM research and development are becoming ever more polarized.

The differing levels of acceptance of CDR and the growing polarization of SRM underscore the complexity of geoengineering governance. This opens up opportunities for cooperation among countries committed to advancing climate justice. The EU, drawing on its middle-power status, could play a pivotal role in shaping collective responses alongside Global South countries by promoting frameworks that ensure transparency, accountability, equity, and justice.

Together, middle-power coalitions could counter unilateral SRM initiatives by major powers, provide monitoring and verification frameworks, shape research norms and standards, advance mitigation commitments, mobilize climate finance for vulnerable communities, and promote inclusive decisionmaking in multilateral forums. These coalitions have a vital opportunity to act as a much-needed stabilizing force for the future of planetary governance.

06

Geoengineering, AI, and Big Tech as the Dei Ex Machina for Climate Change

Mandi Bissett and James Dyke

The 2015 Paris Agreement brought a fundamental shift in global climate governance, with businesses, industries, and investors promoted as indispensable partners of government.[157] A decade later, geoengineering is also being promoted as indispensable. Both carbon dioxide removal (CDR) and solar radiation modification (SRM) carry significant biophysical, socioeconomic, and geopolitical risks, yet decisions about their development and deployment are increasingly influenced by organizations and individuals operating outside formal state systems.[158] This situation introduces a new dimension of complexity to an already controversial and largely unregulated arena of global politics.

Funding of geoengineering is currently small scale compared with other forms of climate tech, such as renewable energy, but nonstate financing is approaching state levels. This trend indicates a shift in who is shaping humanity's future and raises three key questions: What types of nonstate actors are involved in the development of geoengineering? How much money are they channeling toward it? And what are their motivations?

A complex network of entities is working in this space, but one particular industry has been at the forefront: Big Tech. Major Silicon Valley firms are increasingly funding and advocating technological solutions to the climate crisis. Yet, these dei ex machina, or gods in the machine, built out of dollars, data, and compute, may end up being not humanity's salvation but its damnation.

The Rise of Big Tech

Of the top ten companies worth over $1 trillion in August 2026, nine were Big Tech firms.[159] These valuations are closely linked with the rise of AI, producing two key interactions between Big Tech and geoengineering. First, the aggressive growth in data centers means that in the United States, the sector is unlikely to achieve net zero without what one study

called an "unprecedented level of reliance" on CDR.[160] A March 2026 analysis by climate change publication *Carbon Brief* also found that data-center emissions in the UK could be hundreds of times higher than government estimates.[161]

Second, both AI and geoengineering contribute significantly to discourses of delay on climate action. Both promise a "fix later" approach, which relies on accelerating technological development. Google's former chief executive Eric Schmidt has chosen to "bet on AI solving the problem," especially as AI has "too much potential, to let concerns about climate change get in the way."[162] The narrative is that energy-hungry generative AI can fix climate change given sufficient compute capacity—although this claim has been debunked.[163]

Private Funding of Geoengineering

Following the flows of private money provides insights into the trajectory of climate interventions and the motivations of nonstate actors. For example, the public-facing narrative for corporate spending on CDR is one of climate leadership, but in reality, geopolitical and financial gains take precedence. Similarly, while philanthropy for SRM research is often framed as a humanitarian issue, protecting existing political and economic systems is the more plausible motive. Advocates of CDR seek to distance it from the more controversial world of SRM, but both domains are intimately connected via the tech- and finance-backed elite networks that fund them.

1. The incentives for Big Tech to invest in geoengineering are:

2. diverting scrutiny away from the rising energy emissions of data centers;

3. gaining influence and financial advantage from building the next phase of the voluntary carbon market (VCM);

4. generating a continuous stream of profits from forestry-based carbon removal;

5. evading state regulation of net-zero plans; and

6. leveraging SRM as a way of ensuring the growth of AI.

Underpinning all of this is the promise that geoengineering and AI—and, by association, Big Tech itself—will save humanity from catastrophic climate change. Both domains are, however, built on unproven technologies and rely heavily on government policy and spending. In fact, Microsoft's April 2026 decision to pause all CDR purchases may have been due in part to climate change–denialist policy in the United States and the cost of offsetting its increasing emissions. However, Google's recognition that "no company is going to be immune" to the likely rupture of the AI bubble, and therefore the billions sunk into its development, could also have been a decisive factor.[164]

The fragility of both the AI market and the CDR market has been exposed, but the big question is whether these fractures will be filled by a doubling down, not only on AI, but also on SRM. The existential risks of both are enormous.

Carbon Dioxide Removal: Financial Gains vs. Climate Benefit

The VCM is the primary mechanism for companies to buy carbon-avoidance or reduction credits, a key element of corporate net-zero strategies. Carbon removals are a small but growing part of this market, which Big Tech, in particular Microsoft, dominates.

Market Valuations Do Not Equal Climate Impact

The CDR industry narrative, based on a landmark 2018 report by the Intergovernmental Panel on Climate Change, is that 6–10 metric gigatons (Gt) of CDR will be needed annually by 2050 to limit average global warming to 1.5° Celsius above preindustrial levels.[165] This target has created the expectation of a shift in the VCM toward 100 percent removals alongside greater reliance on engineered approaches.[166] With this in mind, management consultants McKinsey concluded that the VCM could be worth $1.2 trillion a year by mid-century.[167] This valuation has become the north star of many nonstate actors working on CDR, as it promises that market mechanisms can be both climate saviors and routes to significant profits.

However, a $1 trillion market built on numerous trades would not equate to $1 trillion worth of CDR. Multiple trades of the same carbon credit do not lead to additional tons of carbon being removed. What is more, there is no guarantee that the original credit has actually removed any carbon from the atmosphere. Monitoring, reporting, and verification protocols are not always robust, particularly for land- and ocean-based CDR.

