Can we have it both ways? On potential trade-offs between mitigation and Solar Radiation Management

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Abstract

Many in the discourse on climate engineering agree that if deployment of Solar Radiation Management (SRM) technologies is ever permissible, then it must be accompanied by far-reaching mitigation of greenhouse gas (GHG) emissions. This raises the question of if and how both strategies interact. Although raised in many publications, there are surprisingly few detailed investigations of this important issue. The paper aims at contributing to closing this research gap by (i) reconstructing moral hazard claims to clarify their aim, (ii) offering one specific normative justification for far-reaching mitigation and (iii) investigating in greater detail different mechanisms potentially causing a trade-off between mitigation and SRM. I conclude that the empirical evidence questioning the trade-off hypothesis is inconclusive. Moreover, theoretical reflections as well as economic model studies point to a trade-off. In our current epistemic situation these findings must be taken seriously. They caution against researching and developing SRM technologies before measures to avoid or minimize a trade-off are implemented.

Keywords: Solar Radiation Management, Mitigation, Moral Hazard, Climate Engineering, Trade-Off

1. Introduction

Climate Engineering (CE) technologies are commonly classified into methods to remove carbon dioxide from the atmosphere (Carbon Dioxide Removal, CDR) and methods to alter the radiation budget of the earth by means other than reducing atmospheric GHG concentrations (Solar Radiation Management, SRM). The different technologies subsumed under CE vary greatly in their risk profiles. While some CDR methods have few risks and are even employed within nature conservation projects (such as small-scale afforestation and renaturation of swamps), large-scale methods to reflect incoming solar radiation are associated with considerable risks. At the same time, some SRM technologies would be highly effective in rapidly lowering global mean temperature. These two aspects cause profound disagreement about their role in combating climate change.

Due to the failure of global mitigation policies so far and the potential effectiveness of large-scale SRM in terms of countering a rise in temperature, an increasing number of commentators argue that SRM must be researched immediately to get a better idea of the opportunities and hazards associated with it (most notably Keith et al., 2010).[1]

One argument warning against negative side-effects of such research is the so-called Moral-Hazard-Argument, which claims that either the deployment or the prospect of deployment of SRM will undermine mitigation efforts. While it is one of the most oft-cited objections to SRM (cf. Rickels et al., 2011: 24) it is regularly dismissed by those advocating extensive research on CDR and SRM (e.g. Blackstock et al., 2009: VI). Although the issue is raised in many publications, there are surprisingly few detailed investigations of this supposedly important argument (recent exceptions are Lin 2013, Reynolds 2014, and Morrow 2014). The paper aims at contributing to closing this research gap. I will (i) reconstruct and discuss the argument to clarify its aim, (ii) show why it is highly relevant for the current debate, and (iii) investigate in much greater detail different mechanisms affecting the relationship between mitigation and SRM. To this end, I will – among others – highlight the intergenerational component of the problem and will specify which agents might actually make trade-off decisions.

Before moving on, let me briefly mention three assumptions on which the paper is based. First, rigorous mitigation, that is the reduction of anthropogenic GHG emissions, is still able to prevent catastrophic climate change – and even 'dangerous' climate change if emissions are reduced both immediately and substantially (cf. IPCC, 2014: 23-28). Second, atmospheric GHG concentrations cannot be reduced by means of CDR technologies alone while GHG emissions remain high or continue to rise.[2] Third, moving towards a low-carbon society is a realistic *scenario*, meaning that such development is technologically, economically, as well as politically possible. To put it the other way around: if one is convinced that robust mitigation will not take place anyway, the argument of this paper is largely pointless. This, however, is a far-reaching and problematic assumption that is not even shared by proponents of SRM

[1] The most prominent SRM technology is to inject sulphate-aerosols into the upper atmosphere, as proposed by Crutzen (2006). A possible alternative is manipulating the albedo of clouds. To date, there is only little knowledge of this option (but see the very recent contributions on marine cloud brightening in Philosophical Transactions of the Royal Society A, vol. 372, issue 2031). Early research suggest that marine cloud brightening exhibits characteristics similar to aerosol injections (highly effective in lowering global mean temperatures, possible termination problem, considerable side-effects, modest deployment costs) (Aswathy et al., 2014). This paper is based on the assumption that all relevant SRM technologies exhibit these features.

[2] Current research suggests that several large-scale CDR measures are either ineffective in lowering global temperatures (afforestation, ocean fertilisation, ocean alkalinisation) or are associated with risks similar to those of SRM (ocean upwelling) (Keller et al. 2014).

research (cf. section 3). To not seriously mitigate is a deeply unjust course of action – whatever else is done. Moreover, the assumption overlooks (i) various first steps towards a low carbon-economy that have already been taken and (ii) the substantial benefits associated with the transformation (cf. WGBU, 2011; see also section 6).

2. The Trade-Off-Argument

The key concern of the Moral-Hazard-Argument is that simply researching into climate engineering and the prospect of a technical solution to the climate problem could deter government and private stakeholders from carrying out (more or less painful) mitigation measures (Rickels et al., 2011: 24; Preston, 2013: 3). Hale has prominently argued that moral hazard claims are ambiguous and vague (2012). Although I disagree with part of his analysis, he is right that the moral hazard terminology is unhelpful (ibid: 130).[3] Rather, the moral hazard claim as stated here describes the phenomenon that introducing SRM will, either inevitably or likely, lead to less mitigation. Such a phenomenon can be adequately captured by the term 'trade-off'. I will therefore avoid the moral hazard terminology and refer to a trade-off between mitigation and SRM instead. Based on the above statement, the trade-off premise can be stated as follows:

P(TO): If SRM is researched, it will (likely) reduce mitigation efforts.

Note that without the 'likely' the premise is stronger and clearer. Including the likely weakens the premise but increases its plausibility due to the uncertainty surrounding the issue. I will return to this in section 7.

