

## Intelligence Briefing

**Cite this article:** Stephens JC, Surprise K (2020). The hidden injustices of advancing solar geoengineering research. *Global Sustainability* 3, e2, 1–6. <https://doi.org/10.1017/sus.2019.28>

Received: 13 September 2019

Revised: 12 December 2019

Accepted: 15 December 2019

**Keywords:**

climate justice; climate mitigation; climate policy; geoengineering

**Author for correspondence:**

Prof Jennie C. Stephens,

E-Mail: [j.stephens@northeastern.edu](mailto:j.stephens@northeastern.edu)

# The hidden injustices of advancing solar geoengineering research

Jennie C. Stephens<sup>1</sup>  and Kevin Surprise<sup>2</sup>

<sup>1</sup>School of Public Policy & Urban Affairs, Civil & Environmental Engineering, Global Resilience Institute, Northeastern University, 360 Huntington Ave, RP 360C, Boston, MA 02115, USA and <sup>2</sup>Environmental Studies, Mount Holyoke College, South Hadley, MA, USA

**Abstract**

Advancing solar geoengineering research is associated with multiple hidden injustices that are revealed by addressing three questions: Who is conducting and funding solar geoengineering research? How do those advocating for solar geoengineering research think about social justice and social change? How is this technology likely to be deployed? Navigating these questions reveals that solar geoengineering research is being advocated for by a small group of primarily white men at elite institutions in the Global North, funded largely by billionaires or their philanthropic arms, who are increasingly adopting militarized approaches and logics. Solar geoengineering research advances an extreme, expert–elite technocratic intervention into the global climate system that would serve to further concentrate contemporary forms of political and economic power. For these reasons, we argue that it is unethical and unjust to advance solar geoengineering research.

**Social media summary**

Solar geoengineering research is rooted in and perpetuates the unjust concentration of political and economic power.

**1. Introduction**

Once relegated to the fringes of climate policy, solar geoengineering is now gaining traction in a range of influential institutions. Internationally, the Intergovernmental Panel on Climate Change (IPCC) included solar geoengineering in the special report on 1.5°C (Watts, 2018), and the United Nations Environment Programme recently debated a resolution to explore geoengineering research (Chemnick, 2019). In the USA there is momentum as well, with the Harvard Solar Geoengineering Research Program (HSGRP) establishing an external advisory board to legitimize their plans for outdoor field experiments (Tollefson, 2019), and the US National Academies of Science, Medicine and Engineering (NAS) convening its second committee charged with examining ‘climate intervention strategies’ (Showstack, 2019). The NAS report, scheduled to be released in mid-2020, is expected to propose a research agenda and suggest research governance approaches laying the groundwork for US federal funding of solar geoengineering research.<sup>1</sup>

As the global impacts of climate change become more severe, solar geoengineering has increasing appeal because it offers the possibility of cooling the planet relatively quickly at a comparatively low cost, without drastic near-term cuts in carbon dioxide emissions (Morton, 2016; Shepherd, 2009). The primary approach, stratospheric aerosol injection (SAI), would aim to reduce Earth’s temperature by continually spraying sulphate aerosols (e.g., sulphur dioxide) into the lower stratosphere to reflect a percentage of shortwave solar radiation back into space (Keith, 2013; National Research Council, 2015). At this critical time, when interest in solar geoengineering is growing, it is important to elevate the public debate regarding the risks of funding research to advance this approach to climate management.

We recognize that robust scientific inquiry is a vital aspect of democratic societies and that technological innovation has an important role to play in solving social and ecological problems. Yet, the social and political implications of solar geoengineering research and funding demand closer scrutiny. In our view, the current structures of solar geoengineering research serve to reinforce existing systems that concentrate wealth and power and perpetuate global inequities and injustices. As climate chaos increases around the world, clearly bold action is desperately needed. Momentum is rapidly building for transformative social change that addresses the root causes of climate change and related injustices by redistributing wealth and power through the transition away from fossil fuels towards a just, democratic, renewable-based society (Aronoff *et al.*, 2019; Burke & Stephens, 2018; Bozuwa, 2018; Claeys & Delgado Pugley, 2017; Mercado, 2019; Smith & Patterson, 2019). Advancing solar geoengineering as a

© The Author(s) 2020 Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike licence (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the same Creative Commons licence is included and the original work is properly cited. The written permission of Cambridge University Press must be obtained for commercial re-use.

'technological fix' that only addresses the symptoms of the climate crisis detracts from and reduces the transformative potential of these growing movements for climate justice. In this way, solar geoengineering research is not merely a form of scientific inquiry; rather, it is a political project rife with multiple power imbalances that produce 'hidden injustices' that have not yet been widely acknowledged.

