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Licence to chill: Building a legitimate authorisation process for commercial SRM operations

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Abstract
Solar Radiation Management (SRM) has been suggested as a technique to counteract some of the changes expected as a result of Anthropogenic Global Warming (AGW).[1] It has been suggested[2] that SRM could be carried out by commercially motivated actors. This process has been envisaged as using the Voluntary Carbon Offset (VCO) market as a mechanism for monetising the SRM process, due to the secondary effects of SRM on the carbon cycle.[3] Current VCO customers are typically businesses: those looking to be 'carbon neutral' or reselling offsets alongside high-carbon goods and services (for example, airlines). Other potential VCO customers include states, or philanthropists. In this short scoping paper we provide a broad overview the issues of regulation and legitimacy, as may be applicable to the activities of future commercial SRM actors. We discuss the need for a two-pronged regulatory approach, encompassing first legal and corporate regulation and second, scientific and technical regulation. In conclusion, we identify differing regulatory requirements, according to whether the intended effect on the climate system of the SRM industry, or of individual firms, can be regarded as *de minimis*. We additionally suggest the use of a two-tier marketplace structure in order to ensure regulatory demands can be efficiently and transparently enacted.

Keywords
Geoengineering, Solar Radiation Management, voluntary carbon offsets, voluntary carbon market, carbon credits

1. National Academy of Sciences, *Climate Intervention: Reflecting Sunlight to Cool Earth*, (National Academies Press: Washington, DC 2001, 2015); J. G. Shepherd *et al*., *Geoengineering the Climate: Science, Governance and Uncertainty* (Royal Society: London 2009).
2. J. Sargoni and A. Lockley 'Solar Radiation Management and the Voluntary Carbon Market' *Environmental Law Review*, 1–4, doi: 10.1177/1461452915611277.
3. A forthcoming research paper on solar radiation management and carbon concentrations is anticipated from C. L. Zabel and D. W. Keith based on a poster presented at the Climate Engineering Research Symposium 2015, organised by GEOMAR Helmholtz Centre for Ocean Research Kiel, 7–10 July, Berlin.

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Introduction

Climate change[4] has been identified as one of the major political issues of the century. Major economic expenditure is required to address this problem.[5] Considerable political effort has been expended to reach the necessary agreements[6] to constrain rises in temperature.

Carbon Credits is a technique used in a variety of ways to tackle climate change. These fall into two broad categories – those mandated by statute (for example, the EU Emissions Trading Scheme (ETS)),[7] and those used by private companies or individuals to voluntarily offset their emissions, known as Voluntary Carbon offsets (VCO).[8] Unless otherwise specified, we refer in this paper only to the VCO market.

SRM is a speculative technology, which involves the artificial management of aerosols in the atmosphere to brighten the Earth – thus reflecting sunlight, and cooling the planet.[9] SRM has been discussed with a view to its use to complement mitigation,[10] buying time to enable the infrastructure and societal changes necessary for mitigation to occur. Furthermore, SRM can be used to deal (to an extent[11]) with the consequences of historic emissions, which linger in the atmosphere for millennia.[12] The use of SRM has been considered by a variety of scientists, social scientists, policy makers and writers from across the political spectrum.[13] These authors have differing views as to its legitimacy, purpose and function.[14,15]

SRM technologies may be deployed by commercial firms in the future. Two models for this deployment of SRM currently exist – depending on whether states or private actors are the customers. For clarity, we do not include discussion of the state as a supplier (of SRM operational deployments or of VCO brokerage) at any point in this paper. Nevertheless, states may be commercially involved in the SRM process: either centrally (for example, by licensing Intellectual Property (IP)); or peripherally (for example, by leasing land).

In the state-commissioned case, the result would be the outsourcing of a state function, in a similar manner to the operation of railways or the construction of hospitals. We do not focus on this scenario, but note that much of our analysis is applicable to the use by states of private contractors for SRM deployment.

4. IPCC 'Summary for Policymakers'. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds)] (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: Cambridge/New York, 2013).
5. N. Stern 'Executive Summary' in *Stern Review on the Economics of Climate Change* (pre-publication edition) (London: HM Treasury, 2006). Archived from the original on 31 January 2010.
6. For example, Report of the Conference of the Parties on its twentieth session, held in Lima from 1 to 14 December 2014, United Nations, FCCC/CP/2014/10. Available at: http://unfccc.int/resource/docs/2014/cop20/eng/10.pdf.
7. 'The EU Emissions Trading System (EU ETS)', European Commission website, http://ec.europa.eu/clima/policies/ets/index_en.htm, extracted 25/10/15.
8. As discussed by S. Tilmes *et al*. (2013) 'The Hydrological Impact of Geoengineering in the Geoengineering Model Intercomparison Project' (GeoMIP) 118(19) *Journal of Geophysical Research: Atmospheres* 11,036–11,058.
9. J.G. Shepherd *et al*., Geoengineering the Climate: Science, Governance and Uncertainty, (Royal Society: London 2009).
10. T.M.L. Wigley 'A Combined Mitigation/Geoengineering Approach to Climate Stabilization' (2006) *Science* **314** (5798): 452–454. Bibcode: 2006Sci...314.452 W.doi:10.1126/science.1131728. ISSN 0036-8075. PMID 16973840.
11. See Tilmes *et al*. above n. 8.
12. M. Inman 'Carbon is Forever' (2008) 812 *Nature Reports Climate Change* 156. doi:10.1038/climate.2008.122.
13. L. Lane and J. E. Bickel 'Solar Radiation Management: An Evolving Climate Policy Option', Hudson Institute, University of Texas at Austin, May 2013, American Enterprise Institute.
14. D. W. Keith and D. G. MacMartin, 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering' (2015) 5 *Nature Climate Change* 201–206, doi:10.1038/nclimate2493.
15. S. Smith and P. Rasch, P. (2012) 'The Long-term Policy Context for Solar Radiation Management' 121(3) *Climatic Change* 487–497.

Nevertheless, the alternative case of privately commissioned SRM throws up many new regulatory challenges.

In privately commissioned SRM, the use of the VCO market has previously been considered as the economic conduit for SRM activity to take place,[16] based on the understanding that SRM is expected to have an indirect, quantifiable effect on the carbon cycle.[17] However, it is also possible that direct commission of SRM services may happen without recourse to the VCO market. In the event that this commission comes from a single individual benefactor, this would constitute a so-called 'Greenfinger'[18] scenario (a portmanteau, based on the James Bond character 'Goldfinger'[19]). A crowd-funded or consortium approach may be used by private actors, for the commission of SRM work without the use of VCOs. However, we focus in this paper on the use of VCOs, as this allows a near-term monetisation of SRM activity, without the creation of novel forms of market demand.

