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Profit-seeking solar geoengineering exemplifies broader risks of market-based climate governance

Kevin Surprise [a,*], Duncan McLaren [b], Ina Möller [c], J.P. Sapinski [d], Doreen Stabinsky [e], Jennie C. Stephens [f]

[a] Environmental Studies, Mount Holyoke College, United States
[b] Climate Intervention Fellow in Environmental Law and Policy UCLA Law School, United States
[c] Environmental Policy Group, Wageningen University, the Netherlands
[d] Environmental Studies, Université de Moncton, Canada
[e] Global Environmental Politics, College of the Atlantic, United States
[f] ICARUS Climate Research Centre, National University of Ireland, Maynooth, Ireland

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ABSTRACT

Despite uncertainties about its feasibility and desirability, start-up companies seeking to profit from solar geoengineering have begun to emerge. One company is releasing balloons filled with sulfur dioxide to sell "cooling credits", claiming that the cooling achieved when 1 g of SO_2 is released is equivalent to offsetting one ton of carbon dioxide for one year. Another aspires to deliver returns to investors from the development of a proprietary aerosol for dispersal in the stratosphere. Such for-profit solar geoengineering enterprises should not be understood merely as rogue opportunists. These proposals are not only scientifically questionable, and premature in the absence of effective governance, but they are a predictable consequence of neoliberal, market-driven climate governance. The structures and incentives of market-based climate policy - circumscribed by neoliberalism's emphasis on technological innovation, venture capital, and the marketization of environmental goods - have generated repeated efforts to profit from various forms of geoengineering. With a climate governance regime wherein private, for-profit actors significantly influence and weaken climate policy, *de facto* governance of solar geoengineering has emerged, dominated by actors linked to Silicon Valley funders and ideologies. Without more explicit efforts to curb the power of private sector actors, including commercial geoengineering bans and non-use provisions, pursuit of techno-market "solutions" could lead to both inadequate mitigation *and* increasingly risky reliance on geoengineering.

1. Introduction

"Cooling credits" are emerging as the latest market-based climate scheme, with commercial efforts to equate climate forcing effects arising from changes in albedo with those caused by greenhouse gasses. On this basis, a small US start-up company called Make Sunsets is launching balloons into the atmosphere filled with sulfur dioxide to sell cooling credits, commodifying an asserted effect of solar geoengineering as a product to be sold in the voluntary carbon offset market (Temple, 2022). The company charges $10 for the release of 1 g of SO_2, claiming that the cooling achieved by reflecting a miniscule amount of sunlight when the SO_2 is released into the stratosphere via balloon is equivalent to offsetting one ton of carbon dioxide for one year (a calculation they glean from existing solar geoengineering research, e.g. Parker and Keith, 2015; Smith, 2020). This company's business model is not only based on dubious assumptions and unverified claims (Diamond et al., 2023), but also demonstrates a serious risk of advancing solar geoengineering: selling cooling credits legitimizes continued carbon emissions instead of cutting them.

Prominent solar geoengineering researchers were quick to publicly denounce this venture as wrongheaded, arguing that solar geoengineering has not yet been sufficiently researched to begin real-world application, and that linking solar geoengineering to profit-based motives is problematic. Such critiques tend to treat emerging for-profit

* Corresponding author.
E-mail addresses: ksurpris@mtholyoke.edu (K. Surprise), mclaren@law.ucla.edu (D. McLaren), ina.moller@wur.nl (I. Möller), jean.philippe.sapinski@umoncton.ca (J.P. Sapinski), dstabinsky@coa.edu (D. Stabinsky), Jennie.Stephens@mu.ie (J.C. Stephens).

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geoengineering schemes as rogue, impetuous efforts (Temple, 2022). We suggest, however, that the emergence of profit-seeking solar geoengineering is not a surprising rogue development, but a predictable consequence of neoliberal climate politics dominated by market-driven policies, and the prominent role played by technology billionaires and Silicon Valley interests in advancing solar geoengineering research (Stephens, 2024). In this climate policy milieu, it is unsurprising that other for-profit tech companies have also begun to emerge in the solar geoengineering space. For example, Stardust Solutions, an Israeli start-up headquartered in Silicon Valley, has raised over $15 million on the basis of a commercially confidential solar geoengineering technology, including from a Canadian venture capital fund with deep ties to the Israeli defense and security sectors (Freedman, 2024).

