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The Political Economy of Geoengineering as Plan B: Technological Rationality, Moral Hazard, and New Technology

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ABSTRACT
Geoengineering would mask and reproduce capital's contradictory needs to self-expand, on the one hand, and maintain a stable climate system, on the other. The Plan B frame, which presents geoengineering as a back-up plan to address climate change in case there is a failure to sufficiently reduce emissions (Plan A), is one means to depict this condition to the public and is a product of, and appeals to, a prevalent 'technological rationality'. Despite its misleading simplicity, logical flaws, and irrational rationality, the Plan B frame is a relatively valid representation of geoengineering in current political-economic conditions. Although the Plan B frame will gain traction because Plan A is too expensive in the short term and does not serve powerful interests, there are alternative social futures in which technology could be used to address climate change in ways that preserve the environment and reduce social risks.

KEYWORDS
Solar radiation management; stratospheric sulfate injection; framing; Frankfurt School; Marcuse; technology studies

Introduction

The media, politicians, and scientists often frame geoengineering responses to climate change as 'Plan B', in contrast to 'Plan A', that is, greenhouse gas (GHG) emissions reductions. For example, Hood (2017) states that we now have 'a plan B menu of geoengineering solutions' and Rex Tillerson, former Exxon Mobil CEO and former United States (US) Secretary of State, claims that a 'plan B has always been grounded in our beliefs around the continued evolution of technology and engineered solutions' (quoted in Lukacs 2017). Others are hesitant about framing geoengineering as Plan B. Janos Pasztor, former United Nations (UN) Assistant Secretary General on Climate Change, states,

> US politicians are talking about stopping all these [emissions reduction] activities that could make a difference and talking about geoengineering, as if it's some sort of plan B … It's not a plan B. Maybe it could buy us some time but it's not a solution. (quoted in Ellison 2018b)

Here we draw on the work of Herbert Marcuse – a member of the 'Frankfurt School', known for developing critical social theory – and his analysis of technological rationality to assess this 'Plan B' frame and embed this frame in political-economic context. We examine critical questions about the Plan B frame: Why does framing geoengineering as Plan B matter? Whose interests does it serve? What does it reveal about our society? What does it mean for other alternatives to address climate change? This introduction provides an overview of research on the framings of geoengineering; summarises geoengineering and risks associated with stratospheric aerosol injection, a prominent geoengineering strategy; and outlines the article's argument.

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'Frames', 'frame analysis', 'issue framing', and related terms are used in a variety of fields and areas of study, including sociology (e.g. Goffman 1974), communication and media studies (e.g. Scheufele 1999, Fairhurst 2005), cognitive psychology (e.g. Tversky and Kahneman 1981), public policy studies (e.g. Schön and Rein 1994), and, most prevalently, in social movements research (e.g. Benford and Snow 2000). The concepts of frame and framing and the method of frame analysis have been adopted in the environmental social sciences to, for example, examine how frames influence climate change perception and climate policy opinion (e.g. Nisbet 2009, McCright *et al.* 2016, Houser 2018); categorise the different discursive frames that make up the environmental movement (Brulle 2000); and explain how framing environmental issues in diverse ways influences the environmental policy-making process (for review, see Guber and Bosso 2013). To frame an issue is 'to select some aspects of a perceived reality and make them more salient' in order to 'promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described' (Entman 1993, p. 52).

Social scientific research has given special attention to framings of geoengineering in the media (e.g. Nerlich and Jaspal 2012, Scholte *et al.* 2013, Anshelm and Hansson 2014, Luokkanen *et al.* 2014) and scientific and policy reports (e.g. Bellamy *et al.* 2012, 2013, Sikka 2012a, Markusson 2013, Huttunen *et al.* 2015). The way geoengineering is framed matters because frames influence public perceptions of geoengineering (Corner *et al.* 2011) and are used to strengthen the case for geoengineering (Luokkanen *et al.* 2014). Geoengineering has commonly been framed as Plan B, a backup measure in the event that Plan A, emissions reductions, fails. The context and validity of the Plan B frame require special attention because Plan B is '[t]he dominant narrative surrounding geoengineering' (Corner *et al.* 2013, p. 945). Further, there was no direct counterargument to the emergency measure frame in the 'national narratives' of geoengineering in the US, UK, and Germany (Harnisch *et al.* 2015). As explained below, the Plan B frame is closely linked to the emergency measure frame, which runs as follows: society must develop/research Plan B now in the event of a future climatic emergency.

Geoengineering refers to 'a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate impacts of climate change' (Boucher *et al.* 2013). Geoengineering strategies are usually analytically separated into two categories: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). CDR aims to address climate change through taking carbon out of the atmosphere and storing them in either oceanic or terrestrial reservoirs (IPCC 2014). For example, iron fertilisation in the oceans can stimulate marine plankton growth and increase the uptake of atmospheric carbon dioxide; however, the effectiveness of fertilisation depends on the carbon falling into the deep ocean for long-term storage (Powell 2008, Royal Society 2009, Keller *et al.* 2014). A prominent CDR method bio-energy with carbon capture and storage (BECCS) is envisioned as the use of tree plantations to take carbon out of the atmosphere, burning these trees for energy, and then capturing and storing the emitted carbon underground. As Hickel (2017) argues, we are already failing to achieve Plan A (emissions reductions) even with this form of geoengineering assumed in institutionalised mitigation pathways, despite being a technology that has never been demonstrated at scale.

SRM strategies do not reduce atmospheric GHGs but instead aim to reduce global temperature increases by deflecting solar radiation. Stratospheric aerosol injection (SAI) is considered the most economical SRM strategy and is the most widely discussed geoengineering strategy overall. We are primarily concerned with SAI in this project as the Plan B frame is most often discussed in the context of SAI (Markusson *et al.* 2014, Horton 2015, Sillmann *et al.* 2015, Fragnière & Gardiner 2016). SAI was first put forth by Crutzen (2006) based on evidence from volcanic eruptions, which have provided a way to assess the effect sulphur particles in the atmosphere have on incoming solar radiation and global temperature. The Mt. Pinatubo eruption in 1991 led to dimming that cooled the earth by 0.5°C for a year (Robock *et al.* 2010). Injecting sulphur particles (sulphur dioxide, hydrogen sulphide, sulphuric acid) into the stratosphere represents an attempt to emulate this process. Sulphate aerosols can be put into the stratosphere by release from planes, balloons or from ground canons. Once in the atmosphere, the particles combine with dust and water, creating aerosols that increase atmospheric albedo. Aerosols would likely last for about one year; therefore, this strategy requires continued sulphate deposition (Keith 2013). In his 2013 book, *A Case for Climate Engineering*, Harvard scientist David Keith made a strong case for developing SAI and, with recent outdoor SAI tests, his ideas are quickly moving from theory to reality (Chen 2017).