There are major potential regulatory challenges for the private commission of SRM whether the commission is by the use of VCOs, or otherwise. Conventional economic activity may alter the environment as an economic externality. By contrast, the use of commercial SRM is expressly designed to effect environmental change. Society has developed some degree of tolerance for various externalities across a range of economic activity in the industrialised world.[20] However, there are few analogues for SRM, in that environmental change is not usually the primary goal of an economic activity. This potentially emergent phenomenon therefore poses significant challenges for regulators and legislators. In this paper, we discuss the regulatory issues, and tentatively suggest a framework for a potentially legitimate regulatory function. If successfully enacted, this would give operators a 'licence to chill' – and to sell the resulting VCOs.

In this context, we consider geoengineering to have a set of attributes that is potentially unique: it is at once a global 'public good'[21,22] (which are typically under-provided by markets); it also has significant potential externalities[23] (an indication of likely overprovision by markets). One approach to the management of externalities is the use of regulation.[24,25,26] We therefore discuss a normative approach to the regulation of SRM. This is a new direction in a young field. Accordingly, our suggested regulatory structures are somewhat speculative. Further, we seek to provide a brief and broad analysis of the potential issues and opportunities, rather than detailing precisely any component of a fully worked-up regulatory model.

Regulation is common in industries that are natural monopolies, not least for the exercise of price control. Instead, we suggest a similar need for regulation based on a public interest theory[27] approach.

16. J. Sargoni and A. Lockley, 'Solar Radiation Management and the Voluntary Carbon Market', *Environmental Law Review*, 1–4, doi: 10.1177/1461452915611277.
17. See above n. 14.
18. G. Wood, 'Re-Engineering the Earth', *The Atlantic*, July/August 2009. Available at: www.theatlantic.com/magazine/archive/2009/07/re-engineering-the-earth/307552/.
19. I. Fleming *Goldfinger* (New York: Macmillan 1959).
20. T. Aidt 'Political Internalization of Economic Externalities and Environmental Policy' (1998) 69(1) *Journal of Public Economics* 1–16.
21. I. Kaul, I. Grunberg and M. Stern *Global Public Goods*. (New York: Oxford University Press, 1999).
22. T. Bergstrom, L. Blume and H. Varian 'On the Private Provision of Public Goods' (1986) 29(1) *Journal of Public Economics* 25–49.
23. P. Macnaghten and B. Szerszynski 'Living the Global Social Experiment: An Analysis of Public Discourse on Solar Radiation Management and its Implications for Governance' (2013) 23(2) *Global Environmental Change* 465–474.
24. R. A. Posner 'Theories of Regulation' (1974) 25(1) *Bell Journal of Economics and Management Science*, Spring, 335–373.
25. J. G Stigler 'The Theory of Economic Regulation' (1971) 2(1) *Bell Journal of Management Science*, Spring, 3–21.
26. S. Peltzman 'The Economic Theory of Regulation after a Decade of Deregulation' (1989) Brookings Papers on Economic Activity: Microeconomics, pp. 1–41.
27. G. Tullock 'A (Partial) Rehabilitation of the Public Interest Theory' (1984) 42(1) *Public Choice* 89–99.

There is no overwhelming evidence that a commercial SRM market would tend towards a natural monopoly; this is, therefore, not the only basis for our suggestion of a regulatory approach. We discuss other, potentially unique risks of SRM including those of an emergent monopoly (and some oligopoly situations) in this market, which would appear to suggest a normative economic case exists for an industry regulator to assume preemptive potent regulatory powers. Nevertheless, the primary economic function of a regulator is usually to prevent profiteering in markets where a natural monopoly exists (for example, railways) or to protect the interests of a cartel-like supplier group in otherwise competitive markets (for example, taxis).[28] While such risks are not shown to be absent in the case of SRM, we focus instead on the non-price aspects of regulation, due to the nature of geoengineering as a public good, and the risk of externalities, as discussed earlier. The dependence of the global economy on the climate system means that the total value of the SRM industry is likely to be dwarfed by its economic impact on the wider economy. As such, it represents an extreme case of the applicability of public-interest-theory regulation over private-interest-theory regulation. [29] A process of regulatory capture (private interest) by a narrow group of consumers or producers is unlikely; too much is at stake. The pressure from the global public or general interest groups is likely to mean that narrow interest groups will be unable to exert meaningful influence against the public interest. Accordingly, we do not consider private interest theory extensively in our discussions; instead, we present a normative regulatory framework.

We note the history of the intersection between geoengineering and the carbon offset market. Firms such as Planktos and Climos[30] have already attempted to privately monetise geoengineering using this approach. However, their offer was fundamentally different, in that the methodology used was the direct drawdown of CO_2 from the atmosphere, by means of Ocean Iron Fertilization (OIF). The carbon credits so generated would not have relied on SRM in any way. However, later research suggests that OIF may indeed have an SRM effect[31] – thus OIF may be one of the techniques that future SRM carbon credit schemes use – regardless of its potential direct effect.

One of the risks of SRM is the potential for 'termination shock' if the deployment suddenly ceases,[32] due to the short lifetime of SRM aerosols in the atmosphere. Sudden termination of SRM is particularly dangerous, as the rate of change of climate is itself a risk factor for the biosphere.[33] Accordingly, any regulatory process for commercial SRM must ensure that any exit from a programme is orderly, and does not expose the climate system to undue pressure.