"Cooling credits" and other for-profit geoengineering ventures are what inevitably emerge from climate policymaking circumscribed by neoliberalism's emphasis on technological innovation, venture capital, and the marketization of environmental goods (Ciplet and Roberts, 2017; Taffel, 2018). Researching solar geoengineering technologies under these conditions, without more restrictive governance concerning commercial activities and powerful private sector actors, is likely to lead to the advancement of solar geoengineering amidst inadequate mitigation. Well-meaning calls for deliberative or participatory governance of solar geoengineering fail to take into account the expanding power and influence of private sector actors in current solar geoengineering governance. And calls for more public funding of solar geoengineering research, in the hope that publicly funded research will *displace* private interests in this space, are insufficient in the face of the structures and incentives of our current political economy (Thorpe, 2020).

In this perspective we first describe past and present attempts to create market-driven, for-profit entities for a variety of geoengineering mechanisms. We then highlight the shortcomings of existing governance frameworks. Finally, we outline the mechanisms - including tech innovation, private philanthropy, venture capital, and patent protection - through which neoliberal institutions and ideologies create and sustain the conditions for profit-driven geoengineering. We conclude that solar geoengineering is emerging within and perpetuating a neoliberal climate framework where direct "climate cooling" is poised to become just another ineffective climate commodity.

2. Thin air: voluntary carbon markets and geoengineering

These recent efforts are not the first time that corporations have attempted to use market mechanisms like carbon credits to mobilize capital for, and profit from, geoengineering technologies. Geoengineering includes two families of technologies that could be deployed 'after-the-fact' of excess emissions: solar geoengineering to reflect sunlight, and carbon removal to draw down atmospheric greenhouse gas concentrations (The Royal Society, 2009). One carbon removal approach with direct parallels to solar geoengineering, particularly stratospheric aerosol injection, is ocean iron fertilization. Both entail deliberately distributing large quantities of material in a global commons. And to be incorporated into market-oriented climate policy, both require markets to be constructed through the establishment of fungibility between emissions and respectively, cooling and removals. In each case the development of commercial business models relies on plausible scientific claims, market (and standard setting) institutions, and speculative venture capital.

Shortly after the 1997 Kyoto Protocol introduced emissions trading as a way to meet climate targets, US-based start-ups like GreenSea Ventures, Climos, and Planktos announced intentions to invest in ocean fertilization and sell carbon credits to governments (Fuentes-George, 2017). At the time, research institutes from the US, Europe, India, Japan and New Zealand were studying the potential of iron to increase plankton growth and sequester CO_2, with advocates portraying it in the media as a cheap, high-leverage way of mitigating climate change, and multiple patent applications being submitted (Adhiya and Chisholm, 2001). The companies' efforts met resistance from critical NGOs and governments, resulting in restrictive measures under both the Convention on Biological Diversity and the London Protocol. Such proposed restrictions on commercial ocean-based geoengineering - including via offset markets - have not yet been extended to atmospheric geoengineering.

The voluntary carbon offset market, which began in the late 1990s but languished for many years, was revived after the 2015 Paris agreement. At this time, offset purveyors seized on the profit potential of selling 'net zero' solutions. Offset markets are an accounting scheme to allow individuals, organizations, or states to compensate in some way for their continued carbon emissions by financially supporting other efforts to avoid or reduce emissions, or to remove carbon dioxide from the atmosphere (Carton et al., 2022). The purportedly avoided, reduced, or removed emissions can be traded. This kind of market has not simply emerged; it has been intentionally constructed. Establishing a market in a public environmental good, such as the climate, requires defining expectations related to goals and targets; institutions and actors; incentives; metrics and measures; and equivalences and fungibility (McLaren and Carver, 2023). Despite the theoretical value of carbon markets as a means of enhancing efficiency in allocating investments in climate action, carbon offsetting has, in practice, undermined progress in addressing the climate crisis with recent research concluding that the majority of offset projects are "likely junk" (Lakhani, 2023; Probst et al., 2024). The lack of accountability and weak standards in carbon offsetting and carbon removal enables corporations and governments to make highly questionable claims, asserting that they are (or are on track to) achieving 'net-zero' targets (Jacobs et al., 2023; Trencher et al., 2023). Efforts to raise standards in both voluntary and compliance carbon trading markets remain patchy and inadequate (Dooley, 2024). Nonetheless, the field is crowded with carbon removal technology companies soliciting investment based on the prospect of profitably selling carbon credits, from both terrestrial and marine removal methods. That the first announcement of COP29 was to approve half-baked and contentious rules for carbon trading under the Paris Agreement is symbolic of the continuing dominance of neoliberal economic ideology in climate policy. This continues despite growing critique that the for-profit carbon market model will misallocate removals to enable continued fossil fuel use (Grubert and Talati, 2024).

