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Bridging the Gaps in Interdisciplinary Research on Solar Radiation Management

Solar radiation management (SRM), a subset of approaches to climate engineering, aims to manipulate the global climate on a large scale. It includes techniques like spraying sulfate aerosols into the stratosphere or brightening marine clouds to reflect more sunlight back into space. In an attempt to examine the socio-political context of SRM, research frequently starts from model projections of physical changes in the environment. But assessing socio-political matters is complex, and while model projections may help, experiences from research on CO_2-induced climate change reveal many blind spots and some unique challenges.

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The recent years have seen an upsurge of solar radiation management (SRM) research in many disciplines. SRM is an umbrella term for individual techniques that aim to directly manipulate global mean temperatures by reflecting sunlight away from earth. The currently most discussed techniques involve spraying sulfate aerosols in the stratosphere and brightening marine clouds (for an overview of these and other techniques, see the figure below). Much of the SRM research focuses on the effects that physical changes in the environment may have on socio-economic and political matters. Such studies rely directly or indirectly on model projections of these changes, and have sought to answer fundamental questions like "Would SRM be worse than unmitigated climate change?" or "What is the optimal level of SRM?" (Goes et al. 2011, Moreno-Cruz et al. 2012). However, applying simplistic assumptions of how changes to the physical environment will affect society, the economy and international relations may lead one astray when attempting to understand the socio-political context of SRM.

Some of these issues also arise in connection with attempts to assess climate change more generally. Nevertheless, there are important differences between SRM and CO_2-induced climate change. SRM techniques are potentially cheap and implementable by a single actor, could have large effects that would materialize quickly, and might offer a choice over a range of climate outcomes. Climate change from increasing CO_2 levels is caused by widely distributed emission sources. Its mitigation thus requires decentralized action on a global scale and involves considerable transformations of economic activity. The climate effects of such action will be visible only decades later. Mitigation offers the possibility to slow and eventually halt the rate of climate change, while SRM may offer control over the type and pattern of changes in the climate. For these reasons the challenges associated with assessing their socio-political context are different.

We identify three important gaps that must be bridged when trying to reach an understanding of the socio-political context of SRM. These are

- the gap between model results and climate impacts,
- the gap between climate impacts and socio-economic realities,
- the gap between model results and international cooperation.

We will revisit each of these gaps and draw some conclusions. This is not an entire survey but a starting point for discussion.

The Gap between Model Results and Climate Impacts

To go beyond the simplest projections of the effects of SRM (i.e., that a global mean cooling is to be expected) *Earth System Models (ESMs)* are helpful (Edwards 2011).[1] These models consist of complex numerical representations of the components of the earth system, covering at least atmospheric, oceanic, vegetation and land surface processes, and additionally the carbon, ice sheet

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and other processes. Due to the sheer scope of these models not all potentially important processes can be represented, and those which are represented must be simplified to make computations tractable. Despite these limitations, state-of-the-art *ESMs,* such as those used by the Intergovernmental Panel on Climate Change (IPCC)[2], endogenously generate many large-scale phenomena of interest that are observed in the real world, such as global circulation patterns, El Niño, and vegetation distribution (Arora et al. 2013). The projections of *ESMs* also agree on many of the broad changes we can expect from climate change: an accelerated warming in the Arctic, rising sea levels, an increased occurrence of high temperature extremes and increased intensity of precipitation, and, in general, that dry areas will get drier and wet areas wetter (Solomon et al. 2007). However, models still do not reproduce the observed climate in precise detail. For example, regional patterns and temporal distributions of precipitation can be noticeably different from model results, and other large-scale problems persist in many models (Sillmann et al. 2013). In summary, *ESMs* are not perfect representations of the earth system. But despite their limitations, they are the best tools available to assess the potential earth system effects of global warming and SRM.

Determining Policy-Relevant Impacts

To be policy relevant, the earth system changes should be translated into climate impacts on human populations, ecosystems and other domains at a reasonable level of detail. Climate impact assessments depend on input from *ESMs* that have a typical resolution of around one by one degree, which translates to roughly 100 by 100 kilometers at the equator (Taylor et al. 2012). The *ESM* results are typically downscaled either using *Regional Climate Models (RCM)* or by statistical approaches for use in impacts models (Colette et al. 2012). Some climate impacts must be derived using sectoral impacts models, such as agricultural models, ecosystem models, and water resource models.[3]

Assessments of the likely impacts of climate change on various human concerns have been conducted, but building an overall picture is challenging. The working group II contribution to the IPCC's *Fourth Assessment Report* synthesized the understanding of the impacts of climate change, but for the reasons discussed above it is very difficult to produce robust projections, particularly at the local level (Parry 2007). Efforts to translate these climate impacts projections into economic damages face even greater challenges, but also ethical questions such as how to properly discount future utility (Nordhaus 1992, Nordhaus 2007, Stern 2007). Despite these difficulties in assessing climate impacts, a number of simple heuristics have been developed and broadly adopted, including the idea that greater global mean warming will lead to greater risks to valued systems (McCarthy 2001, Smith et al. 2009) and greater risks of passing "tipping points" (Lenton et al. 2008).

