Sulfur in the Sky with Diamonds: An Inquiry into the Feasibility of Solar Geoengineering

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Research Article

Abstract

Solar geoengineering (SG) is considered a promising, albeit controversial, climate engineering technology to help reduce predicted global warming. However, the complexity of SG raises serious doubts about its political practicability. The objective of this article is to investigate this technology's feasibility, a fundamental dimension of said practicability. Feasibility is here understood as a political property: the higher the feasibility of a state of affairs ranks, the greater its eventual political practicability. According to this perspective, the less SG clashes with economic, institutional, and moral soft constraints, the more feasible it becomes, and hence the greater its political practicability. An analysis of economic and institutional soft constraints points to a high degree of SG feasibility. This feasibility is, however, limited by the perceived non-bearable moral costs which SG involves. Given the greater weight of moral soft constraints, SG's overall feasibility is therefore low. Based on these indications, the article offers suggestions for lessening SG's friction with soft constraints, especially with the highly sensitive moral ones, with the aim of increasing this technology's feasibility. On the basis of this heightened feasibility, the paper concludes with policy recommendations which improves the practicability of SG.

Policy Implications

- Particular attention should be paid to the many ethical concerns raised by solar geoengineering (SG) since these greatly limit its feasibility.
- In order to improve SG feasibility its governance should consider concerns about legitimacy and procedural justice.
- To obtain SG politically practicability it is crucial to: (1) improve the overall morality of its governance; (2) include intergenerational and international distributive justice in its governance; and (3) carry out this technology in a context of international trust and widespread collaboration.
- Existing international institutions working on climate change, science and education, environmental issues, justice, peace and security, development, international law, health and nutrition and financial matters should be leveraged for supporting the feasibility and political practicability of SG.
- Coordination is necessary at the regional scale between said international institutions and states, the relevant national and sub-national institutions and the appropriate formal and informal governance mechanisms.

Spraying diamond dust in the sky

Scientists at Harvard University have suggested that spraying diamond dust in the sky could lower temperatures on Earth (Weisenstein et al., 2015). Diamond dust is one of the many particles – the most common one is sulfate aerosol – that can be dispersed in the stratosphere in order to cool temperatures on a global scale (Caldeira et al., 2013). This seemingly fantastic proposal referred to as 'stratospheric aerosol injection', is possibly the most promising approach in the solar geoengineering (SG) family of technologies of climate engineering (CE) (Niemeier and Tilmes, 2017). CE, also known as 'geoengineering' or 'climate intervention' was loosely defined in one of the first major works on the subject by the UK Royal Society as 'the deliberate, large-scale manipulation of the planetary environment to counteract anthropogenic climate change' (Shepherd, 2009, p. 1).

Indeed, climate change is already happening and the evidence suggests that political, economic and social inertia will very likely prevent emissions being reduced fast enough to avoid further dangerous climate impacts (National Research Council, 2015a, 2015b; Schäfer et al., 2015). At the same time, although the nationally determined contributions, part of the 2015 Paris Agreement testify to an unprecedented global scale of climate initiatives, they do not set sufficient emission cuts for achieving the goal of safely limiting the rise in global temperatures (Peters et al., 2017).

This bleak outlook has led to the increased contemplation of a range of CE technologies which are emerging as a third category of possible responses to climate change, alongside reducing emissions (mitigation) and modifying socioeconomic systems for lessening climate impacts (adaptation) (National Research Council, 2015a, 2015b; Niemeier and

Tilmes, 2017). According to several observers, the goals of the Paris Agreement require that the climate community should consider the full spectrum of CE techniques, since its ambitious temperature targets would not be attainable through emission cuts alone (Pasztor et al., 2017). To keep an increase of temperatures well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels, the use of uncertain and still controversial CE technologies including SG (Parker and Geden, 2016), would seem, in fact, necessary (MacMartin et al., 2018).

This article concentrates on SG, the most debated branch of CE approaches. It investigates its feasibility, in order to understand if this technology, still in an embryonic phase and so far largely consisting of research conducted through computer modeling (Niemeier and Tilmes, 2017), might at some point in the future be politically practicable, despite current widespread fears of its ungovernability (Talberg et al., 2018).

Among the political properties of climate governance, feasibility is by far the least explored one. For instance, Pickering et al. (2012), acknowledging this deficiency, emphasize the urgency for research on the feasibility of proposals and outcomes in policy if we want to engage with climate change successfully.

The argument proceeds as follows: first, the article introduces SG and outlines its main pros and cons. Then it specifies and clarifies the scalar notion of feasibility employed and the related – economic, institutional and moral – soft constraints relevant for SG; the object and scope of the analysis of feasibility carried out; as well as the rationale behind the choice of this political property. Then it analyses the frictions which surface from this analysis between SG and economic, institutional and moral soft constraints. Finally, the article offers some suggestions for lessening these frictions with soft constraints, in particular with the moral ones, so as to increase SG's feasibility. On this basis, it provides policy recommendations in view of improving SG's political practicability.