To expose these hidden injustices, we first review the leading justifications and critiques of advancing solar geoengineering research, and then we address three simple questions: Who is conducting and funding solar geoengineering research? How do those advocating for solar geoengineering research think about social justice and social change? How is this technology likely to be deployed? Navigating these questions reveals that solar geoengineering research is being advocated for by a small group of primarily white men at elite institutions in the Global North, funded largely by billionaires or their philanthropic arms, who are increasingly adopting militarized approaches and logics. Solar geoengineering research advances an extreme, expert-elite technocratic intervention into the global climate system that would serve to further concentrate contemporary forms of political and economic power. For these reasons, we argue that it is unethical and unjust to advance solar geoengineering research.

## 2. Solar geoengineering justifications and critiques

The complex sensitivities of advancing solar geoengineering research, specifically SAI, are increasingly being recognized by those with divergent perspectives on this controversial approach to climate change. Several initiatives focused on the global governance challenges argue that SAI research should proceed cautiously, transparently and cooperatively, with governance mechanisms established prior to large-scale experimentation (Chhetri *et al.*, 2018). Leading scenarios suggest that SAI should not be utilized to offset all climatic warming, but rather to slow the rate of climate change or to reduce the total global temperature rise. For example, Keith and MacMartin (2015) argue that SAI deployment should be moderate (utilized to slow the rate of change), temporary (gradually reducing its impact as other climate mitigation strategies ramp up) and responsive (adjusted as new information becomes available). A more recent model projects that significant reductions in climate risks could be achieved even if SAI was only deployed with a goal of cutting in half the warming produced by a doubling of preindustrial CO<sub>2</sub> (Irvine *et al.*, 2019).

Assuming the 'limited deployment scenario' of halving the rate of warming, the first 15 years of full-scale deployment of a potential SAI programme are estimated to require 95 aircraft flying 41 flights per day (60,109 flights per year) from four 'bases' to deliver 1.5 million tons of sulphur to the lower stratosphere (Smith & Wagner, 2018, p. 5). The total cost for this programme is projected to be approximately US\$36 billion. Several other scenarios envision cooperative SAI deployment, with governments coordinating an intentional reduction in global mean temperature in order to reduce near-term climate risks while buying time for other mitigation approaches to scale up (Low, 2017; MacMartin *et al.*, 2018; Reynolds, 2019b). Given this potential for reducing climate impacts, leading advocates for geoengineering research have used a social justice lens to frame their justification, arguing that SAI deployment could provide a form of humanitarian relief for the most vulnerable people in the world, including the poor in the Global South (Horton & Keith, 2016).

Multiple risks of advancing SAI have been identified by scholars and activists (Frumhoff & Stephens, 2018). The potential for experimentation or deployment to create drastically uneven and unpredictable regional changes in climate, weather and biodiversity is a major concern (Proctor, 2018; Trisos, 2018). The risks associated with solar geoengineering enabling the expansion of fossil fuels represent another category of concern (Gunderson *et al.*, 2018; Hamilton, 2013; Malm, 2016). Solar geoengineering also portends a highly concentrated, technocratic approach to climate politics (Hulme, 2014; Szerszynski *et al.*, 2013; Wainwright & Mann, 2018) and sits on top of an extremely slippery slope (i.e., how can research be supported and advanced without legitimizing this technological approach and increasing the likelihood of it being deployed?) (Cairns, 2014; Frumhoff & Stephens, 2018). Many of those advocating for solar geoengineering research acknowledge these dangers (Horton *et al.*, 2018; Keith, 2013, 2017), but nevertheless believe the worsening climate crisis necessitates SAI research to potentially minimize the risks of worst-case climate scenarios. In addition to these critiques and concerns, expanding solar geoengineering research at this time has other dangers related to perpetuating injustices that have so far received minimal attention. That is, while there is a rich debate on geoengineering research ethics (see Flegal *et al.*, 2019, for an overview), much of this work is focused on designing future programmes rather than examining the power dynamics of current research. A future research programme will not emerge in a vacuum. The current power imbalances, sources of funding, and links to highly concentrated power that we identify are likely to shape the development of the technology and its governance.

