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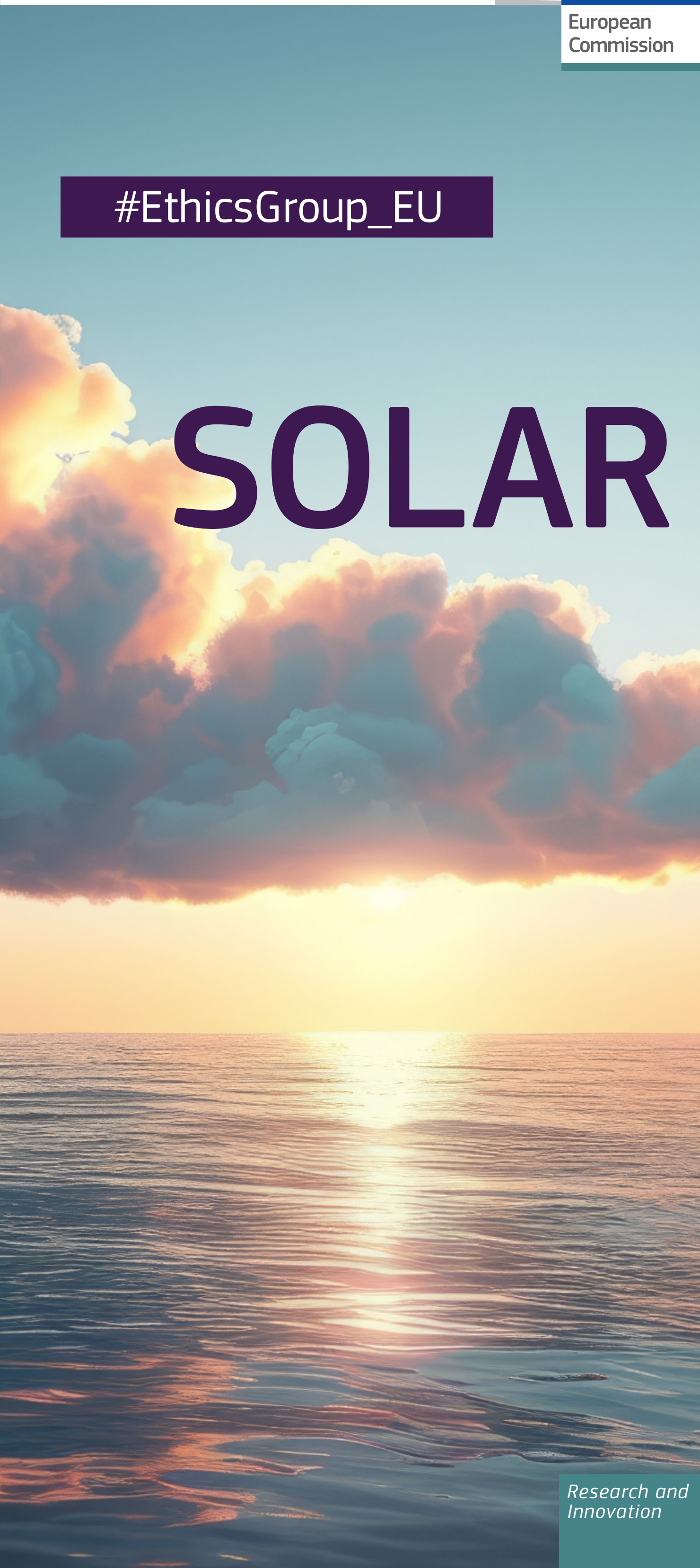

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SOLAR RADIATION MODIFICATION

Ethical perspectives

European Group
on Ethics in Science and
New Technologies

Research and Innovation

Solar Radiation Modification: Ethical perspectives.

European Commission
Directorate-General for Research and Innovation
Unit 0.2 — Science for policy, advice & ethics

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European Group on Ethics
in Science and New Technologies

Opinion on

SOLAR RADIATION MODIFICATION

Ethical perspectives

Brussels, 9 December 2024

2024 Directorate-General for Research and Innovation

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THE OPINION IN BRIEF
SUMMARY

WHAT IS AT STAKE?

The term **'solar radiation modification'** (SRM) refers to **geoengineering techniques designed to reflect more sunlight away from the Earth or increase the escape of infrared radiation,** thereby reducing the amount of solar radiation that reaches the Earth's surface and cooling the climate.

Any **large-scale intervention in the Earth's climatic system comes with severe risks.** The risks include **differential impacts on temperature and precipitation with manifold consequences for global populations,** including those living far away from the place of intervention. Another risk is that **SRM technologies are used unilaterally, or even weaponised, by 'rogue' actors.**

THE CHALLENGES

Large-scale deployment of SRM would entail an intervention into a global commons – our shared planetary environment – with systemic consequences, which raises complex governance challenges.

Not much is yet known about how the deployment of SRM would play out. The discussion is thus fraught with a vast number of uncertainties. It is difficult even to conceptualise the uncertainties, let alone assess how the risks could affect different groups and places. Against this backdrop, the European Group on Ethics in Science and New Technologies (EGE) makes several recommendations, set out below.

WHAT TO DO

The EGE has formulated a wide range of very concrete and **specific recommendations for each group of stakeholders** to follow. The stakeholders are the European Commission, the EU Member States, the international community, the scientific community and civil society. Out of these recommendations, the EGE would highlight the following:

SRM must not deflect from prioritising **first the reduction of greenhouse gas emissions,** followed by carbon removal.

Any technical solutions developed cannot replace the changes needed to social and economic practices to decarbonise our economies. Complex social and environmental problems cannot be solved with technology only.

SRM is seen by some as **'greenwashing'** to serve the interests of powerful businesses instead of meeting the needs of the global community. **Environmental problems and their potential solutions, especially if uncertain, should not become business opportunities outside of democratic control.**

The legitimacy of any future use of SRM must be based on broad, informed civil participation in decision-making. Public participation is crucial to prevent SRM development and deployment from becoming captive to sectarian interests, be they academic-scientific, economic-financial or political. In this Opinion, the EGE considers how to achieve inclusive decision-making in practice (through public consultations, participatory workshops, stakeholder fora, observatory networks, advisory bodies etc.). It proposes suggestions for **how to represent the interests of future generations and non-human entities** in these processes (by creating commissioners or committees for the future, by systematically integrating intergenerational equity principles into policy making, long-term environmental and social impact assessments etc.).

The ethical dilemma here is compounded when decisions to deploy SRM are made by the wealthiest and most technologically advanced nations. **It is crucial to prevent the epistemic and political dominance of more influential countries and regions over others** and to enable a diverse range of populations, including underprivileged regions and marginalised social groups, to participate in the decision-making process. The historical responsibilities of wealthier countries demand this. Without **inclusive and equitable governance,** the pursuit of SRM could exacerbate global inequalities.

Knowledge and experience informing **SRM governance should not be limited to expertise on the technical and 'scientific'** (in the narrow sense of the word) aspects of SRM. Decision-making in a context of deep uncertainty requires **inclusive and participatory processes that value different kinds of perspectives and expertise,** including those of local communities who have long-standing experience and expertise with climate (change) and biodiversity (loss).

OPENING NOTE AND ACKNOWLEDGEMENTS

In the context of the European Commission's work to further the European Green Deal, Executive Vice-President Maroš Šefčovič requested the European Group on Ethics in Science and New Technologies (EGE) to issue a series of three Opinions providing ethical perspectives on different aspects of the green transition.

The Scoping Considerations provided by the Vice-President note that the questions raised by what has been referred to as the triple planetary crisis (climate change, biodiversity loss and pollution) and the policy responses to these questions are deeply ethical. They concern the relationship between humans and the environment, our responsibility vis-à-vis nature on which life on Earth depends, and human action, today and in future, to tackle one of the greatest challenges that humanity has faced. The advice sought from the EGE concerns our relationship with and our responsibilities towards nature and towards each other, now and in the future.

This first of the three Opinions discusses Solar Radiation Modification (SRM). In the context of accelerated global warming, the option of deliberate large-scale intervention in the Earth's natural systems – often referred to as 'geoengineering' or 'climate intervention' (of which SRM is an example) is attracting more attention. It involves multiple known and unknown risks at several levels. This Opinion provides broad ethical and policy-related reflections on different aspects and phases of SRM, from research and development to potential future deployment. The viewpoints provided also feed into the discussions of geoengineering more broadly.

This Opinion is published jointly with reports from the Scientific Advice Mechanism (SAM) of the European Commission: the Scientific Opinion on SRM of the Group of Chief Scientific Advisors (GCSA) to the European Commission and the Evidence Review Report on SRM by the consortium Science Advice for Policy by European Academies (SAPEA). The authors have collaborated constructively during the process of drafting these reports, which provide complementary perspectives.

The authors thank all contributors to this Opinion, be it in discussions or in writing, notably: Dušan Chrenek, the participants of the scoping workshop and the colleagues involved in its follow-up, Andrew Brennan, Norva Yeuk-Sze Lo, Stephen M. Gardiner, Amedeo Santosuosso, members of the Group of Chief Scientific Advisors and their team, Louise Edwards, her team and all other colleagues involved at SAPEA, and Katharine Wright.

INTRODUCTION

This Opinion covers research into, prospective deployment of and governance models for one of the most widely discussed geoengineering methods: solar radiation modification (SRM), sometimes simply referred to as solar geoengineering or solar radiation management.[1] SRM comprises all methods and tools that intentionally alter the Earth's atmosphere or surface to reflect more sunlight back into space, reducing the amount of solar radiation reaching the Earth's surface or allowing more infrared radiation to escape into space, seeking to create a net cooling effect on the climate.

Specifically, the SRM toolbox includes:

i. stratospheric aerosol injection (SAI) – the most studied form of SRM – which involves techniques such as injecting precursor gas sulphur dioxide (SO_2) into the stratosphere, mimicking the effect of large volcanic eruptions;

ii. cloud modification, which involves either brightening clouds (usually marine clouds), thinning high clouds (usually cirrus clouds) or seeding mixed-phase clouds; and

iii. surface brightening (albedo engineering), which includes a range of techniques from urban and agricultural modifications such as changing rooftops or selecting crops that reflect the sunlight more than others, to covering desert areas with highly reflective materials or whitening oceans with small glass spheres, foams or microbubbles.

A fourth possible category of SRM technology is space mirrors (based on dust from moon rocks or asteroids), which is currently even less technologically feasible than other techniques. This technology will not be included in the remit of our discussion and recommendations.

The objective of SRM is to mitigate some of the impacts of climate change and thereby help to meet temperature targets set in the 2015 Paris Agreement.[2] If effective, SRM could lead to less solar energy remaining in

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[1] Another method, which is not covered in this Opinion, is carbon dioxide removal (CDR). CDR aims to remove CO_2 from the atmosphere to reduce atmospheric carbon dioxide, for instance through afforestation, large-scale production of synthetic algae or ocean fertilisation (on the differences between these methods, see Shepherd et. al., 2009).