SRM cannot be considered to be a simple scalar quantity, with one unit being equivalent to another. First, various types of SRM exist: Stratospheric Aerosol Injection (SAI); Marine Cloud Brightening (MCB);[34] and cirrus stripping[35] (the latter is less well-studied). SAI acts longer than MCB (approximately two years

28. D. Flath 'Taxicab Regulation in Japan' (2006) 20(2) *Journal of the Japanese and International Economies* 288–304.
29. B. Shaffer 'Firm-level Responses to Government Regulation: Theoretical and Research Approaches' (1995) 21(3) *Journal of Management* 495–514.
30. 'Planktos, meet Climos. It just got $3.5 million' *SiliconBeat* Available at: www.siliconbeat.com/2008/03/05/planktos-meet-climos-it-just-got-35-million (last accessed 5 March 2008).
31. B. Grandey, C. Wang 'Enhanced Marine Sulphur Emissions Offset Global Warming and Impact Rainfall' (2015) *Scientific Reports* 5, doi:10.1038/srep13055.
32. K. E. McCusker *et al*. 'Rapid and Extensive Warming Following Cessation of Solar Radiation Management' (2014) 9(2) *Environmental Research Letters* 1–9, doi:10.1088/1748-9326/9/2/024005.
33. D. MacMartin, K. Caldeira and D. Keith 'Solar Geoengineering to Limit the Rate of Temperature Change' (2014) 372(2031) *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 134.
34. J. Latham 'Amelioration of Global Warming by Controlled Enhancement of the Albedo and Longevity of Low-level Maritime Clouds' (2002) 3 *Atmospheric Science Letters* 52–58. doi:10.1006/asle.2002.0099.
35. D.L Mitchell, W. Finnegan 'Modification of Cirrus Clouds to Reduce Global Warming'. (2009) 4(4) *Environmental Research Letters* 045102. doi:10.1088/1748-9326/4/4/045102.

versus a few days). SAI effects are also more spatially distributed than those of MCB – SAI deployments tend to spread rapidly on zonal winds,[36] being carried more slowly poleward by the Brewer-Dobson circulation.[37] SAI is, however, generally restricted to the meridional hemisphere in which injection occurs,[38] with any imbalance of injection resulting in significant disruption to the Inter-Tropical Convergence Zone (ITCZ) – and thus to the climate of equatorial regions, notably the Sahel. By contrast, MCB and cirrus stripping are much more local in their climate impact, although their ability to affect teleconnections in the climate system means that they cannot be considered to have a geographically isolated effect.[39] Additionally, SAI and MCB have potentially different effects on precipitation, although the degree of difference depends on the precise injection regime.[40]

Despite the relatively novel challenges of regulating a deliberate intervention in the climate system, there are, nonetheless, analogous processes in existing corporate activity. A range of activities are carried out by private actors that have potential impacts of global significance. For example, the operation of nuclear power stations is conducted by private corporations in many nations,[41,42] despite the associated transboundary risks. It is notable, however, that the risks from nuclear accidents are well-constrained in nature, albeit not in magnitude. Other analogues exist, not just in terms of potential externalities resulting from a technical failure, but where the privatised process is critical for society.[43] The internet, power grids, railways, traffic signals and food distribution are all examples of critical processes; all are frequently carried out (in whole or part) by private firms under varying degrees of state regulation and oversight. Commercial SRM would not, therefore, be without precedent in all aspects of its operations.

When considering the regulation of SRM, it is important to consider the proposed magnitude of the intervention. The global climate is mainly influenced not by individual large processes (such as volcanoes) but by the aggregation of billions of tiny processes (such as trees growing, or car engines running). Individually, these small actions are small in their influence – having essentially no effect. In aggregate, however, they drive the climate system. The action of taking one car off the road, or offsetting its emissions, is a *de minimis* action. It may be significant from a position of personal economics or morality, but it is individually irrelevant to the climate system. Likewise, SRM programmes fall into two broad categories: those that are capable of individually exerting a significant effect on the climate system, and those that are individually insignificant. This latter category would grow through two distinct stages. At first, even the aggregate influence of small SRM interventions would be climatically insignificant. Later, small individual interventions may add up to a significant whole – even if no single intervention ever became large enough to have a global effect. It is reasonable to assume that different regulatory and management considerations should apply to each of these differing circumstances.

36. C. Brühl, J. Lelieveld, H. Tost, M. Höpfner, and N. Glatthor 'Stratospheric Sulfur and its Implications for Radiative Forcing Simulated by the Chemistry Climate Model EMAC' (2015) 120(5) *Journal of Geophysical Research: Atmospheres* 2103–2118.
37. D. Keith 'Photophoretic Levitation of Engineered Aerosols for Geoengineering' (2010) 107(38) *Proceedings of the National Academy of Sciences* 16428–16431.
38. J. Haywood, A. Jones, N. Bellouin and D. Stephenson 'Asymmetric Forcing from Stratospheric Aerosols Impacts Sahelian Rainfall' (2013) 3(7) *Nature Climate Change* 660–665.
39. S. Hilland and Y. Ming 'Nonlinear Climate Response to Regional Brightening of Tropical Marine Stratocumulus' (2012) 39(15) *Geophysical Research Letters*.
40. A. Jones, J. Haywood and O. Boucher 'A Comparison of the Climate Impacts of Geoengineering by Stratospheric SO2 Injection and by Brightening of Marine Stratocumulus Cloud' (2010) 12(2) *Atmospheric Science Letters* 176–183.
41. Nuclearbanks.org, (2015). *Nuclear banks? No thanks!* Available at: www.nuclearbanks.org/#/nuclear%20companies (last accessed 31 October 2015).
42. Wikipedia, (2015). *List of companies in the nuclear sector*. Available at: https://en.wikipedia.org/wiki/List_of_companies_in_the_nuclear_sector (last accessed 31 October 2015).
43. D. Grimsey and M. Lewis *Public Private Partnerships* (Cheltenham: Edward Elgar, 2004).

In this paper, we discuss examples of the regulatory challenges specific to the deployment of SRM by private actors. In doing so, we seek to isolate the relevant issues which merit the attention of policymakers, and of any future corporate actors. Further, we discuss a range of market structures (primarily differentiated by scale), which may characterise the private deployment of SRM. We then consider how these differences may influence the selection of most appropriate regulatory regime.

More general issues may also have to be addressed at an early stage in possible SRM deployment – whether or not this deployment is by private firms. An example of such issues is a consideration of 'slippery slope'[44] arguments (also known as 'path-dependency'). For clarity, a 'slippery-slope' argument postulates that one (possibly benign) step in a process may inevitably lead to another (possibly harmful) step. For example, it could be argued that nuclear power is on the slippery slope to the development of nuclear weapons. Resolving such arguments would not normally be regarded as a regulatory activity, as they are 'in principle' considerations of the merits of SRM – not matters of degree or of operational detail. Despite the need for these matters to be addressed generally, we do not discuss these arguments here, and we do not regard our proposed regulatory process as being appropriate for their consideration. In general, we do not consider any 'in principle' argument to be the proper concern of our proposed regulatory bodies – just as a press complaints regulator would not be expected to rule on whether or not newspapers should exist.