SAI is recognised as risky by critics and advocates alike. It is unclear how SAI may affect weather patterns, especially precipitation and therefore ecological and agricultural systems (Robock 2008a). A recent modelling study supports previous results indicating that pumping sulphate aerosols into the stratosphere may result in drought in South America, Asia, and Africa (Ferraro *et al*. 2014). As stated by a leading geoengineering scientist: 'used recklessly, geoengineering could threaten billions with starvation' (Keith 2013, p. 58). Others highlight how sulphate aerosols do nothing to address ocean acidification and could exacerbate the ozone hole problem, increase acid rain and air pollution, have unknown impacts on plants and clouds, and reduce radiation for solar power – in addition to risks associated with human error, commercial control, military use, and many other possible risks (see Robock 2008b, Robock *et al*. 2009, Boucher *et al*. 2013). A central risk related to SAI is the 'termination effect': if SAI fails, falters, or cannot be maintained, temperatures could increase rapidly due to a build-up of background GHG emissions (Robock *et al*. 2010, McCusker *et al*. 2014). Despite these and other risks, many proponents for increasing geoengineering research continue to frame SAI as a necessary Plan B.

As climate change projections become direr, geoengineering is increasingly discussed as a response to climate change, and is featured in the latest Intergovernmental Panel Climate Change (IPCC) report (2013). This marked a clear shift as geoengineering moved from the fringe to the mainstream of the climate change policy debate (Hamilton 2015). Geoengineering is also receiving increasing support since the election of Donald Trump as the US President. For example, Trump's former Secretary of State Rex Tillerson refers to climate change as 'an engineering problem' and enthusiasm for geoengineering 'appears to be growing' among other high-level officials in the administration (Lukacs 2017). As the possibility of staying within 2 degrees C of pre-industrial levels is becoming increasingly unlikely, and linked to a reduction in economic growth (Kallis 2017), some scientists and policy-makers are now acknowledging that it may be necessary to employ some sort of geoengineering technologies (possibly 'negative emissions' through CDR strategies) to prevent projected warming up to 4 degrees C (Hickel 2017).

Drawing on Marcuse's theorisation of the relations between technology, rationality, and capitalism, we examine both the political-economic context of, and reasoning behind, the Plan B frame. Our arguments can be summarised as follows:

(1) Geoengineering would mask and reproduce capital's contradictory needs to self-expand, on the one hand, and maintain a stable climate system, on the other.
(2) The Plan B frame is one means to depict this condition to a society marked by one-dimensional thinking. The Plan B frame is a product of, and appeals to, a prevalent 'technological rationality' that implicitly relegates or ignores alternative social futures.
(3) Although the Plan B frame will gain traction because Plan A (emissions reductions) is too expensive in the short-term and does not serve powerful interests, there are alternative social futures in which technology could be used to address climate change in ways that preserve and enhance rather than dominate nature – at the same time reducing risks to society.

Our evaluative case against geoengineering can be interpreted as a critical political-economic account of the 'moral hazard' argument against geoengineering (see also Muraca and Neuber 2017).

In what follows, we first provide an overview of Marcuse's sociology of technology. Following, we review the literature on the prevalence and logical limitations of framing geoengineering as Plan B. Then we lay out our critique of geoengineering and the Plan B frame by analysing geoengineering in a political-economic context. We argue that SAI is a risky system-maintenance scheme and the Plan B frame is a product of an instrumental reasoning that conceals alternative social futures, alternatives that may allow society to use technology to reduce emissions while transforming what kinds of technologies are developed. We conclude with a case for Marcuse's broader relevance for the environmental social sciences.

Technology, Capitalism, and the Frankfurt School

> The industrial society which makes technology and science its own is organized for the ever-more-effective domination of man and nature, for the ever-more-effective utilization of its resources. (Herbert Marcuse 1964, p. 17)

We draw from the ideas of the first-generation Frankfurt School, particularly from Marcuse, to examine the political economy and framing of geoengineering. Writing decades before contemporary debates concerning relationships between science, technology, and the environment (for reviews, see Yearley 1997, York and Clark 2010), the Frankfurt School argues that science and technology in capitalist societies – as embedded social projects – are largely utilised to dominate the environment and human beings; however, they maintained that these institutions have the potential to be reformed in a more rational society (for review, see Gunderson 2016). What is considered progress in Western civilisation 'runs in a single strand, on the rails of the mere domination of nature' (Adorno [1963, 1969] 1998, p. 212), an instrumental rationality 'reproduced' in society and the self. The Frankfurt School views the advancement of modern science and technology as a significant development in the project of human domination over nature. Marcuse's central contribution to this thesis is his analysis of technology and technological rationality.

Marcuse ([1941] 1978, pp. 138–139) conceptualises technology broadly, as the totality of late capitalist social organisation, artefacts (instruments/machinery), as well as the modern mode of instrumental thinking. Technology is mediated by society and vice versa. Technical achievements reinforce and alter the way in which domination takes place in social relations and between society and nature and the interests and values of society are embodied in technical achievements. Technology transforms nature into a mechanical and infinitely malleable order for the aims of capital and this transformation of reality into a 'calculable order' is underpinned by a 'technological rationality', a 'pure' instrumentality incapable of formulating substantive end goals (Marcuse [1960] 1989, 1964). Marcuse is critical of modern technology and technological rationality for a number of reasons (e.g. Leiss 1972, Feenberg 1996, 2005b), two of which ground our analysis of geoengineering: (1) technology primarily serves and shaped by dominant interests that may be irrational and (2) technological rationality demotes or masks social alternatives.

Regarding the argument that technology primarily serves powerful interests, Marcuse ([1960] 1989, p. 123), like his colleagues, insists that it is naïve to conceptualise the development of modern science and its applications in isolation from the development of capitalism and, instead, that science and technology must be studied in their political-economic context. Science and technology are, in modern societies, 'bent to the requirements of capitalism' (Marcuse 1972, p. 60). Both science and capitalism, in this relationship, reduce the cosmos to a calculable and quantifiable order – to 'raw material for the expanding and exploiting administration of men and things' (Marcuse 1972, p. 62) – to be mastered for elite interests. Economic interests often shape the force behind, design of, and implementation of modern technology. Techniques and machines are conditioned by the 'presence' of ruling interests 'in' them, determining 'their number, their life span, their power, their place in life, and the need for them' (Marcuse 1969, p. 12). Feenberg (2005b, p. 105) translates Marcuse's argument into contemporary technology studies concepts: 'design embodies only a subset of the values circulating in society at any given time' and capitalism reduces the possible value-mediations of technology to those that benefit 'pecuniary interest' (see also Feenberg 2005a, p. 49, 52).[1]

