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Questions Triggered by Recent Developments Around Solar Radiation Modification (SRM) and Suggestions How to Strengthen the Paris Agreement by Additional Mandatory Requirements

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Abstract

2023 has seen a considerable surge of attention around solar radiation modification (SRM). This raises some questions and this article strives to provide some preliminary answers with the objective to intensify and broaden discussion given the potential implications of decisions that need to be taken urgently, e.g., under the United Nations Framework Convention on Climate Change, the General Assembly of the United Nations and the United Nations Environment Assembly.

1. Recent Developments

The US-based start-up Make Sunsets had begun stratospheric aerosol injection in 2022 to cool the planet by launching balloons containing sulphur dioxide, first from Mexico and later from the US [1]. This activity was funded through the public sale of 'cooling credits', and venture capital. The Mexican government reacted that it would ban such activities on its territory.

Also, a UK researcher reported that he had deployed from the United Kingdom a balloon in September 2022 to test equipment for stratospheric dispersal of sulfur dioxide, sparking further controversy [2].

Following the publication of an open letter calling for an International Non-Use Agreement on Solar Geoengineering in early 2022, early 2023 saw two further groups of scientists calling for more research into, and balanced deliberation about SRM, respectively [3-5].

Meanwhile the Degrees Initiative (DEGREES stands for DEveloping country Governance REsearch and Evaluation for SRM, an NGO dedicated to putting the Global South at the centre of the SRM conversation) announced funding for a further 15 research teams in the Global South to research SRM impacts and the US National Oceanic and Atmospheric Administration (NOAA) commenced research flights over Alaska as part of a project to better assess the potential effectiveness, risks and benefits of future SRM proposals [6,7].

In 2023 also four United Nations (UN) reports addressing SRM have already been published. In February, a draft of a report requested by the UN Human Rights Council (UNHRC) with recommendations concerning SRM governance has been published, followed by the publication of the UN Environment Programme's (UNEP) One Atmosphere report, an independent expert review on SRM research and deployment that concluded on the needs for robust scientific assessment, development of governance frameworks, and promotion of globally inclusive discussions [8,9]. In March 2023 the Synthesis Report of the Intergovernmental Panel on Climate Change's (IPCC) sixth assessment was approved and published, including a paragraph on SRM risks, and how the lack of robust and formal governance itself poses risks, and last but not least in April 2023, the UN High-Level Advisory Board on Effective Multilateralism (HLAB) presented its Breakthrough for People and Planet report to the UN Secretary-General which included a recommendation to establish a forum on the governance of climate-altering technologies [10,11].

2. Is the Further Study of SRM Desirable and Even Necessary? If so, why?

There is the risk to see warming beyond the tipping points of the climate system pretty soon. E.g., global warming between 1 and 3°C can trigger melting of the Arctic sea-ice during summer, the melting of the Greenland Ice Sheet, the disappearance of the Alpine glaciers, melting of the West Antarctic Ice Sheet and coral bleaching. The crossing of the first four tipping points will result in positive feedback resulting in further increase of global warming due to the associated change in albedo. According to the IPCC

AR6, global warming will continue for decades to come and will cross 1.5°C in the coming 10 years. The WMO informed that between 2023 and 2027, there is now a 66% chance that the planet's temperature will climb above 1.5°C of warming above pre-industrial levels for at least one year [12].

The AR6 of the IPCC (10) also shows that global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26 would be similar to or only slightly below 2019 emission levels. However, global modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) are assuming immediate action and imply deep global GHG emissions reductions this decade. Continued greenhouse gas emissions will lead to increasing global warming in the near term, with best estimates of reaching 1.5°C in 2030–2035 in nearly all scenarios and pathways. Without a significant strengthening of current policies, global warming of 3.2°C (2.2°C–3.5°C) is projected by 2100 (medium confidence). Regions and people (3.3 to 3.6 billion in number) with considerable development constraints have high vulnerability to climatic hazards associated with such warming.