[2] https://unfccc.int/process-and-meetings/the-paris-agreement

the atmosphere, which in turn could lead to a decrease in global average temperatures. While the impact of some SRM technologies can be primarily local (e.g. rooftop whitening), other proposed SRM technologies that are in the early stages of conceptualisation or development are intended to have large and possibly irreversible impacts. This Opinion focuses on the latter group of advanced SRM technologies.

SRM is a challenging and unpredictable domain where policy development is in its early stages, the stakes are very high, and there are numerous potential and unquantifiable uncertainties and risks. Large-scale deployment of SRM – that is, all experiments and applications of SRM that could have effects beyond the specific locus of intervention (GCSA 2024) – would be intervention into the global commons – our shared planetary environment – which raises vastly complex governance challenges.

Scientifically, the field is constantly evolving. To date, the effectiveness of any of the proposals to deploy SRM has not been tested in the real world. What we know today comes from laboratory experiments, modelling and simulations or imperfect analogues such as volcanic eruptions, not from evaluations of real-world deployment. There are scattered examples of small-scale outdoor experimentation, some on a commercial rather than research basis. Large-scale real-world experimentation, particularly in SAI, would be a slippery slope to actual deployment (see also SAPEA 2024a, GCSA 2024).

In this context of technological and scientific uncertainty, there are debates about:

a) the most appropriate ethical and normative principles applicable to SRM-related research;

b) the type of governance mechanisms required to manage the environmental, social and individual implications of SRM deployment, whether in the form of small outdoor experimentation or large-scale deployment; and

c) how investment in research could boost deployment.

To accompany and underpin other work relating to the EU’s position on SRM, the European Commission asked the EGE to draft an opinion that specifically addresses the following questions:

- what are the most important ethical considerations in relation to solar radiation modification techniques?

- on the basis of what is currently known or can currently be assumed about this set of technologies, under which circumstances, if any, could their development and deployment be considered ethical?
- what are the relevant ethical perspectives as regards the international governance of solar radiation modification?

We are grateful to the Group of Chief Scientific Advisors (GCSA) for helpful discussions on this topic (GCSA 2024), and to the consortium Scientific Advice for Policy by European Academies (SAPEA), which established an interdisciplinary working group of independent experts to bring together and review existing scientific evidence on the possible effects and impacts of SRM (SAPEA 2024a). These resources and conversations have been very helpful for our own discussions.

In addition, SAPEA conducted a rapid literature review of the ethics of SRM, covering formal academic literature reviews and evidence-informed guidance from globally established organisations (SAPEA 2024b). The review found that ethical deliberations and assessments must distinguish four different aspects of SRM governance:

1) regulating lab-based and other research, e.g. model simulations, that aims to test or deploy SRM (excluding basic research that is foundational for an entire field rather than being SRM-specific);

2) regulating small-scale outdoor experimentation;

3) taking decisions on whether and (if so, under what conditions) to carry out large-scale experimentation or deployment of SRM; and

4) managing the consequences that could emerge after deployment, including how to react if ‘rogue’ countries use SRM against the global consensus.

We will return to these four aspects of governance throughout this Opinion.

1. SCIENTIFIC-TECHNICAL UNCERTAINTIES: AN OVERVIEW

The use of SRM technologies is fraught with uncertainties, both in terms of their likely benefits and their possible risks. This is true of most new, advanced technologies. Evidence on their broader and longer-term effects is likely to be lacking or not robust enough. The problem with SRM, however, is not only the vast number of uncertainties, their complex nature and the gravity of the associated risks. For some applications, it is extremely difficult or even impossible to anticipate and quantify the risks involved, both in the short and long term. It is difficult even to conceptualise the uncertainties, let alone assess how the risks could affect different groups and places. This deep uncertainty makes evidence-based policymaking immensely difficult, even with the best effort and intentions.

Regulating research and deployment of SRM is a typical case of a ‘wicked problem’ (Rittel & Webber 1973). There is no agreed formulation of the problem; no ultimate test of a solution; challenges are interconnected and span several fields of policy and practice; and international organisations that could create binding rules and policies in this area are dependent on the consent of their member states to these very rules (Levin et al. 2012; see also Auld et al., 2021). Policymakers tackling wicked problems often operate without precedents or clear norms (Wexler 2009), and there is a risk that they yield to the interests of economically powerful actors. Kelly Levin and colleagues consider a range of advanced technologies to tackle climate change to be ‘super-wicked problems’, a characterisation that arguably also applies to SRM. Not only does the decision to regulate SRM fall on some of the same states and organisations that have largely contributed to and failed to prevent global warming, but they often have to make decisions about it under great time pressure.

The policy options to tackle the problem cannot be ranked according to different criteria because the evidence-base to do so is lacking. This means that it is even more important for that policymakers to commit to and be explicit about the values, principles, ideals and goals that guide their actions and decisions,[3] rather than merely focusing on how to avoid breaching norms (Chan 2023: 37). Being explicit about these ideals and values and transparent about why they were chosen to guide policymaking

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[3] As Conradie (2020: 239) notes for the climate crisis more broadly, ‘the framing of the problem in scientific and economic terms is dubious since the deepest challenge is ethical – namely, the need to protect the poor and vulnerable, future generations, and nonhuman forms of life’.

not only increases the legitimacy of decision-making but also opens it up for public scrutiny, which is an essential feature of democracies (EGE 2022, 2023, 2024).

1.1. WHAT IS AT STAKE IN RESEARCH AND DEPLOYMENT

Before we explore in further depth the challenge of managing the uncertainties inherent in SRM technologies, we provide a schematic and simplified overview of some of the main arguments, both technical and ethical, that have been put forward to justify or challenge the possible future deployment of SRM (SAPEA 2024a). We note here that simply framing the issues in terms of the 'pros and cons' of deployment is not very helpful for our problem. As we explore in more depth below (see Section 1.2) given the deep uncertainties inherent in these technologies, it is also important to distinguish between the four distinct scenarios outlined above (see Introduction). The nature of the ethical issues that arise during the four stages of research and (possible) deployment may differ.

For instance, with regard to research on SRM (Scenario 1), ethical issues include the need for transparency on the public or private sources of financial support, and researcher compliance with ethical codes (such as The European Code of Conduct for Research Integrity). In particular, this includes researchers' declarations of potential conflicts of interest and acceptance of their individual and collective accountability for the outcomes and implications of the SRM research they carry out. Ethics also comes into play in connection with sharing the results of this research. Given the uncertainties regarding the implications of SRM for the whole planet, making research findings available without cost barriers (e.g. paywalls) is a paramount ethical obligation for anyone involved in research on SRM.

The ethical obligation to share the results of research is also reflected in the provisions of the International Covenant on Economic, Social and Cultural Rights (1966). The Covenant obliges state parties to take the steps 'necessary for the conservation, the development and the diffusion of science' (Article 15(2)), and also to recognise 'the benefits to be derived from the encouragement and development of international contacts and cooperation in the scientific field' (Article 15(4)).

For the small-scale outdoor experimentation of SRM technologies (Scenario 2), ethics comes into play with respect to researchers' duty to assume full responsibility for the outcomes of the experimentation and their duty to recognise that currently the results obtained are limited and will not in themselves provide sufficient evidence to justify, promote or support large-scale deployment of any form of SRM.

For large-scale experimentation and deployment (Scenario 3), ethical issues are numerous and of extreme gravity. Based on the knowledge we have today, the EGE regard large-scale use of SRM as a threat to human safety and health, to the survival of different local communities and less wealthy countries (those that are less prepared to deal with unforeseen climate threats), to planetary wellbeing and to the whole global ecosystem. In light of these threats and given that there is as yet no specifically established governance body nor agreement over the deployment of SRM technologies, Scenario 3 could lead to disaster on a global scale.

Managing the consequences that could emerge post-implementation (Scenario 4) would involve ethical considerations as to how to manage the negative impacts in the event of large-scale deployment. An ethically-informed perspective would involve identifying responsibilities and attributing the corresponding duties for how to attend to the harms caused to (vulnerable) social groups, and particularly to those living in countries that have not participated in the large-scale deployment, yet suffer the consequences.

An argument sometimes used in favour of SRM research is academic, specifically scientific, freedom. This freedom, it could be argued, is particularly salient today, amidst increasing threats to scientists.[4] The argument is backed up by international human rights law, which is informed by – and informs – a global ethical discourse. International human rights law provides that scientific freedom is both 'indispensable for scientific research' (ICESCR 1966, Article 15(3)) and at the same time non-absolute, meaning that it needs to be weighed against other important rights.

In explaining this freedom, the UN Committee on Economic, Social and Cultural Rights emphasises that it includes the 'protection of researchers from undue influence on their independent judgement; the possibility for researchers to set up autonomous research institutions and to specify the aims and objectives of the research and the methods to be adopted; the freedom of researchers to freely and openly question the ethical value of certain projects and the right to withdraw from those projects if their

[4] Two in five scientists around the world working on climate topics have experienced online harassment or abuse related to their research (Global Witness 2023).

conscience so dictates; the freedom of researchers to cooperate with other researchers, both nationally and internationally; and the sharing of scientific data and analysis with policymakers, and with the public wherever possible' (CESCR, 2020, para. 13).

The Committee also notes that private corporate investment in scientific research institutions must not restrict the freedom of scientists or have undue influence on the orientation of their research (para. 43). It also elaborates on the relationship between scientific freedom and scientists' right to publish the results of their research. Linking this to the duty of state entities to ensure that science and culture are preserved, developed and made widely accessible (ICESCR, Article 15(2)), the Committee states that 'scientists have, in principle, the right to publish the results of their research' (CESCR 2020, para. 50). Any contractual or other restrictions placed on this right should therefore be consistent with the public interest and be reasonable and proportionate (ibid.).

However, the Committee is equally clear on boundaries to scientific freedom. In so doing, it takes up a theme pressed by others, including UNESCO, which refers to scientists' responsibilities alongside their freedom and rights in its Recommendation on Science and Scientific Researchers (UNESCO 2017). This emphasis on balancing freedom with boundaries or responsibilities results in part from past abuses of scientific freedom. History has shown that science can be used for malicious ends. It also shows that science can be used in both good and bad faith.

Freedom and responsibility also go hand in hand, given the need to encourage and facilitate science as a public good. This means science that puts at its core respect for the environment as well as for human dignity, progress, justice, peace and the welfare of humankind. Scientific freedom does not, in and of itself, contradict the need for regulation and governance of SRM.