Solar geoengineering

Solar geoengineering also known as 'albedo modification' (National Research Council, 2015b; Schäfer et al., 2015) or 'solar radiation management' (Shepherd, 2009) has the objective of halting, or at least reducing, global warming by lessening the amount of solar energy absorbed by the Earth's surface and atmosphere. The analysis carried out in this article refers to stratospheric aerosol injection, the most interesting and controversial approach of SG (Lohmann and Gasparini, 2017).

Solar geoengineering is by no means a stand-alone technology for substituting mitigation (Keith, 2013); rather it should be considered a complementary tool to mitigation and carbon dioxide removal (CDR), the other family of CE approaches, in offsetting expected global warming (Chhetri et al., 2018; Wigley, 2006).

Solar geoengineering is believed to have potential for three main reasons. First, models prevalently suggest that SG can result in temperature and precipitation closer to preindustrial levels in all regions, compared to a world of unmitigated climate change (Kravitz et al., 2014). Second, SG is believed to act faster in combatting global warming than any other strategy. For instance, for a delivery cost of five to ten billion dollars a year, a fleet of airplanes or balloons could deposit enough aerosols in the stratosphere to counteract within weeks a significant fraction of the global warming caused since industrialization (Moriyama et al., 2017; Pasztor, 2017). Third, SG compared to other approaches, could have regional or global impact with limited economic input, despite no longer being considered 'incredibly cheap' (Moriyama et al., 2017), as originally claimed (Barrett, 2008). At any rate, SG would be able to modify the calculus of climate policy by offering a reasonably inexpensive and welfare-increasing (Moreno-Cruz et al., 2017) means to reduce temperatures that could be undertaken by almost any state – even in the developing world (Rahman et al., 2018) – or small group of states or agents (Barrett, 2014; Bodansky, 2013).

Solar geoengineering's ability to achieve these goals makes it a 'high leverage technology' (Zürn and Schäfer, 2013), i.e. a technology that could 'exert large influence over global climate from relatively small inputs' (Parson and Ernst, 2013, p. 313). Therefore, SG could be used as a stopgap, giving society additional time to cut emissions and develop effective carbon removal techniques, so as to better accommodate the problem of future generations (McKinnon, 2018), one of the core concerns of the climate crisis. Or, it could be used in the case of global or regional climate emergencies (Barrett, 2014), when mitigation alone turns out to be inadequate, despite certain discrepancies in the scientific evidence on climate emergencies and their possible authoritarian political implications (Szerszynski et al., 2013).

The potential of SG is, however, counterbalanced by its many physical, political and existential burdens (Halstead, 2018; Pasztor et al., 2017) that raise a fair number of uncertainties and problems (Horton and Reynolds, 2016; Robock, 2008). Cusack et al. (2014), for instance, developed a framework based on technical, economic, ecological, institutional and ethical dimensions, as well as on public acceptance of CE concluding that SG is the highest risk technology.

More specifically, in physical terms, alongside the impossibility of precisely returning to a preindustrial climate (Keith et al., 2010), SG might contribute to stratospheric ozone depletion, to changing the spatial distribution of temperatures and precipitations in an unpredictable fashion, to altering ocean circulation and the diffusion of incoming light (Barrett, 2014) and may have regionally differentiated effects on tropical cyclone frequency (Jones et al., 2017). SG can thus negatively and differentially impact both humans – especially the most vulnerable – and non-human beings (Suarez and van Aalst, 2017). Additionally, it is often claimed that SG is an exacting technology that must be repeated on a regular basis indefinitely (Pierrehumbert, 2017).

At the same time, SG raises a host of ethical concerns, the most contentious of which are examined in the Section on the moral constraints to feasibility.[1] On sociopolitical grounds researching SG could trigger a competitive political dynamic that would induce agents to match one another's efforts out of fear of being left behind (Maas and Comardicea, 2013). A further major problem derives from SG's relatively undemanding technological and economical delivery (Moriyama et al., 2017), which could engender uncoordinated action leading to unpredictable economic and moral burdens and risks (Pasztor, 2017). Overall, SG may clash with the current international relations and institutions and thus generate conflicts that could radically change geopolitics (Morton, 2017), as well as – if intended as a stopgap – produce a security hazard that could undermine effective global mitigation and even global governance (Corry, 2017).