Despite the ineffectiveness of offsets, the imagined potential to profit from markets in purported global cooling is infiltrating the solar geoengineering field as well. While Make Sunsets' cooling credits function as a new voluntary market, there have also been efforts to establish standards that could underpin formal exchanges of cooling for carbon. For example, in 2018 the idea of 'radiative forcing credits' was introduced to the International Standards Organization (ISO) by SCS Global Services and First Environment, two US-based companies that specialize in sustainability certifications. Their goal was to create a standard that would account for all forms of climate forcing, including negative climate forcers like reflectivity. By including 'climate coolants' into the composition of national 'radiative forcing footprints', countries would need to account for changes in reflectivity when reporting their climate impact. This would also have laid a foundation for extending carbon markets to include the trading of cooling credits by certifying cloud brightening projects and other efforts that change reflectivity. This proposed new standard was met with resistance, primarily from European organizations who feared that such a standard would legitimize solar geoengineering projects and undermine existing metrics for emissions accounting. The draft standard was eventually downgraded to a technical document without any advice-giving character (Möller, 2021).

Cooling credits continue this trend. To create a marketable commodity, entrepreneurs are equating the cooling potential of reflectivity with carbon emission reductions, making these two very different climate forcers fungible. As noted by proponents of solar geoengineering research and experimentation, such claims of equivalence are

scientifically suspect (Diamond et al., 2023). But profit, not science, rules this realm, and it remains to be seen if metrics and equivalences can be constructed that satisfy investors and customers. The fact that a for-profit company is currently raising money, soliciting investors, and finding customers underscores and multiplies the integrity issues faced by the voluntary carbon market, exposing the ease with which a company can make questionable claims to "effective" climate action. Moreover, any cooling-offset trading mechanism would mean allowing emissions to continue that would otherwise have to be cut to deliver net-zero. So, in this model, even if solar geoengineering efforts delivered cooling, it would be done to compensate for continued emissions, not as an additional benefit.

3. Limitations and contradictions of current geoengineering governance

The emergence of such brazen for-profit ventures has triggered increased demands for governance of solar geoengineering. In general, governance can be understood as a mix between public and private authority, in which both state and non-state actors shape circumstances and rules of engagement. Governance is, therefore, not simply the actions taken by governments; it includes the power and influence of industry and individuals as well (Green, 2014). Within the current political-economic context defined by neoliberal capitalism, both solar geoengineering governance and climate governance more broadly are subject to considerable influence by private, profit-driven actors, rendering patentable technologies, emissions trading, and market-directed investments as dominant climate mitigation mechanisms under the Kyoto Protocol, Paris Agreement, and current national policies. These climate policies emerge from and reinforce neoliberal ideologies that private entrepreneurship and technological innovation are key to overcoming the environmental "externalities" associated with endless economic growth (see Fig. 1). Powerful business lobbies fund and advocate not only for specific interventions, but also a whole framework of neoliberal political ideology, and policymakers are hemmed in by market-based thinking, modelling and policy making (Sapinski, 2016).

Solar geoengineering is gaining traction in part because there is a growing recognition among scientists and policymakers that these incremental, market-based policies are unable to respond to the climate crisis quickly enough to stave off its worst effects. This points to a contradictory conception among those advocating for increased investments in solar geoengineering. On one hand, solar geoengineering is proposed *as a response to* ineffective public climate policy. On the other hand, solar geoengineering advocates acknowledge that developing and deploying the technology in an ethical way *depends on* effective public policy (Parson and Reynolds, 2021). Many prominent scenarios envision or imply cooperative governance of solar geoengineering as a means to guide choices in the location, timing, and intensity of deployment, (MacMartin et al., 2019), with some positing rational deployment as a global public good, or in the interests of the poor and climate vulnerable (Horton and Keith, 2016). Moreover, the kind of modeling used to envision such scenarios often implies the possibility of controlling deployment of solar geoengineering in great detail, with intricate scenarios for carefully modulated and well governed deployment used to illustrate desirable outcomes (McLaren, 2018). An unspoken assumption of many functional solar geoengineering scenarios is thus that governments – mired in ineffective climate governance, beholden to private interests, and entrenched in market-driven policy – could somehow find a way to work cooperatively on solar geoengineering deployment. Such a premise is belied by the repeated inability of governments to agree even on initial steps towards such governance (McLaren and Corry, 2025).