The idea behind P(TO) is that if it is believed that SRM allows for counteracting the disastrous effects of climate change at comparatively modest costs, might not be willing anymore to avoid these very effects by far-reaching mitigation efforts (cf. Burns, 2011: 51). Due to the risks and uncertainties associated with SRM, important reasons to mitigate may remain. But the fact that societies as well as humanity as a whole may have good reason *not* to

[3] Moral hazard is a term taken from the insurance industry, and SRM is often presented as an "insurance policy" (e.g. Moreno-Cruz and Keith, 2012) but it should be noted that insurance schemes and CE are not analogous: If B chooses to buy insurance for a certain kind of her risky behavior, this is different from B performing risky action A that generates benefits (largely accruing to her) and risks (partially accruing to her, mostly to others) and additionally performs action C which avoids most of the risk she faces while generating additional risks for others. Taking normative individualism seriously means that one must disaggregate the consequences of actions rather than claiming that SRM should be seen as an insurance policy for humanity. This is not meant to provide a reason against SRM; my sole aim is to point out that the insurance analogy is misleading (see also Lin, 2013: 678).

lessen mitigation efforts, does not militate against P(TO). As plausible as the reasons *against* less mitigation might be from the point of view of a prudential actor called humanity, they might be hardly plausible from the point of view of the many individual present-day actors and lobbies – or may simply be overlooked. To the extent that SRM creates long-term risks or spatially disparate risks, specific actors may (think that they) have good reasons to mitigate less. That is to say, the real question is not so much whether 'humanity' has reasons to do less mitigation but rather how SRM research will impact on today's multiple decision-makers like companies, governments, etc. This has not been investigated in any detail so far (but see exceptions above).

Moreover, P(TO) is an empirical premise. On its own, it has no implication for what should be done regarding SRM (cf. Morrow, 2014: 2). This is different if less mitigation is considered to be problematic. That is, in order to reach any normatively meaningful conclusion, P(TO) must be combined with a normative judgment that offers a reason why less mitigation is problematic. To this I will now turn.

3. Justifying the importance of far-reaching mitigation

It is often stated that researching/employing SRM should be no reason to reduce mitigation efforts (cf. e.g. Keith et al., 2010; Blackstock and Long, 2010; Victor et al., 2009). For instance, Barrett et al. recently said that:

> 'The many problems with geoengineering […] suggest that contemplation of geoengineering does little to diminish the need to address the root causes of climate change. If anything, the prospect of geoengineering should strengthen resolve to tackle climate change by limiting atmospheric concentrations of GHGs' (2014: 529).

There are different ways to justify this and related claims. In the following, I will offer one specific justification for the position that far-reaching mitigation is morally obligatory. The argument developed here is new and links mitigation with potential SRM deployment. If convincing, P(TO) substantially gains in significance – and vice versa.[4]

If the deployment of an SRM scheme is stopped while atmospheric GHG concentration levels are (very) high, the global mean temperature would rise dramatically. McCusker et al. calculate that if a scheme is employed for 50 years or longer, temperatures will rise with a rate

[4] Although the claim defended in this section can be found in many contributions to the debate, it is usually stated without a robust justification.

between 0.6 and 2°C per decade (depending on climate sensitivity) in the first twenty years after its cessation (2014). These results are consistent with those of other studies (e.g. Ross and Matthews 2009; Jones et al. 2013; Izrael et al. 2014; Aswathy et al., 2014) and show that unprecedented and very dangerous warming rates would follow if SRM is stopped and GHG concentrations are high. This is the well-known termination problem. At the same time, SRM technologies are accompanied by other uncertainties and risks.[5] Against this background, William Burns (2011) and Konrad Ott (2012) argued that the deployment of large-scale SRM technologies might put future generations in a dilemma of either terminating deployment and facing a rapid rise in global temperature or coping with unforeseen catastrophic impacts of the technology. This so called Dilemma-Argument roughly consists of three key premises:

(P1): An SRM pathway might result in a moral dilemma.

(P2): A pathway that might result in a moral dilemma ought not to be adopted if alternative pathways are available that will not result in such a moral dilemma.

(P3): Non-SRM pathways that will not result in a moral dilemma are still available at present.

(C): Therefore, an SRM pathway ought not to be adopted at present.

Instead of discussing the Dilemma-Argument in detail, I will focus on highlighting the relevance for the Trade-Off-Argument. The non-SRM pathway in (P3) refers to a combination of stringent mitigation, adaptation and probably some of the less risky CDR measures (cf. Ott, 2012: 37–40). According to climate science, it is still possible to avert catastrophic climate change in this way (IPCC, 2014: 23-28). One might further object that stringent mitigation will not happen anyway given political realities. Pointing out that agents will probably continue not complying with their mitigation duties raises important question regarding non-ideal theory but does not challenge (P3). The Dilemma-Argument is about which strategy ought to be undertaken from the moral point of view. Expected future lack in will to comply with duties to adopt certain strategies (here: mitigation) does not undermine the justification of these duties. It should also be noted that the idea behind (P3) is not that non-SRM

[5] SRM will very likely cause a worldwide decrease in precipitation and a change in precipitation patterns (Matthews and Caldeira, 2007; Schmidt et al., 2012; Tilmes et al., 2013), though there are considerable variations among different SRM methods (Niemeier et al. 2013). Extremes of temperature and precipitation would differ significantly from those under preindustrial conditions if very high atmospheric GHG concentrations would be offset by an SRM scheme (Curry et al., 2014). Furthermore, it does not affect the increasing acidification of the oceans due to rising GHG levels (Brovkin et al., 2009) and its impacts would not be evenly distributed among the globe but affect regional climates differently (Ricke et al., 2010).

pathways are risk-free but rather that they avoid the type of risk involving catastrophic outcomes as outlined by the termination problem.[6]

However, the dilemma argument can be countered in the following way: if accompanied by *sufficient* mitigation, SRM will not result in a moral dilemma of the above kind. How much mitigation is 'sufficient' is hard to say, but it is obvious that *emissions* must be reduced to a very large extent for otherwise GHG *concentrations* will continue to increase. The uncertainty surrounding the question how much mitigation will be enough or sufficient can be captured by describing the situation as follows:

> P(DA): The more mitigation is undertaken, the greater the likelihood that SRM will not result in a termination problem with catastrophic outcomes.

Although more can and should be said in defence of P(DA), I here presume that the premise is not at the heart of the current dispute and acceptable to many commentators of the debate. In section 7 I will discuss what P(DA) implies in combination with P(TO).