Despite the lure of SG and a quite widespread ingenuous faith in science and technology (Stilgoe, 2017), these uncertainties and problems coupled with as yet manifestly insufficient factual knowledge have contributed to generating a rational fear that 'hacking the planet' (Pierrehumbert, 2017) could/would have undesirable and potentially appalling outcomes and implications. Therefore, doubts about the political properties significant for SG's political practicability persist. Consequently, a thorough investigation of such properties starting, at least for reasons of chronological priority, from feasibility is needed.[2]

Feasibility

Apparently, feasibility is an obvious concept: states of affairs – requirements of theories, proposals, actions, processes, outcomes – are feasible if there is some way to bring them about. Despite this deceptive clarity, however, it is almost impossible to agree on a univocal and uncontroversial definition of feasibility, since it is an arguable concept widely used across different scholarly traditions and contexts of analysis.

Given the complexity of SG and its many unknowns (and unknown unknowns), the article delineates a notion of feasibility aligned with the information and factual knowledge currently available and framed according to the scholarly tradition of political theory.

This latter perspective, in its different conceptions of feasibility (for a succinct overview see Gilabert and Lawford-Smith, 2012, pp. 811-812), makes it possible to deal with the 'unknowability' of SG; as yet untried and untested, an empirical approach to the political issues surrounding SG would be otherwise impossible at present. Feasibility, as intended here, does not imply an analytic positive scrutiny of states of affairs like that of political science which, by and large, consists in the investigation of their capacity to satisfy relevant political, institutional, economic, social and technical requirements (Majone, 1975).[3] Nor could an analysis of technical feasibility alone, if it were able to overcome the profound uncertainties that still surround SG, provide adequate information for understanding in broad enough terms the feasibility of this technology in view of its political practicability.

Additionally, despite political theory sometimes conflating feasibility with desirability – the latter being a normative or evaluative construct about moral goodness of states of affairs (Gilabert and Lawford-Smith, 2012) – here the theoretical focus is exclusively on feasibility. It is specifically intended as a conceptual tool for ranking states of affairs along a crucial dimension relevant for their political practicability (Lawford-Smith, 2013).

Indeed, questions of feasibility and desirability cannot be neatly separated even at the theoretical level, since mutual feedbacks and feedforwards inextricably intertwine them. Nonetheless, for analytical purposes, it is possible to distinguish (Lawford-Smith, 2013) considerations about feasibility – those carried out here – that relate to what is morally possible, from considerations about desirability that relate to what is morally appealing (Rawls, 2001). In this regard, some lines of thought (e.g. Shue, 2017) seem to suggest that this technology is not desirable, since it would permit humanity to perpetuate the current carbon-intensive models of development, whereas morality requires preventing further harm to humanity and the planet by decarbonizing socioeconomic systems. Other scholars contend instead that carefully shaped and developed SG would be desirable (Frumhoff and Stephens (2018), for instance argue in this regard that SG ought to be legitimate). This article does not investigate SG's desirability on theoretical grounds. However, it assumes that, given the inevitable connections between feasibility and desirability – especially in 'real' political contexts – increasing the first, for instance through the morally acceptable ideals of legitimacy and procedural justice proposed in the final Section would at the same time make this technology more desirable and, altogether, more politically practicable.

In the relevant literature, this deliberately narrow notion of feasibility – similar to that of Buchanan (2004) and Cohen (2009) – is sometimes coupled with a further requirement of stability that relates to maintaining a state of affairs once it has been reached (Cohen, 2009; Gilabert and Lawford-Smith, 2012). Given the emphasized complexity of SG, here stability is intended as a component of desirability and not considered in the conceptual space of feasibility: therefore a state of affairs can still be feasible even if it is undesirable to pursue it due to its limited stability.

In light of the previous considerations, feasibility is more usefully employed in relation to SG in its scalar understanding than in its binary one. Scalar feasibility supports decisions about what to actually do by ranking states of affairs. Binary feasibility rules out states of affairs as unfeasible if they do not satisfy a set of logical, nomological and biological factors, defined as 'hard constraints' (Gilabert and Lawford-Smith, 2012; Lawford-Smith, 2013). Opportunely, Lawford-Smith (2013, p. 244) notes that binary feasibility is almost useless outside the realm of moral theory, since in any applied context 'we want a way of saying how feasible some alternative is, which is just one consideration that feeds into our deliberation about what, ultimately, we ought politically to do'. In the scalar understanding, feasibility, in combination with other political properties, can be used in support of judgment in political contexts to determine whether as yet non-existent SG can at some point in the future be politically practicable, even if there is obviously no concrete political backing for it yet.

Having thus clarified, a state of affairs is more feasible in scalar terms the less it conflicts with the relevant, context-specific soft constraints. The generally acknowledged families of soft constraints are economic, institutional and cultural – the latter refers to customs, traditions and values of a society or community and includes morality (Lawford-Smith, 2013). Given the host of ethical concerns raised by SG and their severity (Baatz et al., 2016; Hamilton, 2013b), morality is in the current analysis the most relevant soft constraint among the cultural ones.