Beyond issues of valuation, there is the fundamental question of who will benefit from this growth. The answer appears to be the organizations investing in the infrastructure for producing CDR credits. While it is correct that major producers of carbon dioxide (CO_2) emissions should be held financially responsible for their removal, this does not mean that they should profit from or control the supporting ecosystem.

The CDR industry has created significant hype about its technological capabilities to achieve peak market valuation. The three key strategies used to this end are large high-profile purchases of CDR credits, an increased supply of such credits, and private-sector self-regulation of net zero.

Large High-Profile Purchases of CDR Credits

In the first strategy, firms buy significant amounts of carbon-removal credits for either engineered or nature-based methods.

Engineered Removals

As of August 2026, Microsoft had bought 37.2 metric megatons (Mt) of engineered CDR, twenty times more than the tech-led buyer coalition in second place.[168] The total spend on engineered CDR as of that date was $12.4 billion, with Microsoft making up the lion's share. However, the real-world impact of around $10 billion in credits has yet to materialize. In total, only 3.2 percent of the durable CDR credits ever sold have actually been delivered.[169] This works out at 0.0016GtCO_2, which equates to 0.004 percent of just one year of global emissions.[170]

The current political climate in the United States is creating uncertainties for the future of CDR, as is Microsoft's April 2026 decision to pause its purchases. If, as some predict, suppliers start to go out of business, Microsoft will be left with a considerable amount of undelivered credits and tens of millions of tons of emissions on its books.[171] The company has not stopped its CDR program, however, and appears to be taking a longer and broader view of decarbonization.

Google has also been making waves in the CDR space, as it was the first to negotiate $100 per ton, considered to be the holy grail of pricing for engineered removals.[172] In September 2024, the firm spent $10 million on 100,000 carbon credits from Holocene, a company focused on direct air capture (DAC), a technology that uses chemical systems to pull CO_2 out of the air.[173] An important motivation for this purchase was to send "a strong signal to the market, encouraging further investments and innovation."[174] This is also the aim of CDR buyer coalitions such as Frontier and the Symbiosis Coalition, both set up by Google and Meta, alongside other Big Tech firms.

Nature-Based Removals

In May 2025, Microsoft signed the biggest carbon-removal deal to date, for 18Mt of nature-based credits.[175] Along with smaller purchases, this brings the tech giant's total for nature-based CDR to 41Mt. Google's largest nature-based deal so far is only 0.2Mt.[176] Such purchases are attractive because of the limited availability of engineered removals, the much lower costs per ton, and greater public acceptance of nature-based removals, despite their temporary nature.[177]

Critics of nature-based removals reference several issues: carbon grabs, or derisory prices paid for such carbon credits; carbon farming of forests instead of environmental stewardship; and displacement of communities.[178] The climate benefits are also in doubt. Apple has celebrated the financial benefit from the afforestation project it launched in partnership with investment bank Goldman Sachs and semiconductor manufacturer TSMC.[179] However, the carbon sequestered by the project's eucalyptus trees, which are turned into toilet paper or plywood, will be re-released as these products decompose.

Increased Supply of CDR Credits

In the second strategy, companies seek to increase the supply of carbon-removal credits either through investments in CDR suppliers or through prize money for suppliers and grants for advocacy or research projects.

Venture Capital Investments

The Silicon Valley world of venture capital has become increasingly interested in geoengineering. A prime example is Lowercarbon Capital, run by former Google executive Chris Sacca, which has made significant investments in CDR methods such as DAC. Venture capital investment is driven by short-term profit making and is not well aligned with climate justice concerns.

Bill Gates's Breakthrough Energy Ventures (BEV) is an investment vehicle whose portfolio includes CDR suppliers such as Graphyte and Heirloom. Amazon has its own corporate venture capital entity, the Climate Pledge Fund, which invests in similar firms.[180] The number of CDR companies and the amount of money channeled into them, especially for DAC, are considered to be unsustainable; but more importantly, these investments undermine global efforts to decarbonize.[181]

Prize Money and Grants

The hype around CDR has been built up through competitions that offer large cash prizes, which can influence public opinion and mobilize further capital. A prime example is XPRIZE Carbon Removal, funded by Elon Musk and the Musk Foundation, which had 1,133 teams vying for a share of $100 million as of August 2026.[182]

There are also private foundations that are enabling both technology and policy development in the CDR space. For example, ClimateWorks, created by the Hewlett, Packard, and McKnight Foundations, "catalyzed nearly $10 billion in public and private funding" for carbon removal, including $3.5 billion for four DAC hubs in the United States.[183] The Quadrature Climate Foundation, which is financed by Quadrature Capital, a proprietary trading firm with significant investments in Big Tech firms, had donated $46 million to CDR projects as of May 2025.[184]

Private-Sector Self-Regulation of Net Zero

The third strategy can take the form of influencing existing carbon credit certification bodies; setting up new standards, organizations, and norms; or lobbying for changes to energy-emissions reporting.

Existing Certification Bodies

There is a Wild West of frameworks and accreditation schemes tasked with overseeing corporate carbon accounting. Organizations connected with Big Tech billionaires have provided funding to many of these schemes, leading to unease about conflicts of interest and the potential for greenwashing.

For example, the Bezos Earth Fund gave at least $45 million to carbon markets initiatives as of May 2024, including $18 million to the Science Based Targets initiative (SBTi).[185] This is a globally recognized body relied on to set strict limits on the use of carbon credits to achieve corporate net zero. In 2023, Amazon and Microsoft were among hundreds of companies removed from the initiative's list of participating firms for failing to progress toward their climate goals.[186] In May 2026, because of lobbying by Big Tech firms, the SBTi watered down its offsetting rules for gas-powered data centers.[187] The European Commission is set to follow suit by weakening its data-center rating system.[188]

New Initiatives and Norms

To aid firms struggling with strict net-zero rules, Amazon created its own carbon-removal norm and carbon registry. Amazon markets this scheme as more ambitious than other standards, as it has no limit on the use of carbon credits to offset corporate emissions.[189] The Symbiosis Coalition is now using this norm as its benchmark.