Discussion

The regulation process would need to be essentially two-pronged in nature. These two approaches would be expected to be intertwined, to an extent. They are separated here largely to aid discussion, rather than as a description of an inflexible proposed structure. One branch would consist of a legal and corporate regulatory process to address issues of propriety, transparency, resilience, and accountability, plus the separate issue of addressing incidental harms. The other would be a scientific process, to ensure that the specific injection regime proposed was both validly conceived and properly conducted. For clarity, we do not use 'legal' in this context to suggest that only one of the branches would be legally convened or that only one would have the force of law behind it. It is simply that the two branches address two, largely separate, aspects of the regulatory process, and are named accordingly.

Legal, economic and corporate oversight

Functions and phasing

The discussion of legal, market and corporate oversight of VCO SRM operations falls into three broad-brush regulatory functions, which we address in chronological order as they emerge. These correspond with distinct phases in the growth of the market; any successful regulator would need to be developed in lockstep with this scaling.

First, even at *de minimis* deployment scales, there is a need to give confidence to the purchaser. SRM VCO products should be legitimate – something which has frequently been the subject of controversy in the past for non-SRM VCOs.[45] It is potentially possible that a *laissez-faire* approach could work, with market providers willingly self-regulating, to increase demand for their products. However, to implement such an approach may risk extending the controversies and failures of the VCO market to date.

44. S. Schäfer 'The Slippery Slope(s) in Geoengineering Research', Geoengineering, Lock-in and Path Dependence Workshop, Institute for Advanced Sustainability Studies e.V.. Available at: http://geoengineering-governance-research.org/perch/resources/stefan-schferthe-slippery-slopes-in-climate-engineering.pdf (last accessed 1 November 2015).
45. FCA *Carbon Credit Trading – Financial Conduct Authority* (2015). Available at: www.fca.org.uk/consumers/scams/investment-scams/carbon-credit-trading (last accessed 31 October 2015).

Second, there is a potential need for overarching regulation of SRM operations as a whole. This is broadly equivalent to the concept of market regulation, where a regulator seeks to ensure the market as a whole is operating effectively, rather than focusing on individual firms. This becomes important relatively early on in the development of commercial SRM, as the market activity may rapidly cross the *de minimis* threshold of environmental impact. At this stage, the prevailing concerns are those such as stability of provision of SRM services. Furthermore, industry-wide operational concerns become significant (for example, the supply of trained personnel).

Third, regulation of individual firms becomes important as these firms individually cross the *de minimis* threshold, becoming 'too big to fail'. At this point, regulatory priorities require an additional focus on the suitability and viability of individual firms, as well as confidence in the robustness of their operations. An alternative approach would be to set in place rules which prevent this 'too big to fail' situation from arising in the first place. This stage of regulatory activity differs fundamentally from the goals of conventional environmental regulation (a discipline conventionally concerned with externalities, not continuity). By comparison, it is not usually the case that an interruption to operations of another regulated business (for example, landfill sites, power stations, or railway lines) would cause a major environmental crisis. As such, this phase of regulation would focus on novel environmental risks related to business continuity and resilience.

Convention of oversight body

There are many possible structures for an oversight body. It may be convened by statute under international law (for example, the International Maritime Organisation (IMO)).[46] Alternatively, a single-country body could be used. The Internet Corporation for Assigned Names and Numbers[47] (ICANN) offers an appropriate comparator for international regulation, conducted (formerly) by a single state. An additional consideration is the membership of the body. A representative model may be used, such as the International Whaling Commission[48] (IWC). Initially, the IWC was ineffective at properly regulating an activity with global significance; the quality of its regulation only improved when non-whaling nations joined.[49] An alternative comparator is the UK Press Complaints Commission[50] (PCC), which was abolished after its representative self-regulation model was deemed to be unfit for purpose. Its replacement body, the Independent Press Standards Organisation (IPSO),[51] has not been without controversy[52] – highlighting the difficulties of creating useful regulatory structures. Accordingly, it would seem that a structure involving a self-regulating industry council may be expected to result in major challenges for transparency and legitimacy; there appears (in the examples above) to be a trend over time towards a more multilateral and formal approach. As such, even if a 'trade association' regulatory approach might be adequate in the early stages of the field's development, this approach would almost certainly not be viable for long. Notwithstanding the above, there is the

46. International Maritime Organisation, 'Introduction to IMO', Available at: www.imo.org/en/About/Pages/Default.aspx (last accessed 1 November 2015).
47. ICANN (2015). Available at: www.icann.org/get-started (last accessed 1 November 2015).
48. International Whaling Commission (2015). *Commission*. Available at: https://iwc.int/iwcmain (last accessed 1 November 2015).
49. J. Berger-Eforo 'Sanctuary for the Whales: Will this be the Demise of the International Whaling Commission or a Viable Strategy for the Twenty-First Century?' (1996) 8 *Pace International Law Review* 439 at 442.
50. Press Complaints Commission *About the PCC* (2015) Available at: www.pcc.org.uk/about/index.html (last accessed 1 November 2015).
51. Ipso *About Ipso* (2015). Available at: www.ipso.co.uk/IPSO/aboutipso/aboutipso.html (last accessed 1 November 2015).
52. The Week UK, 'Ipso: is New Newspaper Regulator a 'Sham'?' (2015) Available at: www.theweek.co.uk/media/60314/ipso-is-new-newspaper-regulator-a-sham (last accessed 1 November 2015).

opportunity for an effective, small-scale self-regulation operation to be given more time before being subject to additional statutory oversight than may be the case if the self-regulation process is controversial or simply ineffective.

Compliance, consultation, risk and redress

SRM is a controversial activity. Whilst not subject currently to a moratorium, usage may be regarded as being restricted by certain international instruments, such as the Convention on Biological Diversity (CBD).[53,54] For example, CBD decision X/33 para 8(w) states '*. . . no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts*'. One role of a legal and corporate regulator would be to ensure that generation any SRM-derived VCOs did not, *prima facie*, conflict with the strictures of extant laws. Beyond this, the body may be tasked with conducting appropriate consultations on the permissible extent of SRM. When considering the alteration of the global climate at a greater than *de minimis* scale, it is a formidable task to conduct the appropriate consultations needed to achieve agreement. A body conceived to execute previously agreed targets or restrictions would likely be more appropriately tasked than one expected to determine the collective wishes of all worldwide communities or bodies that may seek to express a view. Nevertheless, it may be appropriate for this regulatory body to have a more limited brief (for example, in managing specific risks to individual regions or communities) and ensuring that suitable provision is made for any losses or harms resulting from an SRM programme (see later on insurance). This may include, for example, the requirement to source an insurance policy to compensate farmers in the event of a drought causing crop failure or to provide a compensation fund with similar goals.