This section has shown that whatever the merits of SRM, far-reaching mitigation is required for otherwise GHG *concentrations* will not go down (see also Preston, forthcoming).[7] If this is so, it is justified to investigate the plausibility of P(TO) (saying that "If SRM is researched, it will (likely) reduce mitigation efforts") in greater detail. Thus, the next section (4) discuss empirical evidence against P(TO), section 5 discusses trade-offs in economic model studies and section 6 offers a new argument in defence of P(TO). Note that the following three sections pursue two objectives. First, they aim at identifying and discussing the plausibility of *different* mechanisms that will (not) cause a trade-off (to the extent that this is possible within

[6] It should be noted that MacMartin et al. recently argued that there will be no termination problem if SRM is only used to reduce peak temperatures (2014). This observation is correct and used in this way SRM obviously is associated with fewer risks (for a critical discussion see Preston, forthcoming). However, the dilemma argument acknowledges that the termination problem may never materialise, for instance because SRM is not employed at full scale. It rather states that SRM makes this kind of dilemma possible, absent in other trajectories. Moreover, and probably more important for my argument, in a business as usual mitigation scenario SRM may not result in such a catastrophic termination problem, but the situation may still be very bad, in that climate change impacts are very severe, only moderately countered by SRM that additionally causes unintended side-effects. That is to say, even if SRM is only used to buffer peak temperatures, there are equally strong reasons in favour of far-reaching mitigation.

[7] Note that this leaves room for claiming that slightly lower mitigation levels might be justified if SRM is used. But also note that Reynolds argument that a trade-off might actually be beneficial/rational is made from a welfarist perspective. A welfarist framework faces severe challenges when applied to cases such as climate change. As is known from discussions on cost-benefit-analysis, calculating maximum welfare levels on a global and intergenerational scale in a convincing manner would require addressing a long and thorny list of methodological and normative problems that are unresolved to date (see e.g. Hampicke, 2011; Betz, 2006; Randall, 2002; Broome, 1992).

one paper). Second, they aim at shedding light on what the most plausible formulation of P(TO) is.

4. Critical remarks on the portfolio perspective and the empirical evidence against a trade-off

Before turning to mechanisms that might cause a trade-off in sections 5 and 6, I will briefly address two different issues that are important for the (im)plausibility of P(TO). Rather than discussing these in detail, my sole aim is to highlight the problems of previous arguments. One issue concerns the so-called portfolio perspective, the other issue concerns empirical evidence suggesting that P(TO) is implausible. I will use the Royal Society's *Geoengineering the climate – Science, governance and uncertainty* (Shepherd et al., 2009) as the primary example for it endorses a portfolio perspective and offers some empirical evidence. According to the portfolio perspective, climate engineering technologies are one part of a larger portfolio of measures to counteract climate change. Within this portfolio, a combination of different measures can be selected and adapted accordingly to changing conditions so that risks, uncertainties and benefits are balanced (ibid. 56). The portfolio perspective seems reasonable (Gardiner, 2011b: 175). As there are many uncertainties concerning climate change, it appears that the optimal strategy would be to have as many counter measures which could then be combined with one another according to current circumstances.

However, the portfolio perspective has some shortcomings that are insufficiently acknowledged.[8] The way in which the perspective has been endorsed by the Royal Society and others (e.g. Keith et al. 2010) suggests that different options are on the table and an informed and morally justified decision about the right mix of responses can then be made. But if there are dynamic relations between different strategies in the portfolio, as claimed by P(TO), their interplay could render the best mix unavailable. That is, if SRM research does undermine mitigation, the mitigation level that turns out to be desirable might not be achievable or an inferior portfolio is chosen due to an SRM bias (in detail see Morrow 2014). I think that, in principle, these dynamic relationships can be accounted for in a portfolio perspective, although it would complicate things considerably. However, this has not yet been done.

[8] For a more detailed critique of the Royal Society's portfolio perspective see Gardiner (2011b).

Moreover, the portfolio perspective supposes the existence of a manager or management that prudently optimises the composition of the portfolio over the course of time. However, such a prudent portfolio manager does not exist. Rather, decisions about strategies to fight the impacts of climate change are made by a wide variety of agents that are highly dispersed in place *and* time. A global body to coordinate climate policy does not exist at present, and even if it were created, it would be a very different organisation to a commercial enterprise quickly deciding on how to rearrange its portfolio.[9] Finally, the way in which it has been endorsed so far, a portfolio perspective conceals issues of justice and fairness. For example, deciding on the optimal portfolio-mix is usually done from the perspective of humanity as a whole. Thereby, one fails to account for the fair distribution of burdens and benefits *within* humanity.

My first challenge of the Royal Society's portfolio perspective is, however, far less relevant if P(TO) is implausible. The Royal Society states that there is hardly any empirical evidence for a trade-off (Shepherd et al., 2009: 39). Furthermore, focus groups conducted in the course of the study would rather indicate the contrary, namely, that efforts in the field of mitigation are expedited when SRM is discussed as an alternative or addition (ibid. 43). The reason for this might be that the potential effects of SRM are perceived as so negative that the implementation should be avoided in any case, which would lead to increased mitigation efforts. Similarly, a UK study found that participants expressed that geoengineering must not distract from mitigation and that both responses should be closely linked (IPSOS Mori, 2010: 53) and Kahan et al. recently observed that '[c]ontrary to the "moral hazard" effect [...] subjects in the geoengineering condition […] displayed *more* concern over climate change than ones in the control condition' (2014: 15).

By contrast, Corner and Pidgeon (2014) suggest that things are more complicated. According to the authors, to what extent SRM will increase concern for and willingness to undertake mitigation strongly depends on peoples' value orientations and socio-economic factors. Note also that the authors end their article with the statement that: '[t]he key conclusion is that for people who are sceptical about climate change, wealthier and more self-oriented, the prospect of geoengineering may reduce their own motivation to engage in sustainable behaviour' (ibid.: 13).

[9] A binding global climate treaty that limits overall emissions and also governs other technologies/strategies to counter climate change would increase the possibility of 'rational planning' as implied by the portfolio perspective because it would reduce the problem of the many uncoordinated decision making processes. Still, the problem that this rational planning must take place in the face of great uncertainty is not diminished. Thanks to Nils Markusson for raising and discussing this issue with me.