Silicon Valley–linked firms including BEV and Outlier Projects are involved in the development of monitoring, reporting, and verification methodologies through their funding of the Carbon Removal Standards Initiative. The initiative describes itself as providing "financially unconflicted advice," despite its roster of donors.[190]

Gates also sits on the Taskforce on Scaling Voluntary Carbon Markets, whose aim is to improve the credibility of the VCM. The task force's members include Shell, BlackRock, BP, Boeing, and Goldman Sachs. Additionally, representatives of Microsoft, Amazon, and ExxonMobil sit on the board of the new Bipartisan Policy Center's Voluntary Carbon Market Task Force. It has suggested a federal stamp of approval for VCM projects or private-sector self-regulation with federal oversight. This idea still falls short of a state-regulated VCM.

The proliferation of frameworks and oversight bodies has led to the concern that corporations will pick and choose which standard they want to support, depending on the level of flexibility in allowing carbon credits to count toward net zero. It is questionable whether the biggest carbon polluters should be able to design the frameworks that are meant to hold them to account.

Changes to Emissions Reporting

All of this feeds into the Big Tech approach to sustainability reporting, which is already "obfuscation-by-complexity," according to the *Internet Policy Review*.[191] This approach involves the selective use of emissions figures and best-case carbon-accounting narratives. For example, although Microsoft states its emissions rose by 23 percent between 2020 and 2024, energy analyst Ketan Joshi has asserted that the true rise was closer to 55 percent.[192]

Perhaps aware of this critique, Big Tech has also been lobbying for changes to energy-emissions reporting. Amazon, the Bezos Earth Fund, Google, Meta, Microsoft, and others have been funding the Greenhouse Gas Protocol, a climate-accounting oversight body. The Emissions First Partnership, a corporate lobby group co-founded by Amazon, Meta, Salesforce, and others, has been lobbying for changes to the protocol that would allow companies to significantly underreport their energy emissions. This move would further enable Silicon Valley to downplay the environmental impact of data-center expansion.

Solar Radiation Modification: Protecting Economic Growth

The funding landscape for solar geoengineering is different from that for carbon removal. This is because, at present, there is no market for SRM credits beyond the controversial sale by start-up Make Sunsets of "cooling credits" from launching balloons containing sulfur particles into the atmosphere.[193] Commercialization of SRM is gaining pace, however, with start-ups having raised around $116 million in venture capital funding as of December 2025.[194] Stardust is the front-runner with $75 million, including $60 million from one round in 2025 led by Lowercarbon Capital. This is not only the biggest single amount of private funding allocated so far but is also almost equal to the largest state funding of the sector. Stardust has also been secretly lobbying the U.S. Congress, signaling political influence on SRM as well as future profit making.[195]

This has caused consternation in the SRM world, widening the ideological gap between proponents of responsible research and those who believe in profit-driven climate solutions. But perhaps the aims of the two factions are not so different. Researchers Jennie C. Stephens and Kevin Surprise have argued that all nonstate actors invested in developing and potentially deploying SRM are interested primarily in "further concentrating contemporary forms of political and economic power."[196]

Using SRM to protect political and economic systems is not a new idea. In the late 1990s, Pentagon-linked physicists at the Lawrence Livermore National Laboratory argued for SRM as a way of avoiding the economic costs of climate change mitigation.[197] In 2025, the UK government, while focused on kick-starting economic growth, was the leading funder of SRM research, with £10 million ($13 million) in funding from the Natural Environment Research Council for modeling projects and £56.8 million ($70.7 million) from the Advanced Research and Invention Agency (ARIA) for real-world experiments.[198]

While recent UK government funding is significant, states are playing catch-up, as nonstate entities have been funding research in this area for some time. Gates and various family foundations gifted around $20 million to Harvard University's SRM research between 2008 and 2018.[199] Since then, philanthropic giving to the domain has only increased. For example, SRM advocacy organization SilverLining has received millions in donations and is now setting its sights even higher, suggesting that $13 billion should be the sum invested in climate intervention research to "ensure economic and global security."[200]

Security and Secrecy

In terms of global security, SilverLining has been able to successfully lobby Congress for a $10 million program of the U.S. National Oceanic and Atmospheric Administration (NOAA).[201] By monitoring the stratosphere, NOAA could provide an early-warning system in case a country or other actor deploys large-scale geoengineering.[202] In the UK, ARIA is funding the start-up Voltitude to develop micro-balloons to monitor geoengineering from the stratosphere, which likewise could act as a global warning system.[203]

Further links between SRM and national security can be seen in Israel. Research on space-based SRM is being carried out by the Technion—Israel Institute of Technology, which has a focus on military applications. In addition, Stardust, which has been unwilling to be transparent about its activities, received investment from Awz Ventures, a venture capital firm that works in partnership with Israel's Ministry of Defense.[204]

Big Tech, Big Finance, Big Donors

The increasing leverage of nonstate actors in this space raises serious questions about accountability, transparency, and who shapes public narratives. Behind the start-ups and NGOs is a growing network of powerful individuals and organizations that are channeling millions toward making SRM ready for deployment.