Therefore, the notion of feasibility adopted here requires that the possible frictions of SG with the constraints imposed by the economic, institutional and moral status quo be identified and examined.

Before proceeding, it is necessary to specify and clarify the object and scope of the analysis of SG feasibility, as well as the rationale for its choice as the first necessary political property in view of its practicability. With regards to the first point, the most important specification of the object of a feasibility analysis involves the type of social and political phenomena to which it can be applied. In this article, consistent with part of the CE literature (e.g. Stilgoe, 2015), sociotechnical systems for researching and deploying SG are the general object. Drawing on insights from sociology, institutional theory and innovation studies, a sociotechnical system consists of robust and consolidated technological inputs, infrastructures, markets, regulations, norms, policies, organizations and networks (Geels, 2002) with which SG research and deployment can be governed and carried out in a long-term harmonized way.[4]

Solar geoengineering is therefore the sociotechnical system that 'coordinate[s] the behaviour of different types of . . . users over extended time periods and jurisdictions' (Page, 2012, p. 937) in relation to the goal of cooling temperatures by diminishing absorbed solar energy. Consequently, SG as a system – and not SG research projects, or specific technological plans and measures for deploying SG or the norms, etc. that SG propagates – is the object of the feasibility analysis.

In terms of scope, given that, in the case of SG, research and deployment are believed to differ only in terms of purpose, extent and duration (Tanimura, 2013–2014), its feasibility refers to the three final steps of Keith's (2013) four-step SG scenario. The article therefore excludes Keith's first step – theory and laboratory work based on climate models, virtually the only SG activities carried out so far, as said – and instead concentrates on the feasibility of: (1) very small-scale atmospheric experiments designed to test the theoretical conclusions reached via models and simulations; (2) operationalization of SG projects on the smallest scale from which to gather empirical data for proceeding with subsequent gradual deployment; and (3) gradual deployment combined with other approaches to counter climate change.

The rationale for the choice of feasibility as the basilar political property for the practicability of SG largely depends on the fact that this technology has yet to be implemented. Feasibility as understood here is, in fact, the quintessential political property of sociotechnical systems that do not yet exist. Its investigation does not need any (currently impossible) detailed empirical and/or technical information. Other political properties concur to increase the feasibility of SG; with regards to the morality soft constraints, for instance, they include the ideals (Pettit, 2012) of legitimacy and procedural justice, as shown in the last Section.

These considerations coupled with the – understandably – limited, but steadily growing, literature on the political issues entailed by SG,[5] make the analysis carried out in this article crucial, so to speak. Indeed, it not only concurs to fill a manifest void in the literature, but it should almost take priority over other investigations into the policy and politics of SG, for which feasibility may represent a sort of unavoidable prerequisite.

Constraints to SG feasibility

A state of affairs is believed to be more feasible the less it clashes with soft constraints: reported below are the main frictions with economic, institutional and moral soft constraints. Their investigation allows for a judgment on SG feasibility to be made.

Economic constraints

The less a state of affairs negatively impacts the economic system, the greater its feasibility. SG can significantly modify the flow of very large amounts of resources and thus influence the economic situation of a great number of agents across states and generations. Therefore, economic facts understood broadly to also include non-monetary ones (e.g. opportunity costs) involved in SG research and deployment are indeed significant for SG feasibility.

In general, the lower the cost of bringing about a state of affairs, the more it is likely to be feasible in the long term, at least in democratic societies (Dahl, 1998). It should be noted that sensitivity to the cost of addressing climate change has been heightened in the past few years by the global economic and financial crisis, by the post-Copenhagen sense of disillusion, by a certain – most of the time instrumentally construed – loss of credibility of climate science and policy and by the current pragmatic approach, eventually also endorsed by the Paris Agreement. SG, as already underlined, can be rather inexpensive, if maybe less than previously believed; it is also claimed (e.g. Moreno-Cruz et al., 2017) that it will contribute through temperature reduction to an increase in welfare, thereby counterbalancing the welfare losses associated to climate change.