1.2. RISKS AND BENEFITS: THE UNCERTAINTIES OF UNCERTAINTY

Evidence from experiments and modelling suggests that some SRM techniques have the potential to counteract some of the impacts of greenhouse gas (GHG) forcings, which is the change in the Earth's energy balance caused by greenhouse gases trapping heat in the atmosphere, leading to warming (see SAPEA 2024a: 36). Techniques such as stratospheric aerosol injection, cloud brightening, cirrus cloud thinning and surface brightening may bring significant benefits such as reducing extreme weather events, slowing ice melt or improving air quality. At the same time, the risks of large-scale intervention in the Earth's climatic system are many.

The risks include differential impacts on temperature and precipitation around the world with consequential impacts for populations far from the intervention site; potential changes to plant growth, crop reduction and drought (again uncertain and differing across regions); and the unilateral use or even weaponisation of technologies. As highlighted above (see Section 1.1), these risks differ in type, number and degree of severity. Some uncertainties are so deep that it is doubtful that any reasonable risk assessments can be made.

One reason for the extent of these knowledge gaps is that we have to rely on small-scale laboratory research, simulations and modelling, on outdoor experiments that can be securely contained regionally, or on drawing analogies from 'natural' phenomena that modify solar radiation, such as volcanic eruptions. The conclusions that can be drawn from such 'natural' analogies are imperfect due to differences in time scales and the material used for injections (see SAPEA 2024a: 21). Although the models used to analyse different potential applications of SRM are becoming more sophisticated, the climate system involves complex interactions between the atmosphere, oceans, land surface and biosphere that are not yet fully understood. Together with feedback mechanisms (cloud formation, carbon cycle feedbacks, etc.) that are difficult to represent accurately in models, this means that there are great uncertainties in model predictions. Moreover, many models do not account for the societal implications of SRM technologies (SAPEA 2024a: 51 see also UN 2023: 6).

Decision-making in a context of deep uncertainty

One approach to decision-making in contexts in which the future benefits and harms are well-defined is to use normative ethical theories and theories of decision-making that prescribe action to maximise utility (Sahlin 2012; Sahlin 2014; MacAskill 2020). To follow this approach, relevant knowledge, information, the desires and values of the decision-maker must all be quantifiable. This is not the case with SRM. If the uncertainties cannot be represented in terms of unique probability measures and preferences cannot be represented by a single utility function, maximising expected utility is no longer an option. Other decision rules are required to guide action. But which rules?

In recent years, decision scientists have become interested in issues related to decision-making under deep uncertainty (Marchau 2019), for example, where there are significant knowledge gaps, in the context of complex (adaptive) dynamic systems, or where there are things that we cannot predict with precision. This includes decision problems where we do not know or 'cannot agree on how the system works, how likely various possible future states of the world are, and how important the various outcomes of interest are' (Kwakkel 2017). Jan Kwakkel and others have argued that we must develop decision tools that are sufficiently robust to manage deep uncertainty, and that such tools should be based on three key ideas: exploratory modelling, adaptive planning and joint sense-making. Sets of models rather than individual models should be used to understand how, when and why deep uncertainties influence different actions, and how actions can be 'robust in respect to these uncertainties' (Kwakkel 2017).

Adaptive planning means designing systems that are contingent on how a situation unfolds. Joint sense-making emphasises the importance of 'learning across alternative framings of the problems' (Kwakkel 2017), listening to and learning from each other. In all these situations, structuring decision-making procedures can ensure a substantive outcome is reached in a sustainable, secure manner. This also applies to deliberation and its ethical foundations, which contributes to the substantive decision itself.

At the same time, one must be very clear that adaptive planning tools do not solve the fundamental theoretical problem of deep uncertainty. It is not a meta-theory that enables us to choose between different decision rules depending on the state of knowledge. Instead, it is a method for working together to manage deep uncertainty in a practical way. The deep uncertainties are still there. It is a pragmatic solution to the wicked problem that is exacerbated by uncertainty. The key question when making any decision is why that particular plan or intervention should be adopted instead of another. The choice is a moral issue (EGE 2022). This underscores that, whatever our strategy for dealing with deep uncertainty, it is important to be explicit about which moral choices are used as the basis for the chosen plan or intervention (see also Chan 2023).

In light of the complexity of the system we are dealing with and given that indirect evidence is all we have and will ever have access to, and that the deployment of these technologies may have unforeseeable and global systemic consequences in the future, there is every reason to take a precautionary approach.

The precautionary approach: adaptive and reflexive governance

The precautionary approach was first formulated by the German philosopher Hans Jonas in his seminal book, The Imperative of Responsibility (1979). Although he did not use this term itself, he outlined the approach as a cautious attitude in the face of technological innovations that have the potential to endanger the future of humanity or the environment, and for which substantial scientific certainty is lacking. It has been used in connection with environmental risks since the 1970s, and informed the decision-making of states towards environmental sustainability. At the same time, the approach has enabled sustainable development through forward-looking, anticipatory risk management (Schröder 2014, recital 1, 2, 22).

The notion of precaution was later formulated as a principle, i.e. as an obligation. It is found in various international documents such as the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) of UNESCO (2005), which provides a detailed guide to the precautionary principle, considering that 'the emergence of the precautionary principle has marked a shift from post-damage control (civil liability as a curative tool) to the level of pre-damage control (anticipatory measures) of risks' (COMEST 2005: 7).

Since then, the notion of precaution has taken various interpretations, including in relation to its institutional or procedural focus (Schröder 2014, recital 3, 8 et seq.; see also COMEST 2005). As a result of these different interpretations, there is little consensus on how to derive concrete measures from the principle or draw on it to guide difficult environmental decisions. Ultimately, there is also a risk that the precautionary principle conflicts with the principles of rational decision-making (Peterson 2006, 2007). In addition, in many cases, waiting for comprehensive scientific evidence also brings its own risks.

A careful balance must therefore be struck between, on the one hand, managing the development and application of new technologies and, on the other, enabling innovation in order to collect better evidence on the safety (in the broad sense of the word) of large-scale introduction of SRM to underpin future decisions (e.g. on whether to establish or maintain a moratorium), or detect instances of unauthorised or unregistered SRM deployment. We refer to this approach as the precautionary approach and distinguish it from the precautionary principle, including its precise legal status. We thus stay away from a restrictive interpretation of precaution in favour of a broader and more reflexive meaning of the term.

In this context, we highlight a particularly influential institutional formulation of the precautionary approach in the UN Declaration (Rio Declaration) on Environment and Development (1992). According to the Rio Declaration, 'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (Principle 15)'.

In this particular wording, the terms 'lack of full scientific certainty' and 'cost-effective measures' are particularly important as they indicate the extent of the responsibility of any actor in applying the precautionary approach. Even minimal levels of scientific uncertainty as to the nature or extent of possible harm requires proactive protective measures.

Post-normal science (PNS) is another approach to tackle complex, uncertain science-related issues where traditional methods may fall short. We see it as an example of the precautionary approach as outlined above. In the context of deep uncertainty, which characterises, for example, climate change and many public health crises, PNS emphasises the need to integrate diverse perspectives, including the perspectives of stakeholders and the public into the decision-making process.

This approach acknowledges that scientific findings may be uncertain, that values are often in dispute, and that the stakes can be high. By fostering inclusive, transparent dialogue and integrating a wide range of inputs into the process, PNS helps policymakers navigate uncertainty and make more robust, adaptive decisions (see Funtowicz & Ravetz 1993; Turnpenny 2012; Curry 2012). In the context of governing SRM, taking a PNS approach in line with the precautionary approach would entail the following commitments:

a. Acknowledging, not denying, complexity and uncertainty: adaptive and reflexive governance

We should not pretend that we can reduce complexity where it cannot realistically be reduced. We should explicitly acknowledge complexity and adjust decision-making accordingly. Policy development must include methods to observe developments and readjust course if necessary, and put in place specific means and methods to be attentive to emerging issues in the complex system (i.e. to phenomena and developments that emerge from the interplay of different factors, such as human practices and climate threats). Wagenaar and Prainsack (2021) use 'gardening' as a metaphor to guide policymaking, emphasising that policymakers are always part of the system that they are influencing with their work and must pay attention to emerging issues.

PNS promotes adaptive and reflexive governance structures that can respond to new information and changing conditions: e.g. scenario planning; a cyclical process of decision-making where policies and practices are treated as experiments from which managers can learn, adjusting strategies in real-time; real-time data monitoring; and participatory governance models. SRM research and deployment require flexible regulatory frameworks that can adapt to new scientific findings and societal concerns. Reflexivity involves ongoing critical evaluation of the governance processes and outcomes, ensuring they remain aligned with societal values and ethical norms.

b. Inclusive and participatory processes

PNS emphasises the need to include a broad range of stakeholders in the decision-making process. Insofar as SRM has global implications and could affect different regions and communities in various ways, this emphasis on inclusion and participation is important. Increased inclusion and participation can also improve the legitimacy of decisions made in this way.

c. Transdisciplinary approach

PNS advocates for an approach that transcends traditional disciplinary boundaries. Governing SRM requires expertise from various fields including climate science, ethics, politics, social science, the arts, engineering and economics. This also means that climate models that do not factor in societal implications should not be considered a sufficient basis for policymaking. Collaboration across disciplines, drawing also on traditional knowledge, will help build a more comprehensive understanding of the potential impacts and ethical considerations of SRM, leading to more informed and balanced decisions.

d. Focus on quality, not just quantity

PNS shifts the focus from the quantity of scientific output (such as the number of scientific studies) to the quality and relevance of knowledge. This means that the priority should be given to research that directly addresses the societal, ethical and ecological dimensions of the technology, instead of focusing solely on technical feasibility. Quality assurance is provided via extended peer review, where practical experts, including community members and activists, participate in evaluating the research.

e. Enhancing legitimacy and building trust

By openly addressing uncertainties and involving a diverse range of stakeholders, we can boost the legitimacy of SRM-related decisions (see also COMEST 2005). When stakeholders see that their concerns and values are taken into account, they are more likely to support and trust the decision-making process. This is crucial for SRM, where public acceptance and trust are key to the feasibility and sustainability of any potential interventions.

2. GLOBAL SOCIAL IMPACTS

2.1. POLITICAL ECONOMY ISSUES: RESEARCH AND DEPLOYMENT

The development and deployment of SRM technologies is politically complex and would incur a significant economic cost (SAPEA 2024a: 90-91). One major concern is the potential for power dynamics to be exercised in a way that could further entrench and increase inequities. For example, economically powerful nations or private-sector companies unilaterally deploying SRM would perpetuate the pattern that people in privileged world regions make decisions that affect others without the active participation of the latter in the decision-making process. This potential risk raises ethical questions about sovereignty, justice and the need for a global governance system to oversee any such interventions.