On this basis, leading governance proposals devised to guide state action on solar geoengineering largely assume an *absence* of governance at present, and call for developing solar geoengineering governance systems based on public, government-led research and development with international coordination (National Academies of Sciences, Engineering, and Medicine, 2021). Under current political-economic conditions, however, the highly idealized governance scenarios that dominate the solar geoengineering governance imaginary reside in what Malm (2023) calls the realm of 'pure fantasy'. These kinds of idealistic scenarios do not grapple with more grounded realities where diffuse forms of permissive governance enable private, profit-seeking actors to proliferate, and fail to adequately acknowledge already-existing, largely private, solar geoengineering governance structures shaping the field

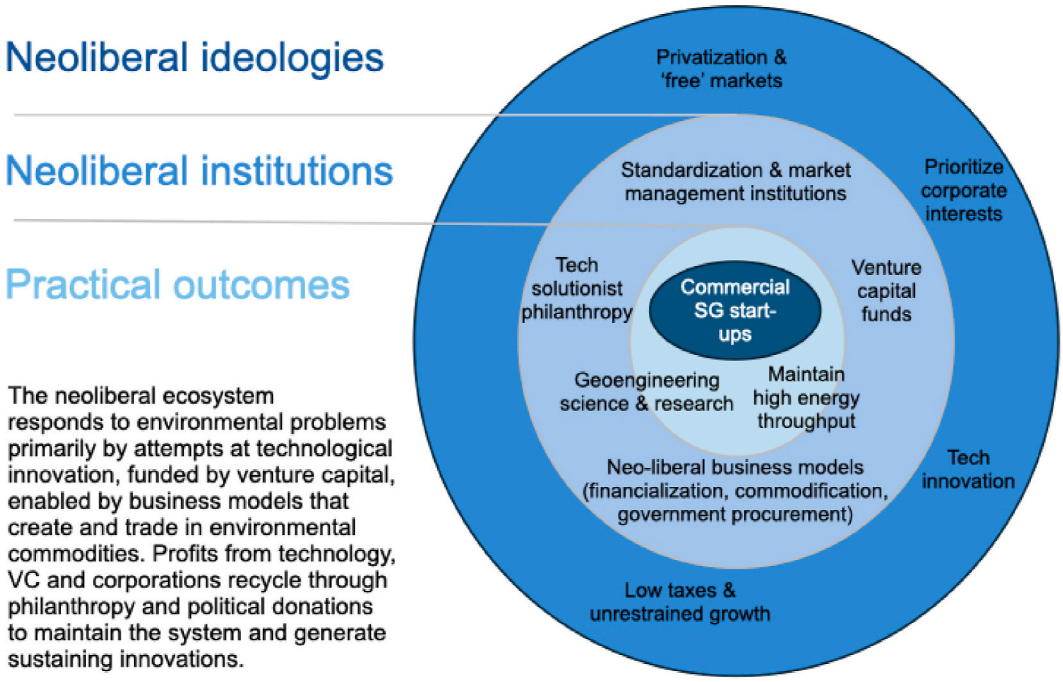

Fig. 1. Solar geoengineering start-ups as embedded within a neoliberal ideological and institutional framework.

(Gupta and Möller, 2019). This is evidenced by the fact that some of the same institutions calling for "just" solar geoengineering governance are actively expecting and preparing for more funding from private philanthropic and venture capital sources (Hiar, 2024).

4. Markets, technology, billionaires

While solar geoengineering technologies are still not openly embraced by mainstream climate policy, their development, including research on stratospheric aerosol injection, has nonetheless been strongly influenced by market-driven approaches. In other words, for-profit solar geoengineering did not emerge in a vacuum. It is the logical result of the brief history outlined above, plus two additional congruent processes: first, "climate tech" is a rapidly growing interest among Silicon Valley investors, entrepreneurs, and philanthropies, and second, solar geoengineering research is funded by - and continues to cultivate funding from - Silicon Valley billionaires and philanthropies connected to large technology companies, venture capital, and tech-focused hedge funds (Surprise and Sapinski, 2023). The broad moniker of "Silicon Valley" represents an approach to technological innovation that Sereni refers to as a *theology*, or an unfounded systematic belief "that technologies should be launched on the market, exempt from any regulation and intervention … the beneficiaries of these technologies are autonomous, rational individuals who exercise their rights and liberties. Thus, improvement of the species will be achieved via countless individual decisions, which will lead to collective benefit" (Sereni, 2021, p. 7). This ideology suffuses the Silicon Valley approach to climate change, presuming that profit-driven market mechanisms, technology investment, and individual entrepreneurship can solve the climate crisis, even as technologies such as blockchain and artificial intelligence are accelerating energy demand.