As indicated above, there is an emerging link between the finance sector and SRM. For example, in June 2024, the Simons Foundation allocated $50 million to SRM research projects.[205] This philanthropy was set up by the founder of Renaissance Technologies, one of the world's most successful hedge funds. Similarly, the climate foundation of Quadrature Capital, one of the UK's most profitable companies, made its largest SRM-related donation to SilverLining.[206] SilverLining's other funders and advisers include prominent finance and tech figures.

Many of these donors also separately fund SRM research projects, such as the University of Washington's 2024 marine cloud brightening experiment off the coast of California. The scientists behind the experiment limited the release of information about it because of concerns about potential opposition to the tests.[207] Local officials ended up halting the experiment partly because of this lack of transparency. An investigation by *Politico* later discovered that this experiment had been the precursor to a much larger, multimillion-dollar project covering 3,900 square miles.[208]

Advanced Research for Climate Emergencies (ARC) is another initiative that funds SRM research. One of ARC's projects is run by the Arctic Stabilization Initiative, a nonprofit that had raised $6.5 million in philanthropic funding as of April 2026.[209] ARC also funds the organization Reflective, which argues that field experiments are essential for research into stratospheric aerosol injection.

Shaping the Narrative

The roster of funders for ARC and Reflective is heavily skewed toward tech-focused finance, including companies led by former executives of Facebook, Cisco Systems, Meta, Google, and YouTube. Many of these funders also donate to the campaigning organizations the Degrees Initiative, Operaatio Arktis, the Alliance for Just Deliberation on Solar Geoengineering, and SRM360. The influence of tech-driven foundations over research, activism, and policy development, especially in regions that are both most vulnerable to climate impacts and less powerful economically, demands deeper scrutiny. As nonprofits tend to be at the forefront of movements for social change, Big Tech funding raises questions about influence over public opinion and the erosion of local autonomy over climate solutions.

Conclusion

In 2024, the UN Environment Programme produced a foresight report.[210] This identified corruption in carbon markets and the deployment of SRM as two signals of change that have the potential to disrupt human well-being and are highly likely to occur within the next decade. Those signals are being amplified by nonstate interventions into research, commercialization, and campaigning.

Big Tech has been the major source of geoengineering funding. Silicon Valley firms have made major purchases and investments in CDR and exerted influence over credit-certification bodies. Similarly, tech-focused venture capitalists believe they can make billions by betting against the climate, with $116 million channeled toward SRM start-ups by the end of 2025.[211] Critical to deployment is public acceptance. Consequently, Silicon Valley foundations are funding NGOs focused on promoting SRM as a viable response to the climate crisis. As nonprofits often stand at the vanguard of social change, this investment raises concerns about influence over public opinion and agenda setting.

Would Big Tech continue to be so invested in geoengineering if its ascent were halted? For CDR, the answer seems to be no. Microsoft's April 2026 pause on all new purchases of carbon-removal credits sent shock waves across the CDR ecosystem. U.S. climate change–denialist policy and Microsoft's ever-increasing data-center emissions could have played their part, but a more likely cause is the company posting its worst quarter since the 2008 financial crash.[212]

This is further evidence that the AI bubble may be about to burst. In the first month of 2026 alone, $1 trillion was wiped off Big Tech market valuations;[213] since then, the proportion of Americans who oppose the development of local data centers has increased to 75 percent, and military strikes on Iran have impacted the manufacture of computer chips.[214] In the face of such financial, societal, and geopolitical headwinds, Big Tech firms are nevertheless doubling down on AI, despite suggestions that an AI crash could wipe $35 trillion off the global economy and erode Silicon Valley's dominance.[215]

Could SRM rescue both capitalism and Big Tech? If the CDR market has actually stalled, policymakers, enticed by bold claims and increasing nonstate finance, may quickly move on to SRM as the next viable climate techno-fix. Its framing as climate repair needs to be revised, however, as it is better understood as an economic policy. In theory, SRM would be deployed to buy time for large-scale CDR, but its true aim is to maintain economic growth and geopolitical power. But more importantly, policymakers should consider which technology is really being developed at pace and at scale—negative emissions or generative AI.

The AI boom is creating a space in which opportunists thrive, and policymakers and the public are willing to overlook its risks. The same is happening in the domain of geoengineering. Both are being pitched as the gods in the machine that will appear in humanity's hour of need. But if they are used to resist the rapid phaseout of fossil fuels and their existential threats are ignored, then these dei ex machina may help bring the curtain down on human civilization.

07

How Can Europe Respond to Geoengineering's Civilizational Wager?

Olivia Lazard

Geostrategic rivalry over the Fourth Industrial Revolution (4IR) is becoming the primary driver of geoengineering and, by extension, of the planet's future. At its core, this rivalry pits two distinct power models against each other: the United States, a petrostate whose hegemony is increasingly under strain; and China, a rising electro-state that is pioneering a model of a low-carbon economy.

Behind these state actors, tech players—from investors to companies—play a primary role in defining the contours and pace of hegemonic competition. The pursuit of artificial general intelligence (AGI), quantum, and other transformative technologies is at the heart of a new securitized competition for global and planetary dominance. The growing fusion of corporate and state interests redefines competition for energy and materials as well as technological frontiers that will determine which power model prevails.

The resulting security dilemmas are not merely reshaping the world order. They are also driving up energy demand, prolonging fossil-fuel use, and worsening the planetary overshoot that geoengineering is then proposed to address. More and more, geoengineering is co-opted within, and partly produced by, hegemonic competition as it collides with ecological limits. It is becoming one of the technological frontiers of the 4IR: The ability to observe, model, modify, control, and experiment with planetary systems is itself becoming a strategic asset.

Geoengineering is also part of a broader ideological project, reinforced by hegemonic competition, that treats nature, biophysics, and Earth systems as things that can be decoded, redesigned, and, ultimately, replaced. In doing so, it risks obscuring nature's constitutive role in human biology and in the long history of civilizational development.