Economic considerations also play an important role in the political economy of SRM. The cost of developing and deploying SRM technologies, although considerable, could still be seen by some policymakers as relatively low compared to the economic impact of climate change mitigation and adaptation strategies, or the economic impact of climate change itself.

An additional problem is that SRM development and deployment that contributes to the gross domestic product (GDP) would be seen as a contribution to economic growth, while urgently needed measures such as reducing pollution, energy savings or forest and wetland conservation may be seen as having no or even the opposite economic effect. This could potentially make SRM attractive to policymakers who are looking for cost-effective and 'business-friendly' solutions to climate change, particularly if SRM applications are seen to provide immediate relief from global warming in situations of urgency (see also UN 2023: 6).

There are at least two problems that pose additional challenges to political decision-making. First, arguments about the relatively low cost of implementing some SRM applications typically overlook the cost of their potential impact on the environment and society, such as changes in precipitation patterns or impacts on biodiversity, which largely remain unknown. This problem complicates any attempt to weigh the benefits against the known and potential costs (in the broadest sense).

It is therefore essential that such cost calculations include not only the construction and operation of the application but also the wider environmental and societal impact (including the impact on future generations and non-human nature; see also Conradie 2020). This poses an important challenge to some established economic metrics and underscores the nature of SRM as a 'wicked problem' for policymaking.

Second, there is the issue of moral hazard, where the prospect of a technological fix might reduce the urgency to reduce GHG emissions, slow down carbon removal initiatives and provide a pretext for states and companies that still rely on fossil fuels not to limit their environmentally damaging activities. If there is an 'escape route', why limit GHG emissions (Nicholson 2020) or why invest in carbon removal? SRM governance should not fall into the trap of a 'tech-fix' approach, which sees technology providing the sole solution to complex social and environmental problems. Technology alone can never be the answer to complex challenges. Robust international cooperation and regulatory frameworks are essential to ensure that SRM research and potential deployment are conducted responsibly and transparently, if at all.

The role of the private sector exacerbates these political challenges, both in terms of power dynamics and the management of threats and uncertainties. SRM should not turn into the 21st century's version of the Klondike Gold Rush, where hope for a better future merged with greed and became fuelled by 'values that taught them [people] to see nature as the raw material for extractive wealth, waiting to be seized by those with the vision and strength of will to make it their own' (Morse 2003: xiii). Just as the Klondike Gold Rush ended up benefiting only a few, resulted in the deaths of many people and had tragic impacts on the local environment including soil erosion, water contamination, deforestation and disastrous consequences for local people, SRM deployment could lead to very similar scenario.

This problem would become even more complex if the private sector invests heavily in SRM by creating job opportunities and be seen to bring prosperity to otherwise economically depressed areas of the world. Such scenarios illustrate the difficulty of balancing respect for the sovereignty of nations (including their right to make their own choices about permitting, rejecting or controlling such investment) on the one hand, and the shared human responsibility for protecting life on the planet on the other.

All these considerations related to sovereignty, prosperity and opportunities should be seen against the backdrop of historical exploitation and commodification to which high-income countries have subjected low- and middle-income countries. Some scholars see the climate crisis as the latest chapter in a long history of multilayered exploitation (e.g. Sultana 2022). In this sense, SRM could become an example of what critics call greenwashing: powerful economies and big industries that neither address abusive power dynamics nor critically assess their own role in the climate crisis, but turn themselves into climate saviours by developing climate credits and similar measures (Moneer 2022). SRM could be added to the list of apparent solutions that may focus more on serving the private interests of powerful parties than on meeting the needs of the global community.

There is also the risk that supposedly environmentally friendly investments in SRM lead to a 'lock-in' to SRM. The more businesses and governments invest in research on SRM, the more research and development related to SRM increases gross domestic product and is thus seen as a driver of economic growth. Returns on investment then become important, driven by both financial and political imperatives. This means that investments will need to be justified and the justification needs a product or service (tangible or not); a result to show the public and investors. If investments in SRM are limited to research, there will be little to show.

Even in the early stages of SRM research and development, the prospect of successful applications could prevent research funders from pursuing other options or lead them to decide to channel funding into SRM instead of investing in ways to reduce emissions. This lock-in effect also highlights the connections between our four governance scenarios (see Introduction): decisions about the most appropriate governance of Scenario 1 (research) must be informed by awareness of the ethical challenges and complexities of Scenarios 3 and 4 (widespread deployment and its after-effects).

The importance of democratic control

As we will discuss further in the next section (see Section 3), our planetary environment is best described as a global common good: a resource that serves the collective interests of humanity and which cannot be claimed or owned by any single entity. Insofar as the deployment of SRM necessarily entails an intervention into the global commons, the prospect that SRM techniques could turn into private initiatives that anyone could undertake should be a particular matter of concern. Some companies have already started to generate reflective clouds as a form of SAI, arguing that SAI could help to cool the planet and thus combat climate change. Such private initiatives that lack democratic control and public accountability are arguably not the way forward when the future of the planet is at stake. This is one of the reasons why robust international governance frameworks are needed that prioritise the common good over commercial profit. Additionally, formats such as public-private partnerships with strong public oversight, non-profits and social enterprise models should be incentivised by law.

Environmental problems (and their uncertain solutions) should not be turned into business opportunities outside of democratic control and without public accountability. The commercialisation of climate problems is an irresponsible attempt to profit from global distress and anxiety. The involvement of private companies in the development of an SRM strategy should therefore not be framed as a welcome move to open up a new free market for products and services. Any role for private companies in implementing targeted programmes will need to be defined by a national framework for action, that in turn, will need to comply with the objectives of an international agreement (see Section 3). The objectives of such an agreement will need to be set by democratically legitimised authorities, not by private companies or 'the market'. Moreover, democratic control needs to be able to stop research and deployment if it seems likely that the risks outweigh the benefits.

This does not mean that the private sector should be excluded from SRM, but that it must be willing to comply, in the same way as public bodies do, with inclusive and participatory forms of global governance. It would be important both to explore the governance systems needed to oversee the action of the private sector, but also to reconsider the scope of patent rights in relation to relevant inventions to avoid undermining the public nature of SRM policy by encouraging speculative pursuits.

2.2. INTERNATIONAL GEOPOLITICAL CHALLENGES

By its nature, SRM also raises important questions of geopolitics. The international community has long been aware of the possibility of weaponising environmental phenomena. For example, during the Vietnam war, the US military conducted cloud-seeding operations to extend the monsoon season (Darack 2019). The 1976 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) defines 'environmental modification techniques' as 'any technique for changing – through the deliberate manipulation of natural processes – the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere or the outer space' (United Nations 1977, Article 2). SRM techniques, if used for 'hostile' purposes, would thus come under this prohibition. However, at the time of writing, only 48 states have signed the Convention.

There may be an even more profound challenge than the limited number of signatories to using the Convention in providing a global governance framework for SRM: the fact that prohibitions under the Convention are based on the concept of 'dual use'. This concept pertains to the ethical, legal and practical challenges associated with technologies and research that have both civil and military applications or may result in both positive and negative outcomes in society. Dual use also highlights the problem that the same knowledge or technology can advance public health, economic growth and scientific understanding, while simultaneously posing risks of misuse such as in bioterrorism, cyberattacks or environmental harm. The dual-use nature of technologies underscores the importance of responsible research and innovation, where scientists and policymakers must collaborate to establish frameworks that ensure the safe and ethical use of advancements (such as the ENMOD Convention). This involves anticipating potential misuse, implementing safeguards and promoting transparency and accountability in scientific practices.

Large-scale uses of SRM do not, in our view, fit neatly into categories of either military v hostile purposes or civil v peaceful purposes. Any large-scale deployment of SRM would have geopolitical consequences and could generate security concerns. This categorical ambiguity of SRM, compounded by the uncertainty related to the different (and contradictory and perilous) uses to which it could be put, makes it difficult to classify SRM using existing classifications of international geopolitical challenges. One implication is that large-scale deployment never falls within the remit of purely civil use. At the same time, however, we note that opposition to SRM – and to climate mitigating technologies more broadly – could also be driven by geopolitical considerations, as some regions would benefit from increasing temperatures. For example, the melting Arctic ice could lead to the opening of new trade routes, permitting many ships to avoid the Suez and Panama channels. The Arctic is also rich in natural gas and minerals. If the world continues to warm, the opportunities for economic gain become more and more accessible. Not surprisingly, in 2022 Russia announced that its military would shift its focus to this region.

In the final section of this Opinion, we will return to the role of international law in regulating SRM. However, we note here that the instrumentalisation of SRM as a method to assert power or as a tool to foster rivalries (Futerman & Beard, 2023) is of clear geopolitical relevance. Geoengineering measures could lead to temperatures that are likely to benefit some countries while disadvantaging others. Counter-geoengineering practices could be employed for the same reason (see Chapter 14 of the IPCC Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Working Group III: Mitigation of Climate Change).

3. GOVERNANCE AND REGULATION

The Earth's atmosphere as a global common good

Our planet, including its atmosphere, is best described as a global common good.[5] Global common goods are resources that provide benefits across multiple countries and populations, transcending national borders, and serving the collective interests of humanity. Once produced, such goods can be accessed by all, whether they contributed to their production or not. These goods are typically non-exclusive and non-rivalrous, meaning that one person's use does not diminish their availability to others. Analogously, public bads, once produced, affect all, not only those who are responsible for their production.

Global common goods are those that no state, single nation or entity should own. The governance of global common goods requires international cooperation and public participation. Against this backdrop, due to the potential of SRM to alter global climate patterns and generate other global effects, the large-scale deployment of SRM constitutes an interference with a global commons. Therefore, any deployment should require a decision under a global governance framework that ensures that the interests of all potentially affected parties have been adequately represented and considered, and that includes mechanisms to compensate those adversely affected. There is currently no such mechanism in place. Today's international institutions may not be adequately prepared to handle the unique challenges posed by SRM, including the need to balance the urgency of climate action with the rights and needs of diverse communities.

The possibility that SRM could interfere in the global commons highlights the critical need for comprehensive governance structures that prioritise the precautionary approach focusing on avoiding harm and promoting equity, justice and solidarity across and within countries. The potential for unilateral action by individual nations or groups also raises concerns about the public accountability of using geoengineering technologies and how to safeguard the interests of all people. Without inclusive and equitable governance, the pursuit of SRM could exacerbate global inequalities and

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[5] In 2022, as part of UNESCO's work, Emma Sabzalieva and José Antonio Quinteiro presented the main characteristics of 'public goods', 'common goods' and 'global common goods': https://www.iesalc.unesco.org/en/2022/04/10/public-goods-common-goods-and-global-common-goods-a-brief-explanation/.

even lead to violent conflicts, rather than mitigating the urgency of the climate crisis (Keith 2000, Roblock 2008, Royal Society 2009, Morrow et al., 2009).