The scrutiny of economic soft constraints must not be limited to a local level, since SG can significantly alter global resource flows, thus raising an international cost-distribution issue. Such flows would originate, by and large, from avoiding risks and enduring impacts produced by the anthropogenic manipulation of the climate system that would generate a resource shift quantifiable in terms of benefits and costs. Other international financial flows could occur if some countries/communities demanded compensation for potential harm from SG as part of a possible international agreement (Horton et al., 2015; Reynolds, 2015). SG may therefore cause countries to worry that, as happens in other situations of international collaboration, some partners are achieving greater material power capabilities and, on this basis, a stronger position (Grieco et al., 1993). Despite the difficulties of envisioning the benefits and costs of SG, it seems sufficiently safe to hold that the more front-runner countries are rewarded by SG (or, the less they are penalized), the less this technique would clash with the economic status quo and the greater its feasibility would eventually be. At the same time, the alleged cost advantage of SG could contribute to transforming international action on it into a self-enforcing situation of cost-efficient international coordination among benefited countries (Schelling, 1996). Coordination would be far less costly to address than the malign cooperation problems that usually characterize climate change (Keohane and Victor, 2016) and it would eventually concur to increase the overall feasibility of SG.

Economic facts are certainly significant for SG. However, the economics of SG, by and large, do not seem to clash with the soft constraints posed by current economic systems and therefore this technology has a certain degree of feasibility with regard to this ambit. Only the international economic dynamics triggered by SG could be significant for its feasibility, albeit not necessarily in a negative way, as long as first-movers can reap part of the benefit and, through their power and authoritativeness, are willing to induce other countries to collaborate.

Institutional constraints

Institutional constraints are an obstacle to bringing about a state of affairs when its elements collide with entrenched institutions. SG does not need radically new institutions, at least until fully-fledged deployment. Therefore, SG, although a complex sociotechnical system, can rely on the current institutions to prevent humanity falling prey to extreme climate change, albeit in an unconventional way. In fact, there are several examples of SG institutions focused on functions, objects and agents involved (e.g. Bodle et al., 2013; Lloyd and Oppenheimer, 2014; Parson and Ernst, 2013), particularly at the international level – the most relevant for this technology. By and large, they do not posit, though, the necessity of new institutions given their potential clash with current ones. Rather, some scholars (e.g. Bodansky, 2013) actively discourage their foundation due to their general burdensomeness and the difficulties caused by the co-existence of their decision-making authority with the current relevant ones.[6] SG's institutional arrangements are, in fact, generally envisaged through the United Nations and through single countries or consortia of countries (Virgoe, 2009). These existing institutional arrangements, even jointly, already have the legal mandates and the political capabilities to govern SG, preferably in a polycentric way (Nicholson et al., 2018).

Moreover, given, the urgency of the climate crisis, SG could be needed at relatively short notice: it must therefore rely on the available institutions (Chhetri et al., 2018), as time constraints would not allow for the establishment of new ones.

These considerations suggest that SG would not severely clash with current institutions. Hence, institutional soft constraints do not seem to be a major hindrance to SG feasibility.[7]

Nonetheless, some factors need to be addressed to better understand the feasibility of SG in relation to institutional soft constraints. First, democracies are not incompatible with SG (Horton et al., 2018). Rather, they are well-suited for providing environment-related goods in the public interest (Bernauer and Böhmelt, 2013) like research and deployment of SG. Moreover, also by virtue of their greater institutional capacity, democracies can better contribute to, and participate in, collaborative international environmental action (Ward, 2008), as required by SG.

Second, public awareness of the threat posed by climate change, of the features and objectives of SG, as well as public engagement are expected to be influential determinants of institutional constraints given the extent to which decision-makers, at least in democratic societies, respond to public pressure. It is generally assumed, in fact, that where awareness of SG technologies (Burns et al., 2016) and public engagement are higher (Carr et al., 2013), SG would clash less with existing institutions, since decision-makers are more willing to accommodate meaningfully agreed social and political requests.

The third factor relates to interest groups – in particular the carbon intensive industries – and the role of non-governmental organizations (NGOs), especially of environmental ones (ENGOs). Since the influential carbon lobby, for reasons of interests is supposed to favor SG, this article assumes that its institutional acceptance is likely to be greater in countries with larger carbon intensive industries (e.g. China the largest carbon exporter with interests in SG). On the other hand, the capacity of the European industry lobby to manipulate the structure of the EU Emission Trading Scheme (EU ETS) in order to maximize the allocation of permits (Skjærseth and Wettestad, 2008) coupled with the industry lobby's support of CE that this article envisages, seem to suggest that SG could be less likely to clash with existing institutions in richer carbon-importing regions like the EU too. The question of NGOs is more nuanced (Reynolds et al., 2016): influential science advocacy NGOs working on climate issues support SG research; none actively opposes it. Similarly, 'moderate' ENGOs cautiously support SG research. On the contrary, 'greener' ENGOs are generally against CE and can mobilize a significant level of political resistance (Zürn and Schäfer, 2013). Their main reason seems to be the fear that SG could be captured and used against the public interest by post-democratic governing elites led by techno-managerial planning, expert management and administration and funders (Hamilton, 2013a; Szerszynski et al., 2013).