## 3. Who is conducting and funding solar geoengineering research?

Solar geoengineering research is being conducted primarily by scientists in the Global North, although some research is occurring in other parts of the world (Biermann & Möller, 2019). The leading effort in terms of funding, scientific research, governance development and experimental preparation is Harvard's HSGRP. The expansive influence of the HSGRP represents the power imbalances in solar geoengineering research. The HSGRP is largely composed of white men at an elite institution advocating research into planetary-scale climate manipulation on behalf of the poor in the Global South (Horton & Keith, 2016). This well-meaning approach does not appear to recognize the structural power imbalances invoked in this stance or the colonial legacies of paternalistic, technocratic humanitarianism flowing from the Global North to the Global South (Escobar, 2011; McCarthy, 2009; Mitchell, 2002). Privileged scientists are justifying their research by making claims that they might be able to fix injustices for the global poor in a way that does nothing to address the root causes of either climate vulnerability or global inequality, amounting to a form of 'expert imperialism' (see Flegal & Gupta, 2018; Hourdequin, 2018; McLaren, 2018; Surprise, 2019).

That solar geoengineering has the potential to reduce climate vulnerability without addressing the structural injustices of global power and inequities makes it an attractive 'philanthropic' venture for billionaires and other wealthy elites concerned with climate change. Major funders of solar geoengineering research include, for example, Bill Gates, whose Fund for Innovative Climate and Energy Research (FICER) authorizes Harvard University Professor David Keith and Ken Caldeira (of the Carnegie Institution for Science) to distribute millions of dollars to solar

geoengineering researchers (FICER, 2019). In addition to Gates, Harvard's research programme is supported by an array of other technology billionaires, hedge fund managers and boutique foundations that serve as philanthropic arms of wealthy individuals (Surprise, 2019). For example, the Open Philanthropy Project, founded by Cari Tuna, billionaire Dustin Moskovitz (a co-founder of Facebook) and Holden Karnofsky (formerly of hedge fund Bridgewater Associates), is another major supporter of SAI research at Harvard and around the world. Although some of these billionaire philanthropists invest in a range of climate change initiatives, solar geoengineering plays a specific role in their climate investment portfolios. Given its capacity to slow the rate of change and reduce the urgency of decarbonization, SAI enables wealthy, corporate-connected philanthropists to support moderate climate policies rather than more transformative, systemic changes that would directly threaten their own concentrations of wealth and power.

In addition to the solar geoengineering research occurring in the USA and Europe, the Solar Radiation Management Governance Initiative (SRMGI) has launched the DECIMALS Project, a strategic initiative to provide funding to encourage geoengineering research at Global South institutions. Although this project diversifies and broadens who is involved in solar geoengineering research, it is funded by the same philanthropies that fund research in the Global North (e.g., Open Philanthropy Project, FICER and other billionaire-connected philanthropies such as Zennström and Carbon War Room; see Necheles *et al.*, 2018). Expanding the global distribution of SAI researchers does not address the structural power imbalances associated with who is advancing solar geoengineering research. In addition, it is well recognized that creating mechanisms for the inclusive 'participation' of Global South organizations in transnational policy networks has often been used as a vehicle to generate consent for policy prescriptions that flow from the Global North (Banerjee, 2003; Goldman, 2007; Peet, 2002; see Frumhoff & Stephens, 2018, on participation in geoengineering).

#### 4. Among those advocating for geoengineering research, how are they conceptualizing social justice and social change?

Given the power and influence of who is currently conducting and funding solar geoengineering research, it is important to consider how they are conceptualizing social justice and social change. What kinds of futures do these researchers envision in their models and scenarios? Solar geoengineering is often considered a mechanism to reduce climate vulnerabilities while 'buying time' for mitigation measures to scale up and energy transformations to occur (Surprise, 2018). If a potentially dangerous, planetary-scale intervention is being advocated to 'buy time' for other solutions, it is important to consider how solar geoengineering researchers envision current global injustices and future social change, including the potential for political and economic shifts. Although the research community is not uniform, few solar geoengineering researchers appear to be advocating strongly for urgent and transformative climate policy. Several influential researchers in the field have expressed alignment with moderate approaches centred on a mix of incremental market mechanisms, policy prescriptions and technological innovations (e.g., Horton *et al.*, 2016; Keith, 2013; Wagner & Weitzman, 2015). Moderation and incrementalism keep the core structures of political and economic power in place.

Indeed, solar geoengineering may appeal to many wealthy climate philanthropists explicitly because it offers an alternative to the growing recognition that responding to climate change will require transformative measures that directly challenge free-market capitalism (Foster *et al.*, 2011; Klein, 2014; Wainwright & Mann, 2018). The idea that confronting climate change demands a rapid, just and fundamental transformation away from our current fossil fuel-dominated capitalist political economies that are concentrating wealth and power seems to be untenable to many wealthy individuals, corporations and elite technocratic managers that profit from current systems that perpetuate inequities (Kenner, 2019; Lynch *et al.*, 2019). For those that feel threatened by the call for radical, social, political and economic change, technological solutions, market mechanisms and moderate policies are appealing, even though they are inadequate responses to the scale of the emergent climate crisis (Huber, 2019). By investing in extreme technical solutions to climate change, those advocating for solar geoengineering research are avoiding extreme (and necessary) social changes that are rapidly gaining political traction.