Marcuse's second argument guiding our analysis is the case that technological rationality demotes or masks social alternatives. He argues that technology as a totalising 'ensemble' devoid of substantive ends creates a 'one-dimensional' society marked by 'a system of thought and behaviour which represses any values, aspirations, or ideas not in conformity with the dominant rationality' (Marcuse [1960] 1989, p. 119). Technological rationality is the common attitude of members of monopoly capitalist societies, where technical progress primarily serves large industries that 'deliver the goods'. Because the technological apparatus delivers the goods, technological rationality is characterised by compliance with what is, i.e. a passive acceptance of reality and identification with technical achievements. This compliance impedes ideas and actions that could locate, let alone usher in, a qualitatively different society. There is an inability to ask critical questions regarding domination and justice, questions deemed useless or, at best, mere opinion. Instead, the 'machine process … itself appears as the embodiment of rationality and expediency' (Marcuse [1941] 1978, p. 143). Because technological rationality reduces the world to goals of capital, it also blocks avenues for social change that could bring about a better and more ecologically sound society. In short, technological rationality reproduces the existing system and works against radical alternatives.

The purpose of formulating these arguments – that technology serves elite interests and reproduces the social order – is to help '[drive] Reason itself to recognize the extent to which it is still unreasonable' (Marcuse 1960, p. xiii). Technological rationality cannot set substantively rational aims on its own terms and has made the domination of humans and nature an end-in-itself in the service of a socially and ecologically destructive society. For Marcuse, technological rationality will remain contradictory until technics are used to free human beings from excessive toil and foster and protect the environment, rather than blindly dominate it.

Applying Marcuse to examine geoengineering and its framing leads to many questions. Is the case for geoengineering an example of Marcuse's assessment of the irrational core of a purely instrumental rationality? Have discussions about the technical means for mastering nature prevailed over the setting of substantive end goals? Is geoengineering an attempt to use technology to further the domination of nature rather than to protect the social-ecological world? How does capitalism shape the framing and development of geoengineering? We contend that Marcuse's work is highly relevant to these questions and, after examining prominent frames for geoengineering, we will return to his work to explore how, in contrast to geoengineering, science and technology could be used to address climate change in ways that preserve and enhance rather than dominate nature while at the same time reducing risks to society.

The Plan B Frame

In its simplest form, the Plan B frame presents geoengineering as a backup plan to address climate change in case there is a failure to sufficiently reduce emissions (Plan A). The frame can be thought about as part of a larger family of 'insurance' frames of geoengineering ('last resort', 'backup plan', etc.) (Fragnière and Gardiner 2016). The Plan B frame is central to the Royal Society's (2009) influential favourable assessment of geoengineering as well as by John Shepherd, who chaired the assessment, in media interactions (Nerlich and Jaspal 2012). Two other geoengineering frames are regularly used along with the Plan B frame: the 'emergency measure' and 'need for research' frames (Harnisch *et al.* 2015). The 'emergency measure' or 'argument by emergency' frame (Nerlich and Jaspal 2012) calls for geoengineering as Plan B because there may be a climatic emergency if Plan A fails (e.g. Crutzen 2006). Geoengineering research proponents have pushed back against the emergency measure frame, arguing that a more likely and rational future scenario is 'peak shaving', or implementing geoengineering strategies, such as SAI, to diminish the gravest climate change impacts while simultaneously pursuing mitigation and adaptation pathways (e.g. Keith 2013, Horton 2015). That is, geoengineering research proponents argue that geoengineering should not be understood as a *replacement* for mitigation, even if it is simplified and framed as such in the media and policy documents.

The prescription either implicit or explicit in the Plan B and emergency measure frames is a call for an immediate commitment to research on geoengineering in preparation for the climatic emergency if Plan A fails, or even to 'arm the future' to tackle climate change when Plan A fails (Gardiner 2010). Taken together, the 'story line' runs as follows:

> although risky (as mitigation is likely to fail to prevent dangerous climate change), CE [climate engineering] could be needed to prevent a climate emergency, and that research into the risks and benefits of CE is needed *now* to allow informed decisions about deployment if a climate emergency situation arises. (Harnisch *et al*. 2015, pp. 61–62)

This narrative is condensed in the Plan B frame.

The Prevalence and Problems of the Plan B Frame

Plan B and emergency measure frames are commonly found in scientific and media framings of geoengineering. In an analysis of assessments of geoengineering (see also Markusson 2013), two dominant frames are identified: (1) geoengineering as a response to insufficient mitigation (reducing emissions will not be enough to address climate change) and (2) geoengineering as a response to a climatic emergency (Bellamy *et al*. 2013, see also Bellamy *et al*. 2012). Both of these frames are regularly invoked to make the case for geoengineering as Plan B. Similarly, Sikka (2012a) critically analyses discursive frames and strategies employed by those associated with pro-geoengineering think tanks. Geoengineering proponents frequently frame geoengineering as the only possible option in the event of a catastrophic tipping point. Further, another frame discussed by Sikka lends support to Marcusean arguments articulated below: geoengineering proponents commonly justify geoengineering proposals through appeals to the market.

In an analysis of newspaper articles (see also Scholte *et al*. 2013, Luokkanen *et al*. 2014), Nerlich and Jesper (2012) find that geoengineering is framed in three 'master-metaphors': the planet as a body, a patient/addict, and, as Marcuse would predict, a machine. Underpinning these three master-metaphors is an 'argument from catastrophe', or that geoengineering will be the only option available to evade a climatic emergency, which is connected to the Plan B frame (see above). Similarly, Anshelm and Hansson (2014) show how the mass media frames geoengineering as a 'last chance to save the planet' from catastrophic climate change. More recently, however, there has been an international shift toward critical framings of geoengineering in the mass media in 2014 and 2015 (Anshelm and Hansson 2016). While we recognise that criticisms of geoengineering are becoming more common and the possibility that the Plan B frame may be 'running out of steam', the recent prevalence of Plan B frame is captured in Harnisch *et al*.'s (2015) comparative discourse analysis of expert assessments of, the mass media reports on, and political discourse surrounding geoengineering in the US, UK, and Germany. The emergency measure frame, which includes the Plan B frame in the study, is frequently found with the 'need for research' frame (for reasons described above), which, together, were the most common frames identified in US and UK media, scientific, and political discourse. Even in Germany, where scepticism of geoengineering is much higher, the emergency measure and need for research frames appears to be central to legitimating geoengineering research (Harnisch *et al*. 2015).