De minimis determination

A climatically *de minimis* intervention may not be regarded as a matter outside society's concern. There are issues around the creation of precedent,[55] and 'slippery slope'[56] arguments. Accordingly, the legal and corporate regulatory arm may seek to set limits on the SRM VCO generation that lie far below the level set by the scientific and technical regulatory process. It may seem perverse that one can pollute at *de minimis* scale with little constraint, but an equivalent SRM intervention may be seen as inherently more controversial – perhaps principally as SRM is deliberate, not incidental.

Fit and proper operators

Existing carbon offset processes have been prone to fraud.[57,58] Accordingly, an appropriate due diligence process would be needed to establish the good faith of prospective operators. Furthermore,

53. Convention on Bio-diversity *History of the Convention* (2015). Available at: www.cbd.int/history/ (last accessed 1 November 2015).
54. Secretariat of the Convention on Biological Diversity; CBD Technical Series No. 66, 'Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters'. Available at: www.cbd.int/doc/publications/cbd-ts-66-en.pdf.
55. J. B. Horton, A Parker, and D. Keith 'Liability for Solar Geoengineering: Historical Precedents, Contemporary Innovations, and Governance Possibilities', v.22. Available at: www.nyuelj.org/wp-content/uploads/2015/02/horton_ready_for_website.pdf.
56. See Schäfer, above n. 44.
57. See FCA, above n. 45.
58. A. Kollmuss, L. Schneider, V. Zhezherin 'Has Joint Implementation reduced GHG emissions? Lessons learned for the design of carbon market mechanisms' Stockholm Environment Institute Working Paper No. 2015-07 Stockholm Environment Institute – U.S. Centre.

climate change has, historically, been a politically controversial topic.[59] It is conceivable that VCO vendors or producers may be perceived (correctly or otherwise) as having an agenda beyond their overt commercial operation. This may, for example, result in operators who deliberately sabotage the process, wilfully generating false offsets in order to damage the market's credibility. Vigilance in operator approval on good faith grounds is, therefore, merited. Furthermore, the ongoing exposure of operators to scrutiny and periodic re-licensing is justified. The assumption should be that the maximum practical degree of transparency should be used – to allay likely civil society or governmental concerns about the propriety of operators.

As discussed above, once the *de minimis* threshold is crossed by an individual firm, there is an additional requirement to ensure the stability and continuity of that firm's operations, so as to avoid termination shock in the event of failure. A review process to ensure the stability of operators, on both a corporate and operational level (discussed below), is then required. At this level, the 'fit and proper' test becomes far more stringent. Concerns at this point include: corporate governance, transparency, and accountability; business continuity and contingency planning; and fiscal solvency. A model organisation for this process could be the UK Financial Conduct Authority (FCA),[60] which seeks to regulate the operations of UK financial services firms in order to protect both their customers and the stability of the market overall (it was established after its predecessor organisation, the Financial Services Authority, was scrapped after the credit crunch). One approach favoured at this stage may be for the regulator to order the break up the firms which are seen as 'too big to fail'.[61] Such an approach may additionally improve competition in the market for SRM services, potentially increasing innovation, and further controlling prices (by the prevention of monopoly or oligopoly). It should be noted that our use of the phrase 'too big to fail' in relation to SRM differs somewhat from its context in finance, in that the potential failure of an SRM firm may directly cause problematic termination shock, as opposed to causing a systemic risk via the mechanism of contagion (as may be the case in finance). Contagion risk is additionally relevant here, typically further up the supply chain for SRM services (for example, if a supplier of critical parts became insolvent after a trade dispute with an operator). For clarity, we do not intend the use of the phrase 'too big to fail' to be construed as a comment on any financial market risk resulting directly from the failure of an SRM firm. Instead, we seek only to discuss climate risks (despite the inevitable financial impact).

Local environmental impacts and regulations

While compliance with local laws may not be the direct concern of the overarching international legal regulator of SRM, there is nevertheless a requirement to guard against two scenarios. First, there is a risk of widespread flouting of ordinary local laws which are ineffectively enforced (for example, flytipping of empty chemical drums). For comparison, many small firms in the mining,[62,63] and waste disposal[64] sectors are noted for their generally poor compliance with local regulations. Second, there is a requirement to avoid

59. A. McCright and R. Dunlap 'The Politicization of Climate Change and Polarization in the American Public's Views of Global Warming, 2001–2010' (2011) 52(2) *Sociological Quarterly* 155–194.
60. Above n. 45.
61. A. Sorkin *Too Big to Fail* (New York: Viking, 2009).
62. Lemaitre *Peru's informal mining sector threatens economic growth – Global Risk Insights* (2014) Global Risk Insights. Available at: http://globalriskinsights.com/2014/02/perus-informal-mining-sector-threatens-economic-growth/ (last accessed 1 November 2015).
63. Sciencedirect.com *Governance Institutions, Resource Rights Regimes, and the Informal Mining Sector: Regulatory Complexities in Indonesia* (2015) Available at: www.sciencedirect.com/science/article/pii/S0305750X11001458 (last accessed 1 November 2015).
64. M. Massari and P. Monzini 'Dirty Businesses in Italy: A Case-study of Illegal Trafficking in Hazardous Waste' (2004) *Global Crime*, 6(3–4) 285-304.

a 'race to the bottom'[65] – where jurisdictions may compete to attract investment from the SRM industry by the provision of generally inadequate legal frameworks. This has been manifest notably in the controversial subject of tax havens,[66] but also applies to polluting industries such as ship breaking.[67] Furthermore, the use of the high seas as a location for SRM operations may be logical for many reasons – both legal and scientific. The high seas fall under international law,[68] which would serve to free operators from potentially restrictive local legal frameworks, making international maritime law the relevant operating framework. Accordingly, determinations would be required as to the appropriateness of such a locus of activity from a legal and regulatory standpoint. The regulator may take the view that all operations must take place under the oversight of a local legal framework, even if physically located outside its jurisdiction. This stance may be regarded as a 'flag of inconvenience' by operators.

Different SRM techniques necessarily have different local and regional scale impacts. These differences exist in both deployment and in regional climate impacts. With SAI, delivery mechanisms require high-altitude access. Accordingly, the regulatory process governing local impacts would typically be contained within extant frameworks – governing matters such as airport expansion, flight paths, etc. For SAI, the actual climate impact locally may be negligible. Conversely, MCB, particularly when conducted near to coastlines, could have significant regional climate impacts,[69] and may accordingly acquire a much more regionally specific governance framework. It is likely, therefore, to be a sensible step for the regulator to insist on a 'flag of inconvenience'.