Planetary intervention is therefore not just a technical matter. It is increasingly a civilization-shaping domain in which different ideologies compete for dominance. A contest is opening up between, on the one hand, publicly funded, transparent, accountable research oriented

toward common planetary goals and, on the other, privately funded, ideological approaches that seek to contain the methods, applications, and governance of geoengineering within concentrated interests.[216]

With the rise of commercial solar radiation modification (SRM), geoengineering risks becoming not a last resort but a hedging instrument within a larger project that presages a shift from technology as a solution toward technology as a substitute for nature. The costs associated with this prospect are likely to be extreme: decoupling states from accountability and collective responsibility, enclosing knowledge over public goods, damaging ecological commons necessary for planetary security, and delinking humans from nature via technological means, thereby creating markets for survival and adaptation.

In this configuration, Europe stands at a civilizational juncture. The EU cannot respond to a civilizational wager over the planet's future with technocratic regulation or single-domain governance. It must act in the same register: by developing its own civilizational wager, rooted in regenerative paradigms, planetary accountability, and an innovation model in which technology serves humane and ecological ends.

Geoengineering as a Function of Geostrategic Rivalry

The 4IR is reaching its acceleration phase. Its foundations were the twin energy and digital transitions—designed, in part, to address climate breakdown by moving to low-carbon, high-efficiency systems while sustaining economic growth. But they have incidentally generated two dynamics that compound energy expansion and fossil-fuel feedback loops.

The first dynamic is structural. The twin transitions create a vessel for geostrategic power shifts. They generate fundamental ruptures in the world order and activate hegemonic competition. Security dilemmas play out across the substrata and innovation horizons of the 4IR—and energy is central to both. It is essential to techno-industrial ecosystems of innovation and supply-chain resilience, and it sits at the frontier of contemporary research.

More fundamentally, energy has been the metabolic foundation of every modern hegemonic order: Pax Britannica was built on coal; Pax Americana on oil and, subsequently, natural gas. The twin transitions therefore go beyond energy to become a world-order story that calls into question the energy base on which U.S. hegemony and the global security apparatus have rested for nearly a century.

In the 4IR, the initial fault line runs through critical minerals, themselves essential for low-carbon energy and digital technologies. For decades, China invested in controlling mineral supply chains, establishing itself as the gatekeeper of global processing capacity. China's supply-chain verticalization produces returns in what flows from minerals: the building blocks of an electro-state model.

China is not just pioneering this model domestically. It is also exporting electro-technologies to regions for which climate change is the primary security threat and where energy security is a main concern for economic development and diversification.[217] Beijing is thereby positioning itself as a climate-security champion, planting a normative flag where the United States once planted the flag of liberal democracy. The contours of a new normative order are beginning to emerge. Its geoeconomic foundations are becoming clearer, but the rules that will govern it are not.

The United States starts from a different structural position to compete with China and maintain its security position. Washington has sought leverage through tariffs, interventions, and defense-specific procurement in mineral supply chains. But given its structural disadvantages across those supply chains, the United States is also drawing on a resource in which it retains considerable strength: fossil fuels. The United States' energy endowment provides leverage through domestic production and monetization, exports that deepen long-term dependencies among allies, and pressure on the energy suppliers of strategic competitors, including China.[218] This strategy generates instability across global energy markets, however: heightened energy insecurity, economically driven returns to fossil fuels, and feedback loops that prolong fossil-fuel dependence even in countries that seek to lead the green transition.

China and the United States are locked in a security dilemma in which energy has become a central instrument of strategic leverage. Beijing weaponizes critical minerals; Washington does the same with fossil fuels. Each move compounds the other's insecurity—and that of the rest of the world. China's concentration of mineral processing impedes the emergence of a diversified production system for low-carbon technologies and digital infrastructure. The U.S. response scrambles fossil-fuel markets, driving third-party states to secure other energy sources as a hedge against future shocks. The resulting uncertainty leads states to rely on fossil-fuel infrastructure as a response to security dilemmas, at least in the medium term, all the while seeking escape routes for the longer term.

A second, compounding driver of the latest fossil-fuel reprieve is the race to AI and the associated demands for compute. U.S. policy increasingly frames energy abundance as a prerequisite for maintaining superiority in a technological race that will determine economic growth, military capability, scientific discovery, and state power.[219] Yet, AI requires an entirely new layer of physical infrastructure and energy. The International Energy Agency projects dramatic growth in the electricity demand of data centers by 2030, while a significant share of new U.S. demand is currently expected to be met by fossil fuels.[220]

Furthermore, the U.S.-China competition is reorganizing global technological development within energy- and material-intensive paradigms. This is a far cry from earlier narratives that argued that digitization would decouple economic growth from greenhouse gas emissions and drive broader dematerialization. In fact, AI-era competitiveness generates cascading demand for compute infrastructure, the minerals required for that buildout, the innovations that support AI's value, and geopolitical control of all these layers. Even states and regions that have sought leaner transition paths are caught in the ratcheting mechanism it generates, Europe included.

As a result, the geopolitical currents under the AI-driven energy expansion are creating the conditions—and markets—for technologies that promise to manage the acceleration of climate change.

A Co-Product of Security Dilemmas

The energy, material, and technological pressures that drive hegemonic competition add to planetary overshoots, which, in turn, accelerate demand for planetary-scale interventions. Tech-based responses are emerging as the dominant solution paradigm to counter said overshoots. Among them, analysts see geoengineering as a tool to stabilize temperatures while technological acceleration runs its course. This view implicitly rests on an unsubstantiated belief that the same acceleration will eventually produce the breakthroughs needed to solve planetary breakdown.