As to the 'humanitarian' social justice rationale, we have already questioned the ethical implications of a small group of privileged researchers from wealthy and powerful institutions propagating dangerous techno-fixes in the name of the global poor. Another problematic aspect of this relates to who gets to declare when the climate crisis is bad enough to justify SAI deployment. Climate change is already causing extreme suffering for millions of people around the world, but most solar geoengineering researchers are not yet advocating for deployment. Most solar geoengineering models do not anticipate deployment in the next decade, so those advocating for solar geoengineering research seem to be more concerned about future rather than current climate impacts and climate injustices. Emergencies are not merely objective circumstances – they are determined by political calculations and power dynamics (Agamben, 2005; Schmitt, 2005; Sillmann *et al.*, 2015). Who will decide when conditions are bad enough to declare a planetary-scale emergency justifying intervention in the climate system? It is unlikely to be poor countries, vulnerable populations or the hundreds of millions – if not billions – of people *already* living in 'emergency' conditions of poverty and climate vulnerability (Ehrenreich, 2019; Tahir, 2019). Solar geoengineering research diverts attention and funding away from immediate systemic changes that could meaningfully address current inequalities and injustices.

The primary political effect of advancing solar geoengineering research is, therefore, to blunt the urgent, transformative proposals emanating from the climate justice movement. In so doing, solar geoengineering research – independent of the desires of individual researchers – maintains contemporary systems of power, which we define as systems of colonial capitalism that thrive on fossil fuels and the perpetuation of inequality, exploitation and domination buttressed by patriarchal white supremacy (Faber *et al.*, 2017; Federici, 2004; Pulido, 2016; Watts, 2006; Whyte, 2016).

#### 5. How and by whom is solar geoengineering likely to be deployed?

An additional set of hidden injustices are revealed when we explore how and by whom solar geoengineering technology is likely to be deployed. These questions have been central to recent geoengineering social science research and governance debates, with a focus on the potential for inappropriate unilateral



deployment by a powerful state or group of states, a corporation or even a wealthy individual (Rabitz, 2016; Victor *et al.*, 2009). The scope of unilateral deployment has been narrowed in recent literature, with consensus emerging that only a few major nation-states are likely to have both the technological capacity and political legitimacy to deploy SAI (Parker & Irvine, 2018; Parker *et al.*, 2018; Rabitz, 2016; Smith & Wagner, 2018), and that, given this possibility, solar geoengineering deployment should ideally be coordinated through international institutions. Despite growing attention being given to governance challenges, the potential injustices associated with the likely *militarization* of solar geoengineering has received minimal consideration. For example, a recent authoritative survey of solar geoengineering governance provides minimal discussion of SAI and militaries, noting only that while military involvement should ideally be restricted, militaries have necessary technological and logistical expertise and so should not be shut out of research and development, and regardless, no practical mechanisms currently exist to prevent military involvement in research and potential deployment (Reynolds, 2019a, p. 207).

Concern about the militarization of solar geoengineering is based on three core points: first, military and security institutions have been involved in advancing solar geoengineering research in recent years, from the Central Intelligence Agency funding the first National Academies reports (Liebelson & Mooney, 2013) to the Defense Advanced Research Projects Agency funding SAI research at the Pacific Northwest National Laboratory (Kravitz *et al.*, 2017). Second, leading deployment scenarios explicitly integrate assumptions about militarization and rely on military discourse and the technological expertise of defence contractors. For example, Parker *et al.* (2018) explore the possibility of so-called ‘counter-geoengineering’ measures (i.e., deploying warming agents to counteract or neutralize an SAI programme) in the context of geopolitical brinkmanship and ‘grey-zone conflict’, and Smith and Wager (2018) consult with major aerospace and defence corporations to inform their cost–technology analysis. Third, the assumption that solar geoengineering cannot be tactically deployed or weaponized avoids the potentially *strategic* role that solar geoengineering could play in the interlinkages among geopolitics, energy and climate change. For example, the US military – the most powerful military force in the world – both runs on and plays a fundamental role in securing the fossil fuels that undergird US geopolitical power (Belcher *et al.*, 2019; Foster & Clark, 2018; Jones, 2012; Lehmann, 2019).