Despite this very clear and alarming assessment of the IPCC, COP27 in Sharm el-Sheikh (Egypt) in November 2022 did little to stop polluters causing more damage.

As expected from those current limited global mitigation efforts, the global GHG emissions continued to grow also in 2022.

Recent independent research from US and China shows that change in ocean heat content (OHC) is a critical indicator for changes in Earth's energy and water cycles and that in 2022, the world's oceans, as given by OHC, were again the hottest in the historical record and exceeded the previous 2021 record maximum [13]. Furthermore, the global long-term warming trend is so steady and robust that annual records continue to be set with each new year – as long as the concentrations of GHGs in the atmosphere will increase.

Another research paper concluded that there might be a Domino effect between tipping points [14]. If a tipping point is triggered, the Earth's climate system could change so that another tipping point is also triggered - similar to a falling domino causes another to fall - and so the effects of climate change will be further intensified. Because of the sheer size of these systems which can be tipping points, it is extremely difficult to prevent entire rows of dominoes from falling, leading to large-scale or even devastating climate damage in human and biological systems. This positive feedback process could lead to the breaking of the Earth's climate system through critical points, and finally to completely breaking away from the glacial-interglacial cycle of the last million years, and a galloping warming of the Earth might occur eventually leading to the beginning of the "hot house" area.

3. The Gross Domestic Climate Risk Ranking by the Cross Dependency Initiative [15]

• reflects physical risk to the built infrastructure from eight climate change hazards: riverine and surface flooding, coastal inundation (coastal flooding), extreme heat, forest fire, soil movement (drought-related), extreme wind and freeze thaw.
• uses global climate models, combined with local weather and environmental data and engineering archetypes, to calculate probable damage to the built environment under the Intergovernmental Panel on Climate Change's RCP 8.5 scenario
• China has 26 states in the 50 high risk states; India, 9, and the US, five. In China, the most affected provinces are concentrated in the east and south, along the floodplains and deltas of the Yangtze and Pearl Rivers. In the US, the economically important states of California, Texas and Florida are most affected. Other countries with multiple provinces and states in the top 50 include Brazil, Pakistan and Indonesia.

Perhaps even more relevant than risks related to physical risk to the built infrastructure driven by climate change driven extreme events is the risk for internal displacement of people (IDP) due to climate change driven extreme events, mainly floods. The year 2022 saw a record number of 8.7 Mio IDP, reported by GRID 2023, the Global Report on Internal Displacement [16]. For comparison: The figure for IDP driven by conflict and violence in 2022 has been 62.5 Mio [16].

Current climate path will lead to collapse of life on Earth, say scientists. Prof. Rockstrom of the Potsdam Institute for Climate Impact Research, said: "1.5°C is not a target. I call it a physical limit. There's one conclusion without any uncertainty whatsoever, and that is that 2.5°C global mean surface temperature rise is a disaster. The talk about going up to 2°C then bringing the temperature down by removing greenhouse gases, that is not good enough. Too many people will die in that period when we allow the temperatures to go up" [17].

Given these above findings, those experts that signed the letters which call for more research of SRM, believe in the potential of SRM to reduce some risks of global warming. Also, aerosols are masking global warming due to the sulfur content of fossil fuels. Such masking occurs regionally and was investigated by scientists e.g., for the North Atlantic ("North Atlantic Warming Hole") and amounts there to about 0.4°C and also the eruption of the Pinatubo resulted in global cooling of about 0.5°C.

But additional scientific research should be conducted to support the assessment of the effectiveness of different SRM interventions to reduce climate warming; how different SRM interventions would affect climate change and climate impacts under different greenhouse gas scenarios; and the capabilities for detecting and attributing the impacts of various SRM interventions. The experts fully support research into SRM approaches, but this does not mean those experts support the use of SRM now. Those experts request that decisions about whether and how SRM might eventu-

ally be implemented must be preceded by both: a comprehensive, international assessment of how SRM interventions would affect climate risks regionally and globally, and cooperative international decision-making on the use of SRM based on the latest science.