The Plan B frame, and related emergency frame, have been criticised on logical grounds. Fragnière and Gardiner (2016) argue that the Plan B frame is based on implicit presuppositions that are difficult to defend when explicitly scrutinised. For example, the Plan B frame implicitly presupposes that SAI is more politically feasible than mitigation. However, it may be even more difficult to create a viable governance system and agreement for SAI than it currently is for mitigation. Further, the usual prescription of the Plan B frame – that we should start geoengineering research now – is problematic for a number of reasons, including the issue of 'institutional momentum': because 'big projects that are started tend to get done. … sometimes the best time to prevent a project proceeding is before the costs are sunk and the institutions created' (Gardiner 2010, p. 289). The related emergency frame is also misleading because there is no reason to predict that SAI could prevent or counteract any of the 'tipping points' that could usher in a climate emergency (see Lenton *et al*. 2008), lessen extreme events (like heat waves), or address socioeconomic and political emergencies that may result from climate change (Sillmann *et al*. 2015, see also Horton 2015).

From a critical theoretical perspective, social structure, techno-political strategies, and patterns of thinking must be analysed in relation to one another and as a whole. Marcuse's theory of technology offers a framework that can attend to the social-structural conditions that brought about geoengineering strategies as well as the frames used to understand and legitimate these strategies. As we explain in the following section, a Marcusean framework reveals the Plan B frame as a product of the same political-economic conditions that gave birth to the geoengineering agenda.

The Political Economy of Geoengineering and the Plan B Frame

The goal of the previous section was to describe the Plan B frame and summarise its prevalence and logical limitations. The goal of this section is to place geoengineering and the Plan B frame in political-economic context. Placing the emergence of geoengineering in social context helps us to understand the Plan B frame and its limitations as well as distinguish between the concrete intentions of geoengineering researchers and what may happen to geoengineering schemes in political-economic context.

Gunderson *et al*. (2018c) identify two systemic contradictions related to climate change, both of which contextualise geoengineering. The first is a contradiction between the need to accumulate capital, on the one hand, and the destructive impacts of economic growth on the climate system, despite the fact that capital accumulation depends on a stable climate system, on the other (the 'capital-climate' contradiction). The second is a contradiction between the potential of adopting technologies that could aid in reducing emissions, on the one hand, and the ossified social relations that block this technical potential, on the other (the 'technical potential-productive relations' contradiction). The technical potential-productive relations contradiction is intimately connected to the capital-climate contradiction because the social relations that hinder the potential of making better use of 'green' technology are rooted in the private ownership of productive forces for the incessant accumulation of capital.

In the remainder of this section, we first argue that geoengineering is an attempt to conceal and reproduce, rather than address, the capital-climate contradiction and strategies like SAI are incomprehensible outside of this context. Following, we argue that the Plan B framing masks, rather than addresses, the technical potential-productive relations contradiction, and that different social conditions would nullify the geoengineering agenda as well as make better use of 'green' technologies.

Geoengineering as a System-maintenance Strategy

The capital-climate contradiction that gave rise to geoengineering strategies is also the most salient case for geoengineering, even if the argument for system maintenance (the reproduction of capitalism) is never made explicit. Geoengineering is perhaps the only climate policy instrument that attempts to overcome the capital-climate contradiction while still allowing for, and further increasing, capital accumulation. To be clear, our argument is not that the only stated rationales for geoengineering relate to system maintenance. Indeed, there are a number of equity- and justice-related justifications for SRM research (for critical review, see Flegal and Gupta 2018, p. 49ff). For example, Horton and Keith (2016) make a climate justice case for SRM research, arguing that there is a moral obligation to the global poor to pursue SRM research due to the unequal drivers and projected impacts of climate change. However, we draw from Marcuse (1964, 1972) to shape our analysis and, therefore, focus on the political-economic dimensions and economic and technological justifications for SAI. We do so because we think economic and technical cases for SAI will be considered the most relevant and valid arguments to those with the most power over policy-making. This is not meant to discredit non-economic justifications for geoengineering.[2] In terms of consequences, the concrete intentions of geoengineering scientists and ethicists may be relatively unimportant. What is more consequential, in our estimation, is what happens to geoengineering research in social, political, and economic context, a context that we think reveals strong reasons for the adoption of geoengineering as a system-maintenance strategy. We follow others who argue that geoengineering implementation is relatively plausible in capitalist societies

(Gunderson et al. 2018b), especially the US's variant of neoliberal capitalism (Ott 2018), due to social structural conditions.

Arguing that geoengineering is a risky system-maintenance strategy is not an abstract functionalist tautology. There are reasons to interpret geoengineering schemes as an explicit attempt to reproduce a contradictory social formation: (1) fossil fuel industry, climate denialist, and elite support for geoengineering research; (2) the prevalence of arguments concerning the cost-effectiveness of geoengineering; and (3) plans to use geoengineering as a money-making strategy. We discuss each point in turn.

Indicators of Support from the Fossil Fuel Industry, Climate Denialist Organisations, and the Elite

Drawing from Marcuse (1964, 1972), this section examines partial though illuminating evidence that suggests SAI could be used as a tool to protect elite interests and the requirements of capitalism. While many of those who support SAI research are scientists who are also calling for emissions reductions and cautioning against the use of geoengineering (Reynolds *et al*. 2016), scholars and journalists studying geoengineering provide limited but crucial evidence that suggests that geoengineering is supported by fossil fuel companies, the elite, and climate change deniers to preserve their current structural position and profit margins (Kintisch 2010, Hamilton 2013, Klein 2014). Hamilton's book *Earthmasters* (2013) contains some of the most convincing evidence of support from the fossil fuel industry: Canadian oil billionaire, N. Murray Edwards, who has a financial interest in developing Alberta's tar sands, invests in David Keith's company Carbon Engineering Ltd.; Royal Dutch Shell funded a study of liming the seas; a top BP scientist chaired a geoengineering meeting in 2009; and ExxonMobil employed a scientist who has contributed to government reports on geoengineering. More recently, Hamilton (2015) identifies Shell and ConocoPhillips as having invested in geoengineering. As most of this evidence is dated (2013), new studies would be useful to identify how fossil fuel companies are supporting geoengineering research and development.

While we cannot know their specific motivations and interests, a number of very wealthy individuals support techno-fixes to climate change and geoengineering in particular. Most notably, Bill Gates supports and funded technological fixes to climate change, including geoengineering, in various ways (Hamiliton 2013). Gates became the 'public face' for Mission Innovation and initiated the Breakthrough Energy Coalition to support technological solutions to climate change (Lukacs 2015). He also funded Climeworks, a Swiss company working on geoengineering (Doyle 2017). Most recently, Bill Gates helped fund the Stratospheric Controlled Perturbation Experiment in Arizona, a SAI experiment involving the launch of balloons containing up to a kilogram of aerosol particles (Chen 2017). As argued by Lukacs (2015), '[b]y his own admission, he [Gates] wants governments to lay the groundwork for a new frontier of green profit-making, then get out of the way'. While Bill Gates garners the most publicity, other elites also support and fund geoengineering strategies. For example, billionaire Richard Branson offered a $25 million prize for the best plan to extract carbon from the atmosphere (Hamilton 2013).