Yet, the US military also considers climate change a threat to national security and global stability (Hagel, 2014; Roberts, 2018). It is therefore entirely possible that the US security establishment could expand its involvement in solar geoengineering development in order to achieve the dichotomous strategic objectives of managing the threat of climate change while simultaneously furthering the expansion of fossil fuels – even if temporarily (Surprise, *forthcoming*). International governance would likely have few tools to prevent this scenario if the USA deemed it in its strategic interest (Chomsky, 2003; McCoy, 2017; Miéville, 2005). Given recent turns away from multilateral cooperation and the global rise of authoritarian leaders employing militarized violence to protect narrowly defined national interests while dismissing individual rights and social justice (Lutz, 2002; Robinson, 2018), the potential for militarized interventions into the climate system seems like too great a risk to continue advancing social geoengineering research.

## 6. Conclusion

Solar geoengineering is the ultimate ‘technological fix’ in that it aims to address the primary symptom of climate change (global warming) without addressing the root causes (Markusson *et al.*, 2017). The three questions we address here reveal dangerous, hidden injustices of advancing solar geoengineering research, where a few elite actors could gain the power to manipulate the Earth’s climate. The exacerbation of global injustices perpetuated by solar geoengineering research should not be tolerated by anyone who is committed to advancing social justice in the world today. We believe that supporting solar geoengineering research is dangerous and unethical, and we call on governments, philanthropists and scientists to speak up about the risks of supporting this research.

Paying attention to who is supporting solar geoengineering research and how they envision social justice and social change is critically important to informing the public discourse and societal debate about how best to invest in confronting climate injustices (Stephens, *forthcoming*). Advocates of solar geoengineering research seem to view the changing climate as a narrow, isolated, discrete problem. Rather than recognizing the social, economic and political complexities of how human systems interact with the climate, many scientists, engineers and others are engaging in a form of ‘climate isolationism’ (Stephens, *forthcoming*). Yet climate science and social science tell us that transformative *social* change is desperately needed in order to ensure a just and liveable planet. Transformation requires challenging, not reinforcing, current power structures that have made it all too easy for billionaires and technocratic elites to focus on altering the climate system rather than altering our social and economic systems. Investing in solar geoengineering research not only detracts from efforts to accelerate transformation, but also creates new pathways for the rich and powerful to have additional control as climate impacts worsen. We believe this to be unjust.

**Acknowledgements.** We thank many colleagues and our students who have engaged with us on these challenging issues. We also appreciate the feedback from Bert de Vries and several anonymous reviewers that strengthened this piece.

**Author contributions.** JCS and KS contributed equally to the design and writing of the paper.

**Financial support.** This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

**Conflicts of interest.** None.

**Ethical standards.** This research and article complies with *Global Sustainability’s* publishing ethics guidelines.

## Note

**i** This information comes from JCS’s personal communication with a member of the study committee and KS’s interview with an NAS officer.

## References

- Agamben, G. (2005). *State of Exception*. University of Chicago Press.
- Aronoff, K., Battistoni, A., Cohen, D. A. & Riofrancos, T. (2019). *A Planet to Win: Why We Need a Green New Deal*. Verso.
- Banerjee, S. B. (2003). Who sustains whose development? Sustainable development and the reinvention of nature. *Organization Studies*, 24(1), 143–180.
- Belcher, O., Bigger, P., Neimark, B. & Kennelly, C. (2019). Hidden carbon costs of the ‘everywhere war’: logistics, geopolitical ecology, and the carbon boot-print of the US military. *Transactions of the Institute of British Geographers*, 2019, 1–16.