And reduction of risks related to the climate system by SRM also has a downside: in particular, there is the risk of moral hazard and the risk of unintended side effects in case of abrupt termination of SRM. In the context of SRM moral hazard describes the lack of incentive to reduce climate change risks by mitigation of GHGs where one could be protected from its consequences at significant lower cost by SRM. Abrupt termination is a significant risk because the long-lived GHGs such as CO_2 would remain in the atmosphere at dangerous high levels in the range of thousands of years and thus there is a significant risk that stratospheric aerosol injection would be terminated before a safe level has been achieved.

Therefore, there are practically no scientists that would recommend to implement SRM now as this would likely end up in even more catastrophic scenarios than the worst-case climate change scenarios assessed by the IPCC.

4. What is the Biggest Challenge in this?

In general, the biggest challenge in addressing the risks of climate change is to overcome the social tipping points that allow to reduce those currently still growing risks. Thus, we have to speed up mitigation of GHG emissions and adaptation to reduce the risks of climate change. If we do not raise the speed of mitigation, we are on the pathway with a global warming of ~ 3°C by 2100. But if we enhance our efforts with the goal to limit warming by mitigation to 2°C by 2100 this would also reduce the scale for masking global warming by SRM in order to limit global warming to 1.5°C from 1.5°C to 0.5°C.

A paper published in 2020 identified the following social tipping points that need to be passed for stabilizing earth's climate by 2050: removing fossil-fuel subsidies, incentivizing decentralized energy generation, building carbon-neutral cities, divesting from assets linked to fossil fuels, strengthening climate education and engagement, disclosing greenhouse gas emissions information [18].

But we also have to overcome the social tipping points to have a proper basis to assess and address the remaining unintended side effects of SRM identified above and to try to reduce those risks.

In short: we would need a quite robust governance at the global level. Such governance would have to manage to reduce the risk of moral hazard by agreement on some strong climate regime that allows to transform the current voluntary commitments for mitigation under the Paris Agreement into mandatory commitments to achieve net zero GHG emissions at a broadly agreed time line, e.g., by 2050.

And such governance would also have to guarantee that a meaningful level of carbon dioxide removal (CDR) combined with permanent storage is available at the latest by a similar point in time.

The clear advantage of the deployment of these two main geoengineering options, CDR and SRM, is to minimize the risks of climate change for biological and human systems.

The scale of deployment of both geoengineering options strongly depends on the speed of deployment of mitigation. If we had started with strong mitigation measures earlier there would have been neither a need for CDR nor for consideration of SRM. Now, in 2023 we are already in a situation which will result in unmanageable global warming risks that can only be controlled by CDR and some limited SRM in addition to mitigation and adaptation.

According to the AR6 of the IPCC all global modelled pathways that limit warming to 2°C by 2100 involve rapid and deep and in most cases immediate greenhouse gas (GHG) emissions reductions in all sectors [10]. But global net zero CO_2 emissions would only need to be achieved by ~2070 and global net zero GHG emissions by ~2100.

However, this more realistic speed of phase out of fossil fuels requires a speedy development to have CDR with permanent storage available at a minimum scale in the range of 10 Gt CO_2 per year and to develop a robust governance for mandatory mitigation of GHGs and deployment of SRM. Overshooting would have to be compensated in the range of 0.1°C to 0.5°C to avoid warming higher than 1.5°C and CDR would be required in the range of ~ 500 Gt CO_2. A recent publication assessed the current status of carbon dioxide removal [19].