Here, I will not discuss which study is more robust. In general, the observation that (some) people show more concern for climate change and mitigation in the face of SRM/CE probably is a good thing. Contra Reynolds (2014: 5-6), this observation does not add much to clarifying the (im)plausibility of P(TO). P(TO) is about how people will act in future. Stating that one is more concerned about climate change or thinks that SRM requires meaningful mitigation efforts says little on how this person will in fact behave and even less about the likelihood of a trade-off in general:

First, what matters is how people are likely to act given the incentive structures they face, given how their peers act, and more. Although people think that mitigation is important, they may not reduce their emissions due to the high costs associated with this and they may not vote for a 'green' party because other issues are more important to these voters than a party's stance on mitigation policies. Or people may think that their individual contribution does not make a difference, or that they have no duty regarding mitigation for this is in the responsibility of governments and corporations (Baatz, 2014). It is a well-known phenomenon that people usually show high concern for climate change and mitigation respectively but that this does not translate into corresponding actions for the reasons just stated (among others) (Kuckartz et al., 2007). That is to say, the fact that people say that mitigation should be undertaken says nothing about whether they also think that *they* should do something in this respect, and even if so, whether they *will actually do it*.

Second, it is likely that information on CE and SRM will be provided very differently compared to the experiments that found no support for the trade-off claim. In these experiments, scientists transparently disclosed the many risks associated with both climate change and SRM. Such a careful framing should not be taken for granted in the public discourse that will actually inform citizens about risks and benefits of mitigation, SRM and other strategies. Lack in public support for climate policies in the USA is certainly connected to the 'careless' framings of the risks associated with climate change that were used by many participants in the public debate. It would therefore be important to know how people think about mitigation and SRM in a polarised and biased discourse.

Third, more important than the decisions of ordinary citizens are those of governments, investors and multinational corporations for these actually affect incentive structures which in turn affect decisions of ordinary citizens. Therefore, it would also be good to know how these key decision makers will in fact behave if and when SRM becomes a serious option. None of the above studies investigates this.

Given these inconclusive findings and given the limited nature of empirical investigations (see also section 7), it is worthwhile discussing other kinds of evidence for or against P(TO).

5. Trade-offs in economic model studies

Another kind of investigation that addresses potential trade-offs between mitigation and SRM is economic modelling. Many papers analyse 'optimal' levels of different responses to climate change, such as mitigation and SRM. A prudent and omniscient decision maker that aims at maximising overall welfare would undertake mitigation as long as its marginal costs do not exceed marginal damage costs resulting from climate change. If mitigations costs equal damage costs this is the 'optimal' mitigation level. Two standard assumptions regarding SRM are that it will reduce (some of) the negative effects of climate change and that it will be cheaper than mitigation. If so, 'optimal' mitigation levels will be lower in case SRM is deployed because SRM can reduce damages at lower costs. This is the basic economic result most studies confirm and, based on this, the studies add further assumptions and complexity.

Juan Moreno-Cruz and Sjak Smulders, for instance, model a 'second-best-economy' in which free riding is possible (2010).[10] This second-best economy contains different countries rather than one prudent decision maker. It is assumed that each country chooses its mitigation level to minimise its own costs but takes mitigation levels of other countries as given. Levels of SRM implementation are also taken as given (for details see ibid.: 22-23). Their result is that the implementation of SRM would further reduce mitigation levels due to free-riding behaviour (ibid.: 26). In general, "countries spend too little on abatement since the benefits accrue partly to other countries while the country bears the full costs of its abatement" (ibid.: 22). If SRM is employed, damage costs from climate change are reduced and therefore even less mitigation than in the first best-economy will maximise the benefits of each country (ibid.: 23).

In another study, however, Moreno-Cruz (2010) argues that under quite specific circumstances, the availability of SRM results in GHG reductions exceeding the 'optimal' level (ibid: 18–22). The economic model used by Moreno-Cruz contains two countries and both countries aim at maximising their own benefit. Mitigation exceeds the level that would be 'optimal' from the perspective of the prudent decision maker (see above), if the countries are affected asymmetrically by climate change and SRM respectively. More specifically,

[10] Free riding in this case means that a country does not reduce its GHG emissions to the 'optimal' level. Thus, the country itself can save costs while profiting from mitigation to the same extent as all other countries.

mitigation exceeds the 'optimal' level if the following conditions hold: country 1 is relatively better off with SRM and worse off with climate change and for country 2 it is the other way around (ibid.: 22). Put in very simple terms, country 1 is negatively affected by climate change and better-off with SRM. Country 2 expects no or little negative effects from climate change, but fears very negative effects from SRM. In such a scenario, country 1 'could attain a better outcome in a climate negotiation if it could credibly threaten to engage in geoengineering' (ibid.). This is a threat to country 2, because if country 1 implements SRM, country 2 would be worse off. Therefore, country 2 has an incentive to mitigate for otherwise country 1 would resort to SRM. And, since country 1 is better off with mitigation anyway, both mitigate rigorously.

How likely is such an outcome? Moreno-Cruz takes it to be realistic scenario and refers to studies indicating great asymmetries in impacts of both climate change and SRM (ibid.: 21–22). This, however, is not convincing. The fact that SRM and climate change impacts vary greatly is not sufficient. Instead, climate change winners must at the same time be SRM losers and the other way around (rather than winning/losing on both) (ibid.) and, in addition, all those in a position similar to country 1 must have the economic and military power to uphold such a threat. What would world leaders do if the AOSIS group (Alliance of Small Island States) threatens to employ SRM? Millard-Ball argues that the 'credible threat from a desperate island nation with no other hope of avoiding annihilation means that other countries' best response is to collectively reduce emissions to the level where it is no longer optimal for Tuvalu to geoengineer' (2012: 1060). It is difficult to imagine this happening, given the current world order. Even if the other states hesitate to intervene militarily, the international community could put huge pressure on small and poor states such a Tuvalu by other means, such as sanctions.[11] In this situation, world leaders could do many things but implementing stringent climate policies on the spot is not likely to be the one chosen. My general point here is that at present there is no such constellation of two sets of agents (countries) that fulfils all of the above criteria (cf. also section 6).

A further serious problem is that in Moreno-Cruz's model countries can free-ride intra-generationally, i.e. on other countries, but they cannot free-ride inter-generationally, i.e. on future generations. The reason is that a country is supposed to represent the interest of its citizens in perpetuity. However, country 1 and 2 might actually not mitigate because *they* (that

[11] Whether it is likely that more powerful states or collectives can use SRM as a credible threat to increase mitigation levels is discussed in the next section.

is to say current citizens of the respective country) are not losers of climate change. Rather, their (distant) successors will lose. This is important, for intergenerational free-riding is the most likely form of free-riding (as I will argue in section 6). Taking countries as the central agents fails to acknowledge the intergenerational component of the problem.