Continuity of supply

Regulatory oversight of industry inputs is required. Particularly as the market develops, there will be a development of specialities within the supply chain. An interruption to the availability of skilled staff or crucial technical equipment could jeopardise the operations of a large number of firms simultaneously, thus risking termination shock. The scientific regulator would likely be responsible for identifying these pinch points. However, the necessary legal or economic interventions on a whole-market level would probably be best conducted by the legal and corporate regulatory function. For example, a levy may be charged on SRM VCO vendors to fund a training academy, ensuring a reliable supply of appropriately qualified personnel.

Guarantees

To ensure confidence in the market, an overarching structure of warranty may be required. For example, car buyers are assumed to be motivated to purchase one vehicle over another, based on the extant practice of bundling VCOs.[70] This practice may continue with SRM VCOs (for example, for reasons of cost). In the event of any SRM-derived VCOs being later shown to be invalid for any reason, a clear process of redress would be required – to ensure confidence in the SRM VCO market as a whole. This could take the form of an obligation (on either the original provider of the VCO or on the car firm) to supply an appropriate, insurance-backed warranty for replacement of any defective credits. The determination of precisely the

65. B. Dong, J. Gong and X. Zhao 'FDI and Environmental Regulation: Pollution Haven or a Race to the Top?' (2011) 41(2) *Journal of Regulatory* Economics 216–237.
66. R. Altshuler and H. Grubert 'The Three Parties in the Race to the Bottom: Host Governments, Home Governments and Multinational Companies'. Available at: http://papers.ssrn.com/abstract=875308.
67. S. Kirsch 'Cultural Geography I: Materialist Turns' (2012) 37(3) *Progress in Human Geography* 433–441.
68. Y. Tanaka *The International Law of the Sea* 2nd rev edn (Cambridge: Cambridge University Press, 2015).
69. J.B. Moreno-Cruz, K.L. Ricke and D.W. Keith 'A Simple Model to Account for Regional Inequalities in the Effectiveness of Solar Radiation Management' (2011) 110(3-4) *Climatic Change* 649–668. doi:10.1007/s10584-011-0103-z.
70. 'Land Rover's CO_2 Offset', *Car Magazine*, 20 December 2007. Available at: www.carmagazine.co.uk/car-news/land-rover/land-rovers-co2-offset-does-it-work/.

nature of any accompanying insurances and guarantees would be an appropriate matter for the regulator to consider.

Preparations for continuity

Once the whole market, or individual firms, become 'too big to fail' without termination shock, there needs to be provision for continuity.[71] From the legal regulator's standpoint, this is likely to include some form of business continuity insurance and specified operational redundancy within firms or the market. The technical aspects of this are discussed below. In this regard, the UK Bank of England provides a relevant model – having held responsibility for arranging the takeover of failing banks – when this has been necessary to avoid contagion[72] (a phenomenon which was amply demonstrated by the collapse of Lehmann Brothers[73]). In extremis, a takeover of operations by the state could be expected, as illustrated by the near-nationalisation of RBS group by the UK Government during the credit crunch.[74] An alternative state intervention model to consider is offered by the US Troubled Assets Relief Programme (TARP).[75]

Insurances, restitutions, and liabilities

Much of the insurance provision required in the SRM industry would be comparable to that for other industries (for example, employers' liability insurance). However, there would additionally be a need to agree and provide appropriate insurance for the SRM activity itself, such as to indemnify communities against flood risks resulting from SRM.[76] The resulting need to balance the risks and benefits is a complex area, which is beyond the scope of this paper. Suffice to say, the legal regulator would be required to ensure that firms operating in the SRM market had clarity as to the requisite level and type of insurance required, commensurate with their scale of operations and technology choices. Appropriate insurance may be seen as a component of a wider requirement to maintain a 'social licence to operate'.[77] (N.B. this discussion overlaps the section on risks and redress.) Furthermore, operators should be required to insure against operational failure, particularly where this risks leading to termination shock. This would include provision of catastrophic risk insurance,[78] as major hazards (for example, hurricanes) have the potential to knock out operational capacity across the market generally. An insurance model which generates organically a large reserve of operational capacity will tend to minimise risks associated with disruption to supply and consequential risk of termination shock. These risks differ between the technologies, with MCB being particularly vulnerable to sudden disruption. In general, it is notable that the market for relevant insurance

71. M. Wallace and L. Webber *The Disaster Recovery Handbook* (New York: AMACOM, 2011).
72. F. Allen and D. Gale 'Financial Contagion' (2000) 108(1) *Journal of Political Economy* 1.
73. F. Longstaff 'The Subprime Credit Crisis and Contagion in Financial Markets' (2010) 97(3) *Journal of Financial Economics* 436–450.
74. E. Henderson *Quasi-Nationalisation in the UK Banking Crisis: A Problematic Policy Option* (2015) Papers.ssrn.com. Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2562301 (last accessed 9 November 2015).
75. A. Nguyen and C. Enomoto (2015). 'The Troubled Asset Relief Program (TARP) and the Financial Crisis of 2007–2008' (2015) 7(12) *Journal of Business & Economics Research (JBER)*. Available at: http://cluteinstitute.com/ojs/index.php/JBER/article/view/2369 (last accessed 9 November 2015).
76. Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering *Ethics, Policy & Environment* (2015) Available at: www.tandfonline.com/doi/abs/10.1080/21550085.2014.927962#.VjYQCbfhDIU (last accessed 1 November 2015).
77. C. Heyward and S. Rayner 'A Curious Asymmetry: Social Science Expertise and Geoengineering Climate Geoengineering' Governance Working Paper Series: 007. Available at: www.geoengineering-governanceresearch.org/perch/resources/workingpaper7heywardrayneracuriousasymmetry.pdf. Published online 29 November 2013.
78. J. Cummins, N. Doherty and A. Lo 'Can Insurers Pay for the "Big One"? Measuring the Capacity of the Insurance Market to Respond to Catastrophic Losses' (2002) 26(2–3) *Journal of Banking & Finance* 557–583.

products will necessarily be immature at the start; this may cause difficulties in obtaining insurance. Furthermore, the complexities of determining cause, liabilities and damages may make insurance complex to structure, difficult to obtain, prohibitively expensive, or simply unavailable. Accordingly, as discussed earlier, a compensation-fund model may be more appropriate.