Lastly, certain conservative groups continue to deny climate change while simultaneously supporting geoengineering (Hamilton 2013, Klein 2014). For example, the Heartland Institute rejects climate change but supports geoengineering (Klein 2014). This has also been the case for the American Enterprise Institute and the Hoover Institution, who challenged climate science but now promote geoengineering (Ellison 2018a). While Reynolds *et al*. (2016) state that only 'a handful of actors on the political right have indeed voiced support for SRM' this number seems to be rapidly growing. Recently, a rising number of conservative politicians who denied climate change have come out in support of geoengineering including Lamar Smith, Randy Weber, Newt Gingrich, and attorney David Schnare – a Trump appointee (Bajak 2018, Ellison 2018a). As explained by Kintisch (2010), geoengineering offers a middle ground for climate change deniers to concede that the world is getting hotter but perpetuate the myth that this is not primarily caused by human activity, or more importantly, fossil fuels. To counter warming they can propose a low–cost geoengineering strategy while, at the same time, criticising opponents for opposing what they claim will be a quick and effective solution. This approach, however, exaggerates the simplicity and effectiveness of geoengineering approaches. Klein (2011, 2014) argues that conservatives realise that climate change represents a serious threat to free market capitalism and they have therefore fiercely opposed its existence to maintain the current system. With increasing pressure to admit the reality of climate change, geoengineering offers a way forward that does not threaten the supremacy of capitalism (Klein 2014). In addition, as argued by Hickel (2017), it has become increasingly clear that the emissions reductions necessary to stay within the 2 degrees C target would require a contraction in economic growth, making technological approaches much more favourable for those who benefit from the current system.

While we have identified and presented evidence that the fossil fuel industry, elites, and climate change denialist organisations like the Heartland Institute, and right-wing politicians – all actors who are well-known for their vested interests in the continuation of fossil fuel extraction and consumption – embrace geoengineering, more research is needed to further and empirically illustrate the degree and breadth of support among fossil fuel companies, wealthy individuals and groups, and conservative groups who have denied climate change.

The Appeal to Cost-effectiveness

Economic reasoning has dominated arguments in support of geoengineering from early on, even among scientists. According to Crutzen (2006), stratospheric sulphate approaches would cost about $25–50 billion per year, over 100 times less expensive than emissions reduction (Keith 2010). Robock *et al.* (2009) estimate that injecting 1 TgS of sulphuric gas into the stratosphere each year would cost between $0.225 and 30 billion and the Royal Society (2009) estimates it would cost $10 billion to inject 1–5 million tons of stratospheric aerosols each year.

McClellan *et al.* (2012) estimate the costs of injecting between 1and 5 million metric tons of reflective aerosols into the stratosphere to be between $1 and 8 billion. These estimates are consistently lower than estimates for global emissions reduction. In fact, they are so low that countries could economically implement them unilaterally (Harding and Moreno-Cruz 2016). As the two leading scientists and dominant voices in current geoengineering discussions, Caldeira and Keith (2010 , p. 57) put it, ‘geoengineering could be the only affordable and fast-acting option to avoid a global catastrophe’. Compared to other approaches, SAI is especially being touted as a cheap approach to protect against the impacts of climate change (Keith 2013). David Keith (2013, p. x) calls SRM ‘a cheap tool that could green the world’.

Some economists have been very explicit about geoengineering being the most rational choice to address climate change. A panel of five leading economists organised by Bjorn Lomborg, including three Nobel Prize winners, ranked the best ways to address climate change: increasing cloud reflection was ranked first with reducing carbon emissions ranked twelfth (Kintisch 2010). Economists Bickel and Lane (2009) conclude that the benefits outweigh the costs of geoengineering: every dollar spent on sulphate aerosol injection will yield $25. The authors of the book *Superfreakonomics,* a popular book on economics for the general public, also argue that lowering carbon emissions is too costly and too complex in comparison to SAI – a cheaper and simpler plan (Levitt and Dubner 2011). In economic terms, geoengineering represents a lower cost alternative to reducing emissions.

While geoengineering proponents claim that aggressively reducing emissions would have devastating impacts on the global economy, the latest section of the IPCC report (2014) reveals that losses would likely entail a relatively small reduction in economic growth over time. They also clearly illustrate how waiting longer to implement mitigation actions will result in greater economic losses in the future. The IPCC report draws from numerous studies that have found that reducing emissions can be done at a relatively low cost now, especially when compared to delayed action. However, geoengineering advocates claim that through technology they can not only address the impacts of climate change but also maintain the current trajectory of economic growth. As discussed by Harding and Moreno-Cruz (2016), many estimates of SAI have underestimated costs (especially indirect costs) and cannot account for unknown tipping points, catastrophic events, and the ‘termination effect’ where upon cessation of SAI temperature increases could resume at a rapid pace. Reynolds *et al.* (2016) argue that cost estimates of SAI, and SRM in general, overlook many factors including costs to compensate countries who experience negative impacts.

A New Accumulation Strategy?

While it is too soon to tell how profitable SAI technologies will be, if at all, scholars such as Buck (2012), Hamilton (2013, 2015), and Klein (2014) suggest that it is reasonable to anticipate that geoengineering could, in the future, represent a way to address climate change while increasing profits and economic growth. Extensive funds have already been invested in geoengineering technology and entrepreneurs and companies have patented SAI technologies in hopes of future returns on their investments (Hamilton 2013, Caldeira 2015). In 2015, Hamilton counted 28 patents issued for geoengineering technologies. An SAI example is Intellectual Ventures' StratoShield that uses hoses suspended by blimps to spray aerosols into the atmosphere. Hamilton (2015) states, 'some commercial outfits can envisage a desperate world paying them princely sums for access to the technology'. Ken Caldeira (2015) a prominent climate scientist explains how, despite no current demand, geoengineering entrepreneurs could be poised to make money in the future:

> there are no existing commercial drivers of this activity, it is hard to see how to make much money from these ideas. Nevertheless, there has been some activity in this area by for-profit corporations … The longer we take to transform our energy system so it no longer uses the sky as a waste dump, the more likely that we will have to rely on climate intervention technologies. Perhaps then there will be greater potential to profit from investments in these technologies.

Buck (2012, p. 261) discusses geoengineering as a possible 'crisis-as-opportunity for capitalism'. Drawing from Moore (2011), she highlights how financialisation and geoengineering could together support a new surge in economic growth: '[i]n theory, successful financialization of carbon, together with geoengineering … could surpass the status quo to become a force for innovation, generating new technologies and new capital accumulation' (Buck 2012, p. 261). Private geoengineering investments in SAI could quickly profit from the responses of the energy, aerospace, and defence sectors to a climate-related crisis (Buck 2012). Lastly, Buck (2012) also acknowledges that geoengineering could remain a relatively small (and not so lucrative) business where capitalist rationality is not a major driver.