In his discussion of economic model studies, Reynolds highlights another factor that might increase mitigation levels. Because SRM (he refers to CE) 'is expected to have very low financial costs while those of mitigation, adaptation and climate change damages will be great, this will liberate some of society's financial resources, a portion of which could be used for mitigation' (2014: 7). Again, this is unconvincing. First, SRM deployment costs may turn out to be much higher than Reynolds and others assume (cf. MacKerron 2014). Second, it is not obvious that deployment costs are the relevant number to look at. As is widely agreed, *total* SRM costs will be much higher due to research costs, unintended side-effects etc. (cf. Rickels et al., 2011: 59). A morally justified course of action would require using said financial recourses to balance harmful side-effects – in addition to high mitigation levels. A fair comparison with mitigation costs would require looking at total rather than deployment costs. Third, additional financial resources can be used for all kinds of purposes. The fact that it is "theoretically possible that climate engineering implementation could increase mitigation through dominant income effects" (Reynolds, 2014: 12) is correct, but how likely is this? Why is it more plausible that governments use the money in this way rather than investing in health care, education, lower tax levels, pensions, etc.? In governmental budget-planning, environmental concerns are usually much less important than the topics just mentioned. Hence, more argument is required to show that an income effect is likely to ease the trade-off in a non-negligible way.[12]

In sum, in economic model studies mitigation will be partially replaced by SRM if it is assumed that (i) the latter avoids or moderates some climate-induced damages and (ii) is cheaper than mitigation. SRM is an imperfect substitute for mitigation, at minimum leading to a partial substitution effect (Goes et al., 2011; Rickels et al., 2011; Gramstad and Tjøtta, 2010; Emmerling and Tavoni 2013). When agents are modelled as different players that seek to maximise their own benefit, mitigation efforts will be even further reduced; and scenarios that do not exhibit this further reduction are usually unrealistic (see also Manoussi and

[12] Reynolds also discusses three distinct mechanisms that might cause a trade-off. He describes each mechanism and then simply states that the reverse (i.e. an increase in mitigation rather than a decrease) is possible as well. The problem with this kind of argument is that in most cases it is indeed *possible* that mitigation increases or decreases. In order to check the plausibility of P(TO), however, it matters which scenario is more *likely* or plausible. In said cases Reynolds offers no reasons why an increase is more likely than a decrease.

Xepapadeas 2014). Note that it is possible to model agents differently. Geoschl et al. assume that current generations care about future generations (2013). In their model, a partial substitution effect can be observed as well but the effect is limited. In order to avoid huge damages from temperature increase in future, current generations undertake substantial mitigation. Among others, the higher climate sensitivity as well as damages from future deployment of SRM are believed to be, the more mitigation will be undertaken today (ibid.: 95).[13]

Compared to benefit-maximising agents, Goeschl et al.'s assumption is much closer to what moral theory has to say on how people ought to act. What actions can be justified from the moral point of view, however, is not relevant for the plausibility of P(TO). Rather, it matters whether agents will or will not act in a self-interested manner (or to what extent will do so). So far, actions of key agents show almost no concern for future generations as well as today's vulnerable. In the following, I will argue that this might not change if SRM is introduced as a further option.

6. Gardiner's Perfect Moral Storm and Solar Radiation Management

Stephen Gardiner has provided a thorough analysis of the problem of climate change (2006; 2011a). His key thesis that the 'peculiar features of the climate change problem pose substantial obstacles to our ability to make the hard choices necessary to address it' (ibid. 2006: 398). With 'hard choices' Gardiner largely means to reduce GHG emissions now and to take over the associated costs. But since the structure of the problem makes us vulnerable to moral corruption this is unlikely to happen (ibid.). Gardiner's aim is not to demonstrate that it will be impossible to sufficiently reduce GHG emissions. The challenges, whilst significant, can be overcome and moral corruption can be avoided. He aims to elaborate why it is so difficult to act appropriately and at highlighting the associated dangers of corruption. By creating awareness of this, he hopes to make it easier to navigate the storm.

Gardiner develops the claim that climate change brings together three different problems that considerably limit our ability to make the right choices. He refers to these problems as the 'global storm', the 'intergenerational storm' and the 'theoretical storm'. Each storm generates mechanisms that increase the likelihood that too little mitigation is undertaken. In addition, the three storms reinforce each other, which makes it all the more challenging to reduce GHG

[13] Thanks to Daniel Heyen for a very helpful discussion of the paper.

emissions (ibid.: 399, 408). The explanatory power of Gardiner's approach is considerable. Although some countries have been successful in lowering their emissions levels, global emissions are still on the rise despite vivid appeals of leading politicians, scientists and the civil society as well as 20 years of climate negotiations. Many of the mechanisms identified in the 'perfect moral storm' seem to play an important role in the causation of the current mitigation failure.

In the following, I will argue that introducing SRM as another option to respond to climate change will either leave the components of each storm unaddressed or reinforces them, thereby further reinforcing the perfect storm and making mitigation even more challenging. My argument in this section can be crudely summarised thus: since present low levels of mitigation can be explained by the features of the prefect moral storm that characterise the climate change problem, and since SRM will reinforce these features, SRM will increase the likelihood that mitigation levels remain low.[14] Assuming that Gardiner's perfect storm analysis has some appeal, I will focus on defending the second premise saying that SRM will reinforce the features of the perfect storm. Consequently, the argument below is contingent on the first premise being largely correct.

I will now briefly introduce the global and the intergenerational storm as outlined by Gardiner and discuss how each is affected by the emergence of possible SRM strategies.[15]

The global storm and SRM

The global storm and the intergenerational storm are constituted by a spatial and temporal reading of the following characteristics: a) the dispersion of cause and effects, b) the fragmentation of agency, and c) institutional inadequacy. The global storm focuses on the spatial dimension (cf. Gardiner, 2011a: 24).

A) Dispersion of cause and effects: Due to the nature of climate change, the impacts of GHG emissions are dispersed around the world (ibid.). The effects of an SRM scheme would be dispersed around the world as well. This feature alone will not hamper mitigation efforts but neither does it ease the global storm.