Two-tier marketplace model

A simple methodology to increase commercial robustness in the SRM VCO market would be the creation of a two-tier marketplace. This could be performed by enacting a simple rule that SRM operators were prohibited from directly retailing SRM VCOs to end users. The effect of such a rule would be to ensure the creation of a marketplace of intermediary traders, standing between operating firms and their retail buyers. These trading businesses would be essentially indifferent to the production element of operations, and would simply source according to a combination of price and regulatory stipulation. Accordingly, the regulator could then seek to specify any chosen blend of SRM loci, technologies, injection regimes, insurances, etc. to form an approved 'retail' SRM VCO. Furthermore, changes to the approved structure of retail SRM VCOs could be made relatively easily by brokers, as the approved 'recipe' for SRM VCOs was changed by the regulator. It should be noted that the 'too big to fail' principle may need to be applied to brokers, as well as to operators. The applicable test must be that, should any given broker fail, the rest of the brokers in the market could reliably accommodate any additional workload. Furthermore, resources must be made available to bring any failed broker to an orderly shutdown – akin to the manner in which a failing bank may be either nationalised or taken over by rivals.

Scientific oversight

Convention of a scientific regulator

Various possible structures for a scientific regulatory body exist. This could be as a scientific sub-committee of the legal regulatory body; or as an independent organisation. The former structure risks groupthink and a lack of independence; the latter may lead to conflicts and turf wars between the two separate regulators. The IPCC/COP dichotomy[79] is perhaps an appropriate model to reflect upon – and one that has not performed particularly well in forging appropriate international action on climate change.

Determination of de minimis *threshold*

A primary task of the scientific oversight progress would be the determination of the *de minimis* threshold. This cannot be considered simply to be an issue of climate impacts, even when legal and moral considerations are disregarded. SRM interventions are expected to have a range of effects, such as on plant growth,[80] and the appearance of the sky.[81] An effect that is *de minimis* in one dimension may be significant in another, thus any regulatory approach must be multi-factorial in its considerations.

The *de minimis* level may not be regarded as a constant; it may instead depend on the state of knowledge at the time. In early years, the precautionary principle[82] would suggest a low threshold in regard to a range of effects. Later, this bar would be lifted as more confident planning and verification can take place. Whilst not seeking to diminish the need for consideration of non-climatic *de minimis* thresholds, our primary concern

79. U. Luterbacher, D. F. Sprinz *International Relations and Global Climate Change*, (MIT Press: Boston 2001).
80. J. Pongratz, D. Lobell, L. Cao and K. Caldeira (2012) 'Crop Yields in a Geoengineered Climate' 2(2) *Nature Climate Change* 101–105.
81. C. Preston 'Ethics and Geoengineering: Reviewing the Moral Issues raised by Solar Radiation Management and Carbon Dioxide Removal' (2012) 4(1) *WIREs Climate Change* 23-37.
82. K. Elliott 'Geoengineering and the Precautionary Principle' (2010) 24(2) *International Journal of Applied Philosophy* 237–253.

in this paper is to consider the threshold in terms of climate impact. Nevertheless, we do not consider in detail the mechanism by which a *de minimis* determination may be made by a future scientific regulator.

Rationing credits

There would be a need to set a maximum permissible level of SRM. Theoretically, a sudden spike in demand for VCO could lead to climate interventions exceeding a safe threshold. This ceiling would likely be set very low during initial deployment. There is not a clear distinction between experimentation and deployment, with respect to SRM,[83] and there exists, consequentially, a requirement for a slow ramp up as the *de minimis* threshold is crossed. After the technology becomes established in deployment, it is then expected that a further ramp-up period would continue, to ensure that there is no reverse of termination shock – a 'switch-on shock'. Even when SRM is fully deployed, there would always need to be a maximum permissible amount or the climate could (in theory) be cooled dangerously. In any event, SRM is an emergent technology. A slow ramp-up would likely be merited in order to protect against externalities that are unknown[84] in magnitude or nature.

Planning for continuous deployment patterns

Two models exist[85] for the conduct of commercial SRM. First, an approach in which the longer-term impact of carbon emissions is approximately compensated by a short pulse of SRM. This is suitable only for *de minimis* interventions; a large demand for VCOs generated by this process would lead to a risk of termination shock, in the event of a later fall in demand. Proper scientific oversight would ensure that only long-term intervention plans would be permitted, once the *de minimis* threshold was crossed, to avoid the risk of termination shock.

Operational Resilience

Whilst the economic and corporate resilience of an SRM programme is a matter for the legal arm of governance, it is also necessary to consider technical and operational risks, when deploying at scale. In this regard, technical and operational pinch points need to be identified – such as: aircraft type approvals (for example, end-of-life of approved types); patents & licensing (for example, expiration of licences); key personnel (for example, retirement of trained pilots); training of engineers; and equipment redundancy (for example, spares stock levels). Some of the above constraints operate at the level of the firm, some at the level of the industry. In all cases, it is necessary for the scientific and technical oversight process to ensure that a failure of critical operational process components does not lead to programme failure, and thus to termination shock. There are two broad approaches to achieve this – heterogeneity and redundancy – they can be combined. In the heterogeneity model, a requirement may be set to ensure that no single point of failure can cause the whole programme to collapse. This approach is common in power generation – with countries rarely relying on a single type of power generation, or powerplant design. To this end, it may be advantageous to insist on a mix of technological approaches among SRM VCO firms, with limits set per technology. For example, there may be rationing of SAI and MCB VCOs, to ensure a breadth of technology is used. Within each category, the use of a variety of equipment or aircraft suppliers may be mandated.

By contrast, redundancy offers a different approach to resilience. A degree of planned waste helps to ensure supply – but critical points of failure may still exist. A VCO vendor may have to prove that they have

83. Robock, A., Bunzl, M., Kravitz, B. and Stenchikov, G. (2010). A Test for Geoengineering?. Science, 327(5965), pp. 530-531.
84. See Horton, Parker and Keith above n. 55.
85. J. Sargoni and A. Lockley 'Solar Radiation Management and the Voluntary Carbon Market', *Environmental Law Review*, 1–4, DOI: 10.1177/1461452915611277.

excess capacity at all pinch points in operations, so that no single point of failure exists. Additional aircraft inventory, staff, landing strips, etc. are examples where excess capacity may be mandated. Depending on the concentration of the resources required, different redundancy thresholds may be set. For example, a firm with 100 aircraft may be required to provide 20% additional capacity, whereas a firm using a single balloon and hose injection[86] may have to provide 100% spare capacity – two balloons instead of one. The regulator's requirements for redundancy may, therefore, be critical to the technology and operational choices made by suppliers.