In this sense, geoengineering is a symptom of the structural forces that are driving the breakdown of the international order through security dilemmas. These forces simultaneously strengthen the arguments for radical planetary interventions and undermine the possibility of robust governance that can establish safeguards against unethical research and deployment.[221]

A Domain of Securitized Experimentation

Because security dilemmas sprawl multiple innovation domains, geoengineering can become an experimental field serving dual uses that blurs the line between climate interventions and potential weapons-adjacent capabilities. In times of great-power rivalry, theaters of war are not only visible fault lines of security dilemmas; they can also become laboratories for experimentation and dual-use innovation.

Atmospheric-intervention technologies are emerging within militarized innovation ecosystems and governance vacuums at the exact historical moment when ecological infrastructures are becoming theaters of war.

The case of Stardust Solutions, a U.S.-Israeli start-up that is developing Stratospheric Aerosol Injection (SAI) technology, illustrates this risk. Some of its investments come from actors connected to Israeli defense and intelligence or American venture capitalist firms, and there have been concerns about possible outdoor testing in Gaza. No confirmed weaponized deployment has yet been documented. But SAI experimentation in an active war zone presupposes an absence of monitoring or ethical behavior. The significance of the case lies in the architecture that is taking shape: a planetary-scale atmospheric technology developing at the intersection of private venture capital, defense institutions, and an active conflict environment—all enabled by the lack of any governance framework.[222] This could generate a black box within security dilemma dynamics that favors the rise of specialized geoengineering competition as a field of technological development.

A Commercial Field Instrumentalized by Private Interests

The same actors that are investing in AI infrastructure are also incubating a parallel field of commercial geoengineering by accumulating research, intellectual property, and a first-mover advantage over SRM and related techno-fixes. What is being built without a multilateral mandate is a privatized claim to planetary commons—from critical materials and ecological resources to data and modeling capacities to, increasingly, technological interference.[223]

The investment logic is coherent: build the infrastructure necessary for technological acceleration while investing in temporary hedges against the acceleration of climate change. These hedges could not only protect heat-sensitive infrastructure but also create a potential market for sovereign demand as temperatures rise and states struggle with legitimacy.[224]

Taken together, these three registers make the pursuits of the actors that are accumulating planetary capabilities strategically consequential. They reveal an emerging contest between two distinct approaches to the future of geoengineering: one rooted in public funding, oversight, accountability, and expert-informed political deliberation; the other grounded in the larger, systematic private capture of the planetary commons and state capability for technological pursuits, which, for some, are ideological.

From Techno-Solutionism to Techno-Substitution

The race to AGI in the United States is being waged by an ecosystem of actors who share more than investment portfolios. Figures such as venture capitalists Peter Thiel and Marc Andreessen, OpenAI's Sam Altman, X's Elon Musk, Palantir's Alex Karp, and others are at the helm of an ideological and financial ecosystem that seeks to rewire politics and governance through markets and technology and, in some cases, reorganize sovereign spaces to serve innovation itself.[225] Across libertarian, extropian, accelerationist, and techno-nationalist currents, an ideological project is taking shape in which technological progress expands the domain of what can be engineered, controlled, or escaped. These currents do not constitute a unified doctrine, but they increasingly converge toward overcoming biological, political, and planetary constraints to innovation, including, at their farthest horizon, by creating a civilizational succession.

This ideology operates across different domains. Applied to the human body, this approach produces research into longevity, cryonics, and human augmentation, which conveniently serves the purpose of assessing how bodies can adapt to unstable, foreign, or modified planetary environments. Applied to political organization, it produces freedom cities, network states, and architectures of political exit that seek to escape democratic governance and regulation. Applied to material production, it takes the form of synthetic biology and cellular agriculture, which increasingly seek to reproduce outside their ecological contexts materials once supplied by living systems. The objective shifts from extracting more efficiently from nature to decoding biological production itself and recreating it within

engineered systems. Applied at a planetary scale, this ideology produces geoengineering and terraforming: the deliberate redesign of planetary systems for a postnatural civilization and the connected pursuit of postplanetary conquest.[226] These domains do not operate in silos; advances in one expand the technological and ideological possibilities of the others.

These pursuits also recur across political positions, investment ecosystems, and technological portfolios in the race to AGI. Thiel has questioned the compatibility of freedom and democracy and argued for "exit" over "voice."[227] Hereticon, a gathering organized and funded by Thiel's venture-capital firm, places fossil-fuel expansion, tech acceleration, and geoengineering as necessary pursuits in the face of the apocalypse, which is itself presented as positive. Andreessen's Techno-Optimist Manifesto identifies environmentalism, the precautionary principle, and degrowth as enemy ideologies and frames the *defeat* of natural limits as a civilizational imperative.[228]

Altman has publicly identified geoengineering as a likely instrument of planetary management in a world reshaped by AGI.[229] Musk's public interventions combine three themes: AI as a potential existential risk, planetary-scale technological management of Earth's climate, and the long-term expansion of humanity beyond Earth.[230] He has repeatedly framed the conquest of Mars as an "insurance policy" against civilizational collapse while endorsing space-based solar geoengineering.[231] Karp represents a more statist variant: He seeks to fuse advanced private technological capability with the state, using security dilemmas and power imperatives as an underpinning narrative to accelerate innovation in all its forms.

Investment clusters turn ideas into experiments, which themselves widen ideological horizons. Thiel funds transhumanism and postplanetary ventures, techno-military industrial innovations and surveillance, U.S. President Donald Trump's election campaigns, and support for political personalities such as U.S. Vice President JD Vance.[232] Andreessen provides theses and investments for critical minerals, grid technologies, energy, and pre-stacks for AI.[233] Musk's portfolio—Neuralink, SpaceX, and xAI—collectively span biological transcendence, planetary exit, and posthuman intelligence.[234] Altman leads the joint venture Stargate, designed to "elevate humanity" and secure U.S. dominance of AI.[235] The significance of these portfolios lies in the technological terrain they collectively build: a growing set of privately developed capabilities for acting on intelligence, biology, political infrastructure, and, ultimately, planetary processes.