Moral constraints

As Lawford-Smith (2013) concedes, soft constraints have different relative strengths depending on the context in which states of affairs occur. Given the moral contentiousness of

SG (Baatz et al., 2016) and its almost endless moral implications, this technology vigorously challenges dominant beliefs and attitudes (Svoboda, 2017), as it would involve new conceptions of the Earth and of human beings (Hamilton, 2013b). Therefore, moral soft constraints are particularly significant for SG feasibility. It is worth clarifying that in this instance the reference is to what people consider to be moral in relation to SG, and not to universal moral principles and theories, for two reasons. First, the scalar notion of feasibility adopted is expected to have a role to play in 'real political decision-making' (Lawford-Smith, 2013): therefore it needs to take into account de facto morality. Second, the 'unknowability' of SG and the consequent enduring uncertainties of its moral dimensions – despite the wealth of emerging moral analyses – imply that moral attitudes held de facto by stakeholders towards this technology are still crucial moral benchmarks.

Among the most critical moral questions that affect SG feasibility is the fear that it undermines the already insufficient efforts in mitigation, in part due to the comparatively greater cost of aggressive emission abatements.[8] This is known as 'moral hazard' (Burns et al., 2016; Schneider, 1996) a way for rich countries to divert attention from their responsibility for their disproportionate emissions, while promising a cheaper and easier alternative (Winickoff et al., 2015). As a consequence, particularly if moral hazard arises, SG might engender a problem of 'moral corruption': instead of tackling climate change seriously, humanity could still find excuses, often embedded in visions of technological omnipotence, to search for technological fixes that make it possible to continue with business-as-usual behavior, which has so far proved extremely harmful for the climate system (Preston, 2013). Those wishing to enact these immoral behaviors will, needless to say, rationalize them proclaiming them as being righteous, rather than acknowledging that they may be grounded in self-interest. So they perceive the moral cost of their own action as far lower than the actual moral cost. A further concern is usually described as the 'slippery slope' argument. This implies that conducting research into SG would generate fear of an irreversible commitment to its future deployment (Keith, 2000).

SG would undeniably convey the impression of substantial moral costs and therefore transitioning to it would quite significantly clash with morality constraints, especially in the deployment stage. Therefore, in this regard, SG feasibility is low.

At the same time, it seems reasonably safe to claim that the better these perceived moral concerns are addressed at a moral cost considered bearable, the less SG is likely to conflict with them; its feasibility would therefore be greater.

As regards research, a general framework that indicates a possible route for minimizing the perceived moral costs of SG can be based on some agreed principles, for instance the five Oxford ones (Rayner et al., 2013), which are specifically aimed at guiding the development of CE technologies from early research to the point where they may be available for deployment in a morally sound way.[9] Such principles also require that SG, especially in the experimental phase, remains a controllable technology carried out through collaborative efforts based on the deliberative engagement of stakeholders with the scientific community and policy-makers (Chhetri et al., 2018; Sugiyama et al., 2017) to pursue development in the public interest (Gregory et al., 2016). Also, the transparency of patterns of scientific research and intellectual property acquisition stressed by the Oxford principles can reduce the expected moral costs of SG research (Oldham et al., 2014).

As for SG deployment, considerations of perceived moral costs are more challenging, even if at this early juncture probably less urgent. To many extents, a possible route for lessening predicted moral costs of SG is largely dependent on deployment corresponding to the experiments in the research process of Keith's above-mentioned taxonomy (Keith, 2013). Therefore, it can be said that if SG deployment is to avoid/reduce clashing with morality soft constraints, SG experiments on an increasing scale must be performed. In other words, the feasibility of SG would increase if the deployment step bore close resemblance to and were consistent with the research phase; this would minimize the perceived moral costs related to SG by preventing the introduction of new, unaddressed – and possibly non-addressable in this final phase – moral concerns.

Reducing SG frictions with soft constraints and policy recommendations

In light of the greater weight of moral constraints, SG seems to have a limited overall degree of feasibility, despite its relatively minor frictions with economic and institutional soft constraints.[10]

This article does not intend to determine a 'blueprint' for increasing SG feasibility and its consequent political practicability. Nonetheless, it is worth trying to connect the analysis carried out herein to the complex realities of global climate policy. The objective is simply to address the challenges of SG feasibility and to provide resultant policy recommendations in view of improving its political practicability.

The article has shown that there are, in fact, some 'entry points' for eroding SG's soft constraints, especially the highly sensitive moral ones that mostly limit the feasibility of this technology. Given the scalar notion of feasibility adopted and the intrinsic malleability of soft constraints (Gilabert and Lawford-Smith, 2012), reducing SG's conflicts with them can eventually make it more feasible.