In both the heterogeneity and redundancy strategies it may be inherently advantageous to provide resilience by avoiding a 'too big to fail' situation. This remains primarily a task for legal, economic and corporate regulation, although the balloon-and-hose example above offers an operational equivalent.

Temporal and spatial distribution

As discussed in the introduction, the temporal and spatial distribution of changes to the radiation budget are significant. It is therefore to be expected that a scientific oversight body will require any above-threshold intervention programme to be properly distributed in time and space. This would require the coordination of activities within, or between, different firms. Accordingly, the two-tier market structure may be beneficial, with vendors selling balanced credits, each constructed from the SRM operations of a number of regional firms. For example, SAI VCO vendors may be required to ensure that each credit is attributed evenly to Northern and Southern Hemisphere (NH/SH, respectively). The actual injections in each hemisphere may be carried out by different firms. Likewise, the legal regulator may insist that each injection firm sells through a minimum number of vendor firms, to ensure both competition and redundancy is preserved in the market.

Attribution of credits

The carbon credits market is heterogeneous in its current regulation, with no single overarching framework ensuring validity of offsets.[87] This variability is manifest in both the legitimacy and permanence of the offsets offered. In some cases, 'offsets' may be offered against non-existent mitigation – as occurred in the corruption of the EU ETS with Ukranian credits.[88] In other cases, the use of impermanent storage of CO_2 results in a marketable credit (such as may be the case in forestry projects). This provides a mere pause in warming, not a true offset. A key part of the scientific regulation of VCO would be to determine the requisite timescales. Would a carbon credit be generated only when an SRM programme is in place that would last 1,000 years? Such a measure may be climatically far more realistic than a decadal or centurial intervention – but the credibility of any plans on such a timescale must surely be called into question. An alternative target would be to engage in 'shaving the peak' (reducing temperatures whilst awaiting the deployment of CO_2 removal technologies) or attenuating the rate of warming.[89] Neither of these strategies would truly offset carbon emissions – but then neither do existing forestry-based carbon credits.

86. K. Kuo and H. Hunt 'Isothermal Pumping Analysis for High-Altitude Tethered Balloons' (2015) 2(6) *Royal Society of Open Science* 140468.
87. E. Corbera, M. Estrada and K. Brown 'How do Regulated and Voluntary Carbon-offset Schemes Compare? (2009) 6(1) *Journal of Integrative Environmental Sciences* 25–50.
88. A.L. Kollmuss, L. Schneider and V. Zhezherin Stokholm (2015) Environmental Institute Working Paper No. 2015-07. Available at: www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2015-07-JI-lessons-for-carbon-mechs.pdf.
89. D. W. Keith and D. G. MacMartin 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering' (2015) 5 *Nature Climate Change* 201–206, doi:10.1038/nclimate2493.

Verification of performance

Proper scientific oversight would have to involve close supervision of the performance of the intervention against any plans filed. Even small deviations from plan details (for example, of aerosol size[90]) may have a dramatic effect on performance, and hence the validity of any VCOs generated. This regulatory requirement applies regardless of a *de minimis* threshold, thus it is an early need. However, it must be noted that the existing VCO market has imperfect regulation in this regard, with the validity of resulting offsets being called into question.[91] Typical problems include claiming emissions reductions that have not occurred (for example, late or ineffective application of landfill methane controls); and selling offsets for mitigation that would have occurred anyway (for example, for the planned replacement of obsolete plant).

Conclusions

We consider the risks of commercial deployments of SRM, principally using the VCO market.

We identified three main regulatory goals:

1. to validate and scrutinise SRM VCO generation;
2. to regulate the local and global side effects of SRM VCO generation, and to specify any necessary damages insurances; and
3. to protect the global climate system, particularly from termination shock in the event of operator failure.

We have identified two fundamental regulatory processes: legal and commercial; and scientific & technical. Each of these needs a separate body, but these may be divisions, or functions, within an overarching organisation.

We identify three distinct phases during SRM expansion, each posing separate regulatory challenges:

1. no significant effect on the climate system;
2. a significant effect on the climate system, but with no individual firm large enough to affect the climate system individually; and
3. a number of larger operators, at least one of which has a significant individual effect on the climate.

We conclude that the process of regulation needs to be adapted as circumstances change. In the first case, where overall climate impacts are *de minimis*, an appropriately tasked regulatory process needs only concern itself with validation, legal compliance, and side effects. In the second scenario, where a number of small operators have a significant overall effect on the climate, there exists a risk of termination shock. Here, the regulatory process should additionally concern itself with: the need to provide stable overall economic, technological and operational conditions for firms; and the provision of guarantees and insurances, to ensure programme continuity. Finally, where one or more operators have a major effect on the climate, a much higher degree of control is required – and state(s) should be able to step in at all times to guarantee the operational continuity of such firms. Due to the risks involved in the latter scenario, we suggest that lessons can be drawn from banking regulation, with the principle of 'too big to fail' being used as a trigger to break up large firms. The regulator should, therefore, ensure a diverse base of suppliers and technologies exist in the market.

90. P. Rasch, P. Crutzenand D. Coleman 'Exploring the Geoengineering of Climate using Stratospheric Sulfate Aerosols: The Role of Particle Size (2008) 35(2) *Geophysical Research Letters*
91. M. Schapiro 'Conning the Climate: Inside the Carbon-trading Shell Game' (2010) *Harper's Magazine* 31–39.

In general, we note the potential advantages of a two-tier marketplace – in which physical operators are separated from their consumers by firms in a brokerage layer. This would enable the regulator to issue brokers with instructions to assemble SRM VCOs from a preferred 'recipe' of services and insurances – then leave the brokers to purchase the necessary services from SRM operators, as they see fit.

We also note the arguments of authors who have argued for moratoria on the use of SRM, and those who have drawn attention to the 'slippery slope'. However, we regard these issues to be outside a workable brief for a regulator of SRM VCOs—they should not be concerned with matters of overriding principle.

This paper is necessarily a broad and early overview of a potentially emerging field, and is therefore somewhat speculative in nature. Much further research is warranted, for example, review of applicable law; detail of proposed licensing and inspection procedures; provision of appropriate insurance products; terms of reference for the regulatory bodies described; quantification of *de minimis* thresholds; application and licensing procedures; and consideration of appropriate liability & compensation regimes.

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