Preventing and controlling unwanted SRM deployment may be its greatest governance challenge [20]. SRM's capacity for widespread environmental effects, technological simplicity, and relatively low direct financial costs of deployment give it—and especially SAI—high leverage. One or a few countries—including those other than superpowers—could begin SRM before and/or contrary to any international consensus. This could be seen as problematic even if SRM were widely expected to be beneficial. Uni- or mini-lateral SRM might be domestically motivated by severe and sudden climate impacts, consequent popular unrest, and/or a desire to provoke the rest of the world to reduce emissions more aggressively and provide more internationally finance for adaptation. Either way, threats or actions in this area could precipitate international tension and conflict. Unfortunately, a publication assessing the current status of SRM which is comparable to the publication "The State of Carbon Dioxide Removal" is not available for the time being. However, the White House is investigating whether geoengineering could temporarily limit global warming and what risks the technology entails. This can be concluded from a report from the US news portal CNBC, citing the Office of Science and Technology Policy (OSTP), responsible for research and technology policy, which informed on the mandate of the US Congress to develop a five-year plan for the scientific evaluation of

rapid climate interventions [21]. US president Biden called global warming bigger threat to humanity than nuclear war during NYC speech (31 January 2023).

Use of SRM would create its own risks and would only make any sense in a world experiencing or expecting severe climate change impacts. As such, consideration of SRM needs to take place in a risk–risk context (whereby the risks of application are judged against the risks from climate change without SRM). Considering the impacts of SRM in isolation can be misleading, as SRM's sole raison d'être is reduction or avoidance of climate impacts stemming from elevated greenhouses gas concentrations. To be relevant, assessment of SRM therefore needs to enhance our understanding of potential effects across a multitude of socially relevant parameters, rather than a single one [22].

Given the many assets at risk in China and the US it is not surprising that the US and China agreed once and again to strengthen co-operation on managing the risks of climate change. US climate envoy Kerry noted on Sunday, 16 April 2023 in Japan, Sapporo, i.a. "But we're not doing everything we said we'd do," he said, after attending a meeting of energy and environment ministers of the Group of Seven wealthy nations. "A lot of countries need to step up including ours to reduce emissions faster, deploy renewables faster, bring new technologies online faster all of that has to happen." Chinese climate envoy Xie Zhenhua has invited his American counterpart John Kerry to China, boosting hopes that the world's two biggest emitters can renew their cooperation on climate change (24 April 2023).
Christophe Béchu, Minister for Ecological Transition and Territorial Cohesion of France, explained on May 23 why France is planning to adapt to a global warming of 3°C – which means for France warming of 4°C [23].

According to an article by RIA Novosti (Russian: РИА Новости), sometimes referred to as RIAN (РИАН) or RIA (РИА), a Russian state-owned domestic news agency, in response to the engagement of the US in relation to SRM, explains that Russia, on the contrary, only benefits from global warming. Scientists calculated that the zone of efficient farming in Siberia will double by 2080 - by almost five million square kilometers. Russia will become the main producer of wheat on the planet with 20 percent of the market. And the explosive growth of agricultural production is only a small part of what, according to climate optimists, awaits Russia. The steady melting of Arctic sea ice will make the Northern Sea Route the shortest and cheapest route for cargo from China and the whole Southeast Asia in Europe. Control over this most important transport artery promises significant benefits and revenues [24].