- Biermann, F. & Möller, I. (2019). Rich man's solution? Climate engineering discourses and the marginalization of the Global South. *International Environmental Agreements: Politics, Law and Economics*, 19(2), 151–167.
- Bozuwa, J. (2018). Public Ownership for Energy Democracy. The Democracy Collaborative. Retrieved from <https://thenextsystem.org/learn/stories/public-ownership-energy-democracy>.
- Burke, M. J. & Stephens, J. C. (2018). Political power and renewable energy futures: a critical review. *Energy Research & Social Science*, 35, 78–93.
- Cairns, R. C. (2014). Climate geoengineering: issues of path-dependence and socio-technical lock-in. *Wiley Interdisciplinary Reviews: Climate Change*, 5(5), 649–661.
- Chemnick, J. (2019). U.S. Block U.N. Resolution on Geoengineering. Scientific American. Retrieved from <https://www.scientificamerican.com/article/u-s-blocks-u-n-resolution-on-geoengineering>.
- Chhetri, N., Chong, D., Conca, K., Falk, R., Gillespie, A., Gupta, A., ..., Nicholson, S. (2018). Governing Solar Radiation Management. *Forum for Climate Engineering Assessment: Report from the Academic Working Group on Climate Engineering Governance*. Forum for Climate Engineering Assessment, American University.
- Chomsky, N. (2003). *Hegemony or Survival?* Hamish Hamilton.
- Claeys, P. & Delgado Pugley, D. (2017). Peasant and indigenous transnational social movements engaging with climate justice. *Canadian Journal of Development Studies/Revue canadienne d'études du développement*, 38(3), 325–340.
- Ehrenreich, B. (2019). Climate change is here – and it looks like starvation. *The Nation*. Retrieved from <https://www.thenation.com/article/climate-change-media-humanitarian-crises>.
- Escobar, A. (2011). *Encountering Development: The Making and Unmaking of the Third World*. Princeton University Press.
- Faber, D., Stephens, J., Wallis, V., Gottlieb, R., Levenstein, C. & CoatarPeter, P. (2017). Trump's electoral triumph: class, race, gender, and the hegemony of the polluter–industrial complex. *Capitalism, Nature, Socialism*, 28(1), 1–15.
- Federici, S. (2004). *Caliban and the Witch*. Autonomedia.
- FICER (2019). Fund for Innovative Climate and Energy Research. The Keith Group. Retrieved from <https://keith.seas.harvard.edu/FICER>.
- Flegal, J. A. & Gupta, A. (2018). Evoking equity as a rationale for solar geoengineering research? Scrutinizing emerging expert visions of equity. *International Environmental Agreements: Politics, Law and Economics*, 18(1), 45–61.
- Flegal, J. A., Hubert, A. M., Morrow, D. R. & Moreno-Cruz, J. B. (2019). Solar geoengineering: social science, legal, ethical, and economic frameworks. *Annual Review of Environment and Resources*, 44, 399–423.
- Foster, J. B. & Clark, B. (2018). The expropriation of nature. *Monthly Review*, 69(10), 1–27.
- Foster, J. B., Clark, B. & York, R. (2011). *The Ecological Rift: Capitalism's War on the Earth*. New York University Press.
- Frumhoff, P. C. & Stephens, J. C. (2018). Towards legitimacy of the solar geoengineering research enterprise. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2119), 20160459.
- Goldman, M. (2007). How 'Water for All!' policy became hegemonic: the power of the World Bank and its transnational policy networks. *Geoforum*, 38(5), 786–800.
- Gunderson, R., Stuart, D. & Petersen, B. (2019). The political economy of geoengineering as plan B: technological rationality, moral hazard, and new technology. *New Political Economy*, 24(5), 696–715.
- Hagel, C. (2014). *Quadrennial Defense Review*. Department of Defense.
- Hamilton, C. (2013). *Earthmasters: The Dawn of the Age of Climate Engineering*. Yale University Press.
- Horton, J. & Keith, D. (2016). Solar geoengineering and obligations to the global poor. In C. J. Preston (ed.), *Climate Justice and Geoengineering: Ethics and Policy in the Atmospheric Anthropocene* (pp. 79–92). Rowman & Littlefield International.
- Horton, J. B., Keith, D. W. & Honegger, M. (2016). Implications of the Paris Agreement for carbon dioxide removal and solar geoengineering. Harvard Project on Climate Agreements. Retrieved from [https://keith.seas.harvard.edu/files/tkg/files/horton\\_et\\_al\\_-\\_2016\\_-\\_implications\\_of\\_the\\_paris\\_agreement\\_for\\_carbon\\_dio.pdf](https://keith.seas.harvard.edu/files/tkg/files/horton_et_al_-_2016_-_implications_of_the_paris_agreement_for_carbon_dio.pdf).