Regarding solar geoengineering specifically, Reynolds *et al.* (2018, p. 3) examine potential profitability and expect that a moderate-sized and profitable business could emerge, stating:

> there might be substantial opportunities to profit from these technologies. We believe that large-scale research, development, and potential implementation of solar geoengineering are most likely to assume a monopsony (or oligopsony) procurement structure, as it has in the national defense and transportation sectors … This implies that providing technology, materials, and services could be a moderately sized industry generating significant profits.

Reynolds *et al.* (2018) explain that the recoupment on investments in solar geoengineering largely relies on policies governing intellectual property. Currently, government and individual philanthropists are funding most solar geoengineering research, not investors, and it is being carried out mostly by universities, not private firms. However, the authors expect that commercial actors will soon have an interest in solar geoengineering (Reynolds *et al.* 2018) especially as solar climate engineering become 'more certain and less contentious' (Reynolds *et al.* 2017).

Long and Scott (2013) raise concerns about the vested interests in geoengineering research, highlighting how individuals and companies who have invested in geoengineering technologies may try to manipulate decision-making processes in order to make money. For example, companies who wish to sell carbon credits through iron fertilisation have conducted rogue experiments without government permission (Long and Scott 2013). In 2012, Russ George was labelled a 'rogue geoengineer' after breaking international rules by dumping 100 tonnes of iron sulphate into the Pacific Ocean (Lukacs 2012). In addition, companies may suppress studies with findings contrary to their best interests, use questionable methods, or misrepresent information (Long and Scott 2013). Long and Scott (2013) also suggest that geoengineering could become an industry similar to biotechnology where companies advertise humanitarian goals, while profiting from innovations that may pose serious risks to society. Alternatively, as the future remains unknown, SAI and other geoengineering technologies could remain a fringe sector of the economy and humanitarian goals could direct implementation (Buck 2012). However, parties with vested interests in continuing to make money in the current fossil fuel dependent system have already shown they are willing to invest significant resources to preserve this system (McCright and Dunlap 2010, Klein 2014).

The case for geoengineering stands to reinforce current economic and power relationships, illustrating Marcuse's critique of technology as a means to maintain dominant interests. Marcuse argues that to understand technology we must also study the political and economic context of technological development and use. In many cases, technological development and use are associated with capital accumulation (Marcuse 1972, p. 60). Powerful economic interests shape the design and use of technology and it remains impossible to separate these interests from the value-mediations of the technology (Feenberg 2005b, p. 105, see also 2005a, p. 49, 52). This is clear in the case of geoengineering.

Plan B, 'Moral Hazard', and New Technology

When geoengineering is interpreted as a risky system-maintenance strategy that emerged to avoid the expense and structural changes required to achieve significant emissions reductions, the Plan B frame acquires a degree of *validity*. In other words, in a contradictory social formation, developing potentially catastrophic strategies to reproduce the status quo appeals to reason, a historically contingent form of reason Marcuse dubs 'technological rationality'. Above, we explicated Marcuse's argument that technological rationality is the common form of reason in contemporary societies and is characterised by a passive and conformist acceptance of reality and identification with technical achievements. The Plan B frame's strength derives from two assumptions: the existing social order is unchangeable and technology can successfully reproduce the social order. Both assumptions are consistent with Marcuse's notion of technological rationality. Further, both assumptions demand critical attention. A product of technological rationality, the Plan B frame implicitly demotes alternative social futures in which technology could be used to help reduce emissions and social and environmental risks.

The 'moral hazard' argument is a common case against geoengineering research, which runs as follows: 'major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature conviction that geoengineering has provided 'insurance' against climate change' (Royal Society 2009, p. 39). Because society is 'insured' by geoengineering research and that the hazards associated with climate change may be reduced by geoengineering, societies are (1) less likely to implement emissions reduction strategies, (2) invest fewer resources in adaptation strategies (Royal Society 2009, pp. 44–45), and/or (3) increase emissions above business as usual projections (Hale 2012).

A critical political-economic position casts the moral hazard argument in a different light: because the system-maintenance potential of geoengineering reproduces the current social order, as argued in above, the Plan B frame redirects attention from alternative social futures that have the potential to significantly reduce carbon emissions. A similar argument is found in Muraca and Neuber (2017), who begin with the case that growth-dependent economies are unsustainable in the long-run. From here, they develop a version of the moral hazard case against geoengineering: in a growth-dependent society geoengineering deployment will create trade-offs with mitigation efforts and delay the transition to a society that reduces material and energy throughput. While our interpretation of the potential for 'moral hazard' is different than his, we agree with Stephen M. Gardiner (2010) that substantive questions about geoengineering necessitate an examination of background social, political, and economic conditions as well as the often unquestioned 'evaluative assumptions' of proponents.

The same background conditions and form of rationality that caused climate change are the same that made the geoengineering agenda possible: a growth-dependent and resource-intensive economy that serves powerful interests legitimated by the modern form of technological rationality, as elucidated by Marcuse. The Plan B frame, a product of technological reason, masks these background conditions, thereby making problematic assumptions about society, technology, and alternative social futures. For example, support from vested interests and conservative movements (see above) indicate that, as geoengineering efforts ramp up, efforts to address carbon emissions will subside. This reflects the argument that the Plan B frame itself is a misleading and deceptive oversimplification that tends to close off important and complex discussions about ethics and alternatives (Scott 2012, Fragnière and Gardiner 2016). While Hale (2012) is critical of the ambiguity and vagueness of common formulations of the moral hazard argument, it is worth remembering that the primary policy mechanism of the Kyoto Protocol (emissions trading) effectively redirected intellectual and financial resources from innovations and social changes that have the potential to actually reduce emissions (Lohmann 2005).

If Marcuse is right about the nature and prevalence of modern technological rationality, we can predict that framing geoengineering as Plan B will increase the likelihood of policy-makers, scientists, and the public taking geoengineering seriously, and why more substantive and even radical alternatives will not. Marcuse maintains that in a one-dimensional society, where technical achievements primarily serve large industries that 'deliver the goods' – and, in this case, deliver the solutions – there is a tendency to identify with the system and dominant rationality. This is what Marcuse ([1941] 1978, p. 143) calls the 'matter of factness' attitude that inhibits forms of thinking and acting that could create a qualitatively different social formation. In the case of geoengineering, it not only fits the dominant rationality and social order, but simultaneously excludes alternative paths that lay outside both. This is especially true when geoengineering is depicted by the Plan B frame. Framing SAI as Plan B implicitly ignores a number of policy options. As Fragnière and Gardiner (2016) put it:

> [f]irst, there are many important policy options beyond mitigation and geoengineering (e.g. global reconstruction funds, economic retrenchment, population measures). Second, even within the category of 'geoengineering', many different kinds of technologies might be considered (e.g. marine cloud brightening, direct air capture, BECCS, space mirrors). Third, there are also multiple possible realizations of each specific kind of technology. … Fourth, there are numerous ways to combine particular technologies with other policy measures, such as mitigation and adaptation, and multiple forms of these measures.