5. How to Stipulate Rapidly Public Debate and Discussions at the Policy Level?

A pragmatic proposal would be to build on the already agreed Global Stock Take under the Paris Agreement and to enhance the topics to be considered under the Global Stock Take in the future.
The current Global Stock Take aims to answer three vital questions:
1. Where are we?
2. Where do we want to go?
3. And critically important, how do we get there?
The Global Stock Take process is designed to inform countries in updating and enhancing their climate actions and support, and to enhance international cooperation for climate action. It shouldn't end with an assessment, but should also look ahead and should provide countries and stakeholders with valuable information on the remaining gaps and opportunities to bridge them to reach the goals of the Paris Agreement.
The Global Stock Take (GST) as planned now facilitates the assessment of global collective progress on three thematic areas:
▪ Mitigation: its effect of countries NDCs on global temperature and ▪ determine what additional cuts to global greenhouse gas emissions are necessary to meet the Paris Agreement's long-term temperature goals
▪ Adaptation: assess progress toward enhancing countries' collective capacity to address climate impacts, strengthen resilience and reduce vulnerability to climate change.
▪ Means of implementation and support: assess progress toward making financial flows consistent with the cutting of GHG emissions and ensuring climate-resilient development.
In light of the need to make use of the two geo-engineering options CDR and SRM as explained above the following extension of the GST process is suggested:
▪ Mitigation: by when net zero GHG emissions will be achieved on a global level and what amount of carbon dioxide will have to be removed from the atmosphere in order to allow stabilization of the temperature at a safe level and the current scale of carbon dioxide removal (CDR) combined with long-term storage as well as information on the current costs of CDR
▪ SRM: information about the options and risks linked to Solar radiation management and in particular Stratospheric Aerosol Injection (SAI) including precautionary approaches that have been suggested;
▪ Adaptation: the risks of crossing tipping points, in particular those with positive climate feedback.
▪ means of implementation, including finance, technology and capacity-building: information on losses and damage at the global level attributable to climate change and options how to enhance the speed of mitigation, of adaptation, of deployment of CDR combined with long-term storage and of closing the research gaps with respect to SRM and SAI.
More detail on the extension of the GST has been published in a short research paper with the title: Policy relevant information with respect to climate change [25].
A schematic graph of a "Peak-shaving Solar Geoengineering deployment scenario", prepared by Matthias Honegger, shows in figure 1 how mitigation, CDR and SRM could work together in order to control climate change risks [26].