[14] Thanks to an anonymous reviewer for suggesting to state this explicitly.

[15] I will not discuss whether SRM exacerbates the theoretical storm. First, I do not think that our "theoretical ineptitude" (Gardiner, 2011a: 41), that is at the heart of the theoretical storm, plays a major role in explaining the current mitigation failure. Second, I do not think that SRM will significantly increase our theoretical ineptitude.

B) Fragmentation of agency: Climate change is caused by a vast number of individuals and institutions and although it is collectively rational to mitigate GHG emissions it is individually rational not to do so. Such a situation is usually described as a prisoners' dilemma, or – provided the earth's climate system is characterised as a global commons – as a tragedy of the commons (ibid.: 24-28).

The agents researching SRM or conducting such a scheme would be less fragmented than emitters of GHG. On its own, this fact will not make mitigation more likely. It would make mitigation more likely if the wish to carry out an SRM scheme leads to a global legally binding regime that also allows to effectively sanction non-compliance regarding mitigation. This brings us to the next component.

C) Institutional Inadequacy: Tragedy of the commons can be resolved by establishing a scheme of cooperation from which all parties benefit. This scheme must allow for sanctioning free-riding. Otherwise it will be ineffective. In the current international order that consists of *sovereign* nation states it is very difficult, if not impossible, to establish reliable enforcement mechanisms (ibid. 29).

One of the often-cited advantages of SRM is the possibility of doing it multi-laterally (Barrett, 2008). It is referred to as an option of last resort or insurance if nothing else works. At this point, proponents keenly point out that we should prepare for this case because it seems unlikely that the world community will agree on any meaningful treaty regulating GHG emissions for the interests in the international realm are just too different (Victor, 2008).[16] Many view SRM as a backup if and when global governance concerning mitigation fails. For this reason it is hard to see how the prospect of SRM can overcome institutional inadequacy.

Against this, Millard-Ball argues that the prospect of SRM can be used as a threat in order to increase compliance with mitigation (2012). If A expects severe disadvantages if SRM is deployed and if A can do nothing to stop B from deployment, and if B will deploy SRM when a certain temperature increase is reached, A has reasons to mitigate (if, and only if, this will be able to sufficiently halt temperature increase).[17] I contend that this is a possible scenario.

[16] The issue of legitimacy of an SRM-scheme is sidestepped here, but see Svoboda et al. (2011) and Gardiner (2010: 293–294).

[17] Millard-Ball discusses five different scenarios in which mitigation levels increase (2012: 1059-1062). In the scenarios countries mitigate more in order to reduce the need for SRM in the first place because they fear that they are worse off once SRM is implemented. A slightly different scenario is that countries mitigate robustly in order to avoid an intergenerational SRM arms race (ibid.: 1061-2). Johannes Urpelainen arrives at a similar conclusion (2012). Gardiner argues that an arms race might be more likely than robust mitigation (2011a, chapter 6). I cannot deal with this additional aspect in a convincing manner. But note that both Millard-Ball's

But who could be B in the real world? Certainly not Tuvalu (cf. section 5). Perhaps the EU is a likely candidate: it showed some interest in mitigation and has considerable economic influence. At present it is barely conceivable though that the EU is willing to adopt such an aggressive policy against other powerful states. And it is even less conceivable that such a policy would be successful given the current international order.[18] Millard-Ball also mentions the US and China as possible candidates to use SRM as a threat. Here, too, one can question the countries' willingness to adopt such policies. Moreover, both showed very little concern for mitigation so far.

The above scenario is not realistic at present for states that are most likely able to make and uphold an SRM threat, at the same time are those countries that are key to the failure of the international climate negotiation. Rather, countries such as the US, Russia, Canada, Saudi-Arabia, and perhaps China, should be threatened to mitigate more. I cannot see a coalition of countries that is able and willing to do this. For these reasons, an SRM threat will not be able to spur international agreement on mitigation as long as the international order does not change considerably. Also note that in Millard-Ball's model the only possible response to an SRM threat is mitigation. In reality, it is much more likely that states react to such a threat with conventional counter-measures such as diplomatic or trade sanctions, military threats, etc. – an option that Millard Ball mentions as well (ibid.: 1063). In sum, since SRM seems unable to attenuate institutional inadequacy and since this inadequacy played an important role in causing current low mitigation levels, it seems very likely that it will also hamper mitigation efforts in future.[19]

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and Urpelainen's models do not account for intergenerational free-riding; that is to say, if current generations stimulate a future arms race by not mitigating while at the same time developing SRM technologies they might not be the ones that have to deal with the consequences.

[18] Recently, the EU tried to extent its emissions trading scheme to the aviation sectors, which would also require non-EU based airlines to purchase emissions permits if they use European airports. But due to international political pressure the EU dropped its plan (Harvey 2012). Compared to building up an SRM threat this is an extraordinary unambitious policy and probably illustrates the EU's willingness to adopt confrontational policies.

[19] One might further object that even if SRM would do nothing to overcome institutional inadequacy, this is not a problem because the motivation to cut emissions is already so low that reducing it further would not matter. Firstly, this is an inadequate assessment of the current situation. A dynamical development of different low-emission technologies can be observed and many citizens, governments, and corporations all over the world are implementing climate-friendly concepts. That is, the transformation towards a low-carbon economy is already underway (WBGU, 2011: 266). This is paralleled by a change in values: 'an ever-growing part of the global population is developing value systems which incorporate focusing on the protection of the natural environment. […] the public is already far more willing to tackle this issue than generally thought' (ibid.: 267). The observed lack in mitigation policies is not rooted in an overall low motivation by citizens and governments to cut GHG emissions. Rather, it can be explained to a substantial extent by actions of lobby groups opposed to decarbonisation strategies that exert great influence on policy-making in many instances (ibid.: 189-191). Secondly, motivation is not a static phenomenon and can change over time. In Germany, the willingness to

Gardiner further argues that there are *exacerbating factors* that make the global agreement necessary to overcome the institutional inadequacy more difficult (in detail see 2011a: 29-32). Such factors also exist regarding SRM. First, there is considerable uncertainty regarding the impacts of climate change, which might cause states to think that they are better off with (moderate) climate change or at least relatively better off (Gardiner, 2011a: 30). Given that there is much less knowledge of potential consequences of an SRM scheme this adds further uncertainties and allows for the possibility of overly optimistic assumptions of (some) decision makers. To that effect, Lin argues that the psychological phenomenon of overconfidence bias 'may lead people to unduly emphasise the dramatic benefits suggested by stratospheric aerosol proposals and to disregard quantitative assessments of risk and uncertainties associated with the technique' (2013: 697). That is, great uncertainty makes overly optimistic assessments of future developments as well as future technologies more likely. Overestimating the possibilities of SRM may cause agents to lessen mitigation efforts because its need is (mistakenly) discounted.