This situation highlights the importance of international cooperation in research and the need to draw up an ethical framework for regulation, implementation and supervision (based on scientific cooperation and a common ethical framework).

Approaches to international regulation: self-regulation, soft and hard law

International cooperation, in the form both of scientific self-regulation and in international law, will be essential in providing guidance and direction on SRM throughout the stages of development, from research to possible deployment, including (any) decision on when to end deployment. If deployment is ever considered ethically permissible, this would likely be one of the most important decisions needed due to the risks that global temperatures would rapidly rebound to equilibrium levels upon abrupt discontinuation of, for example, SAI interventions.

It would therefore be crucial for the international community to put in place procedures to determine when the time is right to end, and to ensure that any reservations do not lead in practice to a decisional deadlock. Of equal importance are instruments and procedures to enforce these decisions effectively, including requirements at national level for monitoring and reporting, and at international level for oversight and the power to issue penalties if signatory countries fail to meet these requirements.

First, international cooperation must start with the capacity for self-regulation and reciprocal supervision among scientists, who have the best and most up-to-date knowledge of the state of the art of research. Self-regulation must draw on the precautionary approach and on social responsibility. It is important that scientific communities set ethical rules for their own conduct that will add specificity to national, supranational and international legal frameworks. While responsible self-regulation on the part of the scientific community is crucial, both ‘soft’ law and ‘hard’ law are also required. We discussed earlier how decision-making in a context of deep uncertainty requires inclusive and participatory processes spanning the entire globe. These regulatory approaches (at both national and international level) must be created and must draw on the views of nonprofessional experts, such as local communities who have long-standing experience and expertise with climate and climate change.

Second, the value of soft law in governing SRM should not be underestimated. 'International soft law' refers to rules of conduct that cannot be assigned to any formal source of law and are not legally binding, but that still exercise influence, for example through professional guidelines or codes of practice (Heintschel von Heinegg, 2014, Thurer, 2008)). Soft law fulfils a variety of functions: it may, for instance, be used to help interpret legal provisions; it can often provide practical assistance in reaching a consensus; and it serves as a basis for drafting legally binding norms (Boyle and Chinkin, 2007). By defining standards of conduct that are expected, soft law also builds extra-legal binding force. It thus plays an important role as intermediary between technology, ethics[6] and law, given that the rapid progress of new technologies contrasts with the lengthy process of drafting an international treaty (Neuhold, 2005).

The practical effect of soft law can be further increased by integrating ethical principles. Technical specifications and standards set by experts involved in developing soft law instruments are frequently integrated into these instruments. Finally, as noted, soft law can also guide the interpretation of traditional sources of law such as contracts, and can document the emergence of customary law (Boyle and Chinkin, 225ff) and lead to obligations in good faith (Amerasinghe, 2005). Breaches of soft law do not have the same legal consequences as breaches of (binding) international law, but hard law can also be combined with 'soft' dispute resolution procedures or 'soft' sanctions. Conversely, soft law can play a role in the reasoning of courts, even if breaches cannot justify action before the International Court of Justice. Soft law can be extremely nuanced and formulated in language that is compelling. On this basis, reference is made to its interconnectedness with the traditional sources of international law. (Molnár-Gábor, 2022).

Soft law should thus be an integral part of any regulatory framework for SRM. It can have a strong de facto binding effect and integrate ethical principles that can guide and justify behaviour outside the law. Furthermore, integrating technical and ethical expertise into the design process of soft law instruments can help ensure that they are informed by

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[6] The factual and extra-legal binding effect of the instruments, i.e. their actual influence on the behaviour of the addressees, can vary. Its binding effect can be increased by properly integrating ethical principles that guide and underpin behaviour outside the legal sphere.

up-to-date knowledge from their earliest development stage. Soft law can thus mould self-regulatory approaches into a coordinated and structured formulation process and benefit from their inclusive approach by motivating precisely those who are closely involved in developing and implementing SRM to assume not only personal but also social responsibility.

Third, both moratoria and bans are possible hard law tools to regulate activities that are seen to pose a serious threat. They differ significantly in their purpose, duration and implications. The primary characteristic of a moratorium is that it is temporary, designed to last for a specific period ranging from a few months to several years, depending on the complexity of the issue and the time required to assess and overcome the threat. Moratoria are flexible tools as they can be extended, modified, or lifted based on the findings and progress made during the suspension period, allowing policymakers to respond to changing circumstances and new data. A moratorium could, for example, be lifted or suspended if research produces solid and robust scientific proof of the feasibility, need, safety and security of SRM deployment.

Bans are permanent prohibitions of specific activities. Unlike moratoria, they are designed to remain in place for a long time – until they are repealed or replaced by new legislation. The primary purpose of a ban is to completely prevent or stop an activity deemed harmful or undesirable due to health risks, environmental damage, or moral and ethical considerations. Bans are thus more stringent than moratoria as they prohibit the activity outright, with little to no flexibility, and breaches typically result in penalties or other legal consequences. The scope of bans can be broad or specific. A broad ban might outlaw all forms of a harmful substance, while a specific ban might target a particular use or demographic. A ban on SRM techniques specifically in polar regions is an example of a specific ban, while a prohibition of all forms of SRM (beyond strictly local and small-scale uses) would be a broad ban.

3.1. ETHICAL PRINCIPLES FOR GLOBAL GOVERNANCE

Good governance requires ethical principles that provide robust ethical pillars for further political and regulatory developments and implementation. Given the nature and characteristics of SRM deployment, in particular their unpredictable and partly irrevocable outcomes, transparency and accountability are normative procedural principles that should underpin the regulation of both research and deployment.

Other – and in this case, substantive – principles that are particularly important in the context of SRM are justice and inclusion. The aspects of justice affected by SRM include distributive, procedural, epistemic and rectificatory (corrective) justice (see also SAPEA 2024a: 81). Our discussion focuses on distributive and procedural justice as particularly pertinent to this topic due to the ethical imperative of fairness in the distribution of the burden and benefits of technological innovation (including the impacts). They are also pertinent due to the importance of integrity and legitimacy of decision-making processes that affect everyone on the planet, insofar as effective international governance systems do not as yet exist.

The next section discusses each of these clusters of principles and the multiple obligations through which the principles unfold and are exercised or fulfilled.

Procedural principles: transparency and accountability

One governance approach that is especially relevant in the context of multiple uncertainties is to regulate the decision-making process itself. This means governing how a decision on the substantive issue should be reached. It could also include specifying the conditions relating to both research and possible employment of a new technology that must be met for a moratorium to be lifted. This is particularly helpful if a substantive decision is not yet possible owing to factors such as unknown risks and ethical uncertainties or disagreements.

Technical rules and standards in a rapidly developing field must be repeatedly adapted to scientific change. It makes little sense to include technical standards in a treaty text, given the lengthy process of amending a treaty. However, it is likely to be important for the main decision on any moratorium or on any authorisation of SRM interventions to remain cast in the concrete form of binding law, considering its formal and substantive requirements.

Whatever specific instruments are chosen, the fundamental basis for global governance must be explicitly ethical in nature, rooted in set ethical principles that form the foundation and orientation for legislative initiative and political action, and that comply with human rights. We turn now to discuss these key principles.

Transparency requires honesty, truthfulness and integrity. Clarity of communication, pitched to each specific audience, is essential in order to achieve civil society participation. Transparency must be provided at two different levels. First, at the level of scientific research into SRM (not only the research initiatives that are explicitly labelled as such): research objectives, processes, results (including failures and null results), funding and any actual and potential conflicts of interest must all be meaningfully disclosed and easily accessible to the public, explicitly recognising the nature and extent of any uncertainties associated with any findings. Second, at the level of political communication with civil society, covering both research and (if relevant) deployment. The groups involved and their specific or even partisan interests, the strategies implemented and their rationale must also be made public, avoiding any form of manipulation and guaranteeing the integrity of the information. These requirements must be in place from the start at Scenario 1 (research) all the way through to Scenario 4 (post-deployment consequences).

Accountability requires recognising liability, including legal liability, setting suitable penalties and compensation mechanisms. It will be very difficult, if not impossible, to assess the scope for compensation for post-deployment consequences (Scenario 4), should this stage ever be reached. Accountability also requires accepting responsibility towards wider society, including willingness to consider the more distant consequences in space and time of any action taken here and now. This should be a basic condition of permitting the deployment of SRM technologies (i.e. permitting progression from Scenarios 1 and 2 to Scenario 3, large-scale deployment). Accountability necessitates compliance with the rule of law and global justice, coupled with the obligation to ensure the fair sharing of risks and benefits. This will require ensuring that the threshold set to start on Scenario 3 is not crossed without due process.

Transparency and accountability have a reciprocal relationship. It is not possible to attribute accountability without transparency in decision-making processes, whether in connection with research policy and strategy, or with potential deployment. In turn, this imposes duties on both public and private actors vis-à-vis those affected, which potentially includes the whole of humanity and future generations, all other living beings and habitats, i.e. planet Earth. The two ethical principles contribute to the distribution and balancing of powers, while facilitating and promoting broad public participation.

Substantive principles: justice and inclusion, inseparable reciprocity

The second cluster of principles includes justice (and equity and solidarity as related concepts) and inclusion, in the form of participation in decision-making processes (valuing public participation), once again with a reciprocal relationship. Justice requires inclusion and inclusion promotes justice; both are mutually reinforcing.

The prospect of SRM entails several forms of justice. We focus here on distributive justice, including the related concept of intergenerational justice (UNESCO 2023). Distributive justice concerns how benefits and costs should be distributed (Schäfer et al. 2015) and relates to the allocation of expected benefits and feared burden among states or private entities. The benefits and risks of SRM techni Schäfer ques, if deployed, would likely be unevenly distributed across different regions. For instance, while some areas might experience a reduction in temperature and associated climate relief, others could suffer unintended consequences such as altered precipitation patterns, leading to droughts or floods.

These changes could have devastating effects on agriculture, water resources and biodiversity, potentially harming vulnerable populations the most. The ethical dilemma here would be compounded if decisions to deploy SRM were to be made by the wealthiest and most technologically advanced nations, potentially without the consent or consideration of those who might bear the brunt of its negative impacts.

For this reason, it is crucial to involve diverse populations, including vulnerable individuals and groups, underprivileged regions of the globe, and marginalised social groups in the process of setting SRM goals and related research agendas. Ideally the process should also consider the interests of future generations and non-human nature. Regarding future generations, this means that 'no generation shall pass on to the next more difficult to reverse conditions than it had inherited itself' (Protzen & Harris 2010: 224). For non-human nature, this means that all policy decisions should be geared to protecting the right of non-human entities to exist too.