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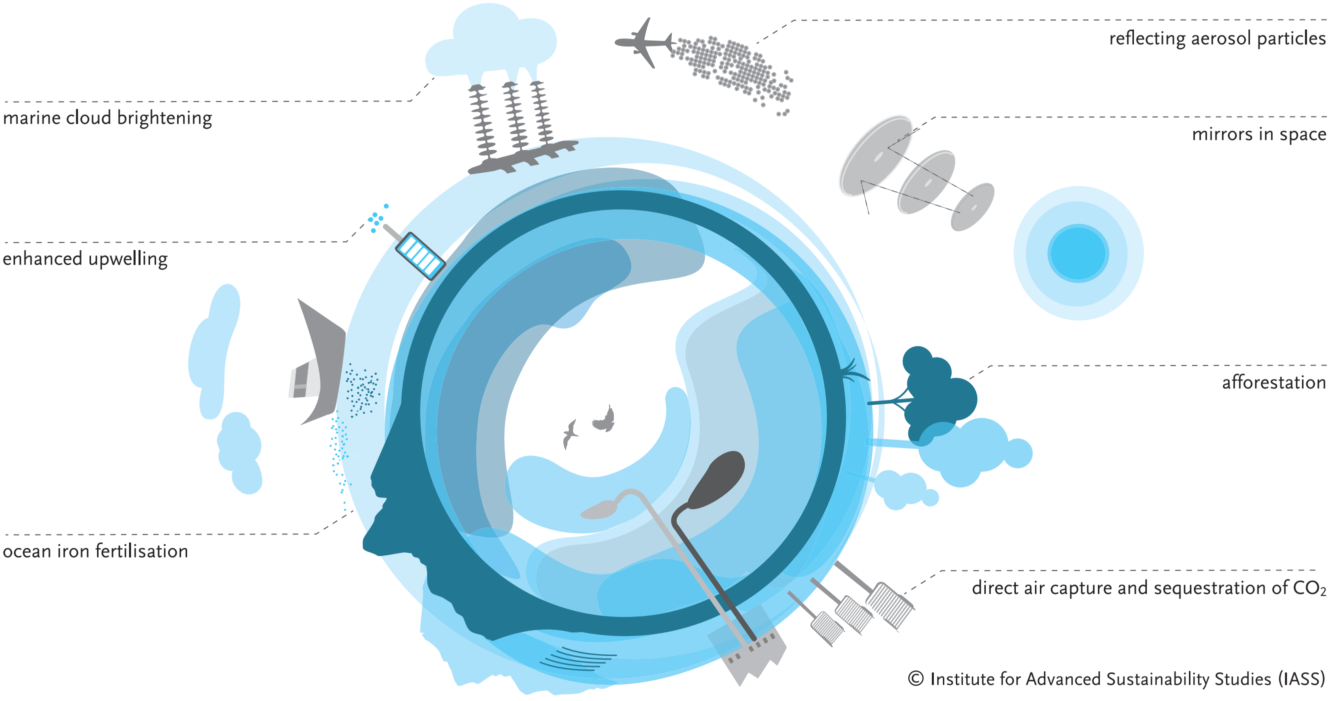
1 We use "*ESM*" in a very broad sense to cover earth system models, climate models and intermediate complexity earth system models.

2 *www.ipcc.ch*

3 These impacts models face similar challenges of *ESMs*, i.e., they attempt to simulate complex processes, and as such there are inevitably missing processes, simplifications, assumptions, etc. that affect the accuracy of the results.

FIGURE: Climate engineering is the deliberate and large-scale intervention in the earth's climatic system with the aim of reducing global warming, including through solar radiation management. The figure shows different techniques that are currently being discussed.



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SRM faces the same challenges for giving detailed projections of climate impacts, but arguably the stakes are higher in such analyses. SRM would not perfectly cancel the effects of global warming – it would reduce the intensity of the global hydrological cycle and change the seasonality and statistics of climate (Bala et al. 2008, Irvine et al. 2010, Kravitz et al. 2013). Thus a climate with high concentrations of greenhouse gases (GHG) and SRM could show no global mean temperature difference from the pre-industrial climate – and yet the climate impacts would differ substantially (Schmidt et al. 2012, Kravitz et al. 2013). The heuristics developed for understanding the climate impacts of CO_2-induced climate change would no longer hold for SRM. To date little work has been done on the climate impacts of SRM, and so the basis for forming simple heuristics for these is largely absent (for some remarkable exceptions see Naik et al. 2003, Pongratz et al. 2012, Couce et al. 2013). Therefore, studies that attempt to assess SRM by using simple heuristics of climate impacts are arguably overreaching, and their conclusions should be viewed with caution (e.g., Moreno-Cruz et al. 2012, Ricke et al. 2013).