Second, the disparate effects of SRM reinforce what Gardiner calls 'skewed vulnerabilities': since those most responsible for and capable of reducing emissions are not hit first and most by climate change, they have little incentives to mitigate at present (Gardiner, 2011a: 31). Regarding SRM, some regions will profit (much) more than others (e.g. Ricke et al., 2010). If powerful countries believe that negative side-effects of an SRM scheme will be mostly borne by others, they have reason to think that they will be better-off with SRM (in absolute terms or just relatively). If negative side-effects are mostly borne by others, they will lose interest in mitigation. Powerless countries, on the other hand, may lack the means to prevent the powerful from deploying an SRM scheme and very likely do lack the power to force them to mitigate. Note that such ruthless behaviour becomes even more likely in the intergenerational storm (see below).

Third, some proponents argue that an SRM scheme would allow forgoing the fundamental social and economic changes required for the transition to a low carbon economy – or at least stretching the process of transition over a longer period of time (Wigley, 2006). It thus relieves developed countries/regions of undertaking 'painful' mitigation measures. This shows that the prospect of SRM delivers agents not interested in mitigation – most likely those that consider themselves as potential losers of a transition to a low-carbon economy –

consider and adopt climate change policies has risen dramatically during the last two decades. Thanks to Toby Svoboda for pressing me on this issue.

with additional arguments to prevent successful mitigation. The opportunity of 'additional arguments' should not be underestimated: in the political debate it is decisive that one can respond to journalists and opponents with arguments that sound plausible, at least on first sight, and it is even better if rebuttals of these arguments are long and complicated. Here, the complexity of the perfect storm plays into the hands of those with simple answers (cf. also Lin, 2013: 706-7).[20] In addition to an increase in 'argumentative power', said lobby groups will also be strengthened in terms of resources, if they are part of research on and development of SRM technologies (which seems very likely at present).

The intergenerational storm and SRM

The three characteristics introduced above have a temporal dimension as well and this is what Gardiner calls the intergenerational storm.

A) Dispersion of cause and effects: Given the long retention time of GHG in the atmosphere impacts are substantially back loaded (Gardiner 2011a: 33). This creates several problems, e.g. the underestimation of impacts, lack of motivation to act, and difficulties to adequately prepare for the impacts (in detail see ibid. 34).

An SRM scheme would have rather immediate effects and potentially provides the possibility of fending off disaster in the last minute, so to speak. Proponents cite that as an advantage and I do think they have a point here. However, although the intended cooling-effect of an SRM scheme will be noticeable within a couple of years, some unintended side-effects might occur after many decades or even later. If so, early success of SRM may give a false sense of security and may further undermine mitigation efforts. If GHG concentrations are still rising while SRM is deployed, the termination problem becomes increasingly severe. A dilemmatic situation as sketched above is largely an intergenerational problem. If current generations invest in SRM technologies but fail to lower emissions correspondingly, this constitutes a risk transfer to future generations par excellence. The second feature of the intergenerational storm, fragmentation of agency, increases the likelihood of such a risk transfer.

[20] To illustrate what I have in mind let me give an example discussed by David Luban (2009). In the public debate on torture in the US, proponents of the permissibility of (some forms of) torture by government officials frequently refer to the so called ticking bomb scenario to justify their claim. In a nutshell the argument runs as follows: a terrorist has planted a bomb that will explode soon. The terrorist is captured in time but is not willing to reveal where he put the bomb. Is torturing the terrorist permissible? The answer is: of course (ibid. 184). The argument is fraught with highly implausible normative *and* empirical assumptions. But it takes some time (and expertise!) to show where the claim goes wrong. Too much time (and perhaps expertise) for the ordinary media user it seems.

B) Fragmentation of agency: While spatially fragmented groups of people may still find means to communicate and cooperate to solve a commons problem, temporally fragmented agents do not have this option. This creates the danger of 'intergenerational buck-passing' (ibid.: 35): each generation has strong incentives to not mitigate because the benefits from GHG emissions mostly accrue to them while the benefits from emissions reductions would mostly accrue to future generations. Since each generation faces the same incentive structure, each generation might further contribute to the problem rather than solving it.

I will now argue that the prospect of SRM contributes to this unfortunate incentive structure. As climate change accelerates, substantial warming within this century becomes more likely. Young adults in developed countries have increasing reason to think that they, too, might be negatively affected by climate change at some later stage in their life. And if they will not, their children will likely be so if emissions are not drastically lowered by then. The fact that they (and/or their children) will be negatively affected by climate change – rather than distant successors or people on other continents – increases incentives to mitigate. Now, with SRM as an option, the spectre of dangerous climate change again diminishes to a certain extent. If one assumes that an SRM scheme will be established, e.g. right before climate change becomes 'dangerous', why should one still try hard to reduce one's emissions? Two plausible answers are, among others, to avoid the possibility of a future dilemma and to stop ocean acidification. Both issues will get much more dramatic in the long-run though. It is therefore likely that strong mitigation efforts will benefit *future* generations in most instances. In consequence, *current* generations would be mostly excluded from the benefits of the cooperative project called mitigation and future generations have no way in coercing current generations to cooperate. My argument thus is that accelerating climate change increases incentives for present generation to mitigate and that these incentives are lowered again if SRM is (believed to be) able to avert immediate and drastic impacts of climate change. This increases the likelihood of low mitigation levels and puts us in the middle of the intergenerational storm identified by Gardiner.

C) Institutional inadequacy: Political institutions are usually biased towards current interests. The time-horizon of democratic decision-making is comparatively short – the next election, a politician's career. Also, implementing an inclusive, democratically ratified system of global governance that has effective sanctioning options will not resolve *this* kind of institutional inadequacy: the incentive to benefit current citizens (and electorate) at the expense of posterity remains (Gardiner, 2011a: 38).