- Horton, J. B., Reynolds, J. L., Buck, H. J., Callies, D., Schäfer, S., Keith, D. W. & Rayner, S. (2018). Solar geoengineering and democracy. *Global Environmental Politics*, 18(3), 5–24.
- Hourdequin, M. (2018). Climate change, climate engineering, and the 'global poor': what does justice require? *Ethics, Policy & Environment*, 21(3), 270–288.
- Huber, M. (2019). Ecological politics for the working class. *Catalyst*, (3)1, n.p.
- Hulme, M. (2014). *Can Science Fix Climate Change? A Case against Climate Engineering*. John Wiley & Sons.
- Irvine, P., Emanuel, K., He, J., Horowitz, L. W., Vecchi, G. & Keith, D. (2019). Halving warming with idealized solar geoengineering moderates key climate hazards. *Nature Climate Change*, 9(4), 295–299.
- Jones, T. C. (2012). America, oil, and war in the Middle East. *Journal of American History*, 99(1), 208–218.
- Keith, D. (2013). *A Case for Climate Engineering*. MIT Press.
- Keith, D. (2017). Toward a responsible solar geoengineering research program. *Issues in Science and Technology*, 33(3), n.p.
- Keith, D. W. & MacMartin, D. G. (2015). A temporary, moderate and responsive scenario for solar geoengineering. *Nature Climate Change*, 5(3), 201.
- Kenner, D. (2019). *Carbon Inequality: The Role of the Richest in Climate Change*. Routledge.
- Klein, N. (2014). *This Changes Everything: Capitalism vs. the Climate*. Simon & Schuster.
- Kravitz, B., MacMartin, D. G., Mills, M. J., Richter, J. H., Tilmes, S., Lamarque, J. F., ..., Vitt, F. (2017). First simulations of designing stratospheric sulfate aerosol geoengineering to meet multiple simultaneous climate objectives. *Journal of Geophysical Research: Atmospheres*, 122(23), 12616–12634.
- Lehmann, T. C. (2019). Honourable spoils? The Iraq War and the American hegemonic system's eternal and perpetual interest in oil. *The Extractive Industries and Society*, 6(2), 428–442.
- Liebelson, B. & Mooney, C. (2013). Climate Intelligence Agency: The CIA is now funding research into manipulating the climate. *Slate*. Retrieved from <https://slate.com/technology/2013/07/cia-funds-nas-study-into-geoengineering-and-climate-change.html>.
- Low, S. (2017). Engineering imaginaries: anticipatory foresight for solar radiation management governance. *Science of the Total Environment*, 580, 90–104.
- Lutz, C. (2002). Making war at home in the United States: militarization and the current crisis. *American Anthropologist*, 104(3), 723–735.
- Lynch, M. J., Long, M. A., Stretesky, P. B. & Barrett, K. L. (2019). Measuring the ecological impact of the wealthy: excessive consumption, ecological disorganization, green crime, and justice. *Social Currents*, 6(4), 377–395.
- MacMartin, D. G., Ricke, K. L. & Keith, D. W. (2018). Solar geoengineering as part of an overall strategy for meeting the 1.5°C Paris target. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2119), 20160454.
- Malm, A. (2016). *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming*. Verso.
- Markusson, N., Dahl Gjefson, M., Stephens, J. C. & Tyfield, D. (2017). The political economy of technical fixes: the (mis)alignment of clean fossil and political regimes. *Energy Research & Social Science* 23, 1–10.
- McCarthy, T. (2009). *Race, Empire, and the Idea of Human Development*. Cambridge University Press.
- McCoy, A. W. (2017). *In the Shadows of the American Century: The Rise and Decline of US Global Power*. Haymarket Books.
- McLaren, D. P. (2018). Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling. *Energy Research & Social Science*, 44, 209–221.
- Mercado, A. (2019). The youth climate movement is just getting started. *The Nation*. Retrieved from <https://www.thenation.com/article/the-youth-climate-movement-is-just-getting-started-global-warming-fridays-for-future>.
- Miéville, C. (2005). *Between Equal Rights: A Marxist Theory of International Law*. Haymarket Books.
- Mitchell, T. (2002). *Rule of Experts: Egypt, Techno-Politics, Modernity*. University of California Press.
- Morton, O. (2016). *The Planet Remade: How Geoengineering Could Change the World*. Princeton University Press.
- National Research Council (2015). *Climate Intervention: Reflecting Sunlight to Cool Earth*. The National Academies Press.