Geoengineering is a product of a society very much aware that large-scale changes must occur to reduce GHG emissions (Plan A), but remains incapable or unwilling to make the necessary *social-structural* changes. Just as technical efforts to prevent an atomic catastrophe during the Cold War 'overshadowed' public examination of the root causes and solutions (Marcuse 1964, p. ix), so too these technical geoengineering efforts overshadow the underlying changes needed to prevent an environmental catastrophe. The 'insurance' of geoengineering schemes (Plan B) would keep the social order in place unscathed, for now.

The case for geoengineering outlined above is rooted in a 'pregiven reality': an ecologically destructive social formation likely incapable of overcoming the capital-climate contradiction. Geoengineering seems incomprehensible outside of this context. Further, the models and techniques put forth by geoengineering are not simply ecologically and socially risky, they are, in line with Marcuse's theory of technological rationality, rooted in a vision of a nature as a set of passive resources that can be fully controlled in line with the demands of capital. Indeed, Marcuse's theory not only helps to contextualise the social-structural basis of the Plan B frame, but also helps understand the prevalence of technological and economic justifications for geoengineering (see Gunderson *et al.* 2018b). For example, various metaphors used to frame geoengineering 'can all be related to one conceptual master metaphor or master frame according to which the earth is a machine or cybernetic system (car, heating system, computer) that is broken but can be fixed' (Nerlich and Jespal 2012, p. 141) and geoengineering proponents have 'focused on a single operational criterion (market efficiency, the economy) at the expense of all others' (Sikka 2012a, p. 172).

Feenberg (2005b, p. 98) argues that modern 'technology cannot simply be "used" to realise radical ends. What sense would it make to try to turn the assembly line into a scene of self-expression, or to broadcast propaganda for free thought?' Indeed, what sense would it make to inject millions of tons of sulphate aerosols into the stratosphere in a society capable of casting off growth-dependence, organising production to meet needs, and interacting with the biophysical world in non-destructive ways? Technological rationality is still irrational when used to serve a destructive society. Seriously addressing climate change remains futile without transforming the social order that requires schemes like SAI to continue the simultaneously instrumentally rational and irrational, 'frantic development of productivity, conquest of nature, [and] enlargement of the mass of goods' (Marcuse [1964] 1968, p. 207). Marcuse would view geoengineering as an inept – and, of course, highly risky – means to solve ecological problems through the same instrumentality that helped cause them.

In addition to offering a critical examination of technological solutions, Marcuse's work also provides insights on how science and technology may be used to offer alternative and non-destructive outcomes. There is no reason to believe we can, or should want to, do away with the technological mediation of human-nature relations. Marcuse, sometimes wrongly framed as a technophobic thinker (Feenberg 1998), calls anti-technological ideas 'propaganda' that '[serve] to teach men distrust of the potential instruments that could liberate them' (Marcuse [1941] 1978, p. 160). He claims that the

> 'liberation of nature' cannot mean returning to a pre-technological stage, but advancing to the use of the achievements of technological civilization for freeing man and nature from the destructive abuse of science and technology in the service of exploitation. (Marcuse 1972, p. 60; see also 1964, p. 238)

However, the common attitude that is taken up toward the biophysical world and the way it is appropriated must change in fundamental ways, requiring significant changes in social systems. His contention that human beings must transform the organisation and *purpose* of their social formations in line with *substantive* goals without compromising the health of the natural environment is an empirically and theoretically defensible claim.

Marcuse recognises the liberatory potential of technology that is constrained in capitalist societies. Technology has the potential to free human beings from excessive toil, which he considers the 'ultimate purpose' of technology. Further, he is convinced that the mastery and exploitation of human beings and nature were interrelated and, thus, to build a better society, both would need to be liberated from a technological rationality embedded in vested interests and the profit motive. As Agger (1976, p. 168) put it, '[b]y damaging nature, technical rationality damages the human spirit'. Marcuse argues that humanity would need to develop a qualitatively different relationship with nature to unleash this potential, which he called an 'aesthetic ethos' or 'the new sensibility' (especially see Marcuse 1969, 1972). Drawing from the early Marx ([1844] 1964, pp. 139f, 181), Marcuse argues that such an ethos could recognise nature as a 'subject-object', making the human use of nature in a rational society qualitatively different from capitalism's: 'its "human appropriation" would be nonviolent, nondestructive: oriented on the life-enhancing, sensuous, aesthetic qualities inherent in nature' (Marcuse 1972, p. 67; see also 1955, ch. 9).

Marcuse proposes a distinction between a repressive mastery and liberating mastery of nature, the latter 'involves the reduction of misery, violence, and cruelty' that follows the development of a new aesthetic attitude (Marcuse 1964, p. 236). As a social-historical human activity, Marcuse controversially claims a new science and technology would necessarily follow the aesthetic attitude toward nature.[3] A science and technology that sought to preserve and enhance life rather than dominate and destroy it.

> For freedom indeed depends largely on technical progress, on the advancement of science. But this fact easily obscures the essential precondition: in order to become vehicles of freedom, science and technology would have to change their present direction and goals; they would have to be reconstructed in accord with a new sensibility – the demands of the life instincts. (Marcuse 1969, p. 19)

Thus, any radical change in values, science, and technology is dependent upon a radically different social order.

Applying these ideas to climate change, instead of using technology for geoengineering and the continuation of projects to dominate nature, technology could be used to support strategies to reduce emissions. Marcuse opens up the possibility for a new, 'aesthetic ethos' that may *direct* the purpose of technology and, thus, the types of technology designed, developed, and adopted. The 'new sensibility' may direct which technologies are developed and adopted if the primary goal is to reduce emissions and improve social and ecological conditions, not to accumulate capital. These would likely include innovations in wind and solar energy as well as technologies that support short- and long-distance public transportation using minimal resources. But social transformation is necessary for these and related technologies to help reduce emissions (e.g. Gunderson *et al.* 2018a). For example, due to social-structural drivers, there is growing evidence that alternative energy substitutes for fossil fuel-generated energy may not result in a one-to-one substitute, and may even increase total energy use (York 2012, 2016).