In this terrain, the connection to commercial SRM is tightening fast. Stardust Solutions has raised what is reported to be the largest commercial funding round in SAI and counts Future Ventures—co-founded by Steve Jurvetson, a long-standing SpaceX investor and board member—among its investors.[236] Within days of Stardust's October 2025 funding announcement, Musk publicly proposed that a "large solar-powered AI satellite constellation could make small adjustments to the amount of solar energy reaching Earth."[237] The statement framed atmospheric management directly as an AI and space-infrastructure opportunity, opening a potential new realm of investments for Musk's companies, complementing and competing with atmosphere-based SRM.

The connections between geoengineering and extropian portfolios point to innovation that pushes frontiers and creates markets, on the one hand, while acting as a *risk-hedging strategy* for accelerated planetary failure and civilizational constraints, on the other. AGI, longevity, extractive biotech, and geoengineering cohere through the interaction of investment, experimentation, crisis, and technological selection.

These co-evolving portfolios make sense if the planet is a *temporary operating environment* to be managed in the short term and transcended in the long run. In this worldview, nature is increasingly presented as obsolete evolutionary code, easily replaceable thanks to technological progress. And planetary instability provides the opportunity to deploy technology at scale. As ecological breakdown generates demand for interventions on the basis of stabilization, humanitarianism, and species survival, this worldview suggests that an improved technological capacity can fill that demand via markets. Socioeconomic Darwinism lies underneath this worldview: Only those with economic resources can opt in to techno-adaptation.

That recursive ideology-investment-capability loop is already penetrating parts of the U.S. political and military infrastructures. The United States relies heavily on private actors to generate technological advantages across AI, defense, space, energy, infrastructure, and other domains; ongoing reductions in public capacity will only deepen its dependence on proprietary systems. Once private firms complement state capability, they can substitute for it. They accumulate expertise, infrastructure, data, and technologies without acquiring any obligations of democratic accountability, scientific scrutiny, or collective security. This is tech-enabled sovereignty-as-a-service. It flips the nature of the state on its head, making it responsive to private interests at the expense of the public good, all the while securitizing the public interest.

Geoengineering brings this logic into the global commons. While the atmosphere cannot be privatized, the capabilities required to modify and monitor it can be. First-mover advantages may give private actors technological and informational leverage over governments and research institutions and security competition could increase demand for any capabilities deemed to be strategically necessary. This is the nature of security dilemmas. The worldviews, strategies, and tools employed by one strategic actor end up informing and shaping adversary behavior and innovation races to secure an ability to defend, compete, and deter. The mirroring effects extract tolls on ecological and social interests, and it creates a ratcheting mechanism both in terms of competition for technological horizons and their material, ecological, and social inputs. Security dilemmas create systemic convergence, in other words, and they narrow the space for reasonable innovation, collective governance, and protection of public goods.

As geoengineering intersects with the hegemonic competition for resources, it risks tilting technological responses applied to various crises, including climate breakdown, from techno-solutionism to techno-substitution: when a technology no longer solves ecological problems but progressively attempts to substitute for the overarching ecological systems. As technological requirements penetrate further in the natural fabrics of the planet, innovation

frontiers and markets engineer or replace the ecological functions necessary for human adaptation and survival. In the process, they also create economic barriers to dignified living and collective governance. Pushed to its extreme, the integration of geoengineering within security dilemmas and competitive ratcheting points to a future in which technology proposes to redesign both nature and humanity, thereby taking over evolutionary processes. This worldview is not confined to science fiction; it already operates within political, market, and geostrategic systems.

State penetration via sovereignty-as-service is a means to an end in this direction, and one already unfolding in the United States. Amid heightened security dilemmas, the risk exists that techno-substitution becomes a dynamic horizon within international competition. Once technological control of ecological functions is framed as a strategic necessity, states facing security dilemmas may mirror one another's investments and dependencies. Mitigation, precaution, and protection of the global commons could become increasingly subordinated to the pursuit of technological optionality and strategic advantage.

The consequences would extend beyond economics, politics, and security. Techno-substitution progressively recasts humanity's biological and ecological embeddedness as a constraint to be engineered around. It is a civilizational proposition about what humans should be when they are decoupled from nature and what forms of intelligence and life can produce civilizational futures. Economically and politically, it is inseparable from knowledge enclosure, market concentration, and state capture, as the capacity to opt in to techno-substitution for survival becomes concentrated among those who control and can afford the relevant infrastructures, knowledge, and technologies. Ecologically, this proposition replaces dependence on living systems with dependence on engineered ones. At its farthest horizon, techno-substitution assumes that nature and humanity are the bootloading system for intelligence's next evolutionary phase and civilizational succession.[238]

What is at stake, then, is whether the civilizational response to planetary crisis remains a collective project—humane, multilateral, ethical, accountable, and ecologically responsive—or is captured within systems that treat planetary limits and the link between humanity and nature primarily as technological problems to be transcended through the decoupling of their co-constitutive relations.

Europe at a Civilizational Juncture

Geoengineering cannot be navigated through regulation or contained to single-domain responses. It first requires an understanding of the geostrategic and ideological terrain at play. Technologies that are not analyzed against the background of hegemonic competition and ideological visions of technology's role in an age of planetary entropy will be shaped by actors who do analyze them that way.