Regarding the economic and institutional constraints, suffice it to say that the design of SG should pay careful attention to the potential fracture lines with current economic systems and existing institutions. In this regard, SG's rough edges are mostly to be found in the distribution of the changes in the associated international resource flows and in its openness, transparency and inclusiveness. Therefore, to be more feasible, SG must show great care in dealing with the challenges presented by such delicate economic and institutional issues.

In the case of morality constraints, considerations are more complex. For SG to deal with, and possibly overcome, the moral concerns outlined at a moral cost perceived as bearable, it may be useful to pinpoint, as said, some ideals with which this sociotechnical system can reduce its tension with de facto morality. In particular, SG should consider ideals able to confer the special standing necessary for carrying out its tasks (Buchanan, 2013). The concept of standing regards the ability of states of affairs to command social respect. The feasibility of SG can be increased by ideals that are rewarding in terms of social esteem; indeed, reciprocated social esteem is a very powerful incentive for compliance (Brennan and Pettit, 2007). The ideals of legitimacy and procedural justice, as other authoritative studies explicitly or implicitly underline,[11] seem to be the most appropriate foundations for morally sounder SG and therefore for lending it greater feasibility. The main reason is that legitimacy and procedural justice can significantly contribute to shaping SG distinct from opaque bureaucracies run by unaccountable elites (Morrow et al., 2013). Said ideals can increase public participation in the SG decisional process, thus obviating, or at least minimizing, the danger that through deceit, disinformation, power and knowledge asymmetries and other malpractices, SG is captured, exploited and used for the pursuit of private interests (Zürn and Schäfer, 2013).[12] SG should preferably include and put into practice the ideals of legitimacy and procedural justice as institutionalized and widely socialized moral norms.

Based on the greater feasibility that legitimacy and procedural justice lend SG, and without the ambition of imparting strict policy guidance, it is worth providing some policy recommendations that would increase SG's political practicability.

A specification is in order. In this Section the article broadens its scope to the 'real' political context. Therefore, the policy recommendations put forward in what follows are not meant to contribute to SG's desirability, as understood in the perspective of political theory delineated above. Rather, they are expected to increase this technology's political practicability. Indeed, for the reasons specified throughout the article, such policy recommendations are mainly concerned with morality issues.

First, the overall morality of SG governance should be reinforced: consistent with the objectives of SG governance proposed by Nicholson et al. (2018), the features best-suited for this task seem to be the following: (1) identification of the public and private agents that should be involved; (2) the modalities of their engagement; and (3) connection with key agents, for example, decision-makers, epistemic communities, investors (Hamilton, 2013a; Bodle et al., 2013; Schäfer et al., 2015) and experts belonging to techno-scientific groups. The moral strengthening of these features would make it possible for this technology to work in a responsible way and in the best interests of the public, important for improving SG's political practicability.

Second, SG should include considerations of distributive justice able to deliver an equitable allocation of burdens and benefits, especially during the deployment phase. A fully-fledged notion of distributive justice that takes account of international and intergenerational issues can increase the political practicability of SG, since this political property would strengthen the support among stakeholders with different commitments and provide useful ground for objectively addressing ethical conflicts.

Third, it is critical to build international trust in SG through agreed forms of mutual collaboration among international institutions, states and other non-state institutions. To this end a limited group of major countries, belonging both to the developed and developing world – possibly led by the most important players in the field, China and the U.S., under the aegis of the United Nations – should take the lead. The major countries' greater political and institutional capacity makes them ready to take advantage of other forms of collaboration on climate issues that can at the same time usefully cement trust and spur the research and deployment of SG. More affluent major economies could also support emerging economies' SG efforts through technology transfer, sufficient and predictable financial assistance, technical and institutional support and capacity building. Moreover, compensation for SG harm, as possibly part of an international political agreement (Horton et al., 2015), can play an important role in increasing trust in SG, thereby boosting its political practicability.

In sum, to favor the political practicability of SG, it is important to weaken resistance to this socio-technical system through the inclusion in its governance of opportune political properties and morally-sound responses. These should be able to stimulate support from citizens, policymakers and all other stakeholders, as well as encourage dialogue on the most up-to-date science and theories, consequently reducing irrational or unjustified resistance. This would be much more effective in promoting SG than any form of imposition or confidence in the visions of politicians. In fact, in the current fragmented and multipolar international climate order, agents' preferences largely differ, authority is divided and compliance with any initiative almost depends solely on voluntary agreements. Therefore, effective international climate initiatives need to operate in this polycentric and quasi-anarchic system through morally-sound, gradual transformation. This applies especially to SG, since it can significantly interfere with vested interests, influence patterns of well-being across states and generations and modify the flow of very large amounts of resources, financial and otherwise. The policy recommendations proposed can help shape converging preferences among stakeholders and political representatives belonging to different traditions and subject to different constraints and eventually increase the political practicability of SG.