Many on the left continue to support the societal transformation needed to achieve Plan A. Naomi Klein (2011) argues that climate change 'demands a new civilizational paradigm, one grounded not in dominance over nature but in respect of natural cycles of renewal – and acutely sensitive to natural limits, including the limits of human intelligence' (see also Klein 2014). She outlines specific actions to reduce emissions that, in contrast to geoengineering, would require increased state intervention and restricting market liberalism. She highlights six key steps: (1) revitalise public infrastructure and transportation for efficiency and low emissions, (2) economic planning to shift economic activities and jobs to low impact activities, (3) regulate corporations to reduce emissions, (4) restrict international trade so countries are responsible for their own pollution, (5) curb consumption and materialist growth imperatives, and (6) tax the rich and polluters to pay for needed changes. Given Klein's and other progressive's ideas about what is needed to address climate change, it is not surprising that many of the groups supporting geoengineering, though not all, are those protecting oil companies, the wealthy, and free market ideologies. In an alternative social order, technology can be applied to create new public infrastructure and transportation and to reduce production and consumption. In short, technology can be used in harmony with nature to reduce the use of fossil fuels and reduce emissions and could be applied to support the needed behavioural and societal changes required to address climate change. This can be contrasted with the development of risky technologies to reproduce an ecologically destructive social order.

To summarise this central yet complex section: after outlining systemic contradictions necessary for contextualising the emergence of geoengineering and arguing that geoengineering is a risky system-maintenance strategy, this subsection makes the case that the Plan B frame demotes alternative social futures in which technology could be used to reduce emissions and social and environmental risks. Like geoengineering strategies, the Plan B frame is a product of, and appeals to, technological rationality. Drawing on Marcuse's conception of a 'new technology', we briefly argue that a substantively rational society could use and direct technology for more rational ends, which would shape the design of new technologies as well as the use of already existing 'green' technologies.

Conclusion

As geoengineering continues to be explored, the public will be further exposed to different framings of geoengineering to support arguments for or against its development and deployment. In recent years, geoengineering has increasingly made news headlines framed as Plan B - the only solution left after having missed our chance for Plan A and our only remaining hope to avoid catastrophe and survive (e.g. Johnston 2017, Gohd 2017). However, others reply that it is a frightening and dangerous endeavour that serves to further the interests of a few at the expense of the many (e.g. Sharping 2017, Bajak 2018, Sullivan 2018). Some will likely be persuaded by the arguments concerning the cost-effectiveness and possible profitability of geoengineering. Others may be lured by the promise of the ultimate techno-fix. Portrayed as a means to control nature, geoengineering may seem like the ultimate techno-scientific achievement and the rational way forward. As put by Hamilton (2013, p. 174): 'technologies gather added political momentum because we live in societies predisposed to seek technological answers to social problems'. Finally, many more may be attracted to geoengineering because it envisions a pathway that maintains the current social order.

As we illustrate, the Plan B frame can be used to depict the system-maintenance potential of geoengineering: addressing climate change without going about making the structural changes necessary to reduce emissions. Drawing from Marcuse, we examine geoengineering as a climate change response that would reproduce the contradictory relationship between capital accumulation and climate stability. Despite an array of rationales for its use, SAI does not involve transcending or moving beyond the existing social order; it ultimately maintains it. It preserves the image of nature as a 'calculable order' that can be fully mastered. The Plan B frame is both a product of, and an appeal to, 'technological rationality'.

In addition to providing a fruitful framework for understanding the emergence and framing of geoengineering, Marcuse's theory of technological rationality's implications for the environmental social sciences stems from his assertion that relating to living structures in entirely instrumental ways is paradoxically antithetical to the wellbeing of the environment. Theories and political programmes that claim technological innovation *within a capitalist social formation* will fundamentally improve society's relationship with nature are an outgrowth of technological rationality; a 'greener' version of which is logically contradictory from a critical theoretical perspective. Marcuse would see the calls of environmental techno-optimists as an inept means to solve environmental crises through the same institutions that caused them.

We agree with others (York and Clark 2010, Gould 2015), that science and technology are embedded social projects that can be used to serve more desirable ends in a more rational society and that technology, technique, and machines are not repressive *per se*, but only due to the 'presence' of ruling interests 'in' them, determining 'their number, their life span, their power, their place in life, and the need for them' (Marcuse 1969, p. 12). Marcuse (e.g. [1960] 1989, pp. 123, 127) adds to this framework, with the argument that technologies – even individual artefacts – are not neutral objects. Some technologies embody the irrational and destructive values of the society that created them. What Marcuse's theory of technology reveals is that the very structure and operation of science and technology, not just their application or use, has the potential to change in a new society. A new technology, requiring a change in our ethos and liberated from the profit motive and pure instrumentality, could protect and foster nature rather than dominate it. Society would have the opportunity to set new substantive *goals*, which would also alter the creation, use, and our relationship with technologies (Marcuse 1964, p. 232). Such an orientation would steer society away from implementing geoengineering as a means to address climate change and would instead promote alternatives aimed at fostering social development and environmental health.

As argued by Gunderson *et al.* (2018a), social alternatives to address climate change could use technology with the explicit goals of reducing emissions and protecting ecological and social wellbeing. This would entail living within planetary boundaries, rather than attempting to change them, and would include using renewable energy sources *and* reducing overall energy and material use through social-structural changes. However, given that policies continue to prioritise economic growth, this transformation would require a strong social movement, an unlikely feat due to a lack of political and social organisation on the Left coupled with the difficulty of envisioning a social order *not* structured around increasing throughput to accumulate capital. The framing of geoengineering as a solution that does not require social transformation makes this movement even less likely. The Plan B frame suggests that society can avoid social-structural change and that society can continue to increase rates of production and consumption. It makes it easier to cast aside social alternatives capable of deep emissions reductions. We anticipate that SAI and other forms of geoengineering that maintain current structures and priorities will be increasingly debated and developed as reaching emissions goals seem progressively impossible and inconvenient and, if a social alternative is not pursued, deployed in response dangerous climate change. Despite its misleading simplicity, logical flaws, and irrational rationality, the Plan B frame is a relatively valid representation of geoengineering in current political-economic conditions.

Notes

1. For an enlightening take on geoengineering governance drawing from Feenberg's critical theory of technology, see Sikka (2012b).
2. However, it is worth noting that even the equity-based justifications for SRM research tend to adopt a 'expert-driven, outcome-oriented, and risk-based understanding of equity' (Flegal and Gupta 2018, p. 56), or, as Marcuse would put it, must amend the concept of justice to fit the one-dimensional logic of technological reason.
3. Marcuse's notion of a new science and technology is often discussed alongside Habermas' ([1968] 1970) criticisms. This has been written about extensively elsewhere (e.g. Agger, 1976, Alford, 1985, Feenberg, 1996, Vogel, 1996, ch. 5).

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