In April 2026, the EU Council announced a moratorium on SRM deployment.[239] But at the same time, Europe is accelerating engines that may increase future pressure for such deployment. The processes of rearming, reindustrializing, and digitizing expand demand for

materials and energy, while European mitigation pathways rely ever more on CDR as a tool to close the emissions gap.[240] CDR has not yet scaled, and SRM is increasingly discussed as a response to climate overshoots.[241]

The EU therefore risks a double bind: adopting a precautionary approach to SRM without giving itself the means either to avoid future deployment pressures or to invest adequately in publicly accountable research that can frame whatever comes next.

The EU cannot respond to a civilizational wager that leads to potential techno-substitution with technical regulation. It must act in the same register. To that end, Europe should focus on four specific priorities, as a start.

Define European Innovation in the AI Race

In Europe, AI must be given a directional purpose beyond economic optimization and innovation as dictated by the United States and China.

Because Europe is warming twice as fast as the global average, AI-related investments must include a well-funded pillar focused on accelerating regeneration and innovation to address planetary overshoots.[242] AI needs to be trained across physics, biology, ecology, and chemistry to identify how to rebuild ecosystem services at multiple scales, embed energy and material demands into ecological carrying capacity, and innovate within rather than against planetary constraints.

Call it regenerative accelerationism: the start of a framework that positions innovation in a co-constitutive relationship with ecological fabrics to regenerate, preserve, and reboot economic competitiveness and strategic autonomy. It would differ from techno-substitution in several ways, with innovation guidance and principles that remain to be fully mapped (see table 1).

Table 1. Regeneration vs. Techno-Substitution

Criterion	Regeneration	Techno-Substitution
What is replaced?	Extractive activity or harmful production	Ecological functions or living sys-tems themselves
What happens to ecosystems?	Pressure falls and ecological integrity recovers	Integrity becomes less relevant to the technological system
Where does agency reside?	Increasingly back in self-organizing living systems	Increasingly in engineered infra-structure and operators
Is intervention tem-porary or structural?	Technology enables regenera-tion or resilience	Permanent technological manage-ment becomes necessary
How is complexity treated?	Preserved because multifunc-tionality matters	Selected functions are isolated, op-timized, reproduced, and replaced
What does success mean?	More autonomous, resilient ecosystems and dignified liv-ing	Greater human decoupling from eco-logical constraint with forced eco-nomic dependencies

Champion Complex Regeneration

Whereas SRM proposes a temperature freeze to buy time while current economic and security ratcheting mechanisms are maintained, complex regeneration seeks to redesign economic and security systems so that industrial development, energy and material transitions, water security, and ecological stability become mutually reinforcing. For Europe, this should inform industrial policy, territorial planning, climate adaptation, food and water security, infrastructure investment, and external partnerships.

Complex regeneration is not about tree planting for carbon sequestration. It is about rebooting ecological complexity, rebuilding green water cycling, and reanchoring the hydrological processes that climate breakdown is dismembering. Restoring the water cycle at multiple scales provides co-benefits for climate change mitigation, adaptation, food security, and territorial resilience that no single geoengineering intervention can match.

This approach requires a minimum of three interconnected modeling capabilities: models of green water cycle restoration that quantify biophysical cooling and precipitation effects beyond carbon sequestration; long-range teleconnection modeling that maps how restoration in specific bioregions affects rainfall in climatically connected regions; and integrated landscape-optimization and ecological-security tools that connect climate outputs to biodiversity, food security, and socioecological resilience. European platforms including ORCHIDEE and HTESSEL provide foundations, but these capacities have not been mobilized in a coordinated program at the scale and resolution required.

Complex regeneration is also a diplomatic instrument. A pilot project has shown that marrying mediation with bioregional regeneration for the Arabian Peninsula can catalyze constructive dialogue in geographies that combine ecological stress with political protraction and latent violence, with co-benefits for temperature and hydrological stabilization.[243]

The EU and the Gulf share a specific vulnerability: Both are warming at twice the global average.[244] Both are also optimal laboratories for joint investment in bioregional economic development.

Invest in Transition Intelligence

The EU needs to invest in *transition profiling*.[245] This means understanding how power incumbents envision adapting their power in a world disrupted by climate change; what roles technological and ecological factors play in those visions; how ideologies shape the methods used to achieve them; how those methods affect other international actors; and how geoengineering and co-evolving investment portfolios fit into the adaptation strategies of the United States, China, and tech companies.

Ban Commercial SRM

The Treaty on the Functioning of the EU enshrines the precautionary principle as the legal basis for restricting technologies whose risks cannot be reliably characterized in advance.[246] A dedicated SRM regulation could prohibit commercial deployment on EU territory and by EU-flagged aircraft and vessels and also require full chemical disclosure for atmospheric-application research.

EU rules on sustainable finance could classify commercial SRM as unsustainable, while the European Commission's Directorate General for Competition could scrutinize monopolistic positions on proprietary atmospheric technologies. In trade negotiations, the EU could seek noncommercialization clauses with willing partners to progressively constrain international commercial deployment.

None of this should translate into withdrawal from SRM research. The EU must be able to assess claims of deployment and shape its direction if it occurs, so it should endeavor to remain technically capable in this field.

The UK operates one of the most ambitious state-supported research programs in this domain, through the Department for Environment, Food, and Rural Affairs on CDR and the Advanced Research and Invention Agency on SRM. Climate security should become an explicit domain of EU-UK cooperation, with the EU contributing research on complex regeneration and multimodal modeling alternatives and the UK offering technical modeling on CDR and SRM. This could lead to complementary experimentation for research governance and geopolitical engagement.

At this moment, the EU can combine multilateral legitimacy, legal precaution, and normative authority to shape planetary interventions in a direction that serves the global commons instead of hegemons or private capital. That is not a modest asset. The question is whether European institutions are willing to exercise it before the window closes.

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