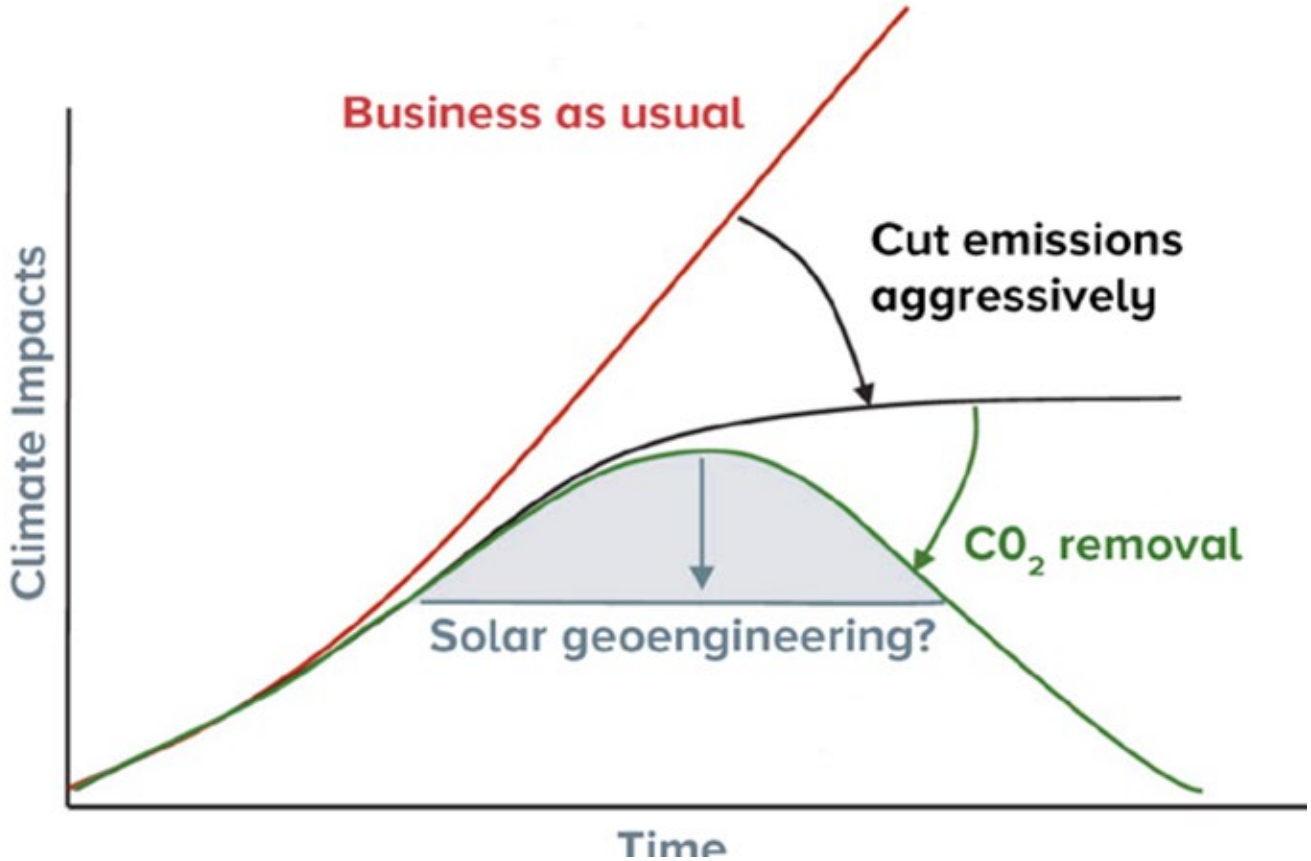

Figure 1: Peak-shaving Solar Geoengineering deployment scenario

An additional proposal is to strengthen the voluntary commitments under the Paris Agreement by introducing in addition to the current voluntary commitments a more stringent and binding commitment to a) mitigate greenhouse gas emissions coherent to limit warming to 2°C. This would still be a goal that could be met by mitigation only. The benefit of such additional agreement would be to limit the amount of carbon dioxide removal to about 500 to 700 Gt CO_2 which can hopefully be managed within a reasonable time period and with reasonable financial resources and to address the challenge of moral hazard.

Another element of this second proposal related to more stringent and binding commitments should be the requirement to invest in a certain amount of carbon dioxide removal by Direct Air Capture and permanent storage. This should support to buy down the learning curve and help manage CDR to realize the necessary negative global GHG emissions to limit the amount of time that requires deployment of SRM. This commitment should see growing amounts of direct carbon dioxide capture from air combined with permanent removal with the goal to remove by 2050 a significant amount in the range of about 10 to 25 Gt CO_2 per year.

The above proposals are in line with an appeal by the Club of Rome earlier this year. This appeal explains inter alia that a planetary emergency has been declared by United Nations Secretary General António Guterres as well as national and local leaders across the globe. However, governments faced with the compound effects of the COVID pandemic, climate change and conflict are using related economic impacts and inflationary effects to dampen climate ambition and delay action for a just global transition [27].

In his message for the World Day of Prayer for the Safeguarding of Creation, next September 1, Pope Francis pleads for a transformation of hearts, ways of life and public policies. The theme of the Ecumenical Season of Creation this year is “Let justice and peace spring forth”. The message was released Thursday, May 25 2023 in this Laudato si’ week [28].

6. Conclusions

This article builds on recent publications on SRM and explains why SRM could help reduce the risks of climate change. The article also informs about the key unintended side effects of this approach and identifies a possible scenario how the Global Stock Take under the Paris Agreement could be further strengthened in order to help Parties identify the governance issues that need to be resolved before deploying of SRM and CDR at scale could become a meaningful option with the goal of avoiding dangerous interference with the climate system.

The three suggested additional mandatory pillars to complement the Paris Agreement would be related a) to adaptation and mitigation of GHG emissions with the goal to limit global warming by those actions to less than 2°C, b) to identify national targets

for deployment of CDR with the goal to reach a yearly scale of deployment above 10 Gt CO_2 and c) to allow masking of global warming by SRM up to 0.5°C for a limited period of time in order to avoid global warming higher than 1.5°C.

In order to further strengthen the climate regime under the UNFCCC strong enforcement rules need to be considered. The EU's Carbon Border Adjustment Mechanism (CBAM), a landmark tool to put a fair price on the carbon emitted during the production of carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries, could be a proper model for such enforcement rules.

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