Such dogmatic technological optimism also undergirds philanthropic and venture capital-linked funding of solar geoengineering research. For example, the Harvard Solar Geoengineering Research Program (HSGRP) was long funded by, and directly solicited funding from, technology billionaires. Perhaps the most well-known funder is Bill Gates, who has famously said that climate change is a technological rather than a political problem. Other investors in solar geoengineering include billionaire founded effective altruism outfit, the Open Philanthropy Project(OPP), which funds actors engaging in solar geoengineering research and policy debate including HSGRP, the DEGREES Initiative, the Overshoot Commission, and The Alliance for Just Deliberation on Solar Geoengineering. Recent entrants from wealthy private philanthropy tied to the technology, venture capital, and hedge fund worlds - providing millions in research funding - include the LAD Climate Fund, The Simons Foundation, and the Quadrature Climate Foundation. The NGO SilverLining, whose 'safe climate research initiative' has distributed millions of dollars to solar geoengineering research programs, is also funded by a host of billionaire philanthropies and venture capital firms (see Surprise and Sapinski, 2023). The credo of one of these funders, Lowercarbon Capital, is stated in large, bold letters on their website: "Fixing the planet is just good business. Shame and guilt won't get us there, markets will."

Yet the markets in question require significant state intervention to materialize and scale. While 'cooling credits' epitomize the entrepreneurial market obsession of neoliberal ideology, neoliberalism in practice often requires state institutions to generate and protect profits, for example, through patent enforcement or public procurement. In this context Stardust Solutions' business model is no less neoliberal than Make Sunsets'. Given the long historical entanglement between defense and security industries, technology firms, and militaries, solar geoengineering's myriad ties to the defense industry (Surprise, 2020) may be a clearer harbinger of its future development, and future routes to profit, than cooling credits.

Moreover, if markets for technologies such as generative AI and massive data centers result in growing energy demand and climate pressures, the answer from Silicon Valley is not to restrain emissions, but to pursue technological breakthroughs such as nuclear fusion, whilst explicitly relying on solar geoengineering as a mechanism for masking the massive energy growth of AI, according to Sam Altman of OpenAI (Marx, 2024). Coopting innovation into the incremental service of capital accumulation is a standard part of the venture capital funded model of neoliberal capitalism. As Jesse Goldstein (2018) has documented for clean technology in general, the model of venture funding of innovation does not deliver environmental transformation. Instead venture investors replace scientific founders with business strategists, and demand business models that maximize profits rather than environmental gain.

5. Conclusion

The emergence of for-profit geoengineering schemes is not surprising, and serves to reinforce the prospect of both increased emissions *and* increased reliance on risky solar geoengineering. The involvement of corporate actors motivated by profit underscores the deep implausibility of achieving collective democratic governance of solar geoengineering within our current political-economic system. Calls for ethical or democratic governance of solar geoengineering will remain of limited impact in a political economy where corporations, venture capital, billionaires, and other powerful actors exert outsized influence and the dominance of market ideology constrains the emergence of alternative economic structures. As the climate justice movement pushes for long-term, structural changes, the dangers of market-based solar geoengineering elevate the urgent, immediate need for strengthening public control of climate governance and limiting private-sector influence (Stephens, 2024).

The sale of cooling credits could be limited, for example, through restrictions on offsetting claims (as proposed more generally in the European Union's draft Green Claims directive) or through requirements for corporate reporting standards. Attempts to profit from solar geoengineering via technology licensing could be restricted by bans on commercial patenting, as proposed in the call for an international Solar Geoengineering Non Use Agreement (Biermann et al., 2022). Governments could more broadly establish regulations around solar geoengineering akin to those in the London Protocol on ocean iron fertilization which aims to prohibit commercial activities, while providing guidelines for permitting legitimate scientific research.

Upon learning of Make Sunsets initial activities in Mexico, the Mexican government announced it would ban unauthorized solar geoengineering launches. In the USA, an organization like NOAA may have - or should seek - the authority to make similar provisions (rather than simply extending notification procedures, see Bravender, 2024). Policy makers in all countries could regulate or ban commercial or for-profit solar geoengineering projects, and consider supporting principles of non-use or non-deployment.

CRediT authorship contribution statement

Kevin Surprise: Writing – review & editing, Writing – original draft, Project administration, Investigation, Conceptualization. **Duncan McLaren:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Ina Möller:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **J.P. Sapinski:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Doreen Stabinsky:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Jennie C. Stephens:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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