Conclusions

Scientific evidence unanimously recommends addressing the climate crisis within the next ten to fifteen years – the last available window of opportunity (Nature Climate Change, 2014). In this regard, besides adequate emission cuts and effective CDR approaches, a management of climate threats based also on the sound use of SG may prove necessary. But, given the complexity and contentiousness of SG, before its research and deployment can be thoroughly and safely implemented, it is extremely beneficial to understand whether this technology can be politically practicable when the time is ripe. To this end, the article maintains, it is first necessary to investigate SG's feasibility, which herein is intended as a conceptual tool for ranking states of affairs along one of the crucial dimensions relevant for their political practicability. In this perspective, SG is more feasible the less it clashes with economic, institutional and moral soft constraints. The analysis carried out shows that the degree of SG feasibility regarding economic and institutional soft constraints is high. On the contrary, its many moral challenges would make it difficult to put SG into practice at a moral cost perceived as bearable. Thus, with regards to moral soft constraints SG is insufficiently feasible. Therefore, all things considered, given the greater relative weight of moral constraints, the overall feasibility of SG is inadequate.

In light of this evidence, the article offers some entry points for lessening SG's frictions with soft constraints, especially with the highly sensitive moral ones, thereby increasingly the potential of its feasibility; on this basis, it provides policy recommendations to improve the likelihood of SG being politically practicable.

Notes

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1. For an in-depth overview see, for instance, Preston (2013), Baatz et al. (2016) and Svoboda (2017).
2. In general, it is the state of affairs scrutinized that determines the political properties that affect its political practicability. Besides feasibility, in the case of SG, desirability and – as explained in the Section on policy recommendations – distributive justice and international trust seem to be relevant.
3. In this perspective – referred to in this article as 'political practicability' – Stilgoe (2015) argues, for instance, that only a fideistic attitude toward technology would make it possible to consider SG a practicable approach. Similarly, Robock (2014) a prominent CE scholar, maintains that SG faces almost unsurmountable problems of political practicability in its last phase – deployment – given the unlikeliness of the emergence of agreed governance.
4. It is worth noting that in innovation studies SG would be a niche, the micro level of a sociotechnical system characterized by intense activity of research and trial-and-error experiments. Given these features, niches tend to stress regimes, the incumbent, stable and resistant sociotechnical structure. This literature emphasizes also the importance of the landscape, an external context of influence for both the regime and the niche composed by a 'set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems' (Geels, 2002, p. 1260). Interestingly, this composite notion of landscape is extremely similar to the notion of soft constraints employed in this article.
5. See for instance, Corry, 2017, Frumhoff and Stephens, 2018, Horton and Reynolds, 2016, Horton et al., 2018, Morrow et al., 2013, Nicholson et al., 2018, Rayner et al., 2013 and Zürn and Schäfer, 2013.
6. Talberg et al. (2018) call instead for more focused forms of SG governance.
7. Indeed, at the present stage, deployment, especially if introduced at a relatively short notice and therefore by existing institutions, would likely be the expression of the will of most powerful countries (Gardiner, 2010).
8. It is worth noting that a reduction in mitigation could arise unintentionally – and possibly be welfare improving – if SG reduced risk more than the lessened efforts in mitigation increased it. An anonymous reviewer opportunely raised this point.
9. The four substantive Oxford principles – (1) geoengineering to be regulated as a public good; (2) public participation in geoengineering decision-making; (3) disclosure of geoengineering research and open publication of results; (4) independent assessment of impacts – emphasise the 'values' on which this technology should be grounded in order not to harm the planet (Rayner et al., 2013). The fifth one is 'governance before deployment' (Rayner et al., 2013, p. 503). Starting from the Oxford principles, an article recently published (Gardiner and Fragnière, 2018) puts forward ten principles (the 'Tollgate principles') that are more demanding in terms of ethical contents for the governance of geoengineering. Despite their undisputable robustness, the broadness of the Tollgate principles seems to make their significance in relation to SG research – and more generally for addressing the moral constraints that hamper SG's overall feasibility as understood here – limited.
10. It should be noted that a paper by Morrow and Svoboda (2016) came to the same conclusion. They, in fact, argue that what mostly reduces SG's feasibility is its conflict with a 'moral permissibility' constraint.
11. For instance Bodle et al., 2013; Chhetri et al., 2018; Frumhoff and Stephens, 2018; Morrow et al., 2013; SRMGI, 2011; Schäfer et al., 2015; Zürn and Schäfer, 2013.
12. Jacobson (2018) argues instead that in 'mainstream' geoengineering science (e.g. Shepherd, 2009; and, especially, National Research Council, 2015a, 2015b) the construction of legitimacy is a strategy for justifying and promoting research.

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