Existing differences in political and economic power may have the potential to produce 'public bads' (negative externalities that affect a large number of people and are non-excludable and non-rivalrous, meaning that their negative effects cannot be confined to those who cause them) by the wealthy and powerful. They may also generate burden for all and benefits only for some.

Distributive justice also raises questions about fairly compensating individuals, communities and ecosystems who may be harmed by SRM. Since some inequities (i.e. unfair inequalities) and injustices are practically unavoidable, acceptable solutions to the problem of the just distribution of benefits and burdens of SRM development and deployment would need to be complemented by systems of fair compensation for SRM-related harm.

Such systems, in turn, would require appropriate international and supranational institutions. These institutions would have to answer many difficult questions, including who should compensate, who should be compensated and what should be compensated for – as well as how to reach consensus on simulations to quantify losses and gains. For example, they would have to decide which types of SRM-related harm requires compensation, especially in cases where it is difficult to attribute a given harm to a given SRM intervention as a cause.

Another question concerns which climate ‘baseline’ to use to provide a comparator for the effects of SRM (pre-industrial, pre-SRM intervention or the scenario of no SRM intervention?). An even more challenging question is how to compensate for harm that transcends political borders or generations.

Decisions on all SRM activities must be taken under a global governance system. The system must additionally be able to withstand the growing populist movements and autocratic tendencies in many parts of the world. Governance must be anticipatory and proactive regarding the challenges that SRM poses. As we outlined earlier, this approach involves adaptive and reflexive governance to respond to emerging and changing information; inclusive and participatory processes that take account of diverse perspectives and the interests of current and future generations and non-human beings; promoting the development of high-quality evidence to support decision-making; and accountable systems that build legitimacy and trust.

Equity is based on a theory of justice focusing on ensuring fair treatment, opportunities and outcomes for all individuals by addressing systemic inequalities. Justice involves the broader concept of upholding what is morally right and lawful, often encompassing equitable practices to achieve fairness and impartiality in society. As noted, in the context of SRM, intergenerational justice is another salient aspect of distributive justice. Intergenerational justice, here, is the responsibility of current generations towards future generations with respect to the benefits and burdens they will experience as a result of action taken now. This is a general ethical concern in the context of the ethics of climate change and climate-engineering, and hence should be considered also in SRM. The reference to intergenerational justice broadens the ethical timeframe, including in our scientific and ethical evaluation of the impact (medium and long-term) of outdoor experiments and the consequences for future generations.

The current climate situation requires action and sacrifice by the current generation to maintain the existence of the future of humanity. There is a wide debate on the justification of duties towards, and the rights of, future generations (e.g. UNESCO's Universal Declaration of Human Rights and Bioethics 2005; IBC 2021). The EGE emphasises the need to be aware of responsibilities to future generations when making decisions relating to SRM, including decisions that nothing should be done.

Our responsibility and care for others (Jonas 1979), including future generations, is the foundation of intergenerational justice. We argue that the fact that future generations are not yet born is not a sufficient criterion to completely disregard their interests in present-day decision-making (see also Prainsack, forthcoming). This argument also has a legal basis recognised in international environmental law, dating back to the Stockholm Declaration (principle 2, 1979) and detailed recently in the Maastricht Principles on the Human Rights of Future Generations (2023). Under the latter, states are held to violate the rights of future generations if they fail 'to effectively regulate, and where appropriate prohibit, scientific research and activities that pose a reasonably foreseeable and substantial risk to the human rights of future generations, including… geoengineering' (Section 19, subsection f). This provision would also support calls for a more proactive assessment of the risks of SRM and a cautious approach to SRM deployment (see also recent case law including BVerfG (2021), Verein KlimaSeniorinnen Schweiz and Others v Switzerland (ECtHR 2024), Carême v France (ECtHR 2024) and Duarte Agostinho and Others v Portugal and 32 Others (ECtHR 2024)).

In order to apply this principle in all four scenarios of SRM, especially Scenarios 2 (small-scale experimentation of SRM), 3 (large-scale testing and deployment) and 4 (post-implementation), research institutions in the widest sense of the word (research institutions, funders, etc.) must commit to carry out rigorous risk assessments in advance of any outdoor experiments that include the consideration of possible and likely consequences for future generations as well as for non-human entities. All stakeholders in SRM (regulators, policymakers, researchers and ethics committees) should also consider the risk of 'termination shock' (see SAPEA 2024a: 37), whereby abrupt termination of SRM interventions such as SAI would result in global temperatures rapidly rebounding to equilibrium levels. A termination shock could limit the agency of future generations (SAPEA 2024a: 107). The impact on future generations living in low- and middle-income countries of unilateral decisions by rich countries to use SRM should also be a matter of particular concern.

Next to justice, **solidarity** arguably provides an important lens for public policy on SRM. Solidarity refers to practices by which people support others with whom they feel a connection (Prainsack & Buyx 2011). Solidarity can take place at different levels: at interpersonal level, at group level, and under binding norms and institutions (ibid.). Although there has been, to date, very little work on solidarity as a framework for action against climate change, we argue that solidarity provides an important complement to the principle of justice. Unlike intergenerational justice, which focuses on what current generations owe to future generations, looking at SRM through the lens of solidarity means not asking what we owe to future generations but how we can care for them. We should do this not from a perspective of privilege, but from a perspective of equality, recognising that we are supposed to protect nature and the climate for future generations as we would have wanted past generations to do it for our sake, and as we will demand it from future generations for the generations of their children and grandchildren (Behrens 2012; Prainsack, forthcoming).

The principle of **inclusion** has multiple dimensions and requires multiple actions. It is, first, a dimension, or condition, of societally responsive science. Specifically, it encourages and scaffolds 'good science' by requiring researchers, funders and policymakers to raise and respond to questions on whose voices and interests are included in the funding, R&D and post-delivery pipeline. An inclusive approach means consulting a diverse range of stakeholders, including governments, international organisations, civil society, disadvantaged and marginalised people and communities, and private-sector bodies in key decisions, from funding and planning research to any decisions on deployment. We detail further below and in our recommendations how this might be achieved in practice.

Second, we must be open to, and facilitate, an inclusive understanding of who is deemed to have relevant expertise. Recent interpretive guidance on the 'human right to science' emphasises that this right encompasses not just the right to share in the benefits of scientific progress and its applications but also to participate in that progress (United Nations 2020). Put differently, the right to science is a right both of access to and participation in science.

The UN Special Rapporteur on cultural rights has recently published a report on participation and the right to science, emphasising that the right to participate in science includes many dimensions including the right to scientific literacy, the right to access to the scientific professions, the right to contribute to scientific progress and the right to participate in policy decisions relating to science (UNGA 2024, para. 43). As the Special Rapporteur reiterates: 'Both dimensions of science – participation in science and access to science, including, for example, the enjoyment of benefits – are crucial and interlinked, in that participation in science is not guaranteed unless access is guaranteed and vice versa' (UNGA 2024, para. 4).

Inclusion further emphasises that participation requires more than an invitation; it requires an enabling environment – one that engages with barriers to participation at the level of countries, organisations, individuals and groups. The principle of participation is breached, and the benefits that flow from participation are lost, if participatory processes are lacking, uneven, late or inaccessible for some. The 'haves' and the 'have-nots' must not be the currency of participation.

As implied above, inclusion requires other more long-term actions too to achieve the aim of diverse participation. The R&D environment should itself be inclusive in terms of people, disciplines and experiences. This means taking action to close skills and participation gaps in education, including for girls and women. Related to this, anticipation and foresight work on the acceptability of research and the potential for future deployment should include a broad range of perspectives, forging an inclusive view of values and risks. This in turn requires making educational resources on SRM accessible and available to broad and diverse audiences.

In this broad concept of inclusion, there are three particularly important aspects to factor in: public participation, future generations and the interests of non-human entities. We explore below what might be needed to achieve these aspects of inclusion in practice in the context of SRM.

3.2. ACHIEVING INCLUSION IN PRACTICE

Public participation

Public participation is crucial to prevent SRM research and possible future application of SRM technologies from becoming captive to sectarian interests, be they academic-scientific, economic-financial or political. Public participation, if achieved in a way that is seen to be meaningful, will be similarly important in helping to eliminate so-called climate populism, in the sense of approaching the climate crisis 'with slogans but without solutions, with blame but without taking responsibility' (Szegöfi 2024).

In light of the inherent uncertainties of the impacts of SRM, the legitimacy of any future use of SRM interventions requires this same broad, informed and responsible approach to public participation. Given the global nature of climate change and its impacts on future generations, decisions about whether and how to implement these techniques must involve public deliberation including diverse voices alongside those with technical expertise, academic experts and governmental bodies.

Citizen assemblies are one possible way to do this, but there is a broad range of deliberative instruments. It will be necessary to plan for and encourage participatory approaches at local, national and international level. Drawing on models such as the UN's Intergovernmental Panel on Climate Change (IPCC), one option might be to create a collaborative network of researchers and ethicists who develop regular reports that present an assessment of the benefits and risks of SRM, the latest results from indoor and outdoor experiments and modelling, and relevant social science, ethics and humanities research. Crucially, this must include evidence relating to public perception and concerns.

If such a network were to be created, it would be essential for it to work with diverse communities to ensure that it presents its findings in a factual and non-technical way that is understandable, transparent and inclusive, clearly setting out the uncertainties or lack of evidence. These activities could also be carried out under the umbrella of a multidisciplinary observatory.

Such approaches depend first and foremost on having accurate, up-to-date and comprehensible information available, including with respect to the manner of its communication, which highlights the role and responsibility of public media. It will then be essential to create transparent and accessible platforms for dialogue and decision-making that facilitate the active participation of underrepresented groups, particularly those from low- and middle-income countries and indigenous communities who are often disproportionately affected by climate change and may bear the brunt of geoengineering interventions. As it may not be realistic to set up global platforms due to differences in time, language, access to digital tools and electricity etc., networks of public consultations, participatory workshops and stakeholder fora would be needed to bring in diverse viewpoints and ensure that the voices of marginalised communities are heard and considered.

In addition to cost, a significant challenge in implementing such initiatives is the fact that some people and communities are hard to reach for good reasons. They are too busy to participate in consultations, or they may have had such bad experiences with authorities or other public bodies that they view any such initiative with suspicion. Based on past experiences with public consultations, many people and communities have little trust in their views being heard or acted upon. It is important to recognise that violence against human rights advocates and climate activists is on the rise worldwide, meaning that some people and groups may be hesitant to engage out of a (sadly well-founded) fear for their lives (see also Macdonald & Macdonald, 2022). This challenge can be overcome, in part, by having community representatives, advocates or even researchers who have the trust of the community in question represent the views of the communities in the policymaking process.