- Necheles, E., Burns, L., Chang, A. & Keith, D. (2018). Funding for Solar Geoengineering from 2008 to 2018. *Harvard Solar Geoengineering Research Program Blog*. Retrieved from <https://geoengineering.environment.harvard.edu/blog/funding-solar-geoengineering>.
- Parker, A. & Irvine, P. J. (2018). The risk of termination shock from solar geoengineering. *Earth's Future*, 6(3), 456–467.
- Parker, A., Horton, J. B. & Keith, D. W. (2018). Stopping solar geoengineering through technical means: a preliminary assessment of counter-geoengineering. *Earth's Future*, 6(8), 1058–1065.
- Peet, R. (2002). Ideology, discourse, and the geography of hegemony: from socialist to neoliberal development in postapartheid South Africa. *Antipode*, 34(1), 54–84.
- Proctor, J., Hsiang, S., Burney, J., Burke, M. & Schlenker, W. (2018). Estimating global agricultural effects of geoengineering using volcanic eruptions. *Nature*, 560(7719), 480.
- Pulido, L. (2016). Flint, environmental racism, and racial capitalism. *Capitalism Nature Socialism*, 27(3), 1–16.
- Rabitz, F. (2016). Going rogue? Scenarios for unilateral geoengineering. *Futures*, 84, 98–107.
- Reynolds, J. L. (2019a). *The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene*. Cambridge University Press.
- Reynolds, J. L. (2019b). Solar geoengineering to reduce climate change: a review of governance proposals. *Proceedings of the Royal Society A*, 475 (2229), 20190255.
- Roberts, D. (2018). The trouble with Trump leaving climate change to the military. *Vox*. Retrieved from <https://www.vox.com/energy-and-environment/2018/1/23/16918280/trump-military-climate-change>.
- Robinson, W. I. (2018). Accumulation crisis and global police state. *Critical Sociology*, 45(6), 845–856.
- Schmitt, C. (2005). *Political Theory: Four Chapters on the Concept of Sovereignty*. University of Chicago Press.
- Shepherd, J. G. (2009). *Geoengineering the Climate: Science, Governance and Uncertainty*. Royal Society.
- Showstack, R. (2019). Study will examine risks and benefits of climate interventions. *Earth and Space Science News*. Retrieved from <https://eos.org/articles/study-will-examine-risks-and-benefits-of-climate-interventions>.
- Sillmann, J., Lenton, T. M., Levermann, A., Ott, K., Hulme, M., Benduhn, F. & Horton, J. B. (2015). Climate emergencies do not justify engineering the climate. *Nature Climate Change*, 5(4), 290.
- Smith, J. & Patterson, J. (2019). Global climate justice activism: 'the new protagonists' and their projects for a just transition. In R. Frey, P. K. Gellert & F. H. Dhams (eds), *Ecologically Unequal Exchange: Environmental Injustice in Comparative and Historical Perspective* (pp. 245–272). Palgrave Macmillan.
- Smith, W. & Wagner, G. (2018). Stratospheric aerosol injection tactics and costs in the first 15 years of deployment. *Environmental Research Letters*, 13(12), 124001.
- Stephens, J. C. (forthcoming). *Diversifying Power: Why We Need Antiracist, Feminist Leadership on Climate and Energy*. Island Press.
- Surprise, K. (2018). Preempting the second contradiction: solar geoengineering as spatiotemporal fix. *Annals of the American Association of Geographers*, 108(5), 1228–1244.
- Surprise, K. (2019). Stratospheric imperialism: liberalism, (eco)modernization, and ideologies of solar geoengineering research. *Environment and Planning E: Nature and Space*. Epub ahead of print. DOI: 10.1177/2514848619844771.
- Surprise, K. (forthcoming). Gramsci in the stratosphere: solar geoengineering and capitalist hegemony. In H. Buck, J. P. Sapinski & A. Malm (eds), *Has It Come to This? The Pitfalls and Promises of Geoengineering on the Brink*. Rutgers University Press, in press.
- Szerszynski, B., Kearnes, M., Macnaghten, P., Owen, R. & Stilgoe, J. (2013). Why solar radiation management geoengineering and democracy won't mix. *Environment and Planning A*, 45(12), 2809–2816.
- Tahir, M. (2019). In Somalia, the climate emergency is already here. The world cannot ignore it. *The Guardian*. Retrieved from <https://www.theguardian.com/commentisfree/2019/jul/08/somalia-climate-emergency-world-drought-somalis>.
- Tollefson, J. (2019). Harvard creates advisory panel to oversee solar geoengineering project. *Nature*. Retrieved from <https://www.nature.com/articles/d41586-019-02331-y>.
- Trisos, C. H., Amatulli, G., Gurevitch, J., Robock, A., Xia, L. & Zambri, B. (2018). Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination. *Nature Ecology & Evolution*, 2 (3), 475.
- Victor, D. G., Morgan, M. G., Apt, F. & Steinbruner, J. (2009). The geoengineering option: a last resort against global warming. *Foreign Affairs*, 88, 64.
- Wagner, G. & Weitzman, M. L. (2015). *Climate Shock: The Economic Consequences of a Hotter Planet*. Princeton University Press.
- Wainwright, J. & Mann, G. (2018). *Climate Leviathan: A Political Theory of Our Planetary Future*. Verso.
- Watts, J. (2018). Geoengineering may be used to combat global warming, experts say. *The Guardian*. Retrieved from <https://www.theguardian.com/environment/2018/oct/08/geoengineering-global-warming-ipcc>.
- Watts, M. J. (2006). Empire of oil: capitalist dispossession and the scramble for Africa. *Monthly Review*, 58(4), 1.
- Whyte, K. P. (2016). Is it colonial déjà vu? Indigenous peoples and climate injustice. In J. Adamson & M. Davis (eds), *Humanities for the Environment: Integrating Knowledge, Forging New Constellations of Practice* (pp. 102–119). Routledge.