As I pointed out regarding the global storm, since SRM can be deployed uni- or multilaterally with respect to technology and costs, it does not seem likely that it will contribute to overcoming institutional deficits. And, more important perhaps, no institutional design can turn off or mute incentives to free-ride on subsequent generations by avoiding cost associated with mitigation.

Summary

This section has been based on Gardiner's 'perfect moral storm'. The 'perfect moral storm' identifies several different mechanisms that lead to less mitigation than is required from the moral point of view and, moreover, less than would be collectively rational for certain sets of agents. I argued that SRM seems unable to attenuate the global institutional inadequacy. Given that this inadequacy played an important role in causing current low mitigation levels, it will also hamper mitigation efforts in future. I further argued that the prospect of SRM will reinforce several of the mechanisms of the perfect storm: First, the uncertainties concerning the distribution of burdens and benefits that would result from an SRM scheme might contribute to an overly optimistic assumption of the net benefits that such a scheme would bring about. This assumption could generate the view that much less mitigation is required than in the absence of an SRM scheme. Second, SRM adds to 'skewed vulnerabilities' in that those who consider themselves to be net-beneficiaries of SRM (rightly or not) might show less interest in mitigation, and this is particularly problematic if these 'expected beneficiaries' are powerful countries. Third, SRM would provide vested interests opposing mitigation policies with arguments and perhaps with additional power. Given the past success of 'anti-mitigation coalitions' this should be a serious cause for concern. Fourth, while the intended cooling-effect of an SRM scheme will be noticeable within a couple of years, some of the risks associated with it arise in the long-run and thus are largely an intergenerational problem. If so, the benefits of mitigation will to a considerable extent accrue to future and not to present generations. This increases incentives for current generations to exploit their temporal position. This is highly important given that there is no way to turn-off or mute intergenerational free-riding because yet non-existing generations have no means to influence behaviour of present generations. If these thoughts are by and large correct, the prospect of SRM will increase the likelihood of continuing high emissions levels.

In the last three sections I have discussed evidence and reason for and against the possibility of a trade-off between mitigation and SRM. I conclude that such a trade-off is likely, i.e. that the prospect of SRM will probably reduce mitigation efforts and hence emissions reductions.

In the next section I will use these findings to specify the trade-off premise P(TO) introduced in section 2 and to discuss what follows from the reasoning so far.

7. What follows?

In section 2, I specified the trade-off claim in the following way:

> P(TO): If SRM is researched, it will (likely) reduce mitigation efforts.

The mechanisms discussed above mostly build on psychological and economic considerations. On the one hand, the discussion shows that SRM and mitigation are partial substitutes: SRM reduces some of the risks caused by climate change and insufficient mitigation respectively. On the other hand, resources to reduce climate-induced risks are limited. These two basic assumptions suggest that said mechanisms are stronger the more resources are invested into SRM and the more likely deployment is. Rather than holding for 'research', the plausibility of P(TO) probably varies with the intensity and kind of research that is undertaken. For instance, an international research consortium with a billion dollar budget will have a greater effect than a few research projects at some universities, and investigating the effects of sulphate-aerosols in the upper atmosphere by means of climate models will have a smaller effect than developing specific technologies to alter the climate. This suggest that the 'if.., then ... structure' of P(TO) is too simple. More accurate is something like:

> P(TO)*: The greater the push towards SRM, the lower mitigation levels will likely be compared to mitigation levels in the absence of a push for SRM.

Note, the formulation 'the push towards SRM' is used as a placeholder for more complex processes briefly outlined in the above paragraph, namely that it matters how much money and time is invested into SRM, how many people are concerned with SRM, how visible it becomes, etc.

But how plausible is P(TO)*? Current arguments against P(TO)* based on empirical evidence are highly unconvincing. In contrast, economic model studies and moral-psychological considerations indicate that there will be a trade-off. These preliminary results suggest that P(TO)* is plausible; but, as always, more research is needed in this respect. Note, though, that it is not possible to verify/falsify P(TO)* ex-ante. Most likely, even ex-post it will be impossible to do so: whether mitigation did (not) occur may have other reasons than the (non-

) existence of an SRM scheme and even in retrospect it will be hard (probably impossible) to verify to what extent SRM actually did (not) hamper mitigation. One implication is that the theoretical arguments developed above cannot be side-stepped by making reference to empirical evidence. Another is that this kind of evidence must be taken seriously although it may cause some frustration due to its tentative nature.

Taking seriously the evidence backing up P(TO)*, what follows from it? In combination with P(DA) (cf. section 3) it yields the following conclusion:

> P(TO)*: The greater the push towards SRM, the lower mitigation levels will likely be compared to mitigation levels in the absence of a push for SRM.
>
> P(DA): The more mitigation is undertaken, the smaller the likelihood that SRM will result in a termination problem with catastrophic outcomes.
>
> C(TO): The greater the push towards SRM, the greater the likelihood that SRM will result in a termination problem with catastrophic outcomes.[21]

The trade-off argument as reconstructed here warns against a serious danger that might emerge if SRM is researched (and deployed). It also says that the more we move towards SRM deployment the greater this danger becomes. This is a significant finding and provides a *pro tanto* reason to avoid or minimize a trade-off between mitigation and SRM. It provides a strong *pro tanto* reason, though, for the risk C(TO) warns against is absent in a far-reaching mitigation scenario that is technologically and economically feasible (cf. section 3).[22] In the way of realising this scenario is political willingness. This highlights that more time and resources should be spend on overcoming the lack in political will.

Measures proposed so far in order to avoid a trade-off either insufficiently tackle the trade-off mechanisms discussed here (Lin, Morrow) or have far-reaching consequences (Betz) that are rejected by many commentators. This paper aimed at demonstrating that there are serious trade-off risks (contra many voices in the debate) and provided *one* weighty reason for adopting 'anti trade-off measures'. What kind of measures can actually be justified by my findings requires another complex debate in which risks and benefits of potential measures must be assessed. This is to be addressed by future research.

[21] Many thanks to Frederike Neuber for detailed discussions of the formalisation of the argument.
[22] Note that the far-reaching mitigation scenario may or may not contain SRM strategies.

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