SRM should be understood as one of many factors that shape outcomes – not as the only one, and likely not as the most important one, either.

The Gap between Climate Impacts and Socio-Economic Realities

Climate engineering research and debate has so far strongly focused on the effects of SRM on climatic variables, e.g., temperature, and on the possible political, legal, and ethical consequences of these effects. In doing so, research has neglected the extent to which SRM might actually remediate or aggravate the challenges of climate change.

The results of environmental models also influence other research areas, sometimes to an unjustified degree. After the IPCC's *Fourth Assessment Report,* a number of rather pessimistic scenarios have been outlined, among others by Welzer (2008), suggesting climate change could lead to widespread famine and breakdown of social order. Burke et al. (2009) estimated that the number of casualties in civil wars would rise as a consequence of global warming. Such gloomy perspectives of the future provide a basis for the "emergency framing" that is often referred to as a possible justification for SRM. However, the relationship between violent conflict and climate change is more complex than often assumed (Scheffran et al. 2012). Consequently, simple correlations between global warming and violent conflict have been refuted for a number of methodological reasons (Buhaug 2010): the role of intervening factors – such as social, economic, political, and cultural institutions – had not been sufficiently considered.

Environmental Factors Are only One Part of a Bigger Picture

An example of a complex environmental and social problem is the world food price crisis in 2007 and 2008. Environmental factors only played a minor role here. Instead, an increasing demand for agricultural non-food products (like biofuels), financial speculation, rising energy prices, and the devaluation of the US Dollar contributed significantly to the sudden spike in food prices in 2007 and 2008 (Headey and Fan 2010). In fact, global food demand never outstripped production capacity; in other words, no one would have had to starve if the physical availability of food had been the only concern. Hence, warming (through climate change) or cooling (through climate engineering) would be one factor among others influencing food security. Addressing the specific challenges of food security requires an identification of the role of climatic changes within that issue area. For example, fish stocks are likely to be negatively affected by ocean acidification, which SRM does not address (Williamson and Turley 2012). Thus, even though SRM would globally cool the planet and may prevent agricultural losses from excess warming (e.g., Pongratz et al. 2012), food prices may still rise as fish stocks decrease, and people may start to substitute fish with other nutritive substances.

A focus on the climate and other environmental effects of climate engineering as a potential instrument for remediating the societal consequences of climate change thus is insufficient. An alternative approach would be to identify and to understand the problem's complexity, where climate change may not be the dominant factor, but rather issues such as the overuse of resources and strong inequalities in wealth distribution between and within societies. This would require a more transdisciplinary approach to research, involving those who are directly affected, with stakeholder involvement beginning ideally in the research design phase.

The Gap between Model Results and International Cooperation

Many studies have shown that rationalist approaches to international cooperation, especially game-theoretic approaches to institutionalism, are in many respects well suited to understand the dynamics of international cooperation to reduce CO_2 emissions (Levy et al. 2009, Heitzig et al. 2011, Wood 2011). In order to effectively mitigate climate change, all large emitters of CO_2 would need to significantly cut their emissions, the immediate costs of which immensely outweigh immediate benefits. In addition, strategic incentives are weak because any potential benefits from reducing emissions are distributed globally, while costs from a reduction occur locally. This is a standard collective action problem: a state is best off if all other states reduce their emissions while it does not, creating incentives for shirking and free-riding. In this situation, states do not trust one another, knowing that the incentives for others to defect from a potential agreement to reduce emissions are very strong, and in the end the state that does the most to reduce its emissions is worst off. A "credible commitment" for reducing emissions is very difficult to achieve (e.g., Victor 2006).

What makes rationalist approaches so applicable to the issue of reducing emissions for mitigating climate change is that here state preferences can be understood through cost-benefit calculations. The collective action problem arises precisely because states know their own preferences and those of other states, based on a calculation of costs and benefits.