Civil society activities should also be encouraged and actively supported – including through public funding – to feed into a critical assessment (in the broad sense of the word) of the possible risks and benefits, and to support a more comprehensive understanding of an equitable process of decarbonisation. Beyond this, individuals across the globe should be encouraged to claim, wherever and whenever possible, their right to a clean, healthy and sustainable environment (UN General Assembly Resolution 76/300), and their right of access to public information, participation and justice in environmental matters, as laid out in the Aarhus Convention (1998) and other relevant treaties (UNECE Aarhus Convention, 1998).

In addition to these methods of promoting dialogue on a global scale, participatory governance can be enhanced by creating advisory bodies (at all levels of governance, from local to international) that include representatives from a range of sectors and communities. These bodies can provide ongoing input and oversight, ensuring that geoengineering projects are aligned with broader social, environmental and ethical considerations. International legal frameworks and treaties can also be adapted or created to mandate inclusive practices and protect the rights and interests of all stakeholders. In our recommendations below, we look more specifically at what could be achieved in Europe.

Acknowledging the past and accounting for the future

It is important to recognise that inclusion extends beyond the present-day. It includes past failures, especially legacy failures – that is, past failures producing intergenerational injustices that persist today – and, above all, future generations.

As far as the past is concerned, even when we recognise that past actions have had a strong negative impact on our present, as with the use of fossil fuels and the uncontrolled production of greenhouse gases in the last century, we should not judge them in the light of today's knowledge, nor develop a logic of blame. Instead, we should learn from the errors of the past, trying to understand the reasons that led to those choices and the variables that were considered at the time to avoid making the same mistakes again. The precautionary approach that we advocate is already the result of this process of learning from past mistakes.

In terms of accounting for the future, scholarship and advocacy on future generations discuss several measures. Examples include appointing independent officials, such as ombudspersons or commissioners for future generations, who advocate within the government, exemplified by the Future Generations Commissioner for Wales (Messham & Sheard 2020). Establishing councils or committees, such as Finland's Committee for the Future, also helps review and advise on policies with long-term impacts (Koskimaa & Raunio 2020). Embedding intergenerational equity principles into constitutions or laws is another way to mandate action to consider the interests of future generations, as seen in a verdict of the German Federal Constitutional Court (Hartwig 2024).[7] Finally, incorporating environmental and social impact assessments can help improve transparency and public participation in evaluating the long-term effects of projects.

[7] The climate verdict of the German Constitutional Court, delivered on 29 April 2021, was a landmark ruling that had significant implications for climate policy in Germany. The court found that the German Climate Protection Act of 2019 was partially unconstitutional because it did not sufficiently protect the rights of future generations.

More broadly, future generations' work requires accessible and inclusive bodies and institutions at all levels (Maastricht Principles 2023). This includes recognising bodies created by indigenous and traditional communities that have developed their own mechanisms to represent future generations. It also includes recognising the right to be heard and other participatory rights (Lundy 2007) of the people closest to future generations: children, adolescents and young people. Considering their rights in decisions made today is a collective interest of people living today. The term 'rights of future generations' has been explicitly used by the UN General Assembly (UN Declaration on Future Generations – Zero Draft, 2024). Many courts currently avoid this terminology, although they recognise the need to protect the 'benefit' of future generations and the 'intergenerational perspective' (ECtHR, Verein Klimaseniorinnen Schweiz and others v Switzerland, 2024).

Non-human entities

We believe that policymakers today have an ethical imperative to consider the interests of non-human entities, in the context of SRM and more broadly in the development of climate and environmental policies. This stems not only from an ethical obligation to protect biodiversity, but also from the intricate interdependencies within ecosystems that support all life forms. Non-human species play critical roles in ecosystem functions such as pollination, nutrient cycling and the maintenance of food chains and biodiversity. Their wellbeing directly impacts ecological balance and the overall health of the environment, which in turn affects human survival and quality of life. Failing to include the interests of these species in decision-making can lead to policies that are ecologically unsustainable and may exacerbate biodiversity loss, habitat destruction and other environmental crises.

It is crucial to take a holistic approach that incorporates the perspectives and needs of all species to create effective and inclusive climate and environmental policies. In addition to advocacy for the consideration of the interests of (elements of) non-human nature for the ultimate goal of protecting human health (anthropocentric approaches), there is also a growing body of scholarship and advocacy that does so for the sake of non-human nature itself (biocentric approaches) - e.g. by granting legal rights to elements of non-human nature (e.g. Lawrence 2022).

In the context of SRM, considering the interests of non-human species in processes of environmental policymaking could include strategies such as environmental impact assessments (EIAs). EIAs critically evaluate the potential environmental impacts of proposed projects or policies before implementation, ensuring that the effects on non-human species and ecosystems are considered upfront.

Complementing EIAs are biodiversity action plans, which focus on protecting and restoring biological systems, guiding policy decisions to factor in the specific needs of threatened habitats and species. In addition, legal frameworks often enforce protections for endangered species, mandating that their conservation is a priority in both the planning and execution stages of development and policy initiatives. Collectively, these measures create a multi-faceted strategy for representing the interests of non-human species in policymaking, with the aim of sustaining ecological balance and promoting biodiversity.

3.3. INTERNATIONAL COLLABORATION ON SRM REGULATION AND GOVERNANCE

As we have noted throughout this Opinion, international collaboration is indispensable in the field of SRM. SRM research and deployment is a global issue. Any unilateral decision can be highly detrimental to others and set problematic precedents in terms of infringing the global commons. The contemporary development of scattered small-scale initiatives, including on a commercial basis (see Section 2.1), compounds the urgent need for a more collaborative approach.

We have already discussed the role of international agreements such as binding treaties on SRM, alongside possible complementary 'soft' law approaches. Here, drawing on the key substantive principles of justice (procedural and distributive) and of inclusion (see Section 3.1), we have emphasised the need to promote global understanding of the gravity of the risks that uncontrolled and unregulated SRM research could lead to, and to achieve alternative ways to address them together, as an essential precursor to concluding international agreements.

As we have noted, it is particularly important that any such mechanisms are participatory and inclusive in terms of drawing in the perspectives from diverse communities, states and regions. This is the case because SRM deployment – and SAI in particular – could have significant impacts in regions far from where the intervention takes place. If one day the decision were to be made to deploy SAI, the decision would need to be based not only on technological feasibility and scientific robustness, but most importantly on local assessments of the acceptability of the risks of such deployment.

It follows that the current availability of economic, human and infrastructure resources for SRM (based on existing disparities in the distribution of economic and political power) should not be the primary driver to guide decision-making. The objectives of SRM technologies (short and long-term), their risks, collateral effects and mitigation strategies, possible strategies and means to halt any experiment, deployment or use of SRM timelines and many other aspects related to SRM research and deployment should be discussed and decided in a participatory and inclusive manner. The aim must be to find a balanced approach that considers the rights and interests of different groups and stakeholders and uses deliberative instruments to mediate between conflicting ones.

The United Nations Framework Convention on Climate Change (1994) was adopted by the majority of states worldwide and led to several follow-up agreements, such as the Kyoto Protocol of 1989 and the Paris Agreement of 2015. These agreements represent a long-standing effort to persuade, secure, promote and build trust among stakeholders and to get states to agree on joint action to fight climate change. Against the backdrop of growing international commitment to tackle climate change, a key concern relates to how the emergence of SRM as a temporary measure could be an excuse not to make good on these commitments – especially when the option to deploy SRM presents itself to countries as more economically and financially appealing than decarbonising national economies.

Towards global governance of SRM: use of international soft law

International cooperation in research and collaboration in the governance of both research and (if this were to be ethically permissible) deployment is essential to achieve good governance of SRM.[8] It will also be necessary to foster agreements, as broad and inclusive as possible, on all four scenarios

[8] As David G. Victor (2008: 324) argued, 'Geoengineering may not require any collective international effort to have an impact on climate. One large nation might justify and fund an effort on its own. A lone Greenfinger, self-appointed protector of the planet and working with a small fraction of the Gates bank account, could force a lot of geoengineering on his own. Bond films of the future might struggle with the dilemma of unilateral planetary engineering.'

of SRM, ranging from the regulation of lab-based research and modelling to consequences emerging post-deployment.

Given the currently very high levels of scientific and technical uncertainty about the possible effects of SRM, as well as the potential harmful uses, we advocate for a moratorium on all large-scale SRM experimentation and deployment in the territory of the EU in the first instance, and potentially at international scale. The moratorium could be reviewed regularly and potentially suspended if research on SRM produced solid and robust scientific proof on the feasibility, need, safety and security of SRM deployment and if a collective decision to do so were taken.

From a legal point of view, reducing GHG is currently the only binding strategy to limit temperatures and tackle climate change at international level, based on the UN Paris Agreement (2015). States that have ratified the Agreement can of course adopt additional strategies at national level, such as SRM, but only as a complement to the strategy of reducing emissions, which requires strict compliance with national targets. These additional strategies must be consolidated by further action such as carbon removal. To make carbon removal deployable on a global scale, we need to continue working on it without delay.

Indeed, the importance of existing legislation in the cost-benefit assessment of SRM applications should not be underestimated. The assessment of impacts on, for example, the state of biodiversity, agricultural production or water resources management do not take place in a legal vacuum. They are assessed against the requirements mandated by relevant international, EU and national legislation. If SRM implementation were to require amendments to existing legislation, wider institutional difficulties or objections are likely to arise, particularly regarding international conventions such as the Rio Convention on Biological Diversity (1993), which enjoy widespread acceptance in the international community.

Therefore, from a governance perspective, the initiative to adopt internationally binding legislation on SRM (referring to the 1994 United Nations Framework Convention on Climate Change) will require harmonisation with the established binding legislative framework.

International treaties come with limitations as regards dealing with pressing environmental issues, given the rapid pace of scientific development and the time-consuming process involved in drafting. In addition, their provisions can be watered down by signatories logging reservations. In such cases, as noted above, soft law – despite all its limitations – often provides a useful and flexible approach to regulation that can achieve consensus more quickly, while allowing a greater differentiation of requirements. It allows a better focus on the relevant issues without the shackle of binding obligations. SRM governance may therefore make use of legally non-binding forms of action at international level before binding international treaties can be negotiated.

In this Opinion, we have distinguished four different aspects of SRM governance: the regulation of research aimed at SRM testing and deployment, of small-scale outdoor experimentation, of large-scale experimentation and deployment of SRM and of post-deployment issues. We have argued for what we call a precautionary approach, guided by concerns for inclusion (inclusion and participation can improve the legitimacy of decisions made); distributive justice (we have a moral obligation to consider how benefits and costs should be distributed); and accountability (which requires liability and respect for the rule of law). A precautionary approach also requires us to respect epistemic virtues, including acknowledging existing uncertainties.