Rationalist approaches to international relations have also been applied in studies about international cooperation and conflict on SRM. This requires an assessment of costs and benefits that would result from the climatic changes an SRM intervention would produce. Such analyses thus focus on how states would interact based on the distribution of costs and benefits from SRM deployment, which are often deduced from climate model projections (as, e.g., in Ricke et al. 2013). This simplification, however, distorts the politics of international cooperation on SRM and at worst might even be misleading. Simple cost-benefit calculations are impossible for SRM due to the deeply uncertain distribution of costs and benefits. While the direct costs for implementing SRM are generally considered to be comparatively low (e.g., McClellan et al. 2012), it is unclear how the environmental impacts of an SRM deployment will be distributed (Irvine et al. 2010, Kravitz et al. 2013). Arriving at estimates of state preferences on SRM via calculations of costs and benefits thus requires far-reaching assumptions that do not adequately represent how states behave under conditions of deep uncertainty.

Unilateralism, Coalition of the Willing, or Broad Cooperation?

One such assumption involves the application of simple damage functions for SRM: these assume that deviations in precipitation and temperature from the first decade of the 21st century (considered the baseline) can be converted directly into damages, and measures restoring the baseline accordingly provide benefits (Moreno-Cruz et al. 2012). The amount of SRM that would restore the baseline differs from region to region due to the heterogeneous effects of such an intervention. One frequent conclusion drawn from this, following the realist tradition of international relations, is the danger of unilateralism in SRM (Barrett 2008, Victor 2008, Victor et al. 2009, for a critique see Horton 2011). One state, it is argued, might feel that the benefits that it is likely to reap from an intervention through climate engineering would so strongly outweigh the costs of deployment that it would go ahead and intervene in the global climate system without consulting the international community. A second account follows the institutionalist tradition and assumes that states will seek mutually beneficial cooperative arrangements in the form of exclusive coalitions (Ricke et al. 2013).

However, the simple rationalist approach underlying these arguments is misleading when it comes to SRM. States cannot be sure of what would be their "optimal" level of SRM, since there is deep uncertainty about how costs and benefits from an SRM intervention will be distributed, because their climate impacts are uncertain. Even if SRM were to be deployed, it would be very challenging to confidently detect and attribute the effects that it might have had on the climate (Stone et al. 2009, MacMynowski et al. 2011). Due to the inherently variable nature of the earth's climate, it can take decades to detect and attribute even fairly large global signals, as has been the case for the global warming signal (Stone et al. 2009). These observational limits, combined with the model limits outlined above, imply that certain knowledge on the climate impacts attributable to SRM would be hard to come by.

A more nuanced account might be achieved through greater consideration of factors that are emphasized by constructivist approaches to international relations, such as collectively held norms and ideas (Katzenstein 1996, Finnemore and Sikkink 1998, Wendt 1999, Risse 2000). From this perspective, the uncertainty surrounding the costs and benefits of an SRM deployment might, in fact, make achieving broad international cooperation on SRM – wheth-

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Projects on solar radiation management (SRM) seek to reflect or intercept sunlight before it reaches the earth and thus to reduce global warming. SRM techniques like introducing sulfate aerosols into the stratosphere are potentially cheap and could have large effects that would materialize quickly.

er for deployment, prohibition, or something in between[4] – easier. The absence of clear-cut state preferences might open up a space for ideational factors to influence states' interactions, which are not easily captured with rationalist approaches. This effect is not self-evident but needs to be explored through additional research. Accordingly, a constructivist approach that takes such factors into account and examines how states' preferences are shaped under conditions of high uncertainty would be a valuable addition to help bridge the gap between model projections of physical impacts from SRM and understanding dynamics of international cooperation and conflict on it.

Bridging the Gaps

We have identified a number of challenges that, if not engaged critically, may result in problematic and even misleading conclusions on SRM. In particular, we underline three challenges:

Firstly, climate impacts of SRM cannot be directly drawn from climate model variables. Instead, impacts models are needed that can predict changes in agricultural productivity, the occurrence of natural hazards, and all the many other aspects of climate impacts. However, these impacts models themselves are complex and uncertain, and thus the climate impacts of SRM are difficult to assess.

Secondly, climate impacts do not directly result in socio-political impacts but are mediated by social, economic, political, and cultural institutions. Moving directly from physical changes to a possible societal outcome may be premature. Instead, the role of intervening societal institutions needs to be considered.

Finally, state preferences and the dynamics of international cooperation and conflict cannot be deduced solely from modeling studies. Simplifying assumptions can help illuminate the dynamics of state interactions, yet other approaches are needed to increase our understanding of potential cooperation and conflict on SRM. A constructivist analysis would be useful for moving away from the environmental determinism often found in current studies.

More specifically, we suggest that the research focus should shift from projecting socio-political consequences directly from environmental changes to a view which shows a greater appreciation of the complex socio-political context of SRM. SRM could then be understood as one of many factors that shape outcomes – not as the only one, and likely not as the most important one, either.

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[4] For example, an institutional arrangement that oversees research according to specific guidelines, with a ban on use of SRM above a certain threshold.

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