A precautionary approach implies that research aiming at SRM development and deployment should be subject to clear regulation and should be conducted with ethical oversight. This oversight process should analyse and assess the benefits, risks and (to the extent possible) uncertainties, and to do so in line with the principles of inclusion, distributive justice and accountability. Plans for small-scale outdoor experimentation should also undergo a vetting process. Insofar as large-scale experimentation and use of SRM is concerned, given the current state of knowledge and the deep uncertainties regarding SRM, the precautionary approach requires a moratorium. If worse comes to worst and the large-scale deployment of SRM is the only remaining way to mitigate climate change, inclusion, participation, distributive justice and accountability in the form both of broad public participation and international collaboration should guide policy and action.

Moreover, a precautionary approach requires the exchange of evidence, information and experience. This should also entail – as quickly as possible - the creation of an international network under the supervision of a specialised international body, where states, academics and researchers, NGOs and civil society organisations, representatives of regions and communities work together to monitor developments relevant to SRM and to devise robust governance mechanisms. This network could also promote international dialogue and strive towards global consensus. We need an open, inclusive and nuanced debate on the ethical and social implications of SRM. This debate must draw from a platform of knowledge, evidence-based information and proven experience. A precautionary approach requires that we work together at all levels and with common goals.

Finally, a precautionary approach also means that regulatory measures with global reach are required to effectively enforce these measures and policies. The moratorium that we call for, initially applicable to EU Member States, could eventually be replaced by an international treaty establishing a global moratorium.

RECOMMENDATIONS

There is deep technical and scientific uncertainty around SRM. And yet it has raised high expectations in the fight against climate change. When there is an urgent need to make choices that have an impact on our planet's future without being able to assess and rely on solid scientific evidence, more than ever, these decisions must be guided by fundamental rights and ethical values. Policymakers should make these values explicit and explain how they help to respect and protect the fundamental rights of humans, the interests of future generations and the value we accord to non-human nature. This means that the fundamental basis for SRM governance is ethical in nature. Against this backdrop, the EGE emphasises that:

- SRM is one of several ways to potentially mitigate climate change, with unknown implications and unconfirmed effects. It must not be treated as an alternative to the measures established under the Green Deal, such as prioritising the reduction of carbon emissions, which is a much safer, scientifically well-understood and technically feasible strategy with a more predictable outcome. We echo the GCSA's recommendation to prioritise the reduction of GHG emissions, followed by carbon removal.
- Whatever technical solutions may be developed, they cannot replace necessary changes in social and economic practices to decarbonise societies. We call for respectful and responsible interaction with each other, with non-human nature, and for better protection of the interests of future generations. We strongly reject any 'tech-fix' approach that assumes that complex social and environmental problems can be solved solely by new technologies.
- Given that investment in research on SRM could lead to a divestment from decarbonisation efforts and could itself be an incentive for the experimentation and deployment of SRM, a robust international ethical and legal framework must be established to guide and regulate this research.
- The large-scale deployment of SRM can have severe and far-reaching geopolitical implications. It cuts across the distinction between civil and military uses. In a dual-use context, no large-scale deployment of SRM can independently claim to fall solely within the 'civil use' category.

- The scale of the uncertainty and the magnitude of the risks related to research into and deployment of SRM imply that it is necessary to:

  - Identify the ethical values at stake in the context of SRM and that must be respected. Particularly relevant values are justice, solidarity, inclusion, transparency and accountability. We also emphasise the need to respect fundamental rights, including the rights of future generations.

  - Strengthen existing – and create new – mechanisms and procedures to protect these rights and values effectively and to monitor and supervise compliance with them by all parties.

  - Invest in the development of better tools (methodologies, strategies etc.) for value-driven decision-making under conditions of deep uncertainty, acknowledging the potential of the SRM debate in offering new ideas and opportunities in this regard. A precautionary approach, adaptive planning and inclusive deliberative decision-making are required at national, European and international levels.

  - Collaborate globally on developing ethically and legally sound guidelines on regulating research into and potential use of SRM in inclusive ways that prevent the epistemic and political dominance of more influential countries and regions over others. From a global justice perspective, it is essential to account for the specific ways in how low- and middle-income countries and regions are affected by the climate crisis, as well as for the historical responsibilities of wealthier countries in this context.

- Political decision-making should acknowledge and account for the scientific and technical complexity of SRM, for the planetary and social challenges which it gives rise to, and for the ethical requirements that decisions about it must meet. In this context, the ramifications of complexity and uncertainty should not be ignored or simplified. The debate on SRM is a prime opportunity to reconsider and recalibrate economic systems that have focused on short-term economic gains, while disregarding negative externalities and issues of justice within and across countries.

Hence, the EGE calls upon:

1. The European Commission to:

- Issue a moratorium on any large-scale use of SRM (on all experiments and applications of SRM that could have effects beyond the specific locus of intervention) within the territory of the EU, due to the extensive knowledge gaps around SRM technologies and the potential severity of risks they imply. The moratorium could be reviewed regularly and could be suspended if research on SRM produced solid and robust scientific proof on the feasibility, need, safety and security of SRM deployment.
- Propose an international treaty committing to the above moratorium and to work together to develop other international regulation and governance mechanisms, including oversight and the capacity to issue penalties if signatory countries fail to meet requirements. These mechanisms should include soft law instruments, which can be effective in guiding behaviour.
- Work together with the European Patent Organisation to ensure that intellectual property regimes (patents in particular) will not be used to develop a new market for SRM products and services within the EU.
- Engage in and encourage critical reflection on the effects of research on (and research funding for) SRM, and to draw on such reflection to contribute to establishing a robust international ethical and legal framework that guides and delimits research related to SRM and strengthens overall social and environmental responsibility in research into SRM and climate change more broadly.
- If research on SRM is to be funded in Europe at all, prioritise projects that address societal, ecological and ethical dimensions, rather than projects focusing on technical feasibility.
- Set up a multidisciplinary observatory in Europe on research into SRM (whether explicitly labelled as such or not), with the aim of monitoring and critically assessing techno-scientific developments, projecting impacts and assessing the risks of SRM. The observatory must also include experts on ethics.

2. EU Member States to:

- Develop national regulation and governance mechanisms, including requirements for monitoring and reporting.
- Organise broad and inclusive public deliberations about how to most effectively counter climate change, mindful of the broader and systemic aspects, including raising awareness about SRM and other approaches and encouraging debate in citizen assemblies across Europe.
- Prevent SRM, including research into SRM, from becoming a lucrative opportunity for business. An exception is research into the detection of unauthorised ('rogue') deployment of SRM.
- Discourage the development of a new market for SRM products and services that current intellectual property regimes (patents in particular) might lead to.

3. The international community to:

- Develop international regulation and governance mechanisms, including effective oversight and capacity to issue penalties if signatory countries fail to meet requirements.
- Create an international network under the supervision of a specialised international body where states, academics and researchers, NGOs and civil society organisations, representatives of regions and communities work together to monitor developments relevant to SRM to feed into the development of robust governance mechanisms. This network should be based on and promote inclusiveness and participation. It must ensure that representatives of the local populations that may be directly affected by any kind of SRM deployment are fully informed about the risks and potential benefits of these technologies and can participate actively in the decision-making processes related to them. The network, in the same way as all other governance fora, should reflect, discuss and communicate clearly and transparently about the ideals and values behind policy considerations and decisions to open them up for public scrutiny and increase the quality and legitimacy of decisions. The network should engage in ongoing critical evaluation of the governance processes and outcomes, ensuring they remain aligned

with societal values and ethical norms. The international network would complement the work of regional observatories as proposed for Europe above, and vice versa.

- Consider the interests of future generations and non-human nature in decisions about SRM development and deployment, and more broadly to consider them as key to creating effective and inclusive climate and environmental policies.
- Acknowledge that, as every large-scale deployment of SRM has geopolitical implications, all restrictions pertaining to dual-use technology are potentially applicable to SRM as well.
- Consider the large-scale deployment of SRM as a breach of the Paris Agreement[9], signalling that any state that initiated or condoned it would no longer be honouring its obligations under related treaties and agreements.

4. The scientific community to:

- Comply with the European Code of Conduct for Research Integrity, particularly with regard to:
    - the declaration of potential conflicts of interest, and
    - the assumption of social responsibility, including the proactive consideration of possible uses and potential societal and environmental impacts of the research they are carrying out.
- Expand the ethics review process of research aimed at the development of SRM. Moreover, members of research ethics review committees deciding on the ethical nature of any research that could materially form part of SRM later on in the development pipeline should be provided with the training and resources needed for supervising SRM research in strict compliance with fundamental

[9] SRM may lead to unforeseen environmental consequences, which could violate the spirit of the Paris Agreement that emphasises sustainable solutions (esp. Articles 2, 3, 7 and 23). Moreover, the Paris Agreement is built on cooperative action, and unilateral or poorly governed SRM deployment could undermine international trust and collaboration, violating the Agreement's ethos. While no article explicitly bans SRM, large-scale deployment could violate the Paris Agreement's mitigation, adaptation and transparency frameworks, especially if it undermines emission reductions or causes environmental harm.

rights, values and approved protocols. Ethicists, lawyers and social scientists should be involved in these review processes. Research ethics review policies should require review bodies to consider the environmental and societal implications of proposed and ongoing research, such as the sustainability, health equity and public health implications.

- Take all measures necessary to provide free access to the findings of research projects in this field. Research institutions and research funders have a duty to facilitate access to the data for all. All research outputs and ideally also research data should be made available without cost barriers, according to the principles of open access and open science respectively.

5. Civil society to:

- Support public participation in broader public debates about how to most effectively counter climate change (Council of Europe, Code of Good Practice for Civil Participation in the Decision-Making Process, 2019) and engage in the critical assessment of the potential risks related to SRM and similar approaches.
- Support a more comprehensive and widespread understanding of an equitable process of decarbonisation as an ethical choice forward.
- Claim, wherever and whenever possible, their right to a clean, healthy and sustainable environment (UN General Assembly Resolution 76/300), and to increase pressure on governments to decarbonise economies in a socially and economically equitable manner.
- Claim, wherever and whenever possible, their right of access to information, participation and justice in environmental matters, as laid out in the Aarhus Convention and other relevant treaties.

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In this Opinion, the European Group on Ethics in Science and New Technologies (EGE) presents ethical perspectives on Solar Radiation Modification (SRM), a set of potential geoengineering techniques that could create a net cooling effect on the climate and thus help with addressing the triple planetary crisis. Little is known about how large-scale deployment of SRM would play out and the risks it would incur are major and hard to predict.The EGE analyses knowledge gaps and uncertainties around SRM and maps societal and ethical concerns. It makes the case for values-based and sound participatory deliberation and decision-making in the context of a precautionary approach to SRM governance. It also calls for instituting a moratorium on large-scale SRM deployment and for research to be directed by the principle of social and environmental responsibility.

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